INTERNATIONAL LEAD ZINC RESEARCH ORGANIZATION, INC.

GALFAN TECHNICAL RESOURCE CENTER

2525 MERIDIAN PARKWAY
POST OFFICE BOX 12036
RESEARCH TRIANGLE PARK, N.C. 27709-2036
TELEPHONE 361-4647 (AREA CODE 919)
TELEX: 261533
FACSIMILE: (919) 361-1957

MEMORANDUM

TO: GALFAN Process Licensees
GALFAN Alloy Licensees
GALFAN Suppliers
GALFAN Contacts
M. Lamberigts, C.R.M.

FROM: John L. Hostetler, P.E., Director
GALFAN Technical Resource Center

DATE: 27 January 1992

SUBJECT: Minutes of 16th GALFAN Licensees Meeting

The minutes of the 16th GALFAN Licensee Meeting are attached. This meeting was significant for many reasons and demonstrated again the vitality and growth of GALFAN in the three regions Japan, Europe, and North America. Projections from the producing licensees is already enough to show a healthy continuing growth. Additionally, I think 1992 will show GALFAN starts-ups in other regions which have huge potential for profiled pre-painted strip, unpainted corrugated and standing seam roofing and siding, and wire products.

Additionally, there are some new technologies which may impact the GALFAN coating process, especially for wire, tubing, and narrow strip which have the potential to improve quality and at the same time reduce line modification cost and production costs.

The more GALFAN is compared to other coil coatings, the better it looks. The maturing operating and process control experiences by the GALFAN Sheet Producers is showing the advantages and benefits of GALFAN more than ever before. The 1992 Coil Characterization Program to be done by C.R.M. promises to add even more knowledge to the technology.

Thus, the 17th Licensee Meeting promises to be the best ever. We have tried to accommodate the request to move the meetings to an early summer date for 1992 but for many reasons, we must keep the late September-early October date for 1992 in Japan. We will go to the summer date starting with the 1993 meeting in Austria.

Next year's minutes will be published in color to get the full impact of photographs, slides, etc. This is also a CALL FOR PAPERS and a request for any comments or suggestions for improving the meeting.

JLH/ja

Encl.

GALFAN™

IMPROVED GALVANIZING

16th LICENSEE MEETING PROCEEDINGS

October 2-4, 1991

Sheraton Station Square

Pittsburgh, Pennsylvania, USA

Sponsored by

International Lead Zinc Research Organization, Inc.
GALFAN Technical Resource Center
Research Triangle Park, NC

PROCEEDINGS OF THE 16TH GALFAN LICENSEE MEETING

Sheraton Station Square Hotel
Pittsburgh, PA, U.S.A.

October 2-4, 1991

TABLE OF CONTENTS

Statement Regarding *Confidentiality*

Much of what is reported in these sessions will become public information but some must be considered *CONFIDENTIAL* and proprietary to ILZRO, a GALFAN Licensee, or a Supplier.

Every company here has agreed to terms in a *Confidentiality Agreement* with ILZRO and as such, is legally and ethically bound to receive any information from these sessions under the terms of that Agreement.

One of the reasons for this policy is to encourage a safe exchange of information whether it comes from Reports or from off-the-record question and answer discussions.

All Proceedings of these sessions including the published minutes shall therefore be considered as *confidential* material.

We live in an information society. This group certainly knows the value of good information. The Licensee Meeting is a tremendously effective forum for transferring information. We need however, to be sure the information, usually hard won, profits the legitimate group first.

Minutes of the

16th GALFAN Licensees Meeting

Sheraton Station Square Hotel
Pittsburgh, Pennsylvania, USA

October 2-4, 1991

RESEARCH SESSION
MARKETING SESSION

Attendance:

Name	Company
Aufderheide, H.	Wheeling-Pittsburgh Steel Corp.
Bibey, D.	Wheeling-Pittsburgh Steel Corp.
Blondeau, J.	SOLLAC
Brassart, E.	ACEC - VM
Brinsky, J.	Weirton Steel Corp.
Bush, G.	Busch and Associates
Capul, T.	Weirton Steel
Celestin, A.	Weirton Steel
Decker, C.	Hostetler and Decker, Inc.
Dewitte, M.	N.V. Bekaert
Dubois, M.	Cockerill Sambre
Elser, P.	Indiana Steel & Wire
Faderl, J.	Voest-Alpine Stahl Linz
Feron, S.	Cockerill Sambre
Fukami, S.	Kawatetsu Galvanizing
Furukawa, K.	Nisshin Steel
Gailliez, B.	FFM - France
Gibbs, G.	ITT Automotive
Goodwin, F.	ILZRO
Grimm, R.	Wean Industries
Harada, W.	Nisshin Steel
Heiler, H.	Thyssen Stahl AG
Hirose, Y.	Nisshin Steel
Hostetler, J.	ILZRO-GTRC
Imai, H.	Nippon Denro
Klotzki, H.	Thyssen Stahl AG
Kobatasu, M.	Nippon Denro
Lamberigts, M.	C.R.M.
Lebeck, R.	Handy & Harman Automotive Group
Lewis, G.	Cominco Ltd.

Attendance (cont'd.)

Malmgreen, J.	Eastern Alloys, Inc.
Marder, A.	Lehigh University
McDowell, R.	Inland Steel
McLean, G.	Worthington Industries
Mengen, H.	Wheeling-Pittsburgh Steel Corp.
Morin, M.	Mid-Western Processes
Mossgrove, D.	Weirton Steel
Nagasaki, H.	Sumitomo Metals
Nivoche, C.	Selas, S.A.
Nunninghoff, R.	University of Wuppertal &Trefilarbed
Oshimura, K.	Sumitomo Metals
Pankert, R.	Vieille-Montagne
Pelini, L.	Cockerill Sambre
Ranta-Eskola, A.	Rautaruukki
Reynolds, R.	Wheeling-Pittsburgh Steel Corp.
Schwarz, W.	Hoesch Stahl AG
Sherrick, K.	ITT Automotive
Skipp, Jr., A.	ADS Machinery Corp.
Skubick, S.	Eastern Alloys, Inc.
Subramanian, V.	ILZIC
Turgeon, J.	Zaclon, Inc.
Ueda, N.	Sumitomo Metals
Wakushima, H.	Kobe Steel Ltd.
Wegria, J.	ACEC-VM
+ 1 Mouse	

RESEARCH SESSION
Thursday A.M., October 3, 1991

Meeting Convened:

The meeting was convened at 8:30 a.m. by John Hostetler, who served as chairman. In order to efficiently introduce all attendees, a list of each group of licensees by classification, i.e. sheet producer, alloy producer, supplier, etc., was projected and the attendee invited to stand and introduce himself to the group in the order shown.

Mr. Hostetler then asked Dr. Goodwin to give welcoming remarks for the meeting. Dr. Goodwin noted that the purpose of the meeting is to hear about the progress in the last year resulting from licensees' activities and from the sponsored research projects on GALFAN. He noted the importance of sharing results from the technical operations and marketing activities of companies that have made progress with GALFAN. He also thanked the ILZRO members present at this meeting, Big River Zinc, Cominco, Eastern Alloys, and Vieille-Montagne, for their involvement and also thanked the steel companies present who sponsored the 1991 research which will be reported today.

Approximately half of the GALFAN research being carried out through ILZRO is sponsored by steel companies. He urged them to continue their sponsorship of GALFAN research in 1992.

Presentation of CRM Research Results:

Dr. Goodwin then introduced Mr. Lamberigts of Centre de Recherches Metallurgiques who presented an update on their research activities and results. A detailed summary of these results is shown in Progress Report No. 24 of ILZRO project ZM-285. Mr. Lamberigts described the phenomena of intercellular corrosion which is observed in humid atmospheres on GALFAN of certain compositions, mostly being of lower aluminum levels. This has been noticed to occur with different steel substrates. Examination of the coating cross section shows that after humidity corrosion testing has taken place, severe oxygen penetration deep into the coating can be found. It is felt that this must be related to surface phenomena.

Significant segregation of corrosion products on the surface is seen which should be related to the coating structure underneath. An Auger distribution of elements in the coating at various nanometer depths under the surface was shown. The carbon pollution on the surface is a remnant of the protective oils which were applied after the GALFAN coating. Also, a thermal oxide film was present on the surface which is formed upon solidification of the coating. Under this, strong aluminum segregation to cell boundaries is seen. These are heavily oxidized after wet corrosion tests. During the corrosion tests, it is believed that a continuous liquid film on the coating of corrosion products is formed. To provide further information, clues from the mechanisms of intercellular corrosion were sought from the electrochemical tests which were performed in the last year. A buffer solution prepared from de-aerated ammonium phosphate at a pH level of 7 was used. This gives a neutral immersion solution in which mechanisms can be studied. Extra-low carbon cold rolled samples were used which were coated with GALFAN and then skin passed. Also, typical deep drawing quality steel was used. In addition, pure zinc, pure aluminum, and normal hot dip galvanized sheet were used for comparisons.

By "aerating" the solution with nitrogen or by bubbling air through it, it was hoped to learn about the passivation and corrosion behavior of these samples. Sodium chloride solution was also injected in the solution up to a level of 0.1M. Samples were exposed for up to 300 hours. Rolled impurities on intercellular corrosion was sought. Polarization curves for iron and aluminum were shown. These dropped to the rust potential during initial tests with nitrogen bubbling and staying at a steady level. The potential increases when oxygen is bubbled in. Both metals become more anodic and then passivate possibly by the formation of hydroxide. If chlorine is then introduced by the addition of sodium chloride, the samples depassivate and go back to their initial corrosion values. Zinc has similar behavior but it is more erratic in its stabilization behavior. It oscillates between passivation and depassivation of voltage levels.

Zinc has been observed to be more anodic than aluminum. It was suspected that GALFAN would behave like a combination of zinc and aluminum, however the GALFAN oscillated in its potential as zinc did, with more of an anodic behavior than zinc in oxygen free solutions, however when oxygen is introduced into the solution, GALFAN is more cathodic than zinc.

Surface analysis was carried out and showed that the thermal oxide was only present in the uncorroded areas. Other corroded areas have surface products which were found during corrosion testing to be aluminum and zinc hydroxides. In the corrosion tests, these are present in liquid form, however they come up to the surface by capillary action. The surface then dries and the hydroxide solidifies. Aluminum hydroxide solidifies first, after which zinc hydroxide solidifies on top. Thus, all zinc hydroxides were found in the top 60 nanometers of the corroded samples. To prevent this segregation, solutions were sought from a survey of samples prepared by Sollac. Damage ratings were formulated after wet corrosion testing of a variety of their materials. It was found that higher aluminum contents in the GALFAN coating, up to a level of around 5%, resulted in less damage by wet corrosion. One should try to keep near the eutectic composition, Mr. Lamberigts noted. Also annealing temperature should be kept low. However, these correlations were made on samples prepared using a method similar to the Zinquench process. They may need to be adapted to more typical GALFAN operations. One way to solve this problem may be the addition of magnesium, according to Mr. Lamberigts. This segregates aluminum to the eutectic phase. Material from Nisshin has been examined which contained 0.1% magnesium and a lower aluminum content, around 4.2%.

Sollac has also done qualitative glow discharge spectroscopy, looking at compositions across the coating/steel interface. Nisshin samples were also examined by wet corrosion. Oxygen diffusion was seen along grain boundary paths, therefore magnesium additions do not improve the penetration of oxygen into the zinc-aluminum coatings. It may be possible to adjust aluminum to bring the magnesium-containing GALFAN to the fully eutectic state. Vieille-Montagne has done some work on this and found that aluminum would need to be around 2%. As part of this work, CRM also did a short assessment of the crack-free coating which is being considered by several steel producers. This has a lower aluminum content than GALFAN, however solidification is controlled to segregate aluminum to the surface. One might think that the cell boundaries would be caused to disappear by this treatment, however the grain boundaries are much enriched in aluminum as in GALFAN. Therefore, it was concluded by Mr. Lamberigts that the best way to get rid of intercellular corrosion is to use magnesium with an increased aluminum content. Another way of solving the problem is possibly to better control the solidification process.

In discussing these results, Mr. Dubois asked about the Sollac samples in more detail. He asked if the line speed was the same in all samples because this would alter the annealing treatments which were the basis of the damage index work prepared by CRM. He also asked if CRM has studied the intergranular corrosion performance of Crack-free's coating in a method similar to that used for GALFAN. Mr. Lamberigts noted that the Sollac material is made under a wide variety of conditions and thus the correlations are very far from perfect. They have not carried out wet corrosion studies on Crack-free coating but find that some claims made by Crack-free promoters are questionable. They do not intend to do a detailed characterization on this work.

Mr. Hirose asked about the aluminum segregations to the cell boundaries. He believed that this was understandable, however he asked if the aluminum oxide would really give a bad effect on the coating. He also asked why hydrogen segregation was seen in the results which were shown and also noted that in the crack-free coating his personal view is that this is such a low aluminum coating that the total corrosion resistance should be inferior. The 5% aluminum composition is best for this, according to his past studies. He also noted that if the lead in the coating was very low in the low aluminum coatings, then the ductility would be no better than that seen in the higher aluminum coatings. Even conventionally galvanized steel can have very good formability with very low lead levels, he noted.

Mr. Lamberigts stated that it would be very difficult to remove the initial oxide from the surface of the coating because it penetrates into the cell boundaries. If it could be removed, then one could conceive of the crevices which would be there instead which would likely reduce corrosion performance. A chemical method could possibly be used to dissolve the aluminum oxide and zinc oxide. Regarding hydrogen, he believed that GALFAN should be basically impermeable to hydrogen, however it could come from any sources such as pickling, annealing, furnace adsorption, and cooling and water. The hydrogen would then try to escape from the steel. The desorbed hydrogen from the steel is likely seen at the coating/steel interface. He also observed from his studies on galling of coated steels that GALFAN has the better formability than normal galvanized steel.

The complete Progress Report #24 was mailed to all Licensees October 17, 1991, and is not repeated herein.

<u>Confidentiality Agreement Statement:</u>

Mr. Hostetler then read the *Confidentiality Statement* which is attached to these minutes. These govern the obligations of all attendees to the meetings covered in this proceedings in accordance with agreements they have signed with ILZRO.

Lehigh University Presentation:

Mr. Hostetler then introduced Professor Marder who described the solidification mechanisms and denting behavior in GALFAN. Dr. Marder noted that the approach in his presentation is to describe how coatings solidify in steel which will enable a better use of process controls. A particular issue to be solved is grain boundary denting. He noted that aluminum is added at levels of 0.005 to 0.2% to brighten the surface of galvanized steel. When aluminum is added at levels between 0.1 and 0.3%, it controls intermetallic growth. Over 1% aluminum improves the corrosion resistance of galvanized steel.

In hot dip galvanized coating with a spangle surface, iron reacts with aluminum to make inhibition of the intermetallic layer occur at low aluminum levels. Different alloy layer compositions have been reported from equal amounts of iron-aluminum to iron-aluminum-zinc compounds. To understand these compounds, we need to know the equilibrium of the iron-aluminum-zinc phase diagram. An isothermal section through such a diagram was shown. Dr. Marder then showed the solidification mechanism for conventional galvanized steel. Zinc grains grow on the intermetallic layer on top of the steel surface. Impurities are segregated between the grains, producing the typical surface seen. In Galvalume, dendritic aluminum forms the primary phase. Inter-dendritic zinc is found between these along with silicon particles. Also, an important intermetallic layer is present between the coating and the steel. The inter-dendritic particles have been observed to contain around 20% zinc, whereas in eutectic around 80% zinc is present. The silicon particles are the first to nucleate and grow on the steel in the Galvalume bath. These then nucleate aluminum dendrites which impinge and leave zinc-rich inter-dendritic regions. The intermetallic layer in Galvalume inhibits corrosion but is brittle and can crack. On the ternary diagram, it has been observed that one can have complex diffusion paths going through many complex compounds along the solidification route of galvalume.

With GALFAN, there are a lot of similarities with the *Pearlite* structure found in the iron-carbon system. GALFAN solidifies with a eutectic growth mechanism in many cases. The nucleation sites are pro-eutectic zinc. Eutectic colonies developed around these sites; when they impinge a boundary is formed. Alloy layers were investigated by transmission electron miscroscopy and are shown to be very small. In most commercially produced GALFAN, growth occurs by both eutectic and dendritic means. Intermetallic layers have been seen with transmission electron miscroscopy which have a very fine scale. Zinc dendrites nucleate off of these which coarsen eutectic solidification that occurs around the zinc dendrites. Grain boundary dents are a pattern of surface depressions on GALFAN, resulting from the solidification process. Surface depressions are usually formed at triple points which can be seen at low magnifications. Cracks are also observed at grain boundaries which follow the eutectic colony boundaries. Lamellar eutectic structures in these colonies blunt microcracks and keep them from growing. This explains part of GALFAN's good ductility.

Dr. Marder referred to past CRM work which showed that grain boundary dents are half as shallow in interstitial-free steels as in drawing quality steels. This was traced to a stronger interface reaction with the interstitial-free steels. Intermetallic compounds can act as a sink for aluminum and effect the overall solidification pattern on the surface. With interstitial-free steels, smaller and more numerous eutectic domains are seen.

Another issue is the cleanliness of the steel. It is thought that surface oxides on interstitial-free steels effect nucleation and growth of the coating. Because of the presence of elements like titanium it is very difficult to clean these steels. The higher reactivity of these steels also effects the rate of diffusion between the coating and the steel. This higher reactivity can come from grain boundaries in the steel. Past investigations have correlated the locations of grain boundaries in the steel with alloy bursts in the coating. Lower carbon contents are also known to effect steel reactivity.

Mr. Dubois noted that there was a need to focus on the nature of solidification patterns in GALFAN, however he did not think that the interstitial-free steel approach is the only way to reduce denting in GALFAN. He noted the need to confirm this work with material from different lines to see if the observations made in this presentation were still valid. The grain boundary dents seen from material produced at Phenix Works were not as severe as those from other producers as reported here.

A copy of Professor Marder's paper is attached.

Mr. Hostetler then introduced Mr. McLean from Worthington Industries. Mr. McLean noted that his company purchases one million tons of steel per year for coil coating and that they are now in the final stages of reviewing bids for a GALFAN line.

Presentation by Sumitomo Metal Industries on Automotive Performance of GALFAN:

Mr. Hostetler then introduced Mr. Ueda of Sumitomo Metal Industries who described their work on characterizing GALFAN for automotive applications. A text of Mr. Ueda's remarks is attached to these minutes.

He noted the need to evaluate other important automotive properties such as spot welding besides those described in this report. Mr. Klotzki also noted the need to evaluate the performance of GALFAN and other coatings by the stone chipping test. He asked if they have done this. Mr. Ueda noted that he does not have information on this with him, however he believes that GALFAN should have stone chipping results.

Mr. Faderl asked if phosphating times used in the Sumitomo study were the same as those used in the automotive industry. These tend to be quite a lot longer than laboratory dips. Mr. Ueda replied that the long dips typical of automotive production were used. Mr. Faderl asked about Figure 1 which shows the depths of attacks in fractions of a micron, however the paint depths are shown in the text as 0-5 microns. Mr. Ueda noted that bare panels were used for the information shown in Figure 1. Mr. Hirose asked about the pretreatability. He asked what the aluminum content in the phosphate solution was after testing. He believed that contamination of the phosphate solution will be a difficult problem. He also noted that spot welding of GALFAN has proven to be difficult but possible.

Mr. Ueda noted that accumulation of aluminum in the phosphate solution can be prevented by adding chlorides. This technique has been carried out in the past and is being further refined by the automotive industry where aluminum sheets are being phosphated before painting. Thus, much progress in the area is expected. He agreed that spot welding would be an important problem to solve for more general automotive usage of GALFAN.

Wheeling-Pittsburgh Steel Report on Culvert Performance:

Mr. Hostetler then introduced Mr. Reynolds who presented the results of Wheeling-Pittsburgh's tests on culvert. Copies of the Report are attached to these minutes. He noted that Wheeling-Pittsburgh Steel is heavily involved in the culvert market. Some portions of culvert require significant deformation for seaming. Several years ago, Wheeling-Pittsburgh Steel did a study in their engineering laboratory on galvanized vs. aluminized culvert. They now have repeated this study to compare galvanized, GALFAN, and aluminized coatings. They looked at different coating weights but were interested mostly in GALFAN at 2 oz/ft^2 coating vs. aluminized type 2 at 1 oz/ft^2 coating. They also looked at 2 ounce all-zinc galvanized coatings. Immersion, corrosion testing, and salt spray testing were done, as described in the attachments. Immersion testing was focused upon, using different electrolytes and pH levels. GALFAN was found superior to aluminized in this test program, especially with regard to red rust formation. The pH levels of 5 and 9 were equivalent in Type II aluminized or GALFAN, however in the pH levels of 3 and 12 GALFAN was superior. Aluminum showed poor coating adhesion under culvert forming processes which cause its poor performance. GALFAN was found to be superior to the galvanized coatings also.

Painted panels were run in a similar test. Aluminum was compared to GALFAN in this way. GALFAN appeared to provide the best protection characteristics of aluminum and galvanized. Salt spray testing was also described. Both flat and deformed panels were used with coated edges. Regarding the flat panels, the Type II aluminized was found to be better than GALFAN, which in turn was better than aluminized, however for deformed panels, galvanized material was found to be the best.

Trefilarbed Presentation on Wire Developments:

Mr. Hostetler than introduced Professor Nunninghoff who was representing Trefilarbed . A copy of Professor Nunninghoff's remarks are attached to these minutes. Wire testing has been carried out on both sulfur dioxide and sodium chloride environments for around 500 hours. GALFAN has been compared with aluminized, galvanized, and electrogalvanized wire. Severe delamination from the surface was found to occur with the electrogalvanized wire, however uniformity of attack was seen with the GALFAN and galvanized wires.

The lead content was also checked. Some fairly high lead levels, between 200 and 500 ppm, were checked in their work. Microprobe work was carried out using a scanning electron microprobe at the Arbed Research Centre. Segregation of elements was examined across the steel coating interface. Typical changes in iron, zinc, and aluminum were shown.

Professor Nunninghoff has also worked on galvanizing of fasteners, especially steel screws and rivets. Micrographs were shown of these components. GALFAN parts are made after dipping in a galvanizing bath. It is found that there is a complete transformation of the initial iron-zinc layer to a layer containing about 8% aluminum. Better corrosion performance was seen with the steel bolts coated with GALFAN than those coated with galvanized coatings. Rivet testing compared sherardized and GALFAN-coated products. The GALFAN-coated rivets were found to be far more formable and gave superior performance in sulfur dioxide testing.

Regarding markets, GALFAN has been found to be a good substitute for the more expensive PVC coatings. Arbed has recently received their first very large order for GALFAN-coated chain link fence. The Munich airport will be one of the locations where this fence is installed. Also radio mast guy wires are an increasing market. Five masts have been done in Germany. In Scandinavia this has also been an important new market with wire supplied by Bridon Rope.

General Discussion:

Mr. Hostetler then asked for any questions regarding the first series of presentations. Mr. Capul asked if the culvert tested by Wheeling-Pittsburgh was chemically treated, i.e. chromated. Mr. Reynolds replied that the material was tested as-is without any treatment. Mr. Dewitte asked if the Wheeling-Pittsburgh results had shown any pitting with the aluminum-coated samples. His past work with Bekaert showed that a lot of pitting corrosion occurred with aluminum-coated wire. Mr. Reynolds noted that the micrographs showed pitting corrosion in the aluminized product. This can be seen from the micrographs attached to these minutes.

Mr. Gibbs asked if anyone has looked at CASS (Cuprite-acid-salt spray) testing. Dr. Goodwin noted that this was not very common, however it was used in the electrical industry to check for coating uniformity. Most work carried out by the licensees to date has been neutral salt spray testing. Regarding CASS testing, past work has shown that GALFAN behaves about the same as all-zinc galvanizing.

Mr. Hostetler noted that the paper by Bundy Tube on automotive fuel lines will be distributed after the Society of Automotive Engineers Meeting in last October but was not available for presentation at this meeting. Also, New Zealand Steel has undergone a change of ownership and hence none of their personnel were present at this meeting. Mr. Hostetler acknowledged the important contributions which New Zealand Steel has made to past GALFAN licensees meetings and the body of knowledge on corrosion testing which they have contributed.

Nisshin Steel-Treatment to Prevent Gray Patina on GALFAN:

Dr. Hirose presented the information shown in Nisshin Steel's attachment to these minutes. He noted that the inhibition of gray patina can be accomplished by spray treatment of a cobalt solution. Nisshin Steel has made important inroads into the construction business, however the gray patina was seen as a handicap to future development. The GALFAN coatings manufactured by Nisshin Steel have between 4.1 and 4.2% aluminum, along with 0.1% magnesium and mischmetal. To prevent gray patina, they spray on a nitrate solution of cobalt. Iron and nickel have also been tried. Compositions between 2 and 20 grams per liter of these elements are used in the spray composition. They deposit a layer between 1 and 2 mg/cm^2 in density. This layer is then chromated in the usual way. Cobalt has the best effect on preventing darkening, however iron and nickel can also reduce darkening as shown in the curves in his paper.

Cobalt rich deposits are between 0.1 and 0.2 microns thick. Oxidation work has shown that the cobalt nitrate initially formed on the surface changes to cobalt oxide at a temperature above 280°C. Thus, it is believed that this transformation occurs on the galvanizing line before the coating is cooled. Cobalt is not uniformly dispersed, however it still provides complete protection. When it is on the surface it acts like a barrier. It also provides an inhibition effect for the uncovered areas adjacent to it. Only 20% of the coating surface area is covered with the cobalt compound.

To apply the coating, a high pressure spray with a pressure between 40 and 50 kg/mm^2 can be used to provide good protection. To get a bright finish, only 3-4 kg/cm^2 are applied together with air pressure of 3.5 to 5.0 kg/cm^2.

Mr. Lamberigts asked how this coating would work on higher aluminum coatings like 5% aluminum in the absence of magnesium. Mr. Hirose thought that it would likely have the same effect.

Bekaert Report on Wire Corrosion:

Mr. Hostetler then introduced Dr. Dewitte who described the important advantages which the eutectic structure has on zinc-coated wire. A transition layer between the steel and the GALFAN coating is also noted which has a composition containing iron, zinc, and aluminum. Bekaert sells GALFAN as having the good corrosions of zinc along with the passivation behavior of aluminum. GALFAN is applied at only half the weight of normal zinc on their fishing ropes but gives a longer life. Corrosion testing was carried out on core for fishing rope by flushing seawater through the rope. Not much difference in corrosion between zinc and GALFAN was seen, however if corrosion density was examined, then an eight times higher corrosion resistance for GALFAN was seen compared to zinc. This agrees with the potential curves from their laboratory tests. The same results were also seen with nitrogen flushed through the core instead of seawater.

Bekaert has compared double galvanized wire with GALFAN. After 180 hours, red rust is seen with the galvanized wire, versus 768 hours for GALFAN. If one expresses the results in salt spray hours per coating consumed, the results are five times better for GALFAN than galvanized.

Bekaert has lately encountered a problem with sulfur-containing grease from the cabling operation used to make fishing rope. Distress was seen in cables which had been in service on fishing boats after three months. A milk-like gel was seen as the corrosion product. The greases used in this operation were found to be high in sulfur. Corrosion tests were done which found much higher corrosion rates with greased wire. Threading occurred and almost no chloride compounds were involved. A similar problem had been found in the past with ACSR wires in Great Britain using both aluminum and galvanized wire. Crevice corrosion was the main problem which was accelerated by sulfur dioxide. Thus a new grease using a low sulfur formulation was recommended which solved the problem. A coating with aluminum oxide in it gives aluminum sulfide. When this coating is then wound tight, low oxygen levels result. Also, an aerobic bacteria can enter into the reaction. These biologically corrode the coating to aluminum sulfate in the presence of light.

MARKETING SESSION
Thursday P.M., October 3, 1991

Review of Attributes of GALFAN for the Coil Coating Market:

Mr. Hostetler then asked Dr. Goodwin to review the advantages of coil coated GALFAN for this market. Dr. Goodwin noted that the overwhelming quantity of GALFAN produced is coil coated. Of this, 78.1% goes to the architectural/construction market, 6.5% to appliance, 6.4% to automotive, 4.6% to miscellaneous applications, 3.6% to agriculture, and 0.8% to the utility market. The reason for the great advantage of coil coated GALFAN is the compatibility of GALFAN with pretreatments and paints commonly used with conventional galvanizing, in most cases. Lower coating corrosion rates allow the use of lighter coating weights to maintain acceptable life. This also improves formability. Good passivation characteristics are seen with GALFAN which slows paint delamination. A fine dense network of cracks form in GALFAN upon severe bending which prevents further distress of the paint.

CRM work from several years ago which demonstrated the lower edge creep and scribe creep performance of GALFAN compared to galvanized steel was also shown. Dr. Goodwin then reviewed a paper recently presented at the National Association of Corrosion Engineers Conference which described the evaluation of painted GALFAN versus other products using automotive and on-vehicle tests. Although not directly applicable to coil coating, GALFAN was found to be the higher strength product of those tested. The on-vehicle work is continuing.

Coil coated GALFAN has also been used by manufacturers in the appliance markets. A paper by Hoesch presented at Intergalva '91 showed that GALFAN has better corrosion resistance under detergents than regular galvanized or electrogalvanized coatings. It also has a good aesthetic appearance and can be used with structured paint systems. Bend diameters ≥ 1T can be made without cracks. Coating masses can also be reduced. Hoesch has proceeded to sell large quantities of GALFAN after coil coating to the premanufactured housing market. Roofing and siding are both sold. Roofing tiles, rain goods, sectional doors, window frame sections, room partitions, cold storage walls, and domestic appliances are also important new applications for them.

Introduction of the North American GALFAN Development Association:

Mr. Hostetler then asked Mr. Celestin to describe the North American GALFAN Development Association to the group. Mr. Celestin noted that work on NAGDA began in early 1991. An organizational meeting was held after which a board of directors was elected. This was followed by a planning meeting and a formal board meeting. Participants in NAGDA include sheet, wire, and tube producers, alloy producers, zinc suppliers, machine, coating and chemical suppliers, and ILZRO. Mr. Celestin then reviewed NAGDA's accomplishments to date.

Its purpose was defined and a name chosen. By-laws were drafted and articles of incorporation filed making it a non-profit corporation. The board of directors was elected. The board consists of Mr. Celestin of Weirton Steel, Mr. Parrish of Wheeling-Pittsburgh Steel, Mr. Elser of Indiana Steel & Wire, Mr. Ranck of Dolphin Chemical, Mr. Hostetler from ILZRO, Mr. Wilkinson from Cominco, and Mr. Malmgreen from Eastern Alloys.

Two classes of membership were defined - active and associate. To be eligible for either class of membership, the nominee must manufacture or produce GALFAN product in North America. Eighteen potential active members and twelve potential associate members have been identified. Of these 6 active and 12 associate members have agreed to membership. A GALFAN logo has also been made up which was shown to the group. Two committees have been formed to date; the marketing committee, headed by Steve Wilkinson, and a membership committee headed by John Hostetler. The marketing committee has hired a public relations and advertising firm which will make a public relations release and distribute it to magazine and newspaper editors. Also, a speakers bureau has been established to allow presentations on GALFAN to various functions. A generic GALFAN brochure is also underway. This will be issued to cover all products made in North America. A press kit is currently being designed by the advertising agency and performance sheets on GALFAN are also being designed.

The preliminary budget for NAGDA depends on dues of $500 per year from active members and $300 per year from associate members. This will fund the press kit, a toll-free 800 information number, stationery and supplies. Additional items like the brochure are funded by subscribing of the members to these specific activities. Mr. Celestin concluded by noting that the North American producers firmly believe that formation of NAGDA was necessary.

Mr. Hostetler noted that a meeting will be convened on this same night to discuss the formation of a European association to generically promote GALFAN.

Discussion of Production Development:

Mr. Hostetler then asked Mr. Gibbs to describe development of GALFAN at Higbie Tube. Mr. Gibbs noted that his company is involved with production of automotive tube and pipe. They are now running one primary GALFAN tube line in New Lexington, Kentucky. They are in the fortunate position of having over-sold the line. GALFAN with aluminum-rich paint on top is sold for various automotive tubing applications. He is heavily involved with GALFAN tubing promotion to automakers.

Mr. Hostetler noted that Belgo-Miniera has taken a GALFAN license within the last year. They are the largest wire galvanizer in Brazil and seek to begin development of their production capabilities soon. Mr. Hostetler noted that tubing is not a large tonnage product, however it demonstrates GALFAN's attributes within the automotive industry and can lead to other applications.

Mr. Hostetler then asked Mr. Lebeck to introduce Handy & Harman to the group. Mr. Lebeck noted that Handy & Harman is a large corporation of which the automotive parts division is involved with GALFAN. They manufacture tube and cable. He believes that the automotive segment of GALFAN will grow considerably in the next year. Mr. Parrish asked about the possible applications of condensor tubing for refrigeration. He asked if corrosion problems were seen and whether Handy & Harman would take a look at this market. Mr. Lebeck noted that the tubular division rather than the automotive division is examining this problem. GALFAN is viewed as a possible solution here.

Status of Standards:

Mr. Hostetler then requested that Dr. Klotzki review the status of the *Euronorms* which are currently under development. Dr. Klotzki noted that the first draft of the *Euronorm* for GALFAN was put out early in 1991. Both galvanized, Galvalume, and GALFAN standards will have the same configuration and grades. There will be four grades of steel consisting of commercial quality, drawing quality, extra-deep drawing quality, and specialty drawing quality. In the construction sector, there will be five grades leading up to the full hard material. Coating weights will be at six levels of which two will be from special requests made by the French market. A new draft is currently underway and will be reviewed at the next meeting in January 1992.

Mr. Dubois asked about the possibility of adding coating specifications where thickness in microns is shown rather than weight. They need to convince their customers in some cases that the GALFAN coating they are buying has equivalent properties based upon its lower density compared to normal zinc. Dr. Klotzki noted that Thyssen has prepared a brochure for their customers which show these differences and also the differences between Galvalume and all-zinc galvanized.

Laser Welding of GALFAN:

Dr. Klotzki continued his presentation by giving a brief preliminary report on laser welding of GALFAN and conventionally galvanized sheet. A copy of his remarks is attached to these minutes. A 5.1 kilowatt carbon dioxide laser was used. They were able to reach speeds of 4.6 meters per minute with GALFAN and 5.2 meters per minute with galvanized. Micrographs of welded samples are shown and a deep drawn cup made by laser welding was circulated. The welds were found to be free of porosity and the heat effect zone appeared to be small. Mr. Ranta-Eskola asked why the speeds were slower with GALFAN than with galvanized. Dr. Klotzki stated that slower speeds were needed to obtain good quality just as even slower speeds are required for Galvalume and aluminized sheets. These can only use speeds at half the rate of GALFAN and galvanized.

Dr. Goodwin noted that pulsing was found to be an important way to improve quality and speed in U.S. trials with laser welding. He asked if this had been tried. Dr. Klotzki noted that Thyssen is developing a new facility and will commence a larger program very soon. Overall, he believed that speed was not that important for small enclosures such as motor housings. This is seen as one of the major areas in which they have interest. A weld gap of 0.1 mm is used.

Dr. Dewitte asked if Thyssen had seen any growth of the alloy layer in the laser welded steel. Dr. Klotzki noted that the coating disappears in areas where the weld is formed. Mr. Skipp asked about the effect of coating thickness and steel thickness on the welding speed. Dr. Klotzki replied that not much of an effect was seen. He stated that GALFAN has not been found to have good spot weldability up to now. Laser welding appears to be better.

ASTM Specifications Review:

Mr. Hostetler then asked Mr. Brinsky to review the ASTM specifications for sheet. Mr. Brinsky noted that B750 continues as the ingot specification, A875 applies to sheet products, A755 is a new standard for coil coated sheet. This is applied to exposed building products. F1234 is a new specification for fence frameworks. Pending specifications include four specifications for corrugated pipe. Also a storm and sewer drain pipe specification is underway.

Mr. Hostetler then asked Mr. Elser to describe the wire specifications which exist and are underway. Mr. Elser circulated a document attached to these minutes which show the six existing specifications. These are A817 for chain line fence, A855 for wire strand, A876 for carbon steel wire, B802 for ACSR wire, B803 for core wire in ACSR, and F1234 for chain link fence fabric.

Discussion of Future Production Plans:

Mr. Hostetler showed a series of bar charts which are attached to these minutes which indicated the production history of GALFAN; the forecast production is also shown. He asked Dr. Hirose of Nisshin Steel if they would like to make comments about their current and future tonnage. Dr. Hirose noted that the estimated 1991 production of GALFAN tonnage at Nisshin Steel will be 200,000 MT. They now make between 19,000-20,000 per month. Of this, between 2,000-3,000 MT is put into coil coating, the balance being for bare GALFAN. In 1992, the same tonnage is predicted as in 1991.

Mr. Hostetler then asked Mr. Schwarz for his summary and forecast. Mr. Schwarz noted that he was optimistic about the future of GALFAN but his figures were not as high as Nisshin's. During 1989, 57,000 tons of GALFAN were produced at Hoesch. During 1990 this figure increased to 80,000 and in 1991 it further increased to 90,000 tons. For 1992, they are forecasting GALFAN production at a level of 100,000 MT. Mr. Schwarz stated that GALFAN is now well-known among their customers. The customers expect GALFAN to be in stock and don't want to buy other hot dip products. The construction market is stable whereas the appliance market appears to be growing. Good formability is the key point for their customers, also good paintability is needed. This was described at the Intergalva meeting in the Hoesch paper.

Mr. Capul asked about the distribution of Nisshin's products. Dr. Hirose replied that 70% is thick gauge with thicknesses between 1.6 and 3.2 mm. Thirty percent (30%) is thinner product of which a portion goes to prepaint. Mr. Schwarz noted that the average thickness of their product is 0.7 mm which likely gives far more surface area of product than Nisshin. Mr. Ranta-Eskola asked Mr. Schwarz to confirm that the construction products made by Hoesch out of GALFAN were all prepainted. Mr. Schwarz replied that all their material for construction was prepainted.

Mr. Hostetler then asked Mr. Elser for comments on Indiana Steel & Wire's operations. Mr. Elser noted that his company started an experimental line four years ago. This was a pot-within-a-pot line and ran for two years with high carbon wire products. A production line was built in early 1990 and was put into commercial operation in September 1990. The company experienced problems using the electroflux process; a lot of coating variations and some bare spots were seen. They have since switched to the double-dip wire manufacturing process and modified their wiping methods. They now make a uniform coating and consistently get three to five times the salt spray corrosion resistance with GALFAN as they see with all0zinc galvanize. They are still in slow production and currently produce a few hundred tons per year, however they expect to triple this for 1992.

There being no further discussion, the Session was adjourned at 4:30 p.m.

GENERAL SESSION
Friday A.M., October 4, 1991

Attendance:

Name	Company
Aufderheide, H.	Wheeling-Pittsburgh Steel
Blankenship, M.	NGI Technology
Blondeau, J.	Sollac
Brassart, E.	ACEC-VM
Brinsky, J.	Weirton Steel Corporation
Bush, G.	Bush and Associates
Capul, T.	Weirton Steel Corporation
Day, H.	Big River Zinc
Dewitte, M.	Bekaert

General Session - Attendane (cont'd.)

Dubois, M.	Cockerill Sambre
Elser, P.	Indiana Steel & Wire
Faderl, J.	Voest-Alpine Stahl Linz
Feron, S.	Cockerill Sambre
Fukamizu, S.	Kawatetsu Galvanizing
Furukawa, K.	Nisshin Steel
Gailliez, B.	F.F.M.
Gibbs, G.	ITT Automotive
Goodhart, R.	Weirton Steel Corporation
Goodwin, F.	ILZRO
Grimm, R.	Wean Industries
Harada, W.	Nisshin Steel
Heiler, J.	Thyssen Stahl A.G.
Hirose, Y.	Nisshin Steel
Hostetler, J.	ILZRO
Klotzki, H.	Thyssen Stahl AG
Lamberigts, M.	C.R.M.
Lebeck, R.	Handy & Harman Automotive
Lester, B.	Weirton Steel Corporation
Malmgreen, J.	Eastern Alloys, Inc.
McLean, G.	Worthington Industries
Morin, M.	Mid-Western Processes
Mossgrove, D.	Weirton Steel Corporation
Nunninghoff, R.	Univ. Wuppertal/Trefilarbed
Oshima, K.	Sumitomo Metals
Pankert, R.	Vieille-Montagne
Parrish, D.	Wheeling-Pittsburgh Steel
Pelini, L.	Cockerill Sambre
Ranck, T.	Dolphin, Inc.
Ranta-Eskola, A,.	Rautaruukki
Schwarz, W.	Hoesch Stahl AG
Sherrick, K.	ITT Automotive
Skipp, Jr., A.	ADS Machinery Corporation
Skubick, S.	Eastern Alloys, Inc.
Snyder, H.	Weirton Steel Corporation
Subramanian, V.	ILZIC
Turgeon, J.	Zaclon, Inc.
Ueda, N.	Sumitomo Metals
Wakushima, H.	Kobe Steel Ltd.
Wegria, J.	ACEC-VM
White, G.	Hudson Bay Mining & Smelting

Mr. Hostetler began this session by describing the cooperative trial on pipe galvanizing which was proposed to a group of U.S. pipe galvanizers. This development will carry the preparation of steel for GALFAN a step further than in the past by looking at electroless plating of zinc. Ultrasonic pretreatments are being examined in another effort as well. Mr. Hostetler also asked the group for its cooperation in updating the current GALFAN Directory. Research, engineering, marketing, and operations personnel should all be listed.

<u>Future Direction of GALFAN Research:</u>

Mr. Hostetler then asked Dr. Goodwin to cover this subject. Dr. Goodwin noted that in the past the research on GALFAN at CRM has been directed toward product improvement by alloy optimization. In the past years, the level of aluminum has been optimized as being near to the eutectic point of 5%. Silicon and magnesium have been found to be useful under certain circumstances. Copper, nickel, and zirconium have been tried and found to have no beneficial purposes but on the other hand are not harmful either. Rapid cooling has been investigated and found to improve the corrosion resistance, deformation properties, and smoothness of the coating. Work continues on long-term corrosion behavior of GALFAN technical service and deformation properties.

In the future, Dr. Goodwin explained that the GALFAN project would need to pay closer attention to samples produced in actual production. Samples produced by licensees would be very important and are requested for the 1992 program. A questionnaire which had been circulated to licensees was described to the group. A copy of this questionnaire is attached to these minutes. Samples are requested for the beginning of 1992, along with a copy of the filled-out questionnaire which describes the conditions under which the samples were made. CRM will then be able to characterize the samples and correlate desirable characteristics with process conditions used to make samples.

Mr. Parrish asked about where the samples should be sent. Dr. Goodwin asked that they be sent to Mr. Lamberigts at CRM. Mr. Dubois also thought it would be very useful to mark the samples as to their sequence incoming from a coil. Also the front and back of the samples should be noted. Mr. Lamberigts that it would be very good to number the samples in the order in which they are taken from the coil. This will enable CRM to correlate features seen with their position. Mr. Capul stated that it would be very good to note if the conditions used to produce GALFAN were different from those used to produce conventional galvanized. This should be noted in the questionnaire. Dr. Goodwin asked that this be included alongside the information. A separate column can be used for this in the questionnaire.

Mr. Dubois asked also how the confidentiality of material sources would be handled. He wanted to be sure that any undesirable information did not get used against the various companies contributing to this. Mr. Lamberigts stated that the results would be mixed and therefore not identifiable to a particular source. Mr. Goodhart asked about the gauges which were desired. Dr. Goodwin stated that 0.8 mm had been selected as the target gauge. Mr. Goodhart also asked about the coating weights desired and Mr. Lamberigts stated that 10 microns per side was the desired target.

Mr. Lamberigts then explained the entire program. It was gone over in further detail in the CRM 1992 proposal which has been sent separately to licensees. Mr. Dubois asked about the task in the proposal which dealt with rapid cooling. Dr. Goodwin asked Mr. Lamberigts to explain this portion of the proposal to the group. Mr. Lamberigts explained the overall 1992 research program as described in his proposal. They have seen in the past an effective cooling rate on grain boundary dent depths. The coating can be 30% smoother as measured by dent depths if rapid cooling is used, however the cell intercept does not change. He explained that Sollac has made samples using very rapid cooling which has superior surface quantities. It was agreed that this information would be presented in the Sheet Operating Session.

Dr. Goodwin concluded this discussion by asking the licensees to fill out the new questionnaire very soon, giving target production values. This should be returned to ILZRO within the next month. When the sheet is supplied, the actual values to manufacture the sheet should be supplied to CRM. The samples should be coil width by 1 meter. Three of each sample should be provided. They should be sent to CRM to arrive around the beginning of the year. He noted that the proposals from CRM and Lehigh University on GALFAN will be submitted to all GALFAN licensees and urged that they consider supporting them for 1992.

GALFAN Continuous Improvement Program (GCIP):

Mr. Hostetler explained this new program which has been set up to help licensees improve their product quality. A manual has been developed which can be continuously updated as new information is developed on quality problems and their solutions. He asked that the people involved in the GALFAN process become involved with the GALFAN Technical Resource Center to improve this manual.

The first manual was issued in mid-August 1991 and included a section of ten problems. The next volume will be printed when the next series of problems and their solutions is written up. His scheme for continuously improving GALFAN was shown. Under this scheme, the licensees are expected to make suggestions as to ways to improve the quality of GALFAN. The Technical Resource Center will refine them by polling other licensees, publishing the solutions, and distributing them to the licensees for additional comments. The solution will then be further defined and distributed in its final form. Mr. Hostetler asked the licensees to take this program seriously because it can really help them solve their problems. He also asked that they register the continuous improvement manual in the name of someone in the operating department because this person has the most exposure to the problems and their solutions. Finally, he asked each licensee to nominate problems to the program.

Voest-Alpine Presentation on GALFAN Operations:

Mr. Hostetler noted that Voest-Alpine has recently started GALFAN production and asked Dr. Faderl to present his report to the group. A copy of this report is attached to these minutes.

Dr. Faderl showed a sample of the production which satisfied them as to its general appearance. A general introduction to Voest-Alpine's capabilities was given. They produce over 4 million MT of steel per year. The new No. 2 galvanizing line is described in the handout. The cost of this line was US $70 million. The only dissatisfaction they had were problems with formability and soldering in their GALFAN product. Regarding soldering, they have changed from a normal chloride-based flux to organic-based fluxes as described in their report. This is a flux normally used to solder aluminum. They then tried different solders and found that the tin-10% zinc solder worked the best, however it is more expensive then conventional solder.

He noted that they had been very pleased with the smoothness of their GALFAN coating operation. Good quality material was found from a time 10 minutes after initial start-up until the end of the trial. He noted the need to do a lot of work to introduce the product to the market. They have run into the darkening problem which has been a handicap in the opinion of their customers. Much more market development work needs to be done in the future.

Mr. Dubois asked if Voest-Alpine used a pot cooler in their operations. Dr. Faderl replied that they did not. Mr. Dubois asked why an Armco iron pot had been used to hold the zinc alloy. It was noted that this had resulted in severe contamination by iron. Dr. Faderl noted that his operations people had had a long discussion on the subject and finally decided to use the pot. Mr. Dubois asked if they had an electric heating arrangement for the holding pot or gas heating. Dr. Faderl noted that it was electrically heated. Mr. Dubois asked if there was any coating used on the Armco pot to prevent dissolution of the iron. Dr. Faderl replied that none was used. Mr. Ranta-Eskola asked if any accelerated cooling had been used in the Voest-Alpine trial. Dr. Faderl noted that they use a Heurtey device. This was used at several points during the GALFAN campaign, however he is not sure if it works very well. They did not see much difference in the quality of coatings which were treated this way versus the untreated coatings.

Mr. Busch asked how the hot gauge worked on the line. Dr. Faderl stated that it worked very well. Good readouts were obtained. Mr. Snyder asked if the air knife profiles were changeable on line. Dr. Faderl replied that they were and they used six profiles. Mr. Snyder asked if when Voest-Alpine changed nozzles if they could check the profile of the knife or whether its consequence for coating weights had to be determined. Dr. Faderl stated that they knew the profile of the knife when it was installed. The coating weight is obtained after this point.

Description of Thyssen Steel Trial:

Mr. Heiler described the recent production trial at Thyssen which had only occurred in the previous week.

Other Business:

Mr. Hostetler introduced Mr. Vogel of Wheeling-Pittsburgh Steel. Mr. Vogel noted that because the first Wheeling-Pittsburgh trial had only occurred in the last week, the information from the trial has not yet been written up. He did not wish to present it today so that it could be checked to be sure that it was correct, however they will assemble this information in the near future. Mr. Hostetler asked if there were any questions for Mr. Vogel. There were none at this point.

Mr. Hostetler then described the partnership which was proposed for developing GALFAN. As a partner, ILZRO is doing its part to improve the product and protect the patents. Alloy suppliers have a role in insuring the integrity of the alloy which is supplied to the GALFAN process licensees. He stated that their help is needed in minimizing the consequences in new trials also. Good equipment suppliers are also needed. Suppliers who join in the effort must be willing to help improve and promote GALFAN. The coating licensees must also do their part in the continuous improvement program.

Mr. Hostetler acknowledged the past important contributions of Austin Matthews of British Steel Corporation to the GALFAN licensees meetings. He regretted to inform the group that Mr. Matthews had been unable to attend this meeting, however Mr. Hostetler had been impressed with Mr. Matthews' paper which was given at Intergalva '91 in Barcelona. Mr. Hostetler had asked Mr. Matthews to prepare a paper for the licensees meeting. A copy of this paper is attached to these minutes. Mr. Hostetler then presented this paper to the group.

Mr. Hostetler then asked if any other points needed to be raised during the meeting. Dr. Faderl noted several points regarding the GALFAN development. First of all, he believed that an overview of all GALFAN research carried out in the past would be very useful to do. An interpretation of this research should be made part of the overview. He also asked that ILZRO supply recently-presented papers to the licensees. In the past this had been done and was found to be very useful. This should be done in addition to supplying the progress reports which appear periodically.

Technical support for lines starting up need to be provided by members of the licensees group. Their capabilities can be very valuable to others and prevent unnecessary expense. Finally, GALFAN members need an overview of the different lines which are used to coat GALFAN. Different technologies are used and should be common knowledge. Information on line operations needs to be shared to a greater extent. He also thought that newsletters on activities of GALFAN licensees regarding tonnages produced, start ups and interesting applications and developments were very useful to help promote GALFAN within the licensees as well as to the customers. He noted the need for more promotion work and thought that the cooperative project which was proposed for the European licensees would be very useful. He thought that we needed to share all of the problems with GALFAN along with all the accomplishments.

Mr. Hostetler asked for the licensees preferences in the scheduling of the meeting. Some of the group preferred it for the Spring while others thought it would be better in the fall. The group did not appear to have any strong preference.

Summary and Adjournment:

Dr. Goodwin summarized the outcome of the meetings of the last two days. The major outcomes from the presentations given by each of the licensees in these minutes was noted. Dr. Goodwin then thanked all the licensees for attending the meeting and especially gave his thanks to Weirton Steel and Wheeling-Pittsburgh Steel for hosting the licensees in their plants on October 2nd. Mr. Hostetler then adjourned the meeting at 11:40 a.m.

END

GALFAN LICENSEE MEETING

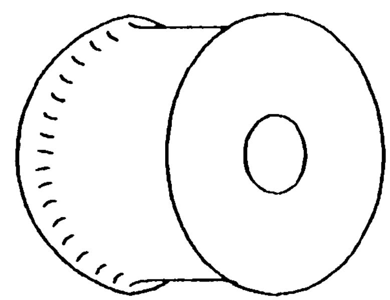
ROBUST DESIGN EXPERIMENT TO PREVENT SPOOLING ON GALFAN

Weirton Steel Corporation

October 2, 1991

WHAT IS SPOOLING?

- Coil edges are larger in diameter than the coil center.



- Results from heavier coating on strip edges.
- Must use stagger winding as remedial action.
- Can cause wavy edges during temper rolling.

WHAT IS ROBUST DESIGN?

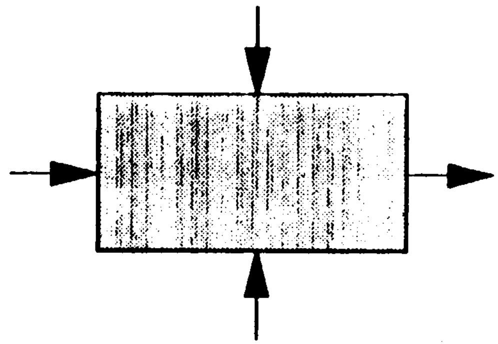
- A quality engineering technique aimed at "minimizing the effect of the causes of variation without eliminating the causes."
- Two important tasks:
  - Measurement of quality during design/ development.
  - Efficient experimentation to find dependable information about the design parameters.
- Based on the book QUALITY ENGINEERING USING ROBUST DESIGN by Dr. Madhav S. Phadke and guidance from the author.

GENERAL CLASSIFICATION OF PARAMETERS

"P" DIAGRAM

NOISE:
Parameters that cannot be controlled by the designer. Also those that are difficult or expensive to control.

SIGNAL:
Parameters set by the user or operator of the product to express the intended response of the product.



RESPONSE:
The output or some other suitable characteristic of the product.

CONTROL:
Parameters that can be specified freely by the designer. It is the designer's responsibility to determine the best values of these parameters. These parameters may be set at different levels.

"P" DIAGRAM FOR SPOOLING EXPERIMENT

NOISE:
Bath composition
Incoming strip profile
Incoming surface roughness
Tracking
Tandem mill (hold constant)
Gauge (hold constant)
Width (hold constant)

SIGNAL:
Horizontal
die distance

RESPONSE:
Coating weight from
tensile coupons;
5 positions across strip
(extreme edge to
extreme edge);
top and bottom

CONTROL:
Pickler
Line speed
Strip temp. entering bath
Bath temperature
Die pressure
Die height
Top die tilt
Bottom die tilt
Wiping medium (hold constant)
Die gap (hold constant)

CONTROL FACTORS TO VARY AND LEVELS SELECTED

FACTOR	*LEVEL 1*	*LEVEL 2*	*LEVEL 3*
a. Pickler	3	5	---
A. Bath Temperature (°F) (°C)	930 499	890 477	850 454
B. Line Speed (fpm) (mpm)	150 46	120 37	90 27
C. Strip Temperature Entering Bath (°F) (°C)	910 488	880 471	850 454
D. Die Pressure (psi) (kPa)	4.5 31	3.0 21	1.5 10
E. Die Height (in) (mm)	14 355	10 255	6 150
F. Top Die Angle (°)	-5 (down)	0 (even)	+5 (up)
G. Bottom Die Offset (° difference from top)	-1 (down)	0 (same)	+1 (up)

Normal starting level is identified by an underscore.

SIGNAL FACTOR TO VARY AND LEVELS SELECTED

FACTOR	*LEVEL 1*	*LEVEL 2*
Horizontal Die Distance (in) (mm)	1 25	2 51

STRUCTURE OF L_{18} ORTHOGONAL ARRAY PRESCRIBED FOR THE EXPERIMENT

Experiment		*Control Factors and Prescribed Levels*						
Number	***a***	***A***	***B***	***C***	***D***	***E***	***F***	***G***
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Run 18 experiments for each signal factor level.

PRESCRIBED EXPERIMENTAL CONDITIONS

EXP. NO.	DIE DIST. (in)	a PICK. NO.	A BATH TEMP. (°F)	B LINE SPEED (fpm)	C STRIP TEMP. (°F)	D DIE PRES. (psi)	E DIE HT. (in)	F TOP DIE ANGLE (°)	G BTM. DIE ANGLE (°)
1A	1	3	930	150	910	4.5	14	-5	-6
2A	1	3	930	120	880	3.0	10	0	0
3A	1	3	930	90	850	1.5	6	+5	+6
4A	1	3	890	150	910	3.0	10	+5	+6
5A	1	3	890	120	880	1.5	6	-5	-6
6A	1	3	890	90	850	4.5	14	0	0
7A	1	3	850	150	880	4.5	6	0	+1
8A	1	3	850	120	850	3.0	14	+5	+4
9A	1	3	850	90	910	1.5	10	-5	-5
10A	1	5	930	150	850	1.5	10	0	-1
11A	1	5	930	120	910	4.5	6	+5	+5
12A	1	5	930	90	880	3.0	14	-5	-4
13A	1	5	890	150	880	1.5	14	+5	+5
14A	1	5	890	120	850	4.5	10	-5	-4
15A	1	5	890	90	910	3.0	6	0	-1
16A	1	5	850	150	850	3.0	6	-5	-5
17A	1	5	850	120	910	1.5	14	0	+1
18A	1	5	850	90	880	4.5	10	+5	+4
1B	2	3	930	150	910	4.5	14	-5	-6
2B	2	3	930	120	880	3.0	10	0	0
3B	2	3	930	90	850	1.5	6	+5	+6
4B	2	3	890	150	910	3.0	10	+5	+6
5B	2	3	890	120	880	1.5	6	-5	-6
6B	2	3	890	90	850	4.5	14	0	0
7B	2	3	850	150	880	4.5	6	0	+1
8B	2	3	850	120	850	3.0	14	+5	+4
9B	2	3	850	90	910	1.5	10	-5	-5
10B	2	5	930	150	850	1.5	10	0	-1
11B	2	5	930	120	910	4.5	6	+5	+5
12B	2	5	930	90	880	3.0	14	-5	-4
13B	2	5	890	150	880	1.5	14	+5	+5
14B	2	5	890	120	850	4.5	10	-5	-4
15B	2	5	890	90	910	3.0	6	0	-1
16B	2	5	850	150	850	3.0	6	-5	-5
17B	2	5	850	120	910	1.5	14	0	+1
18B	2	5	850	90	880	4.5	10	+5	+4

REARRANGED ORDER FOR RUNNING EXPERIMENTS

RUN ORDER	EXP. NO.	DIE DIST. (in)	a PICK. NO.	A BATH TEMP. (°F)	B LINE SPEED (fpm)	C STRIP TEMP. (°F)	D DIE PRES. (psi)	E DIE HT. (in)	F TOP DIE ANGLE (°)	G BTM. DIE ANGLE (°)
1	3B	2	3	930	90	850	1.5	6	+5	+6
2	2B	2	3	930	120	880	3.0	10	0	0
3	1B	2	3	930	150	910	4.5	14	-5	-6
4	1A	1	3	930	150	910	4.5	14	-5	-6
5	2A	1	3	930	120	880	3.0	10	0	0
6	3A	1	3	930	90	850	1.5	6	+5	+6
7	12A	1	5	930	90	880	3.0	14	-5	-4
8	11A	1	5	930	120	910	4.5	6	+5	+5
9	10A	1	5	930	150	850	1.5	10	0	-1
10	13A	1	5	890	150	880	1.5	14	+5	+5
11	14A	1	5	890	120	850	4.5	10	-5	-4
12	15A	1	5	890	90	910	3.0	6	0	-1
13	15B	2	5	890	90	910	3.0	6	0	-1
14	14B	2	5	890	120	850	4.5	10	-5	-4
15	6A	1	3	890	90	850	4.5	14	0	0
16	5A	1	3	890	120	880	1.5	6	-5	-6
17	4A	1	3	890	150	910	3.0	10	+5	+6
18	7A	1	3	850	150	880	4.5	6	0	+1
19	8A	1	3	850	120	850	3.0	14	+5	+4
20	9A	1	3	850	90	910	1.5	10	-5	-5
21	9B	2	3	850	90	910	1.5	10	-5	-5
22	8B	2	3	850	120	850	3.0	14	+5	+4
23	18A	1	5	850	90	880	4.5	10	+5	+4
24	17A	1	5	850	120	910	1.5	14	0	+1
25	16A	1	5	850	150	850	3.0	6	-5	-5
26	16B	2	5	850	150	850	3.0	6	-5	-5
27	17B	2	5	850	120	910	1.5	14	0	+1
28	18B	2	5	850	90	880	4.5	10	+5	+4
29	12B	2	5	930	90	880	3.0	14	-5	-4
30	11B	2	5	930	120	910	4.5	6	+5	+5
31	10B	2	5	930	150	850	1.5	10	0	-1
32	13B	2	5	890	150	880	1.5	14	+5	+5
33	6B	2	3	890	90	850	4.5	14	0	0
34	5B	2	3	890	120	880	1.5	6	-5	-6
35	4B	2	3	890	150	910	3.0	10	+5	+6
36	7B	2	3	850	150	880	4.5	6	0	+1

PERSONNEL REQUIREMENTS AND DUTIES

#3 ENTRY → **#3 POT** → **#3 DELIVERY**

#3 ENTRY

1 Person required.
Responsible for:

a. Following line-up

#3 POT

7 people required.
Responsible for:

a. Die height & tilt
b. Die distance
c. Bath temperature
d. Marking strip
e. Line speed, knife pressure & strip temperature
f. Recording strip temperature at knives
g. Timing & coordinating

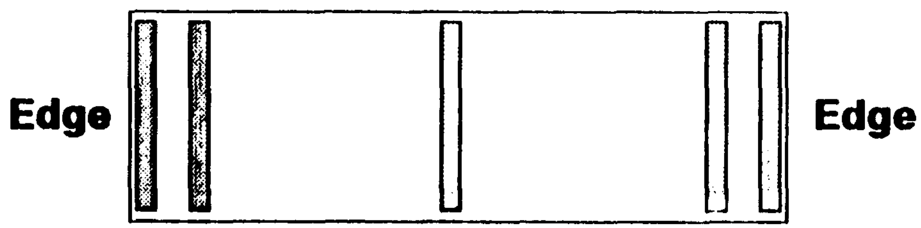
#3 DELIVERY

2 people required.
Responsible for:

a. Cutting samples
b. Labeling samples

DATA FROM EXPERIMENT

- Check that actual conditions were close to target.
- Two sheets obtained for each set of conditions.
  - First immediately after settings were on target.
  - Second just before adjusting settings for next experiment.
- Five tensile blanks punched across each sheet.

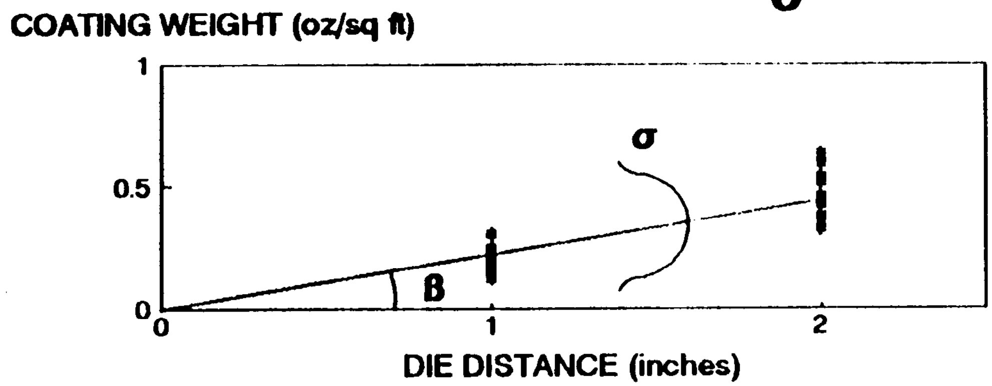


- Coating weights obtained top and bottom by weigh-strip-weigh.
  - Twenty individual coating weights for each set of conditions:

2 sheets X 5 blanks X 2 surfaces = 20 measurements

DEFINE SIGNAL TO NOISE RATIO

- Signal to Noise Ratio, Eta = $10\log_{10} \frac{\beta^2}{\sigma^2}$



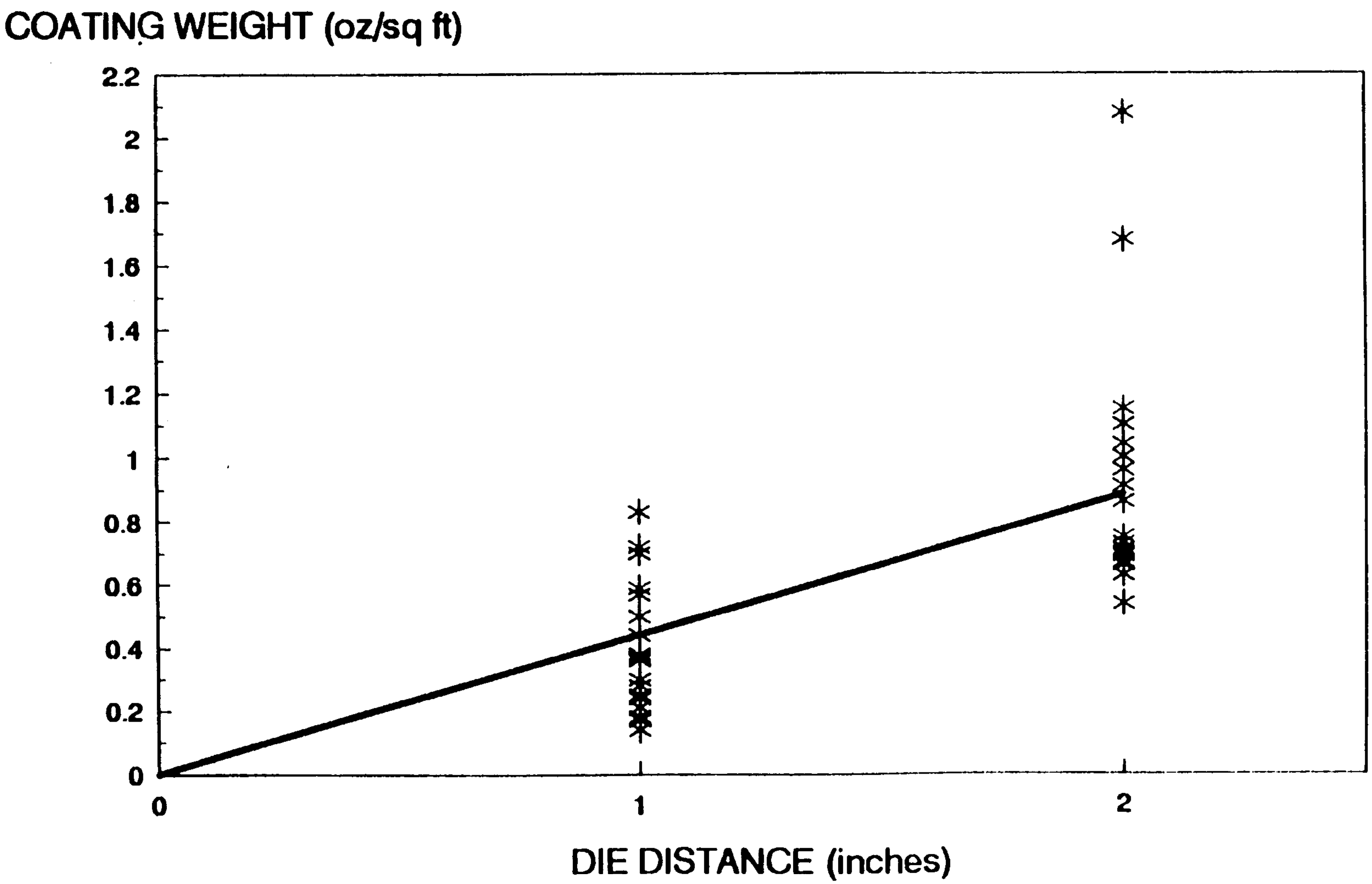
- Plot coating weight data versus die distance for the pair of experiments with common operating conditions.
  - ß is the slope of the best fit regression line constrained through 0.
  - σ is the standard error of the y estimate.
- It is desirable to have a high signal to noise ratio.

CALCULATE ETA FOR ALL 18 PAIRS OF EXPERIMENTS

	e	A	B	C	D	E	F	G	
EXP. NO.	PICK. NO.	BATH TEMP. (°F)	LINE SPEED (fpm)	STRIP TEMP. (°F)	DIE PRES. (psi)	DIE HT. (in)	TOP DIE ANGLE (°)	BTM. DIE OFFSET (°)	ETA
1	3	930	150	910	4.5	14	-5	-1	8.0
2	3	930	120	880	3.0	10	0	0	7.7
3	3	930	90	850	1.5	6	+5	+1	5.2
4	3	890	150	910	3.0	10	+5	+1	7.1
5	3	890	120	880	1.5	6	-5	-1	3.6
6	3	890	90	850	4.5	14	0	0	6.2
7	3	850	150	880	4.5	6	0	+1	7.6
8	3	850	120	850	3.0	14	+5	-1	4.8
9	3	850	90	910	1.5	10	-5	0	5.1
10	5	930	150	850	1.5	10	0	-1	3.3
11	5	930	120	910	4.5	6	+5	0	5.2
12	5	930	90	880	3.0	14	-5	+1	4.9
13	5	890	150	880	1.5	14	+5	0	6.8
14	5	890	120	850	4.5	10	-5	+1	9.5
15	5	890	90	910	3.0	6	0	-1	7.5
16	5	850	150	850	3.0	6	-5	0	5.5
17	5	850	120	910	1.5	14	0	+1	5.3
18	5	850	90	880	4.5	10	+5	-1	8.1
								AVG. ETA	6.2

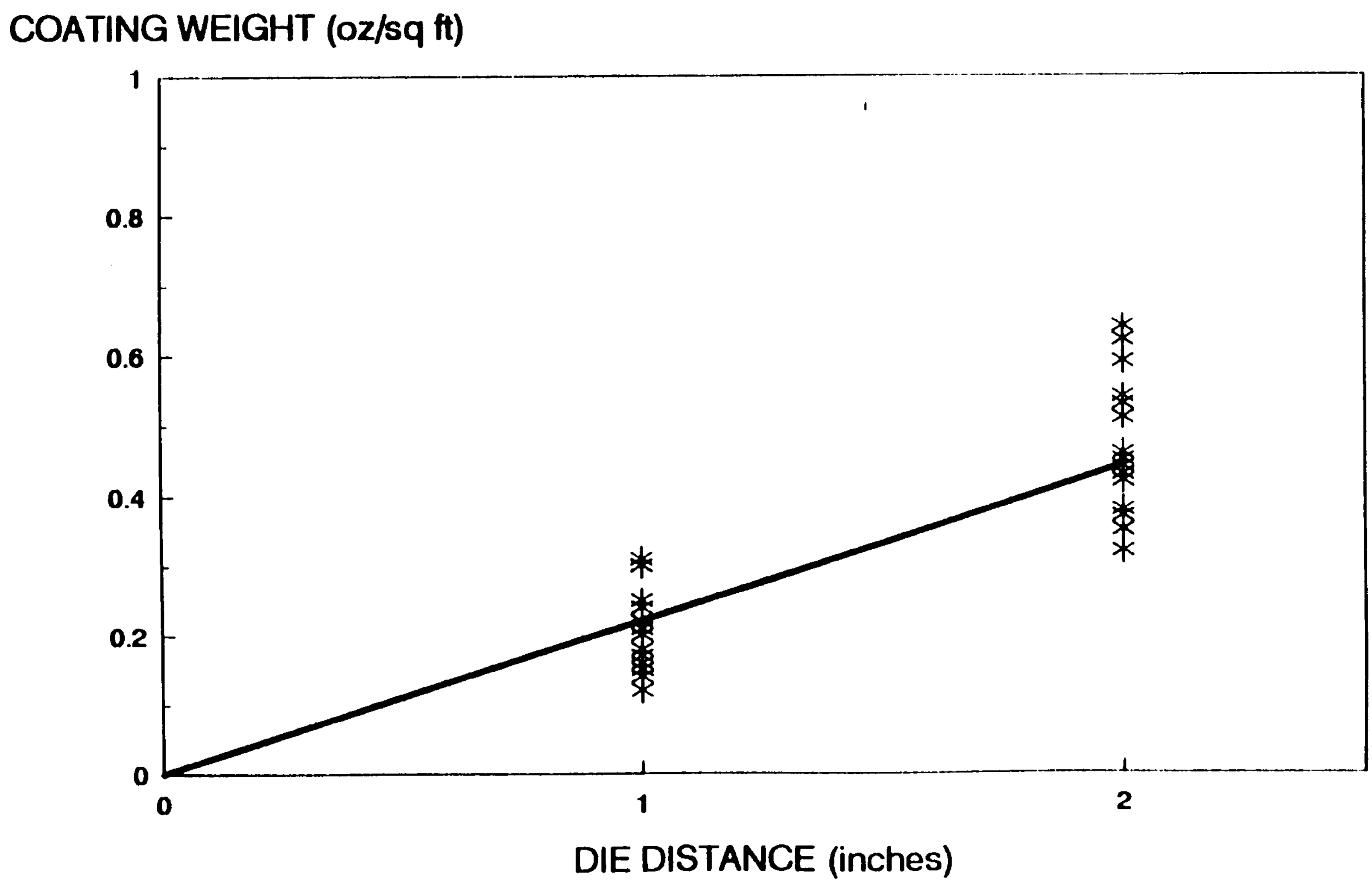
COATING WEIGHT VS. DIE DISTANCE

EXPERIMENT WITH LOWEST ETA - EXPERIMENT 10 ETA = 3.3



COATING WEIGHT VS. DIE DISTANCE

EXPERIMENT WITH HIGHEST ETA - EXPERIMENT 14 ETA = 9.5



CALCULATE AVERAGE ETA FOR EACH LEVEL OF EACH FACTOR

EXAMPLE: PICKLER NUMBER

EXP. NO.	a PICK. NO.	A BATH TEMP. (°F)	B LINE SPEED (fpm)	C STRIP TEMP. (°F)	D DIE PRES. (psi)	E DIE HT. (in)	F TOP DIE ANGLE (°)	G BTM. DIE OFFSET (°)	ETA	AVG. ETA FOR EACH LEVEL
1	3	930	150	910	4.5	14	-5	-1	8.0	
2	3	930	120	880	3.0	10	0	0	7.7	
3	3	930	90	850	1.5	6	+5	+1	5.2	
4	3	890	150	910	3.0	10	+5	+1	7.1	6.1
5	3	890	120	880	1.5	6	-5	-1	3.6	AVG.
6	3	890	90	850	4.5	14	0	0	6.2	LEVEL 1
7	3	850	150	880	4.5	6	0	+1	7.6	
8	3	850	120	850	3.0	14	+5	-1	4.8	
9	3	850	90	910	1.5	10	-5	0	5.1	
10	5	930	150	850	1.5	10	0	-1	3.3	
11	5	930	120	910	4.5	6	+5	0	5.2	
12	5	930	90	880	3.0	14	-5	+1	4.9	
13	5	890	150	880	1.5	14	+5	0	6.8	6.2
14	5	890	120	850	4.5	10	-5	+1	9.5	AVG.
15	5	890	90	910	3.0	6	0	-1	7.5	LEVEL 2
16	5	850	150	850	3.0	6	-5	0	5.5	
17	5	850	120	910	1.5	14	0	+1	5.3	
18	5	850	90	880	4.5	10	+5	-1	8.1	

CALCULATE AVERAGE ETA FOR EACH LEVEL OF EACH FACTOR

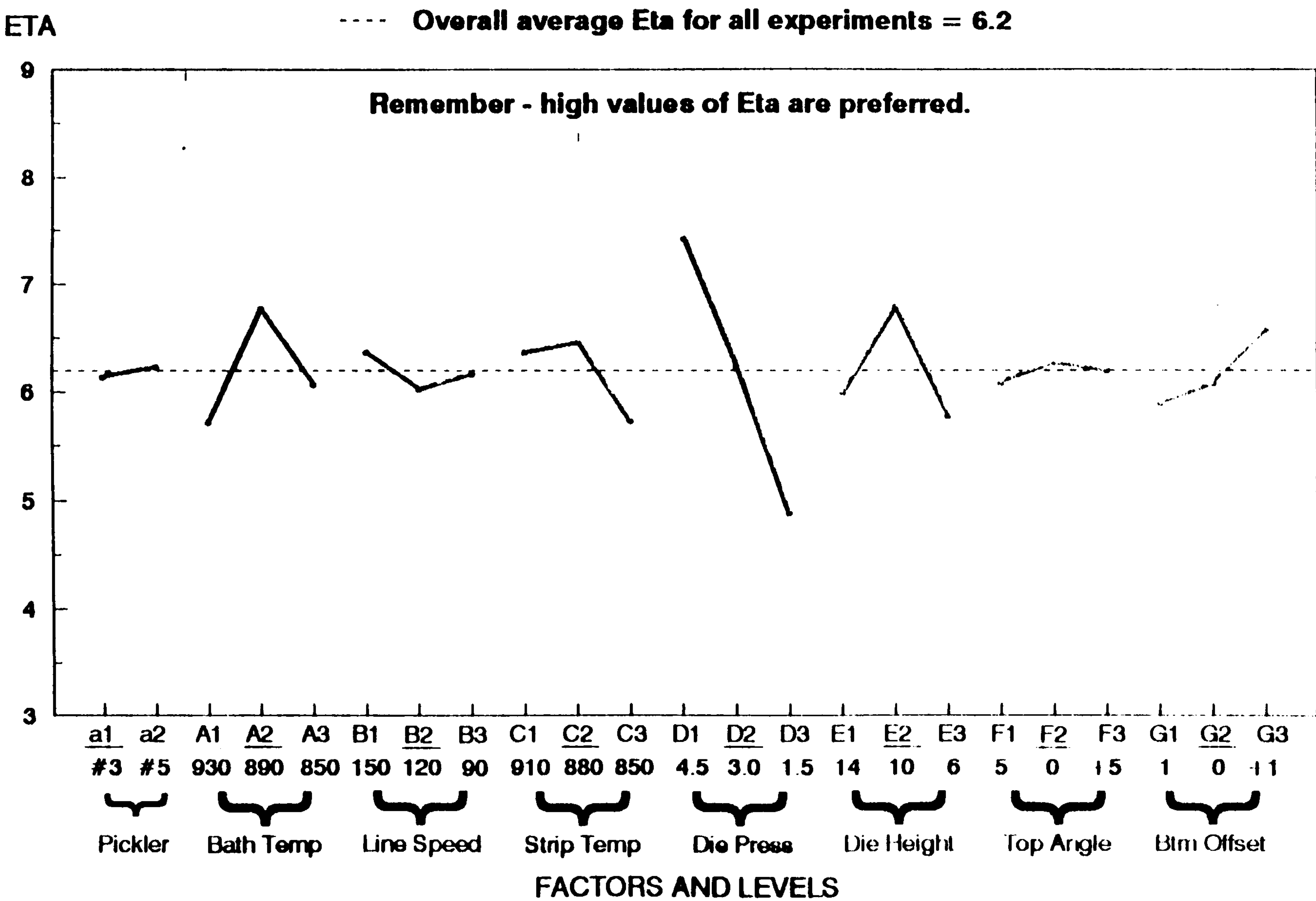
EXAMPLE: BATH TEMPERATURE

EXP. NO.	PICK. NO.	A BATH TEMP. (°F)	B LINE SPEED (fpm)	C STRIP TEMP. (°F)	D DIE PRES. (psi)	E DIE HT. (in)	F TOP DIE ANGLE (°)	G BTM. DIE OFFSET (°)	ETA	AVG. ETA FOR EACH LEVEL
1	3	930	150	910	4.5	14	-5	-1	8.0	
2	3	930	120	880	3.0	10	0	0	7.7	
3	3	930	90	850	1.5	6	+5	+1	5.2	5.7 AVG. LEVEL 1
10	5	930	150	850	1.5	10	0	-1	3.3	
11	5	930	120	910	4.5	6	+5	0	5.2	
12	5	930	90	880	3.0	14	-5	+1	4.9	
4	3	890	150	910	3.0	10	+5	+1	7.1	
5	3	890	120	880	1.5	6	-5	-1	3.6	
6	3	890	90	850	4.5	14	0	0	6.2	6.8 AVG. LEVEL 2
13	5	890	150	880	1.5	14	+5	0	6.8	
14	5	890	120	850	4.5	10	-5	+1	9.5	
15	5	890	90	910	3.0	6	0	-1	7.5	
7	3	850	150	880	4.5	6	0	+1	7.6	
8	3	850	120	850	3.0	14	+5	-1	4.8	
9	3	850	90	910	1.5	10	-5	0	5.1	6.1 AVG. LEVEL 3
16	5	850	150	850	3.0	6	-5	0	5.5	
17	5	850	120	910	1.5	14	0	+1	5.3	
18	5	850	90	880	4.5	10	+5	-1	8.1	

TABULATE AVERAGE ETA VALUES

FACTOR	*AVG. ETA FOR LEVEL 1*	*AVG. ETA FOR LEVEL 2*	*AVG. ETA FOR LEVEL 3*
a. Pickler	6.1	6.2	---
A. Bath Temperature (°F)	5.7	6.8	6.1
B. Line Speed (fpm)	6.4	6.0	6.2
C. Strip Temperature Entering Bath (°F)	6.4	6.5	5.7
D. Die Pressure (psi)	7.4	6.2	4.9
E. Die Height (in)	6.0	6.8	5.8
F. Top Die Angle (°)	6.1	6.3	6.2
G. Bottom Die Offset (° difference from top)	5.9	6.1	6.6

PLOT AVERAGE ETA VALUES (FACTOR EFFECTS)



SELECT OPTIMUM LEVELS

FACTOR	*LEVEL 1*	*LEVEL 2*	*LEVEL 3*
a. Pickler	3	5	---
A. Bath Temperature (°F)	930	890	850
B. Line Speed (fpm)	150	120	90
C. Strip Temperature Entering Bath (°F)	910	880	850
D. Die Pressure (psi)	4.5	3.0	1.5
E. Die Height (in)	14	10	6
F. Top Die Angle (°)	-5 (down)	0 (even)	+5 (up)
G. Bottom Die Offset (° difference from top)	-1 (down)	0 (same)	+1 (up)

Normal starting level is identified by an underscore.
Optimum level is shown in BOLD

EXPERIMENTS RUN AT NEAR OPTIMUM SETTINGS

FACTOR	*OPTIMUM SETTINGS*	*INTERIM VERIFICATION EXPERIMENT*	*EXP. #14 (HIGHEST ETA)*
a. Pickler	3 or 5	3	5
A. Bath Temperature (°F)	890	910	885
B. Line Speed (fpm)	150	120	120
C. Strip Temperature Entering Bath (°F)	880	910	850
D. Die Pressure (psi)	4.5	4.1	4.5
E. Die Height (in)	10	10	10
F. Top Die Angle (°)	-5 or 0 or +5	+5 (up)	-5 (down)
G. Bottom Die Offset (° difference from top)	+1	0 (same)	+1 (up)
Eta		7.6	9.5

Settings in blue are close to optimum.

CONCLUSIONS

- Valuable information was obtained on factors which contribute to uniform coating.
- Nearly all of the optimum conditions have been incorporated into standard operating procedures.
- Die pressure had the largest single effect on coating uniformity.
- Optimum die pressure of 4.5 psi was not adopted.
  - Cannot sustain this pressure without draining nitrogen supply to furnace atmosphere.
  - Dies cannot be moved far enough away from strip to obtain required coating weights because of pot hardware restrictions.

CONCLUSIONS (cont.)

- Strip surface appearance varied widely as conditions were changed.
- Additional benefits of experiment beyond initial objectives:
  - Data and samples available for other analyses.
  - Learned which parameters would "outrun" the jet coolers.
- Experimental design was efficient.
  36 experiments for robust design.
  8748 experiments for full factorial design.
- Experiments required considerable planning and teamwork.

NEXT STEPS

- Further analysis of data and consultation on results.
- Evaluation of samples to optimize surface appearance and minimize intermetallic formation.
- Verification experiments using optimum (or best practical) conditions.
- Calibration experiments varying die distance over the range necessary to achieve all ordered coating weights.
- Additional consideration of coating die parameters.
- Extend findings to other gages and widths of product.

WEIRTON STEEL

GALFAN/GALVANIZE COATING ANALYSIS

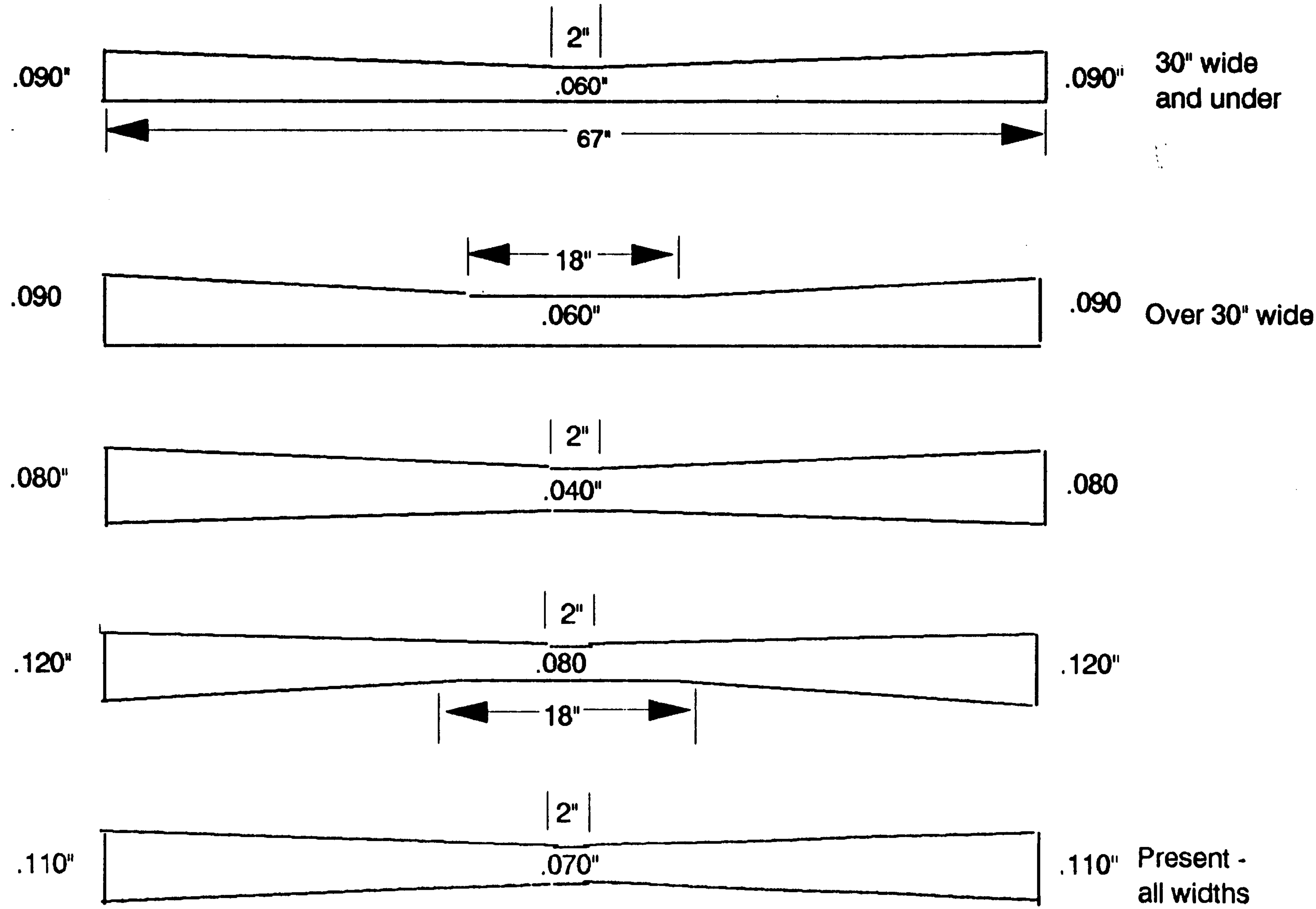
16TH GALFAN LICENSEES' MEETING
PITTSBURGH, PA.
OCTOBER 2-4, 1991

BASIS OF COATING ANALYSIS

- 18% OF ALL IN-HOUSE REJECTS WERE COATING RELATED (RIDGE, SPOOL, POOR COATING AND DIE LINES).
- EDGE-CENTER-EDGE COATING DIFFERENTIALS WERE TOO GREAT .
- 2 SETS OF DIES WERE USED TO COAT ENTIRE PRODUCT RANGE .

- GAP CONFIGURATION
- INCREASED COOLING VS. SPEED
- STRIP VS. BATH TEMPERATURES
- N_2 WIPING
- BURR MASHERS AFTER COATING
- OUTFLOW (IF POSSIBLE)

DIE GAP CONFIGURATIONS

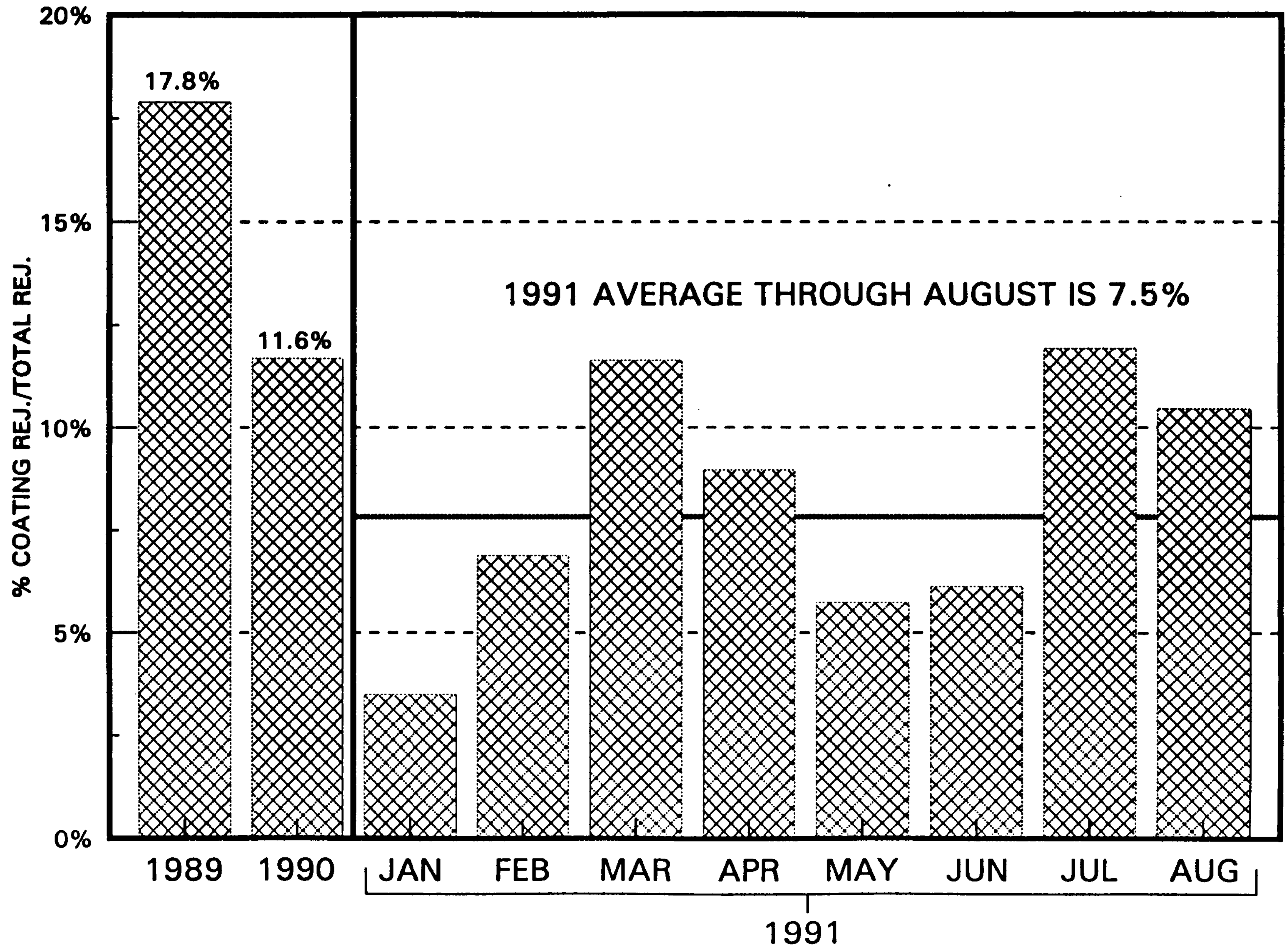


GALFAN S.O.P.

.057 X 29, G90 U COATING

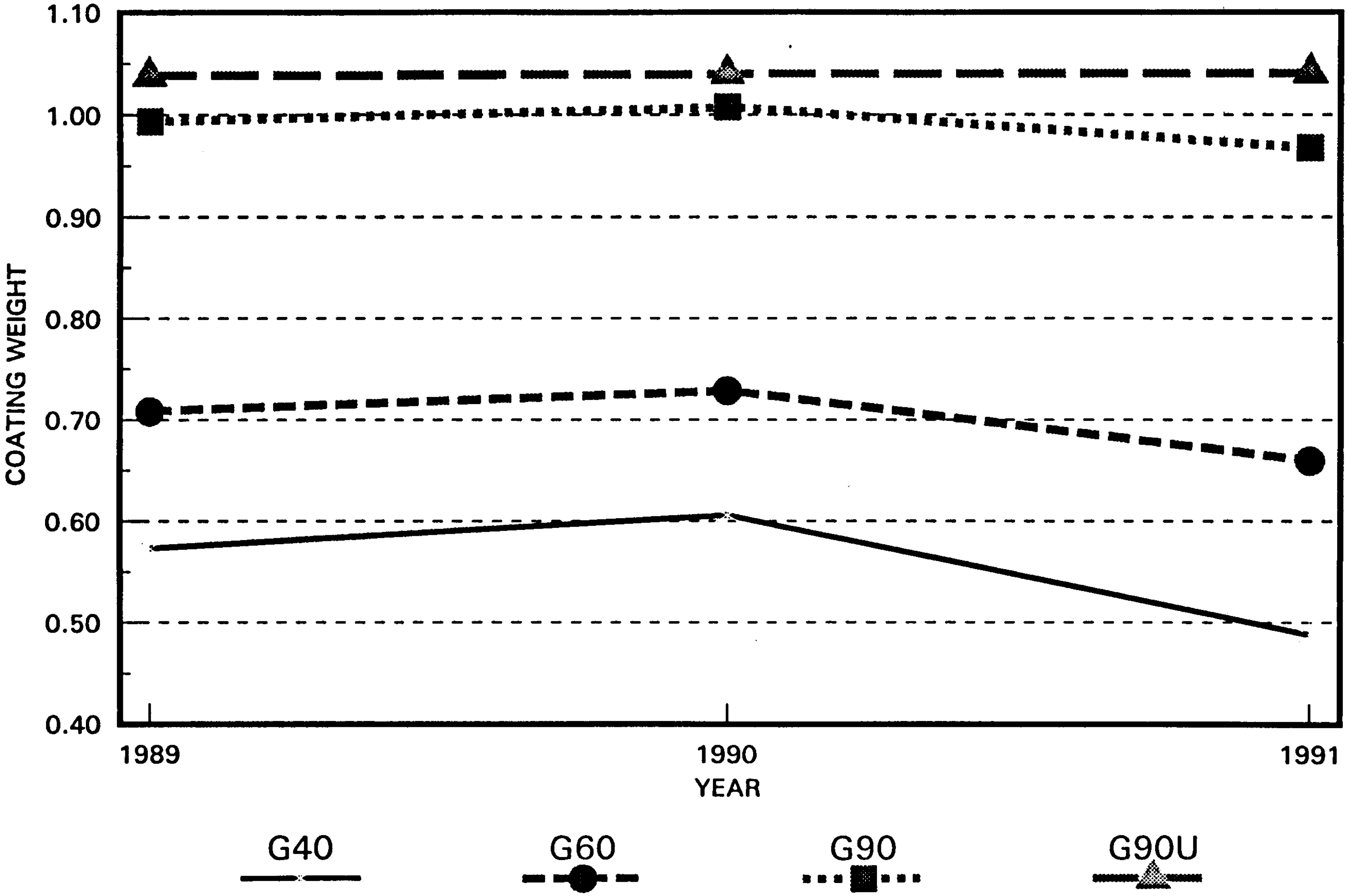
	SPOOLED AND STAGGER WRAPPED COILS	COILS WRAPPED STRAIGHT UP
SPEED	120 FPM	150 FPM
AFTERCOOLING	14,100 CFM	20,000 CFM
TOWER ROLL STRIP TEMPERATURE	668° F.	668° F.
WIPING AGENT	AIR	NITROGEN
KNIFE PRESSURE	1.5 PSI	1.5 PSI
STRIP TEMPERATURE ENTERING BATH	896° F.	891° F.
GALFAN BATH TEMP.	882° F.	902° F.
COATING PROFILE	140-111-159 $\frac{OZ.}{FT^2}$	97-108-94 $\frac{OZ.}{FT^2}$
BURR MASHER AFTER COATING	NO	YES

SHEET MILL COATING RELATED REJECTS



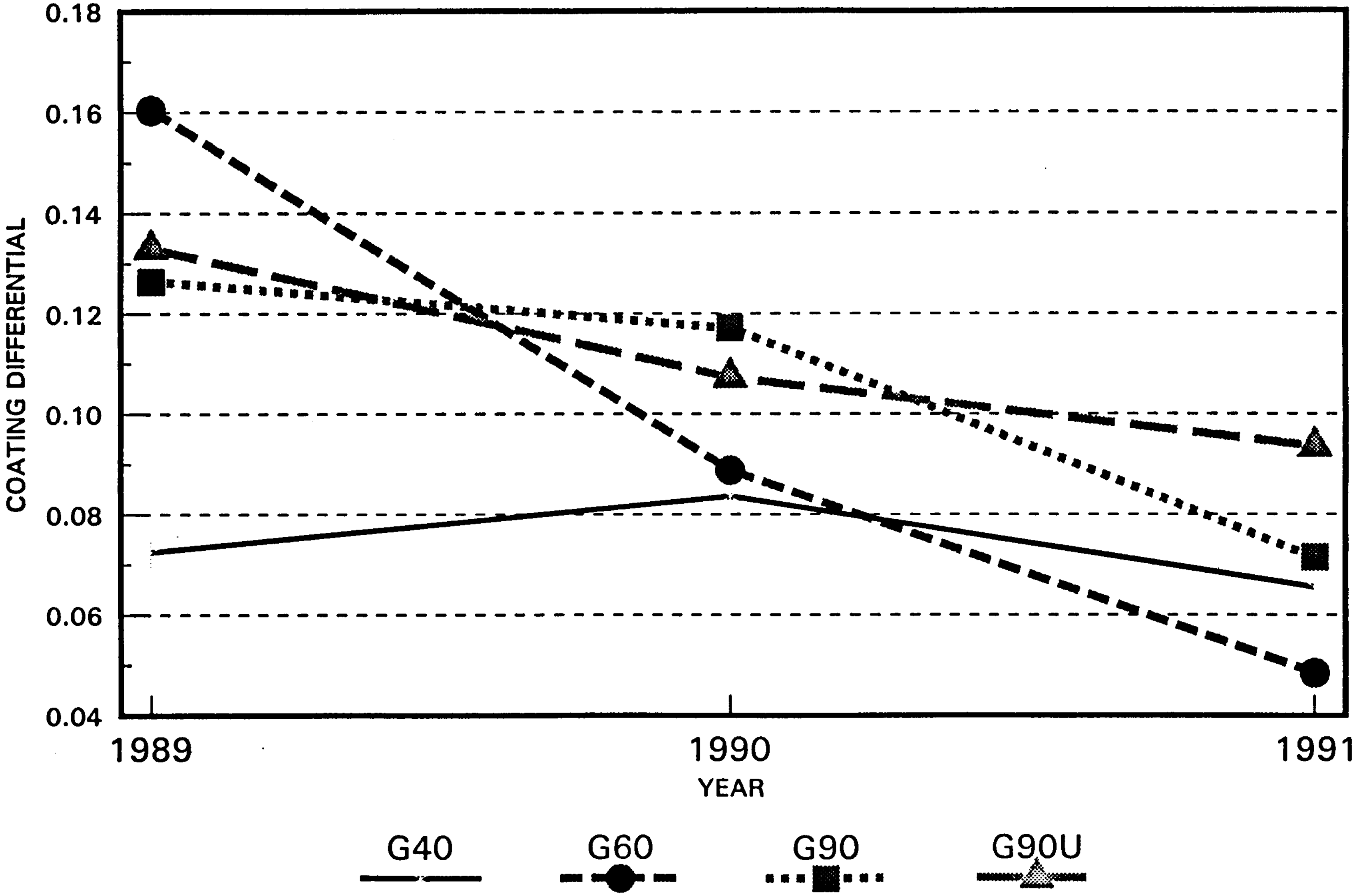
SHEET MILL COATING ANALYSIS

AVERAGE CROSS SHEET COATING



SHEET MILL COATING ANALYSIS

AVERAGE CROSS SHEET DIFFERENTIALS



5/14/91 7-3

#3 GALVANIZE LINE OPERATING PARAMETERS

CUSTOMER		
MILL ORDER NO.	243705-018	
GAUGE	.057	
WIDTH	29.5	
COATING	G90	
ID		
OIL		
CHEMTREAT	YES	
SPEC	HD1989889	
END USE	BASE FOR WASHER	
MIN. WEIGHT	10,000	LBS.
MAX. WEIGHT	19,450	LBS.
SPEED	150	FPM
2 ZONE STRIP TEMP.	900	°F
4 ZONE STRIP TEMP.	1330	°F
8 ZONE STRIP TEMP.	1395	°F
12 ZONE STRIP TEMP.	1320	°F
CHUTE STRIP TEMP.	891	°F
JET COOLER SETPT.	900	°F
JET COOLER RUNNING	100	%
POT TEMPERATURE	897	°F
TOWER ROLL TEMP.	668	°F
GALFAN POT TEMP.	902	°F
TOP AFTERCOOLER FLOW	7116	CFM
BTM AFTERCOOLER FLOW	12839	CFM
TOP DIE PRESSURE	1.5	PSI
BOTTOM DIE PRESSURE	1.5	PSI
TOP DIE FLOW	628	CFM
BOTTOM DIE FLOW	595	CFM
AIR/NITROGEN	NITROGEN - 80°	

	ACTUAL/SETPT.	
ZONE 1	1720 / 1720	°F
ZONE 2	1700 / 1700	°F
ZONE 3	1740 / 1800	°F
ZONE 4	1660 / 1700	°F
ZONE 5	1700 / 1700	°F
ZONE 6	1700 / 1700	°F
ZONE 7	1700 / 1700	°F
ZONE 8	1720 / 1750	°F
ZONE 9	1240 / 1200	°F
ZONE 10	1200 / 1200	°F
ZONE 11	1140 / 1120	°F
ZONE 12	1140 / 1120	°F
ZONE 13	800 / 800	°F
ZONE 14	740 / 700	°F
ZONE 15	640 / 700	°F
DEWPOINT	+17.2	°F
%HYDROGEN	20	%
FURNACE PRESSURE	+.05	"W.C.
COAT WEIGHT TEST	97-106-94 ~~108-115-99~~	
ROCKWELL TEST	53-53-52	
OLSEN TEST	540-540-535	
DIE HEIGHT ABOVE BATH	8	IN.
ENTRY WINCH AMPS		
DELY. WINCH AMPS		
TENSION		LBS

CAPTION DQ SP KILLED WEIRKOTE PLUS GALFAN - #

L# OR C# DATA TAKEN FROM L344528, 29,-39

SPECIAL NOTES: COAT WEIGHTS 91/92 -- 106/107 -- 97/102 -- STRIP RIDING ON 60-40-60

- ADDED METAL -- 5 MIN. POT DROPPED TO 874. SET JET COOL FROM 900 TO 940 TO HEAT POT UP. STRIP APPEARANCE STAYED SAME. IN 10 MIN. POT CAME UP TO 892.
- START REEL TENSION AT 100 AMPS AND DROPPED TO 60 AMPS AFTER 600 FT. ON REEL ~~KEEP AT 50 AMPS.~~ AIR BLOWER PIPES ON. #4 BLOWER ON -- #5 BLOWER OFF

ZINC COATING OF INTERSTITIAL-FREE STEEL SHEET

A. R. Marder

Energy Research Center, Lehigh University
Bethlehem, Pennsylvania, USA 18015

Abstract: - The improved formability and high strength of interstitial-free steel offers great promise as a coated sheet product. However, The presence of a reactive solute element such as titanium, may greatly affect the reaction kinetics during the coating process. The formation of extremely stable oxides during deoxidation of the sheet steel prior to immersion in the zinc bath can influence coatability. As a result of carbon and nitrogen stabilization by titanium, the presence of highly reactive surfaces and grain boundaries increase the occurrence of "outburst" structures in IF steels during galvanizing. Consequently, Ti and Ti+Nb stabilized IF steel significantly influence the formation kinetics of galvanneal coatings. The solidification sequence of zinc coatings with increased aluminum additions, like that found in eutectic decomposition alloys such as GALFAN, are particularly improved with the use of IF steel substrates. Nevertheless, the role of solute Ti and Ti+Nb in Fe-Zn-Al ternary diffusion is not clearly defined and as a result the optimum solute composition for improved coating performance has not been determined. Furthermore, the effect of the coating thermal cycle on IF steel substrate properties needs to be evaluated. Although improved formability and high strength can be obtained with zinc coated sheet steel products, the role of IF steel solutes on coating reaction kinetics is not well defined.

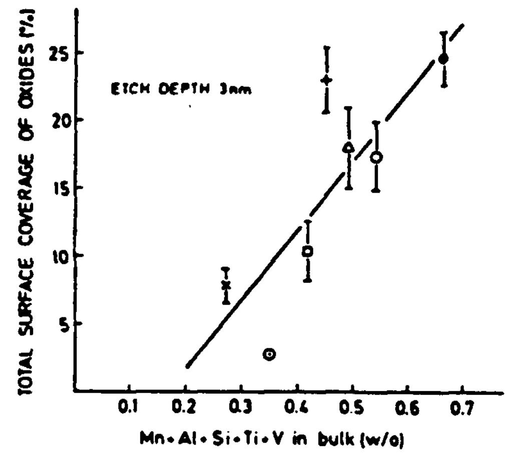
INTRODUCTION

Interstitial-free (IF) steel (1), produced by additions of titanium and/or niobium to an extra low-carbon grade to precipitate interstitial carbon and nitrogen atoms, is being utilized as a steel sheet product with excellent deep drawability and non-aging properties. Low carbon aluminum-killed deep drawing quality sheet is difficult to produce by the continuous annealing process. Continuous annealing is more easily utilized with titanium steels to produce high r value deep-drawing quality sheet (2). In 1979, IF steel, in addition to aluminum-killed steel, was first applied in production quantities when hot-dip galvanized steel sheet was initially used for corrosion-resistant automotive panels. The continuous galvanizing line (CGL), continuous annealing equipment without an over-aging heat treatment furnace, is most suitable for the production of excellent formable coated IF sheet. The use of IF steel is less costly and provides coated sheet products with better formability than that of the alternative low-carbon aluminum killed steel by the heat treatment achievable on the CGL (3). However, the various carbide forming elements in IF steel can significantly influence the alloying kinetics and adherence of the zinc coating of hot-dip galvanized and galvanneal steel sheet. It is the purpose of this paper to review the present understanding of the use of IF steel as a coated sheet product.

ANNEALING PRIOR TO GALVANIZING - SURFACE EFFECTS

In the CGL Sendzimir process, cold rolled sheet is continuously annealed in a N_2/H_2 atmosphere before it is immersed in the Zn bath. The objectives of this heat treatment step are: (a) to recrystallize the structure after cold rolling and (b) to reduce the surface oxides. A complexity of the process is that the hold time at the annealing temperature is made shorter than is usually found in batch annealing. The surface chemical composition of low carbon steel is critical to the sheet surface properties such as: phosphatability, paint adhesion and the adhesion of metallic and intermetallic compounds formed during metallic coating. Investigations of the surface of annealed sheet steel have shown that selective surface oxidation of Mn, Si, Al, V, Cr and Ti occurs (4-9). According to most authors, the oxide particles are concentrated at the grain boundaries. The oxide particles on the surface can influence Zn coating formation by decreasing surface wetting and providing a barrier to the diffusion necessary for the formation of the intermetallic Fe-Zn compounds.

In the process of cold rolling, the newly created surface is spontaneously oxidized to Fe-oxide and Fe-hydroxide (4). Olefjord et. al. (4) showed that the original film is completely reduced and that noticeable selected surface oxidation of the strongly oxide forming elements - Mn, Si, Al, V and Ti, occurs. The total oxide coverage as a function of the sum of the oxide forming elements is given in Figure 1. The oxides do not form a continuous layer on the surface but are present as islands. In the case of Ti stabilized steel, TiO_2 is present on the surface as a separate phase down to 10nm. For the Nb stabilized steel, Nb or niobium oxide was not detected on the surface. The nonuniform distribution is to be expected since the available time for the diffusion of the elements is so limited that easy diffusion paths, such as grain and subgrain boundaries, must clearly be favored sites for oxidation of the reactive elements. It is of interest to note that because discrete particles are formed at the grain boundaries, there are other particle-free grain boundary areas that can still react with the Zn bath.



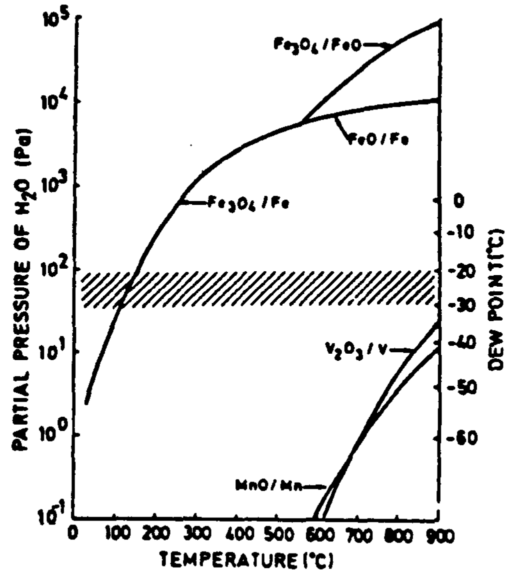


Fig. 1. Total surface coverage of the oxides versus the sum of the bulk concentration of the elements - Mn, Al, Si, Ti and V.

Fig. 2. Equilibrium partial pressure of water pH_2O, for reactions of the type: $x/y\ M + H_2O \rightleftarrows y^{-1}\ M_xO_y + H_2$.

Figure 2 shows the equilibrium diagram for reactions of the type:

$$x/y\ M + H_2O \rightleftarrows y^{-1}M_xO_y + H_2$$

where M is the cation forming element. The shaded area in the figure represents the range of temperature and dew points investigated by Olefjord, et. al. (4). From this figure it is obvious that Fe_3O_4 would be reduced above 150°C at a dew point of -20 to -30°C, while the alloy elements will be oxidized over the entire temperature range. The equilibrium curves for oxidation of Ti, Si and Al are beneath the bottom of the figure.

Although some investigators show discrete oxide particles forming, others discuss the possibilities of surface enrichment and internal oxidation. In a recent study (10), it was found that high titanium contents favored alloy formation in simulated hot-dip galvanized alloys. The increase in titanium provided a higher amount of free titanium that led to enhanced surface enrichment. Although it was found that with higher dew points surface enrichment with highly oxidizable elements (Al, Ti, Si, Mn) is lower, the layer affected by internal oxidation is thicker. However, no quantitative measure of titanium segregation or internal oxidation was determined. In addition, the influence of cooling rate after hot rolling was studied and it was found that surface enrichments were more important when samples were slowly cooled. Slow cooling was found to favor Fe-Zn alloy formation and not the inhibiting Fe-Al alloy layer. Thus, the results were in good agreement with the proposal that surface oxides favor the formation of Fe-Zn alloy (11) and in conflict with proposal that Fe-Zn alloy formation is due to higher reactivity of the grain boundary as a result of a deficiency of free carbon and nitrogen (12), a mechanism to be discussed in the next section. The effect of substrate grain size and the influence of soluble Ti on the kinetics Fe-Zn alloy formation was not discussed.

HOT-DIP PROCESSING - INTERFACE KINETICS

Galvanize (Zn)

As documented by other researchers (12, 13), in low Al (<0.25%) Zn baths, galvanizing interstitial free steel results in localized areas of accelerated Fe-Zn alloy phase growth, or what is referred to as outburst structures. Because outburst structures formed during galvanizing directly influence the final galvanneal coating microstructure and properties, an understanding of outburst formation is critical. The following outlines the development of outburst structures.

Due to the high chemical affinity iron has for aluminum, rapid growth of an Fe_2Al_5 intermetallic compound layer occurs upon immersion of the sheet into the zinc bath. Lucas et. al. (14) determined through atomic absorption analysis and coulometric dissolution that the aluminum content of galvanized coatings on titanium stabilized interstitial free steel was 2.5 to 2.7 times greater than the aluminum level measured in the bath, and that 87-90% of the total aluminum content in the coating was situated at the steel/coating interface, at the location of the Fe-Al intermetallic compound layer. Fukuzuka et. al. (15) did similar work on determining aluminum concentration gradients within a galvanized coating on both low carbon and titanium stabilized steel using electron microprobe analysis. For the case of the low carbon steel, the aluminum concentration in the coating increased at the steel/coating interface, but for the Ti-stabilized steel there was no change in aluminum concentration throughout the coating. In the as galvanized condition there seems to be some discrepancy of aluminum concentration fluctuations within the coating.

After the formation of the Fe-Al intermetallic compound, zinc diffuses into the interfacial layer and reacts with iron at chemically active grain boundaries where there has been a depletion of aluminum. Breakdown of the Fe-Al inhibition layer initially occurs at substrate grain boundaries (12, 13). Due to the volume expansion of the Fe-Zn compound that forms within the Fe_2Al_5 layer, cracks develop in the intermetallic compound and thus allow for the rapid diffusion of zinc into the localized area and subsequent growth of Fe-Zn phase occurs at grain boundaries. A schematic for this theory of outburst formation is shown in both Figure 3 (13), and Figure 4 (12).

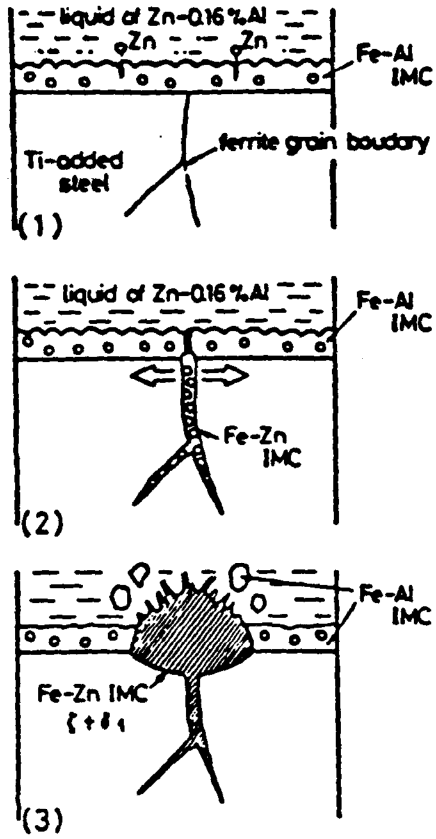


Fig. 3. Schematic diagram showing the outburst behavior.

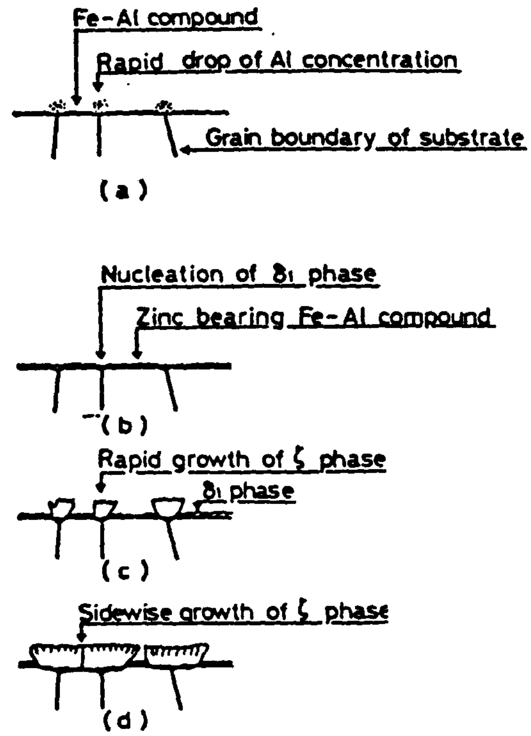


Fig. 4. Schematic illustration showing a formation model of Fe-Zn compounds.

Hisamatsu (13) has demonstrated that outbursts are directly related to a grain boundary and Figure 5 shows an example for a Ti added steel immersed for 15 seconds in a bath with 0.16% Al (450°C, Fe saturated). In steels with C or P, these elements easily segregate to grain boundaries and retard outburst formation of the Fe-Zn intermetallic compound. However, in steels with Ti or Nb, interstitial elements of C and N are stabilized and the ferrite grain boundaries remains pure of solute. As a result, the outburst of Fe-Zn intermetallic compound at the grain boundary is accelerated. Figure 6 shows the effect of total carbon content on outburst formation in several steel substrates. The results appear to confirm the concept that increased carbon and phosphorous will segregate at grain boundaries and retard outburst formation. Although free solute carbon was not measured, the data shows that IF steels will enhance the Fe-Zn intermetallic reaction.

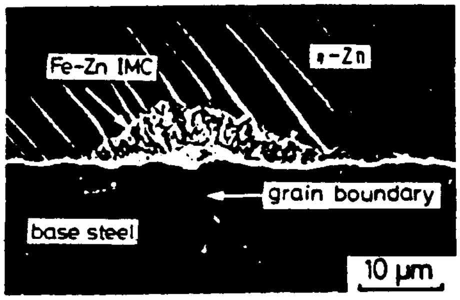


Fig. 5. Outburst reaction at a ferrite grain boundary in a Ti-IF steel.

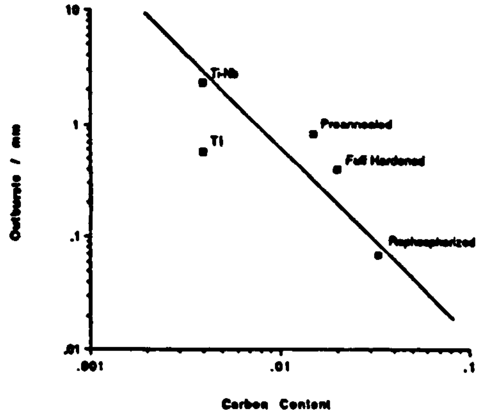


Fig. 6. The effect of total carbon content on outburst formation in several steel substrates.

GALFAN (Zn - 5% Al)

Eutectic Zn - 5% Al GALFAN coatings provide much higher Al contents in the bath that can react with the steel substrate. Recently (16, 17) it has been found that IF steels can improve the surface properties of GALFAN coatings, which are often characterized by dents that can be as deep as 20 microns. The resulting rough surface appearance often renders the coating improper for many applications. This problem has been associated with the Zn-Al eutectic lamellar morphology, with dents occurring at the junction of differently oriented eutectic cells, Figure 7a. The lamellar morphology is inherent to the eutectic composition due to solute and curvature undercooling effects (16). Denting has been observed at aluminum concentrations of 4.0-7.0 wt% and quantified with the use of mechanical scanning microscopy and Fourier-modified measurement techniques. Roughness is, however, most severe at the eutectic composition (approximately 5.2 wt% Al), as the lamellar morphology is obviously most prevalent at this composition.

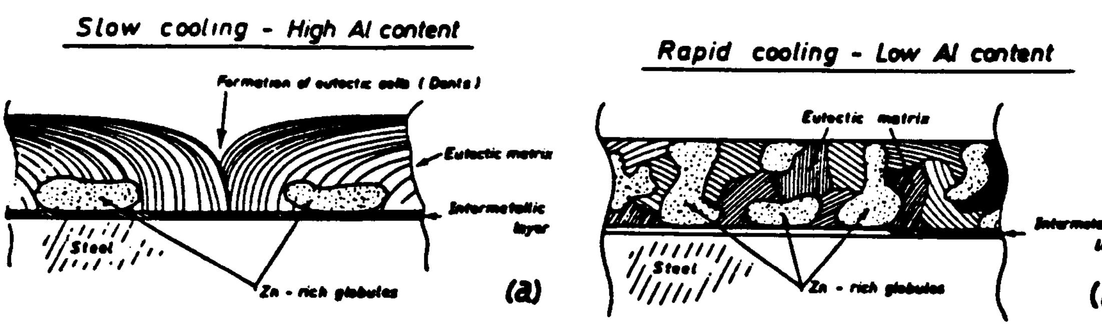


Fig. 7. Effect of Al content and cooling rate on intercellular dents.

Past efforts to remedy the denting problem have included (1) reductions in aluminum concentration, and (2) increased coating solidification rates. By the former method, large zinc-rich particles form across the coating thickness and the eutectic morphology formation is therefore limited (16), Figure 7b. Although the depth of denting can be slightly decreased by this method, the resulting coating may possess inadequate corrosion resistance in humid environments and suffer a considerable reduction in ductility when compared to eutectic GALFAN. By the second method, the zinc-rich globules typical to GALFAN coatings are smaller and more numerous, and act to inhibit interlamellar dent formation. In addition, the interlamellar spacing of the eutectic morphology and the subsequent susceptibility to denting is decreased at higher cooling rates. Moderate reductions in dent depths have been attained by this technique, although the total number of dents can be increased significantly.

Recently, the use of IF steel as a GALFAN substrate material has been found to substantially reduce the depth of interlamellar denting (16, 17). The resulting dents are much more shallow than those achieved by the other noted techniques, with depths being reduced by up to 50% when compared to those found when traditional extra low carbon (ELC) steel is used as a substrate, Figure 8. The coating microstructures for both substrates are similar, as both are primarily eutectic in nature with equivalent mean eutectic cell sizes. In the case of the IF steel substrate, however, the zinc-rich particles are smaller and more numerous, and the bulk coating aluminum distribution is much more homogeneous due to the formation of large $FeAl_x$ (x=2 or 3) particles at the steel-coating interface. The occurrence of these intermetallics is thought to be controlled by the steel grain boundary reactivity and/or the presence of titanium oxide at the steel surface prior to dipping. The cause for dent depth reduction is not clear, but is thought to be associated with the non-homogeneous aluminum distribution in the coating, which reduces the potential for chemical segregation and subsequent denting.

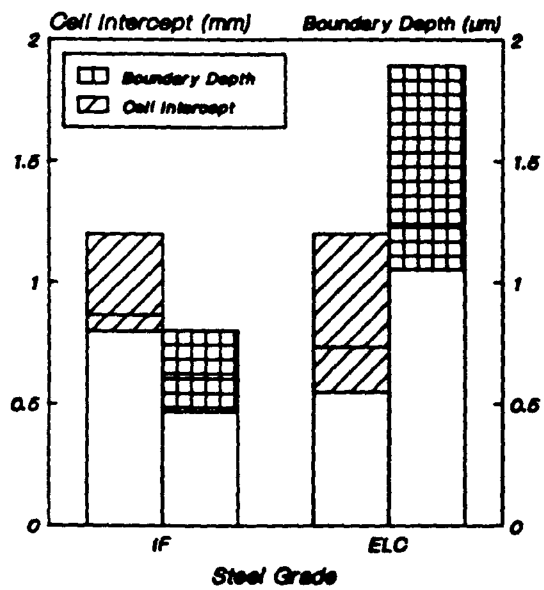


Fig. 8. Effect of steel substrate on GALFAN cell structure and boundary depth.

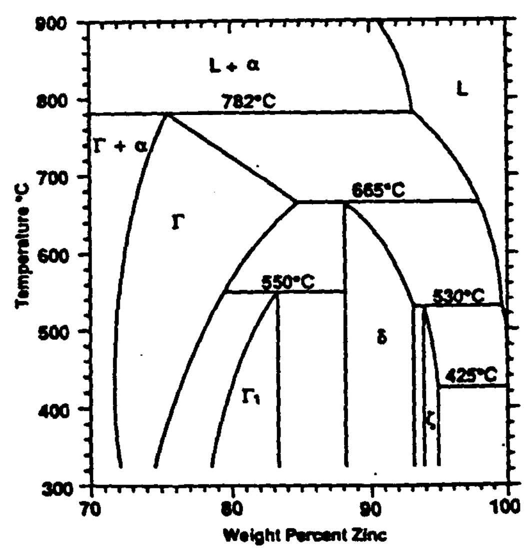


Fig. 9. Zinc-iron binary phase diagram.

GALVANNEALING - MORPHOLOGY AND POWDERING

Galvannealing is the process of heat treating the sheet following galvanizing. The sheet is annealed for a time sufficient enough to allow for the conversion of the zinc layer to an alloyed coating containing iron-zinc intermetallic compounds. Galvannealed coatings have superior weldability, paintability and cosmetic corrosion resistance over that of pure zinc coatings.

Understanding the reaction between iron and zinc is the basis for developing a high performance galvannealed sheet. Because the galvannealing process is dependent upon the interdiffusion of iron and zinc, Fe-Zn compounds form in order of increasing iron content, with the most iron rich phases forming last (see Figure 9). Upon annealing the as-galvanized structure, the first phase to develop is the zeta phase. Following zeta phase formation is a delta phase layer and subsequent mixed gamma layers. An example of this layered phase formation is shown in Figure 10. The growth rate of the entire coating is governed by the parabolic rate law.

In addition to the processing parameters that affect Fe-Zn phase growth, material variables such as substrate steel and coating chemistry also contribute to the alloying rate of the coating. The carbon content of the steel sheet is believed to be inversely related to the alloying rate of the coating. As the carbon content of the steel increases the alloying rate decreases (12). The carbon inhibition effect decreases during carbide formation, indicating that soluble carbon, not carbon content is the more important variable. Another substrate chemistry consideration is the effect of phosphorous. Phosphorous is a major alloying element in the production of high strength low alloy steel used in automotive applications. Phosphorous segregates to grain boundaries especially in the presence of a carbide former. The migration of phosphorous acts to lower the thermodynamic activity at the substrate grain boundaries and delay Fe-Zn alloy layer growth (18).

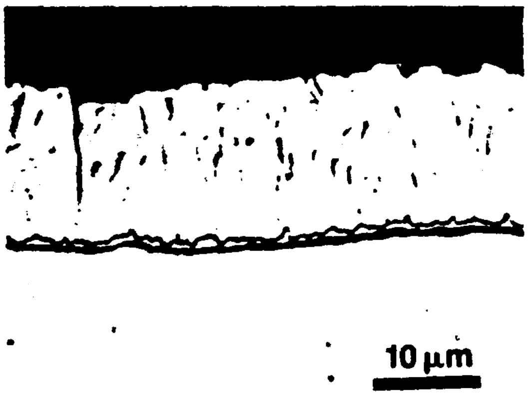


Fig. 10. Fully alloyed galvanneal coating.

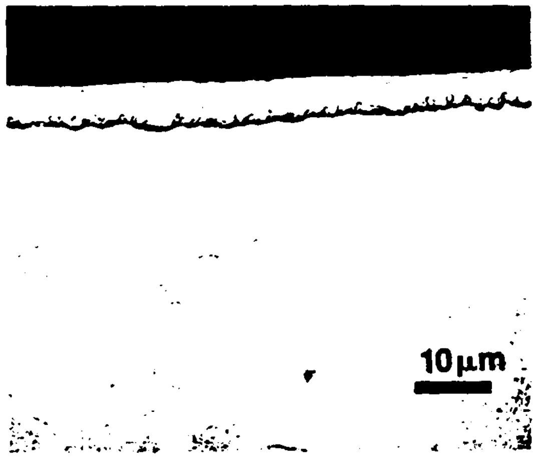


Fig. 11. Galvanized coating.

In galvannealing the major addition to the zinc bath is aluminum. Aluminum additions of 0.1-0.3 weight percent are typical of commercial lines. Because iron has a high chemical affinity for aluminum, an Fe-Al or Fe-Al-Zn thin intermetallic compound layer initially forms during galvanizing and it acts as an inhibition layer for the interdiffusion of iron and zinc (19). Aluminum additions in the bath act much like carbon and phosphorous in the substrate in that it slows down the rate of alloying in the coating.

To understand the development of a fully alloyed coating or galvannealed structure it is important to characterize the starting structure in the as-galvanized condition. The morphology of the galvanized coating consists of an FeAl or FeAlZn intermetallic compound at the steel/coating interface and an essentially pure zinc eta phase layer above the inhibition layer. A typical hot-dipped galvanized structure is shown in Figure 11. After heat treatment of the as-galvanized material, the microstructure can be characterized as either unalloyed or fully alloyed. A fully alloyed coating appears at longer times and higher temperatures with the structure being characterized by a significant gamma layer along with cracks that have developed in the delta phase perpendicular to the steel surface, Figure 10. The kinetics of a fully alloyed coating for an DQSK steel are shown in Figure 12a. The inhibition effect of a higher aluminum coating is seen in Figure 12b. The appearance of a fully alloyed structure occurs at longer times for the more aluminum rich bath.

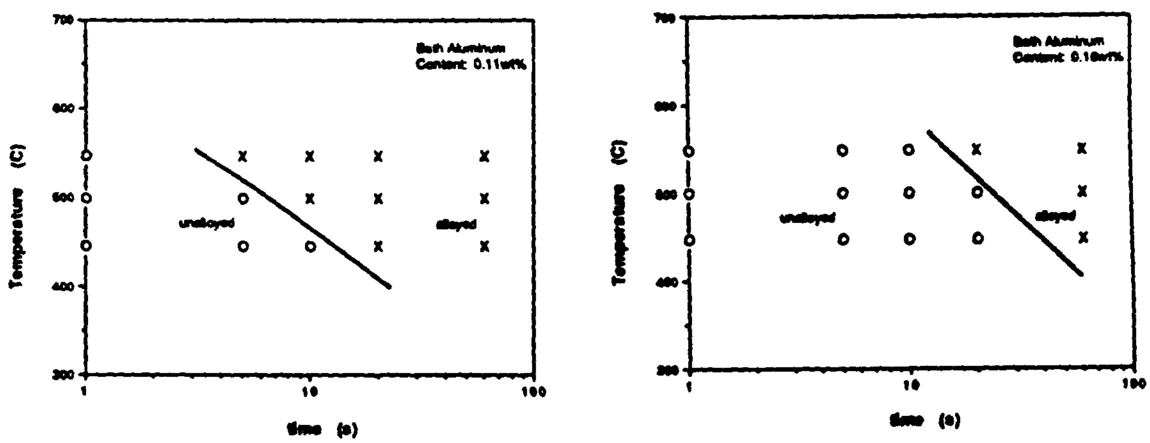


Fig. 12. The effect of Al bath composition on the galvannealed structure of DQSK steel. (a) 0.11 wt% Al and (b) 0.16 wt% Al

The effect of a 0.11% Ti addition on the time to form a fully alloyed layer is shown in Figure 13 (15). It appears that Ti reduces the temperature and time for full alloying. Figure 14 contrasts the effect of aluminum bath composition on the time for the formation of fully alloyed coatings in a 0.078% Ti IF steel. Al content is an extremely important influence in coating kinetics. Figure 15 shows a similar result for a Ti+Nb substrate with a 0.14% Al-Zn coating. The addition of Nb appears to greatly increase the reaction kinetics.

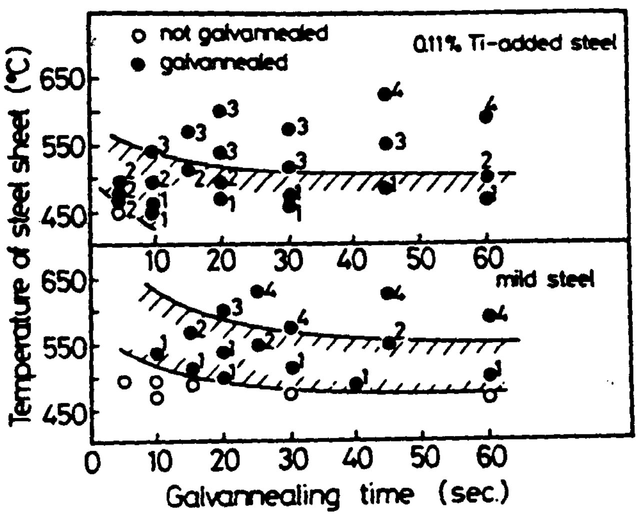


Fig. 13. The optimum range for galvannealing a Ti-added steel. (Coating bath: Zn-0.13% Al at 470°C.)

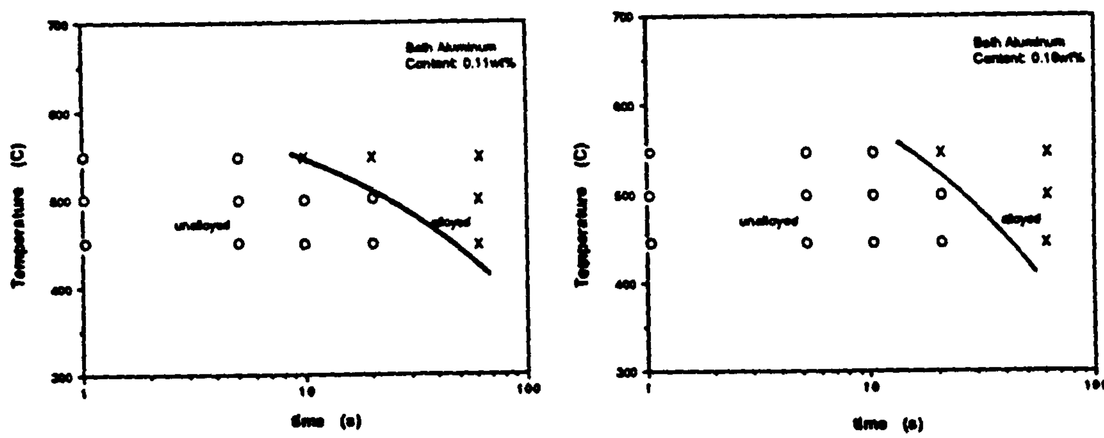


Fig. 14. The effect of Al bath composition on the galvannealed structure of a Ti stabilized IF steel. (a) 0.11 wt% Al and (b) 0.16 wt% Al.

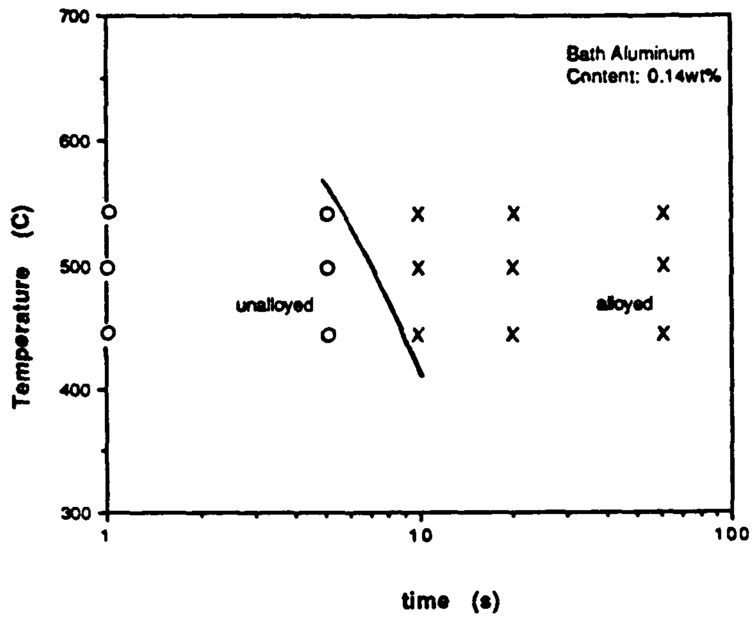


Fig. 15. The effect time and temperature on the galvannealed structure in a Ti+Nb IF steel.

The formation of iron-zinc layers in the coating may enhance weldability, paintability and cosmetic corrosion resistance, but they also reduce coating formability. Galvanneal is produced on a continuous line therefore the coated sheet must be stamped to shape. Powdering of the coating can result in the adherence of the powder to the forming dies and cause surface damage to subsequent sheets stamped in the dies. It is evident from Figure 16 that as the iron content in the coating increases, the amount of powdering increases correspondingly. It is thought that there exists an optimum iron content to achieve the best coating formability properties (20, 21). An iron content of 10 - 13 weight percent has been shown by a number of investigators to be the range in which good adherence of the coating is maintained. The onset of poor formability has been attributed to the thickness of the gamma layer, the most brittle Fe-Zn phase (20). It has been shown, Figure 17, that as this layer becomes thicker, poor powdering resistance results.

Lucas et. al. (14) has shown that lower alloying temperatures (<500°C) and low bath aluminum content result in very good powdering resistance in IF steel coatings. However, it was shown that higher alloying conditions with a very short soaking time may also produce good coatings. Furthermore, they found that a decrease of powdering resistance was attributed to an increase of δ phase in the coating. Hisamatsu (13) has proposed that coating formability was related to the zeta/delta ratio with the amount of powdering increasing as the zeta/delta ratio decreases, Figures 18 and 19. It appears that powdering is more dependent on galvannealing time and temperature to produce the proper zeta/delta ratio. Figure 20 contrasts unalloyed and alloyed coating for a Ti and DQSK substrate. The results show that Ti additions can improve the powdering resistance of fully alloyed coatings.

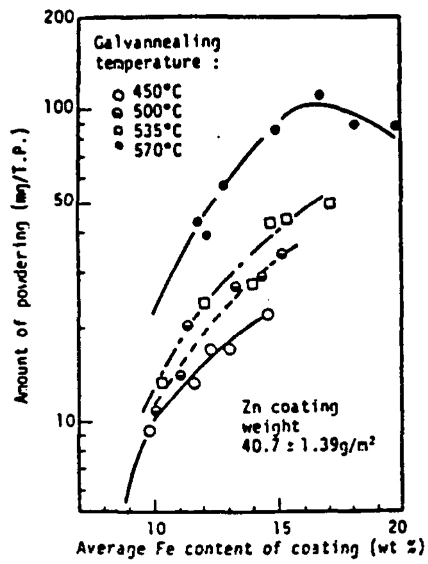


Fig. 16. The effect of galvannealing temperature and iron content on powdering resistance.

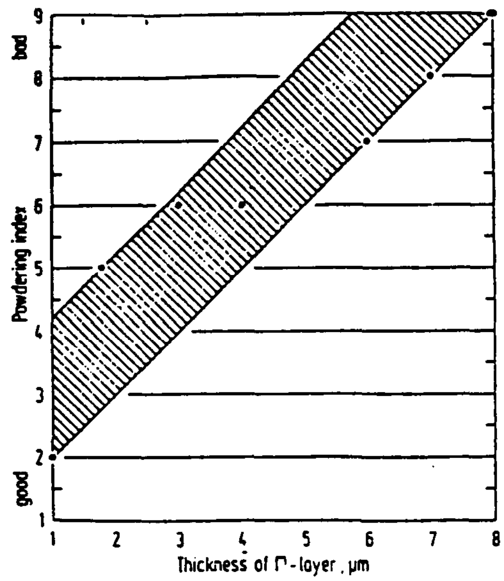


Fig. 17. Relation between the thickness of the gamma layer and the powdering resistance.

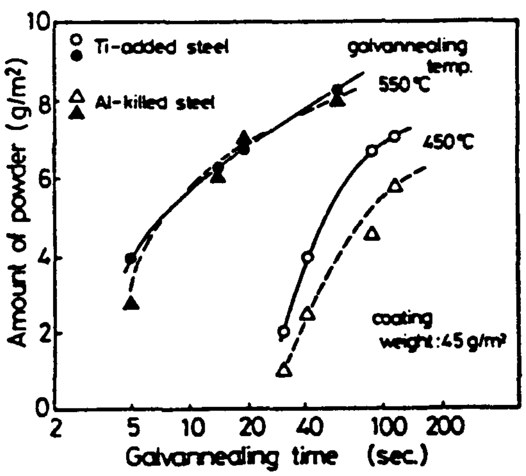


Fig. 18. Effects of base steel type and galvannealling condition on anti-powdering properties.

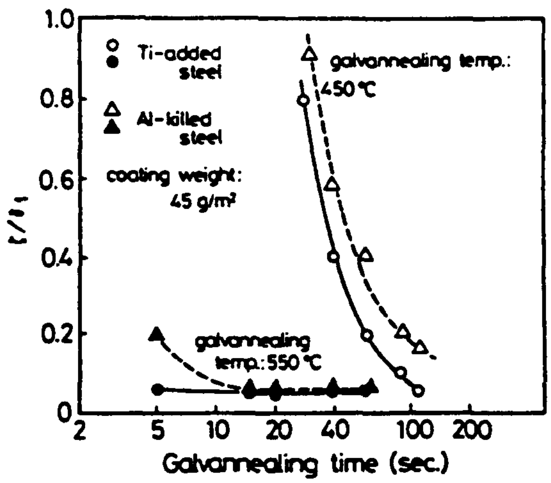


Fig. 19. Effects of base steel type and galvannealing condition on ζ/δ.

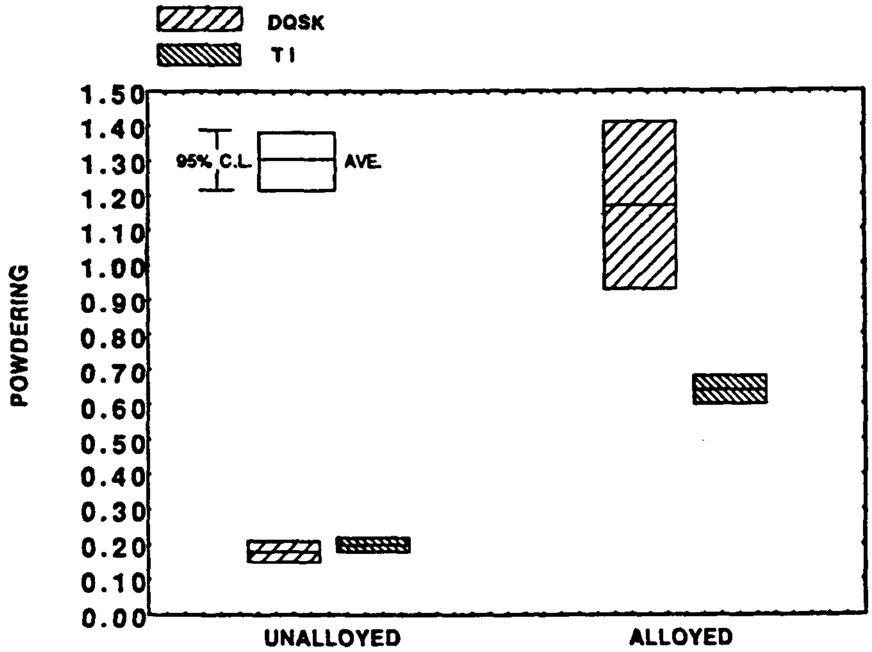


Fig. 20. Powdering properties of DQSK and Ti stabilized galvanneal coatings.

ADDITIONAL CONSIDERATIONS

Denting/Bake Hardening

In order to reduce vehicle weight, lighter gauge steel is being specified, but unfortunately this down-gauging can lead to denting problems as a result of handling during assembly or during normal use. One approach to alleviate the problem is to make use of bake-hardening steels. However, the plain-C bake-hardenable grades are not applicable to the more difficult to form parts where higher n and r-values are required.

Bake hardenability refers to the increase in the yield point due to strain aging by soluble carbon during paint baking at 170°C for 20 minutes, after press forming. Since bake hardenability requires the presence of soluble carbon and nitrogen as interstitial elements, IF steels would not be expected to bake harden. However, bake hardening was produced in a Nb IF steel by increasing the annealing temperature to at least 850°C, which decomposed the NbC forming soluble carbon (22). Unfortunately, continuous annealing at these high temperatures can lead to shape flaws (heat buckles). Formable bake hardening IF steels can be produced from compositions with a Ti_{eff}/C and Nb/C atomic ratio close to unity, by annealing at high temperatures (23). However, with Ti IF steels, it is difficult to control the Ti_{eff}/C atomic ratio close to unity since Ti combines with N and S prior to combining with C (24). Thus, Nb-Ti and Nb steels are preferable to produce bake hardenable IF steels.

The bake hardening effect increases with more dissolution and retention of solute carbon in the steel (23, 24) as well as grain size (26). Thus, the bake hardening effect in continuously annealed IF steels increases with:

a) Lower Nb/C ratio (<1).

b) High annealing temperatures (> 850°C).

c) Rapid cooling (≥ 20°C/sec) to prevent reprecipitation at lower temperatures.

d) No in-line overaging.

In addition, for processing on a hot-dip galvanizing line, sufficiently rapid cooling between the zinc pot temperature (~450°C) and 200°C is necessary to further prevent precipitation of solute C as Fe_3C (27). Therefore, the critical thermal cycle processing variables required to produce solute C can have a profound effect on galvanizing and galvannealing. Particularly since the IF steels were originally used to produce reactive grain boundaries without soluble carbon, zinc coating reaction kinetics can be expected to be significantly influenced by the continuous annealing thermal cycle in bake hardenable IF steels.

High-Strength IF Sheet Steel

High-strength sheets with good formability can be produced by continuous annealing IF steels with solid solution strengthening additions of phosphorous, silicon and manganese (28-30). Phosphorous compared to Si and Mn, is widely used for high strength because it has little adverse effect on formability (31). However, cold work embrittlement can occur when the P is too high (32) due to boundary segregation. B is added to these steels to alleviate the problem (33) since B is known to segregate at the grain boundaries (34). However, B tends to increase the r value and raise the recrystallization temperature (35). When B is not added, an enrichment of P, which is about 10 times the bulk concentration, is observed at the grain boundaries. Furthermore, the decrease in enrichment of P at the grain boundaries by the addition of B, varies with chemical composition of the steel (36).

In Nb-added steel, a considerable proportion of B exists as BN whereas, in Nb-Ti or Ti-added steels, nearly all the B added exists in solution because all of the N precipitates as TiN before hot rolling. Thus, B can act to inhibit the enrichment of P at the grain boundaries in Ti-added IF steel. The reactivity of the grain boundaries in these high strength P- and B-added IF steels will certainly effect the reaction kinetics in the galvanizing bath and therefore influence Fe-Zn intermetallic compound formation during galvannealing.

Sheet Properties Degradation

Galvanneal coatings reduce the r-value (~ 0.20) and elongation (1-1.5%) in both Nb and Nb-Ti IF steels (24). In order to obtain high elongations and r-values in galvannealed steels that are comparable to cold rolled and galvanized products, the composition and processing must be further refined to compensate for the decrease in properties due to galvannealing. To achieve the higher level of properties in the galvannealed product, Tanaka et. al. (37) suggested the following:

a) Reduce C level to ≤ 0.0024%.

b) Use thermomechanical treatment.

c) Anneal at high temperatures 860-870°C (prior to hot-dipping) in the galvanizing line.

Thus, the composition and processing of IF steels must be adjusted in order to compensate for the loss of properties due to the galvannealed coating. These changes can alter the soluble C which in turn can significantly influence zinc coating reaction kinetics.

SUMMARY

Interstitial free steel offers significant advantages as a coated sheet product with improved formability and high strength. However, the presence of reactive solute elements such as titanium or titanium + niobium greatly influence the coating process. It is clear that the properties of any coating are dependent upon the microstructure of the coating. Specifically the coating microstructure develops from the initial surface reaction in the bath. Ti and Ti+Nb IF sheet steel provide solute free grain boundaries for accelerated zinc interface reactions. On the other hand, thermodynamics dictate that a reactive element such as Ti will form surface oxides during the continuous annealing process. These oxides form on the grain boundaries, thus they also can modify surface reaction kinetics. However, the quantitative contribution of oxides and interstitial free grain boundaries to coating formation has not been determined. Furthermore, the role of solute elements on the formation kinetics and formability of galvanneal coatings has yet to be examined. Finally, the efforts to improve the strength of IF steels has led to additions of other alloying elements that can significantly confound the kinetics of coating formation.

ACKNOWLEDGEMENTS

I would like to acknowledge the following people at Lehigh University for their technical support and lively discussions in the preparation of this manuscript: A. O. Benscoter, J. I. Goldstein, K. Goggins, S. Bluni, L. Rehrig, J. Lenner and in particular C. Jordan. The discussions with F. Goodwin of the International Lead Zinc Research Organization (ILZRO) and R. Pradhan of Bethlehem Steel were extremely helpful in developing this paper.

References

1. J. A. Elias and R. E. Hook, "Interstitial Free Sheet Steel Applications and Performance", SAE Paper No. 720018, January, 1972.

2. R. H. Goodenow and J. F. Held, "Recrystallization of Low-Carbon Titanium Stabilized Steel", Met. Trans., 1, 1970, 2507.

3. Y. Tokunaga and H. Kato, "Application of Interstitial-Free (IF) Steel Sheets to Automobile Parts", in Metallurgy of Vacuum-Degassed Steel Products, R. Pradhan, ed., TMS, 1990, 91.

4. I. Olefjord, W. Leijon and U. Jelvestam, "Selective Surface Oxidation During Annealing of Steel Sheets in H_2/N_2", App. Surface Sci. 6, 1980, 241.

5. D. J. Blickwede, "The Importance of Surface Composition", Metal Prog.", 1969, 77.

6. J-P Servais, H. Grass and V. Leroy, "Influence of Heat Treatments on the Surface of Low Carbon Steels", Met. Rep. CRM, 44, 1975, 29.

7. R. M. Hudson, H. E. Biber, E. J. Oks, Jr. and C. J. Warning, "Kinetic Studies in Surface Segregation of Manganese During Annealing of Low Carbon Steel", Met. Trans., 8A, 1977, 1713.

8. E. Janssen, "Chemical Characterization of Industrial Steel and Aluminum Sheet Surfaces by Secondary Ion Mass Spectrometry, Glow Discharge Optical Spectroscopy and Other Surface-Sensitive Techniques", Mat'l. Sci. and Engr., 42, 1980, 309.

9. W. Leijon and I. Olefjord, "Surface State of Batch Annealed Low-Carbon Steel Sheets", Scand. J. Metallurgy, 12, 1984, 239.

10. A. Aubry and B. Vialatte, "Reactivity of Synthetic Titanium Interstitial-Free Steel in the Liquid Zinc Bath", Intergalva, Barcelona, 1991, S4E1.

11. A. Nishimoto, J. Inagaki and K. Nakaoka, Tetsu-to-Hagane, 68, 1982, 1404.

12. A. Nishimoto, J. Inagaki and K. Nakaoka, "Effects of Surface Microstructure and Chemical Compositions of Steel on the Formation of Fe-Zn Compounds During Continuous Galvanizing", Trans. ISIJ, 26, 1986, 807.

13. Y. Hisamatsu, "Science and Technology of Zinc and Zinc Alloy Coated Steel Sheet", Galvatech, ISIJ, Tokyo, 1989, 3.

14. P.L. Lucas, D. Quantin and C.G. Brun, "Effects of Alloying Parameters on Formability of Galvannealed Sheets", Galvatech, ISIJ, Tokyo, 1989, 138.

15. T. Fukuzuka, M. Urai and K. Wakayama, "Galvannealing Characteristics of Galvanized Sheet Containing Titanium", Kobe Steel Eng. Reports, 30, 1980, 77.

16. M. Lamberigts, V. Leroy and F. Goodwin, "Galfan Solidification Control and Associated Effects on Coating Quality and Microstructure", Intergalva, Barcelona, 1991, SID/1.

17. S. Mathieu, F. Goodwin and M. Lamberigts, "Experiments on Deformation and Surface Appearance Characteristics of Galfan-Coated Sheet Steel", Intergalva, Barcelona, 1991, S4H/1.

18. M. Abe, S. Kanbara and T. Okuyama, "Iron-Zinc Alloying Behavior in Galvannealing of P and P-Si Containing Steel", Trans. ISIJ, 25, 1, 1985, B-15.

19. H. Smith and W. Batz, "Iron-Zinc Alloy Formation During Galvannealing", JISI, Dec. 1972, 895.

20. T. Nakamori and A. Shibuya, "Effects of Galvannealing Conditions and Coating Weight on Powdering Resistance of Galvannealed Steel Sheet", Corrosion Resistant Automotive Sheet Steels, L. Allegra, ed., ASM International, Metals Park, Ohio, 1988, 139.

21. G. M. Smith, D. W. Gomersall and D. Hreso, "Control of Adhesion in Galvannealed Products", Proc. 1989 Mechanical Working and Steel Processing Conference, ISS, Warrendale, Pennsylvania, 1990, 17.

22. S. Satoh, O. Hashimoto and T. Irie, "Effect of Continuous Annealing Conditions on Mechanical Properties in Extra-Low Carbon Cold-Rolled Steel Sheet Bearing Niobium", Tetsu-to-Hagane, 67, 1981, S1183.

23. T. Irie, S. Satoh, Y. Yasuda and O. Hashimoto, "Development of Deep Drawable and Bake Hardenable High Strength Steel Sheet by Continuous Annealing of Extra Low Carbon Steel with Nb or Ti", Metallurgy of Continuous-Annealed Sheet Steel, B. L. Bramfitt and P. L. Manganon, eds., TMS-AIME, New York, 1982, 155.

24. I. Gupta and D. Bhattacharya, "Metallurgy of Formable Vacuum Degassed Interstitial-Free Steels", Metallurgy of Vacuum-Degassed Steel Products, R. Pradhan, ed., TMS, 1990, 43.

25. H. Takechi, "Developments in High-Strength Hot and Cold-Rolled Steels for Automotive Applications", Hot and Cold Rolled Sheet Steels, R. Pardhan and G. Ludkovsky, eds., TMS-AIME, Warrendale, PA, 1988, 117.

26. S. Hanai, "Effects of Grain Size and Solid Solution Strengthening Elements on the Bake Hardenability of Low Carbon Aluminum-Killed Steel", Trans. ISIJ, 24, 1984, 17.

27. R. Pradhan, "Dent-Resistant Bake-hardening Steels for Automotive Outer-Body Applications", presented at Steel in Motor Vehicle Manufacture, Wurzburg, Germany, 1990.

28. N. Takahashi, "Effect of Alloying Elements and Annealing Cycles in Strengthening of Continuously Annealing Cold Rolled Sheet", Tetsu-to-Hagane, 69, 1982, 1378.

29. S. Satoh, "Development of High Strength Cold Rolled Sheet Steel with Ultra-Deep Drawability by Addition of P to Extra-Low-Carbon Niobium Steel", Tetsu-to-Hagane, 66, 1980, S1123.

30. K. Matsumura, "Production of High Strength Steel Sheet with Ultra-Deep-Drawability", Tetsu-to-Hagane, 66, 1980, S838.

31. H. Hisashi, "Development of High Strength Galvannealed Steel Sheets with Extra Deep Drawability", Tetsu-to-Hagane, 68, 1982, 1397.

32. M. Konishi, "Fracture at Grain Boundary on the Denitrized and Decarbonized Sheet Steel After Annealing", Tetsu-to-Hagane, 63, 1977, S874.

33. M. Yamada, Y. Tokunaga and M. Yamamoto, "Effect of Nb and Ti on Resistance to Cold-Work Embrittlement of Extra-Low-Carbon High Strength Cold-Rolled Steel Sheet Containing Phosphorous", Tetsu-to-Hagane, 73, 1987, 1049.

34. M. Yamada, "Manufacturing Method of 45 kgf/m^2 Class High Strength Cold Rolled Steel Sheet with High r-value and Excellent Resistance for Deep Drawing Induced Brittleness", Tetsu-to-Hagane, 70, 1984, S555.

35. K. Tayama, "Improvement of Resistance to Brittle Fracture in Extra-Low-Carbon Niobium Stabilized Steel with Less Tendency for Brittleness", Tetsu-to-Hagane, 69, 1983, S1365.

36. N. Kino, M. Yamada, Y. Tokunaga and H. Tsuchiya, "Production of Nb-Ti Added Ultra-Low-Carbon Steel for Galvannealed Application", Metallurgy of Vacuum-Degassed Steel Products, R. Pradhan, ed., TMS, 1990, 197.

37. H. Tanaka, Y. Ogura, K. Yoshioka, T. Hirose, H. Yamada and M. Sako, "Development of Ultra Low Carbon Steel Sheet with Excellent Formability", NKK Technical report (Overseas), 48, 1987, 21.

CORROSION RESISTANCE OF GALFAN FOR AUTOMOBILES

Naotaka Ueda, Tatsuo Kurimoto and Yoshihiko Hoboh
Wakayama Steel Works, Sumitomo Metal Industries, LTD.
1850 Minato, Wakayama City, Japan

Synopsis: Galfan was evaluated for automobile bodies. Its phosphatability, wet adhesion, perforation corrosion resistance and cosmetic corrosion resistance were examined. Galfan was found to be superior to galvannealed and hot-dipped galvanized steel for perforation corrosion resistance. Moreover, galfan was superior to zinc-nickel alloy electroplated steel for cosmetic corrosion resistance. Therefore, at least concerning corrosion resistance, galfan has a great potential, but has some properties to be improved for automobile bodies.

1. Intoroduction

Galfan (Zn-5%Al-0.1%Mischmetal) and Galvalume (Zn-55%Al-1.6%Si) have been widely used for construction industries. However, galfan and galvalume, which have excellent corrosion resistance and passable paintability, seem not to have been used for automobile bodies. Therefore, in this study, galfan was evaluated for automobiles, compared with galvannealed, hot-dipped galvanized and zinc-nickel alloy electroplated steel which have been used for automobile bodies, concerning corrosion resistance (wet adhesion, perforation corrosion resistance and cosmetic corrosion resistance).

2. Experimental Procedure

Phosphatability, wet adhesion, perforation corrosion resistance and cosmetic corrosion resistance (cyclic corrosion test and out door exposure) were examined on galfan, galvannealed, hot-dipped galvanized, zinc-nickel alloy electroplated and cold rolled steel (Table 1) . Each experiment, which was carried out (Table 2), was based on our philosophy of corrosion resistance evaluation for automobile bodies.

2.1 Wet adhesion

The Adhesion of paint film deteriorates in high humidity. This phenomenon can be simulated by immersing coated panels in hot water.

2.2 Perforation corrosion resistance

Based on the observation of perforation corrosion on actual automobiles and the result of simulation tests, we feel:

(1) The purpose of using corrosion resistant steel sheets is to obtain superior corrosion protecoion at the hemmed portion, the inside surface of enclosed parts, etc., where the primer is inperfectly applied. Therefore, it is very suitable to prepare corrosion resistance test

panels with 0 to 5μm thick cathodic electro-deposited (ED) paint film.

(2) Panels should be prepared without scribing because, on an actual automobile, the inside surface, where perforation corrosion is initiated, has no chance for scribing to reach the substrate.

2.3 Cosmetic corrosion resistance

When corrosion resistant steel sheets are used for the purpose of cosmetic corrosion prevention, contrary to the perforation corrosion resistance test, painted panels should be scribed to the substrate. Two types of scribes were done on fully painted panels.

3. Results

3.1 Phosphatability

Photo.1 shows SEM micrographs of phosphate crystals. Phosphate crystals were densely and uniformaly deposited on galfan. Tano, et al. reported influences of Al contents in the phosphate solution on phosphatability [1]. They showed that an increase of Al contents in the phosphate solution decreases deposited phosphate weight. In this study, the influence of Al was not examined.

3.2 Wet adhesion

Wet adhesion of galfan was acceptable (Table 3).

3.3 Perforation corrosion resistance

Fig.1 shows the maximum corrosion depth on various kinds of panels under the cyclic corrosion test. The corrosion rate depended on the incubation time when substrate steels began to corrode. Therefore, the corrosion rate mainly depended on the corrosion resistance of the plated film itself. With the same coating weight, perforation corrosion resistance was as follows: Zn-Ni is superior to GF which is superior to both GA and GI.

3.4 Cosmetic corrosion resistance

Photo.2 and Photo.3 show the appearances of panels after the cyclic corrosion test and outdoor exposure test. Galfan was superior to Zn-Ni alloy electroplated steel in resisting red rust on scribed lines. Moreover, concerning scribe creepage, galfan was as good as Zn-Ni electroplated steel (Fig.2). Therefore, galfan had excellent cosmetic corrosion resistance.

4. Conclusion

Galfan had good perforation corrosion resistance compared with galvannealed and hot-dipped galvanized steel. Moreover, galfan had good cosmetic corrosion resistance - especially against red rust. Therefore, galfan has great potential concerning corrosion resistance, but has some properties that should be improved for automotive applications.

1)Kazuhiro Tano, et al.;SEITETS KENKYU, No.315, p.39 (1984)

Table 1 Samples and experiments on this study

Symbol	Description	Coating Weight (g/m2)	Phosphat-ability	Wet adhesion	Perforation corrosion	Cosmetic corrosion	
						Cyclic test	Exposure test
GF70	Galfan	70	*	*	*	*	*
GF43	Galfan	43			*		
GF66	Galfan	66			*		
GF83	Galfan	83			*		
Zn-Ni31	Zn-Ni alloy electroplated steel	31	*	*	*	*	*
GA53	Galvannealed steel	53	*	*	*	*	*
GI131	Galvanized steel	131	*	*	*	*	*
CR	Cold rolled steel	-	*	*	*	*	*

Table 2 Experimental Procedure

1. Phosphatability

SEM micrograph and coating weight were examined.

2. Wet adhesion

Paint coated panels

↓

Immersion in de-ionized water

50℃*240hours

↓

Cross cutting 2mm

↓

Peeling-off with adhesive tape

Remaining paint sections (%) were numbered.

3. Perforation corrosion resistance

As-plated panels without scribe were used.

Salt Spray	Dry	Humidity
JIS Z2371 (ASTM B117) 35℃	50℃	50℃ R.H.95%<
→ 6 h	→ 2 h	→ 16 h

1 cycle = 24hours

Maximum corrosion depth was measured after 15,30, 45,60 and 75 cycles

Paint coating procedure

Alkaline degreasing

↓

Zinc-phospating (SD=2500MZ*)
Standard Condition

↓

Cathodic ED-coat (u-52*)
15 μm

↓

Primer Surfacer (OTO-811*)
35 μm

↓

Top coats (OTO-626*)
35 μm

*Products of Nippon Paint Co., LTD.
SD2500MZ: Tricationphosphate

4. Cosmetic corrosion resistance

Paint coated panels were used *with two kinds of scribes* whose width were 0.1 and ～ 0.5 mm.

Scribe creepage was measured after a cyclic corrosion test and outdoor exposure test.

(1) Cyclic corrosion test

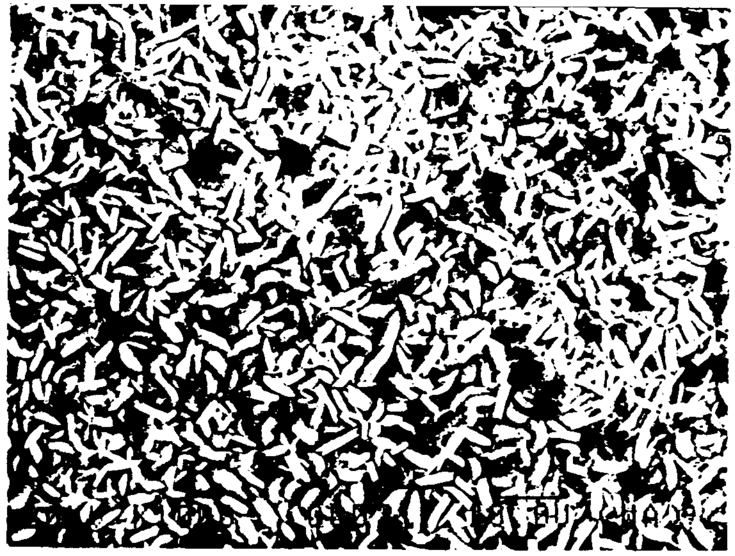
Salt Spray	Dry	Humidity
JIS Z2371 (ASTM B117) 35℃	50℃	50℃ R.H.95%<
→ 2 h	→ 16 h	→ 6 h

1 cycle = 24hours

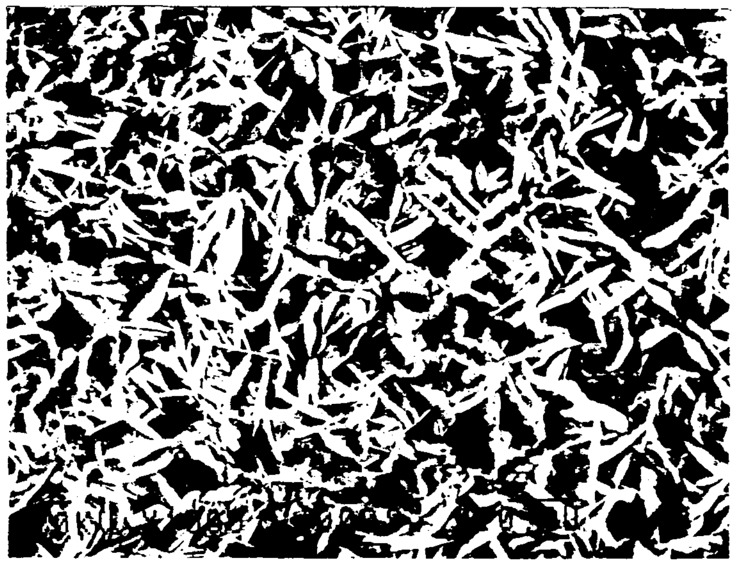
(2) Outdoor exposure test

Outdoor exposure with 5% NaCl spraying twice a week.

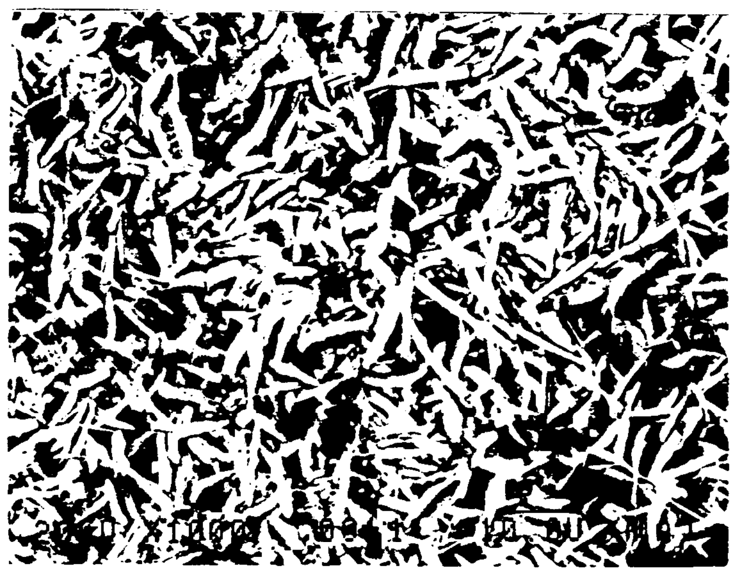
GF70 2.1 (g/m^2)



Zn−Ni31 1.6 (g/m^2)



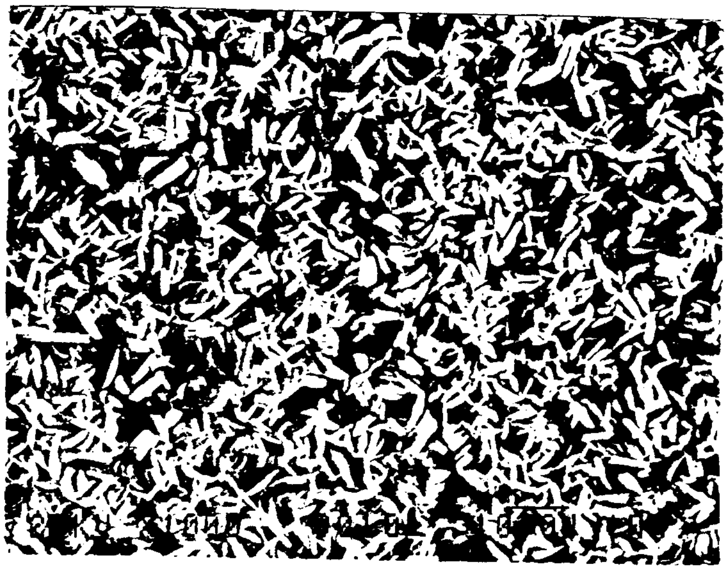
GA53 3.1 (g/m^2)



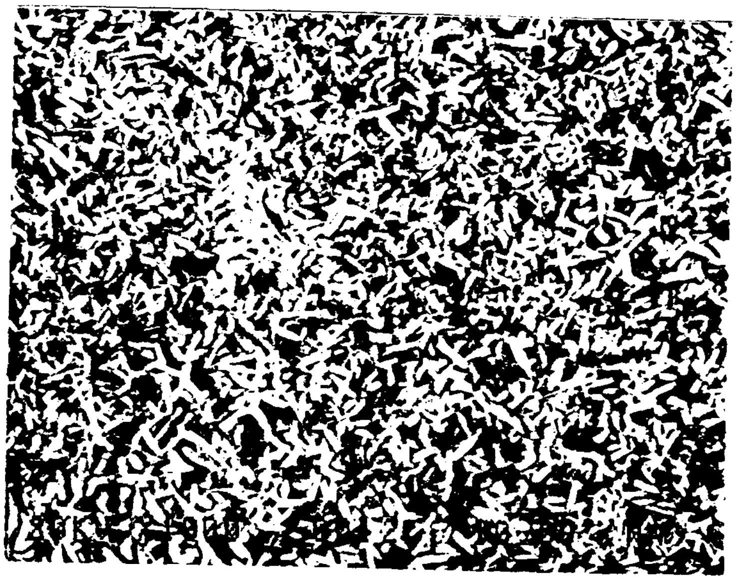
10 μm

Photo. 1 SEM micrograph and coating weight of phosphate crystals

G I 1 3 1 3.7 (g/m²)



C R 1.9 (g/m²)



10μm

Photo. 1 SEM micrograph and coating weight of phosphate crystals

Table 3 Wet adhesion

	Remaining paint sections (%)
GF70	99
Zn-Ni31	100
GA53	99
GI131	95
CR	100

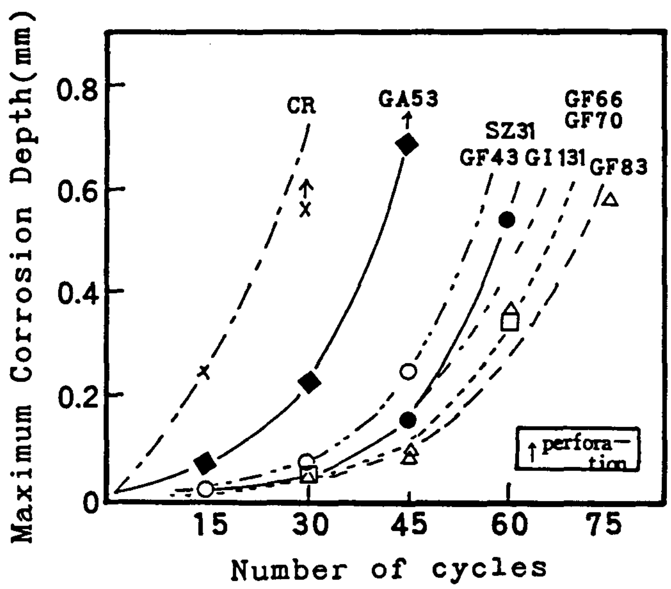


Fig. 1 Perforation corrosion resistance

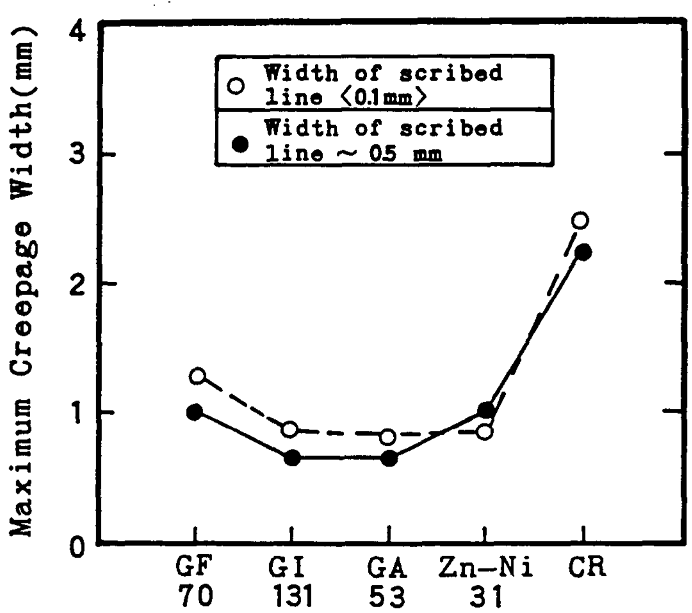
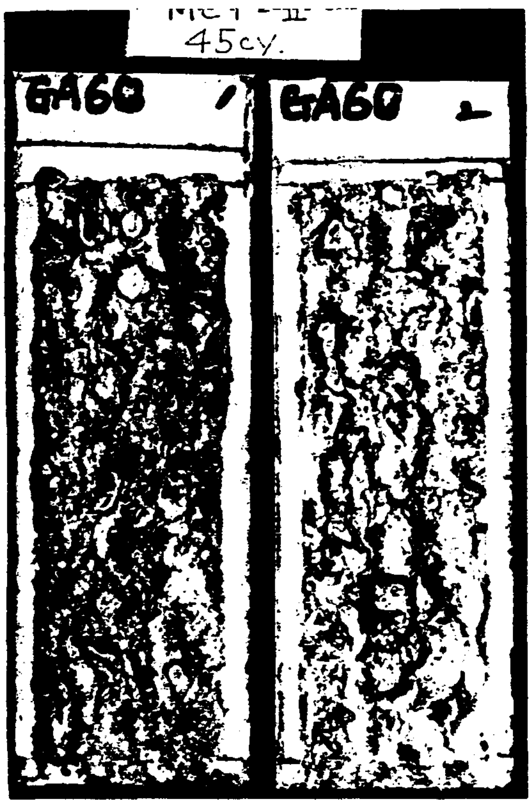


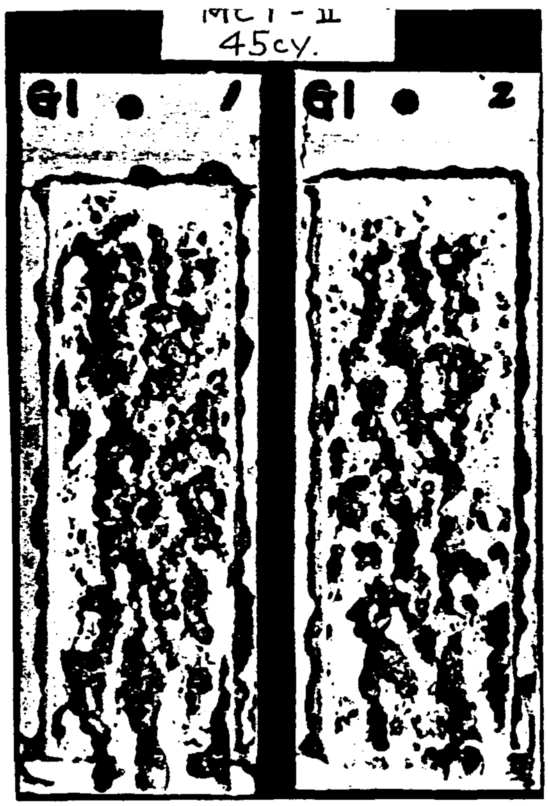
Fig. 2 Cosmetic corrosion resistance after 45 cycles

GF70

Zn−Ni31



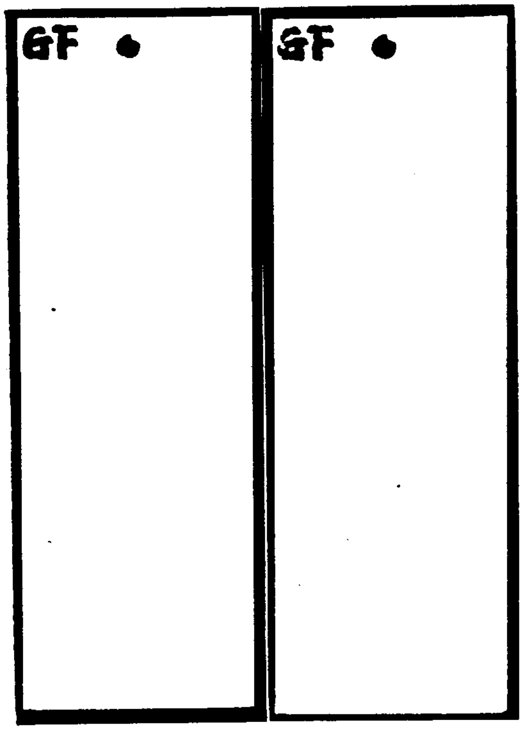
GA53



GI131

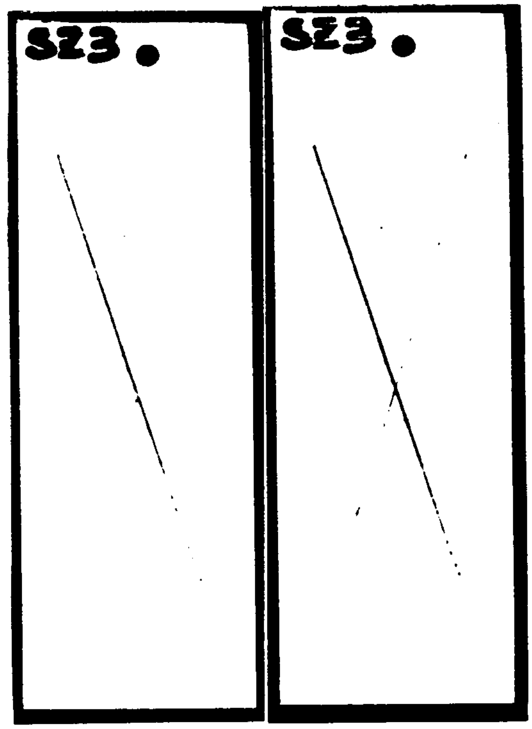
CR

Photo. 2 The appearances of panels after perfolation corrosion test (45 cycles)

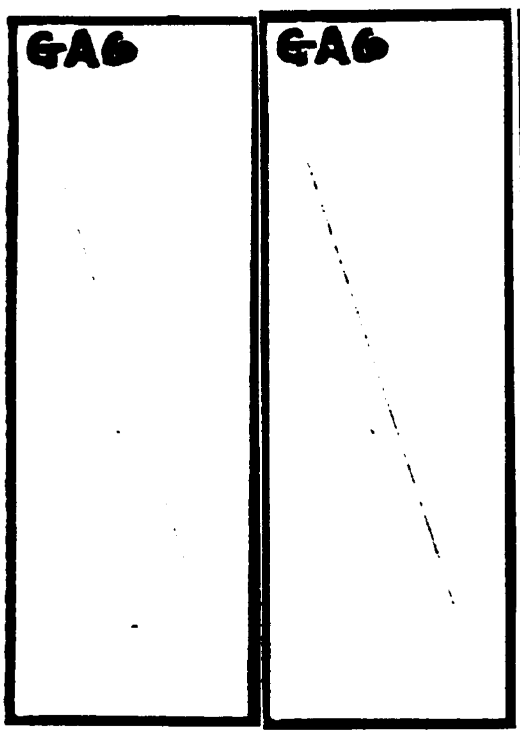


GF70 ／1.4 ＼1.0

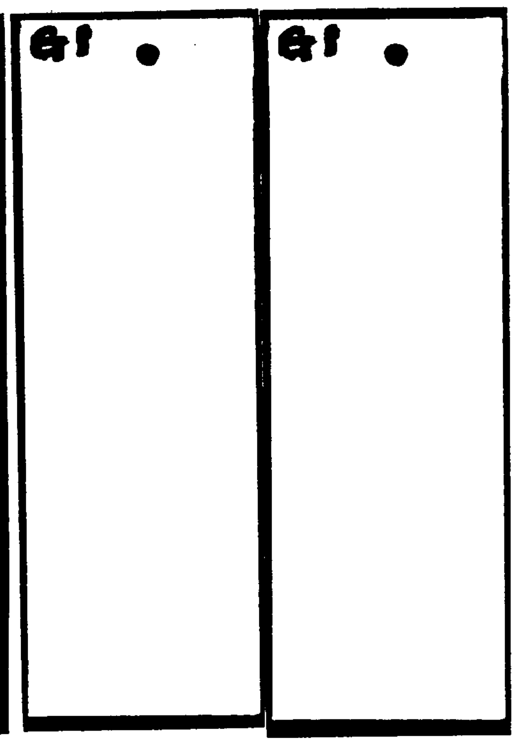
Scribe creepage (mm)



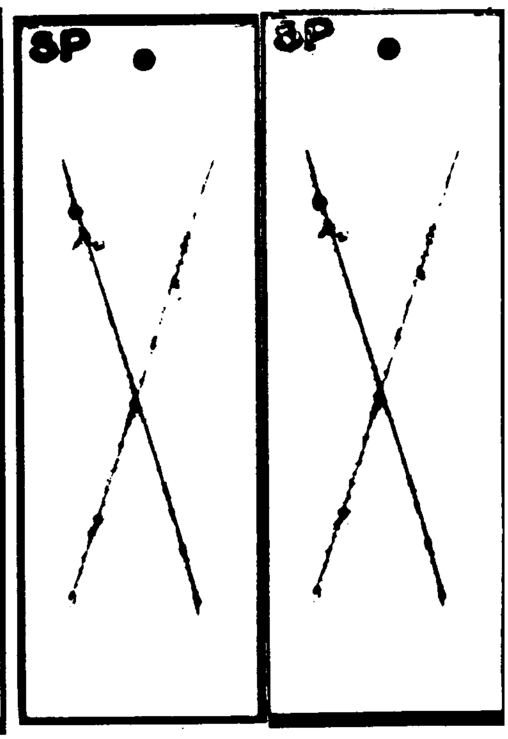
Zn−Ni31 ／0.8 ＼1.0



GA53 ／0.6 ＼0.6



GI131 ／0.8 ＼0.6

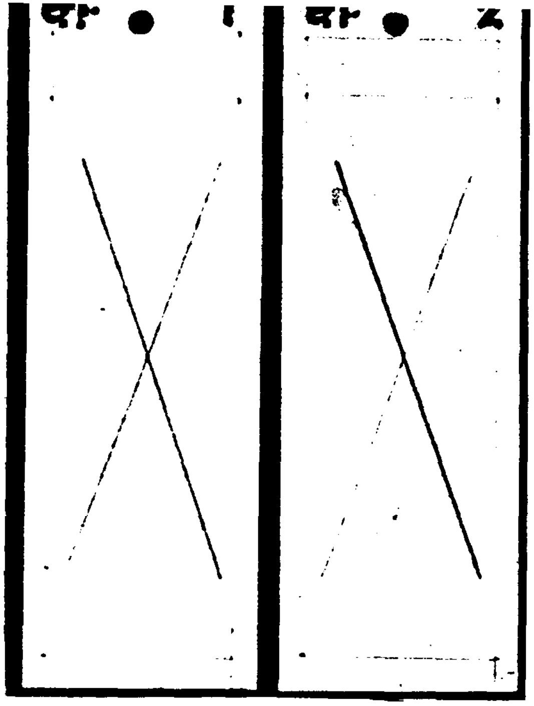


CR ／2.4 ＼2.2

Photo. 3 The appearances and scribe creepage of panels after cosmetic corrosion test (45 cycles)

Left: As tested ／: Width of scribed line (0.1mm)

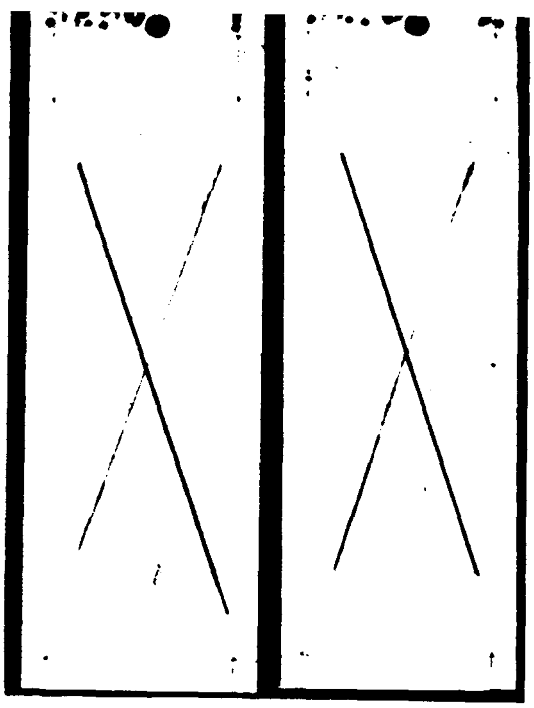
Right: Peeled off with adhesive tape ＼: Width of scribed line (~0.5mm)



0.6 0.8 0.6 0.8

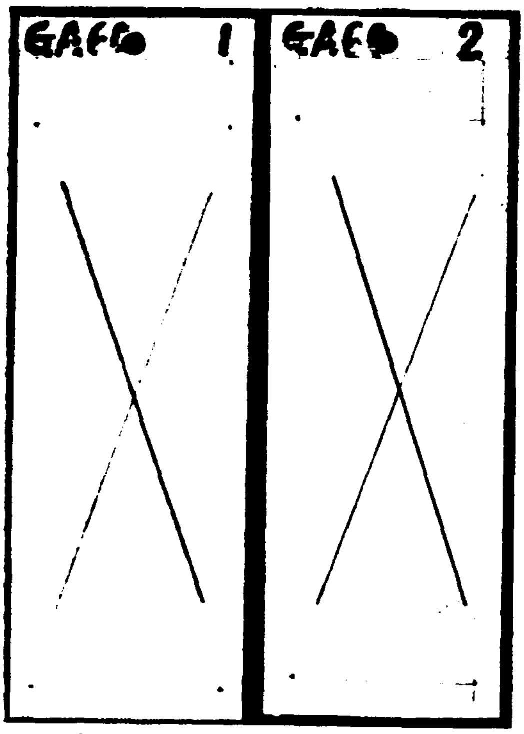
Scribe Creepage (mm)

GF70



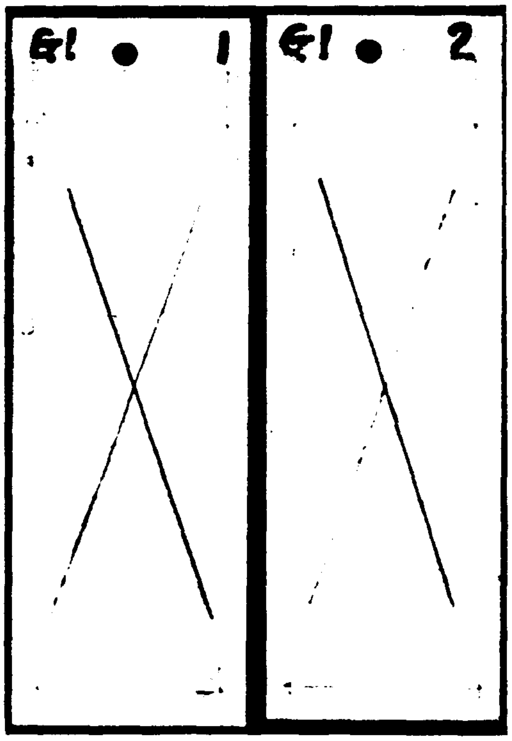
1.2 1.4 1.0 1.2

Zn−Ni31



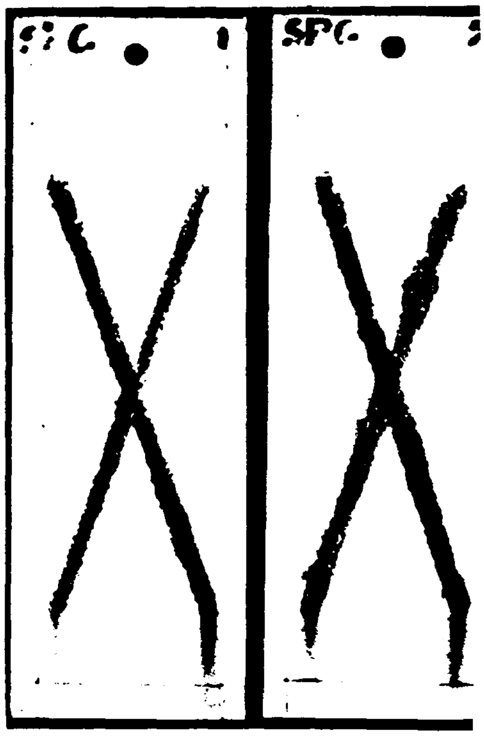
0.3 0.2 0.4 0.1

GA53



0.4 0.4 0.4 0.2

GI131



1.2 1.6 2.6 2.0

CR

Photo. 4 The appearances and scribe creepage of panels after cosmetic corrosion test (Outdoor exposure: 6 months)

／ : Width of scribed line (0.1mm)

＼ : Width of scribed line (~0.5mm)

WHEELING-PITTSBURGH STEEL CORPORATION

Metallurgical Engineering Laboratory
Department of Metallurgy & Quality Control

CORROSION PERFORMANCE STUDY OF METALLIC COATED STEEL AND CULVERT PRODUCT

LABORATORY TEST REPORT 24-590

DECEMBER, 1990

PREPARED BY

H. T. Mengeu

H. T. MENGEU

F. C. Rosenberger

F. C. ROSENBERGER

INTRODUCTION

In late 1980, a corrosion performance study was conducted at the Metallurgical Engineering Laboratory (Report #20-663, dated December 22, 1980) to evaluate the comparative merits of zinc-coated and aluminum-coated steel as a culvert pipe product when exposed to certain test conditions. The conclusion of that study reported a superior performance by the galvanized product.

With the planned introduction in 1991 of Galfan (95% Zn - 5% Al) coated steel, a second study, patterned after the one above, was conducted to evaluate the comparative merits of this new product and aluminum-coated steel as a culvert pipe product. In addition, galvanized materials of various coating weight classifications were included for performance evaluation.

Extensive historical information was also included in this study; e.g., metallographic examination, physical testing, salt spray testing, chemical analysis, coating weight data and photographic documentation.

Corrosion performance testing of the involved coated materials began on February 26, 1990, and was concluded on May 31, 1990, for a test period of 94 days.

PURPOSE

The purpose of this corrosion performance study included the following:

1. To evaluate the corrosion performance of Galfan-coated steel (2.0 oz.) compared to aluminum-coated steel (1.0 oz.) in both the flat sheet and the formed culvert pipe product.

2. To obtain a corrosion performance comparison of Galfan-coated steel (2.0 oz.) and galvanized steel (2.0 oz.). The latter product was reported superior to aluminum-coated steel (1.0 oz.) in the previous corrosion performance study (1980).

3. To obtain corrosion performance information on Galfan-coated and galvanized steel of other coating weight classifications.

IMMERSION CORROSION TESTING

TEST CONDITIONS

The test conditions established for the 1980 corrosion performance study served as the model for the current program. Those conditions included the following:

1. The primary test solution consisted of 1% weight per volume each of sodium chloride (NaCl), sodium sulfate (Na_2SO_4) and sodium carbonate (Na_2CO_3) in deionized water.

2. Test solutions were maintained at four (4) pH levels (3, 5, 9, 12).

3. Initial pH level adjustment and ongoing pH adjustments were made with appropriate hydrochloric acid (HCl) and sodium hydroxide (NaOH) solutions.

4. Individual test containers were maintained for each type and coating weight class material evaluated.

5. Test panels were suspended to provide approximately 70% panel area immersion.

Some modifications of the original test conditions were made and include the following:

1. Test panel size was increased from 3" x 5" to 5" x 7".

2. Larger test containers were required to accommodate the change in test panel size. Covered polypropylene tanks, 8" x 8" x 8", of two (2) gallon capacity were used. Volume of test solution was approximately six (6) liters.

3. Each type and coating weight class material was represented with three (3) test panels; flat coil panel, formed culvert pipe panel, including the lockseam and formed culvert pipe reformed end panel, including the lockseam.

4. The three (3) panels for each type and coating weight class material were combined in a single container, suspended from a common glass rod.

5. Also tested were formed culvert pipe reformed end panels, including the lockseam, which were painted with a zinc enriched zinc oxide primer supplied by the Beech Bottom Culvert Plant. Material represented was galfan-coated (2.0 oz.) and aluminum-coated (1.0 oz.) product. Individual test containers were maintained for each test panel.

6. Adjustment of the pH level of individual test solutions was done with greater frequency than the previous study practice of weekly adjustments.

7. Color photographic documentation was maintained at approximately ten (10) day intervals to monitor the progress of the corrosion performance study.

Because of the large number of corrosion panels (80) and corrosion tanks (32) involved in this study, a simple coding system was used, based on the alpha identification of the culvert pipe material (see sample identification section). The panel types were coded as follows:

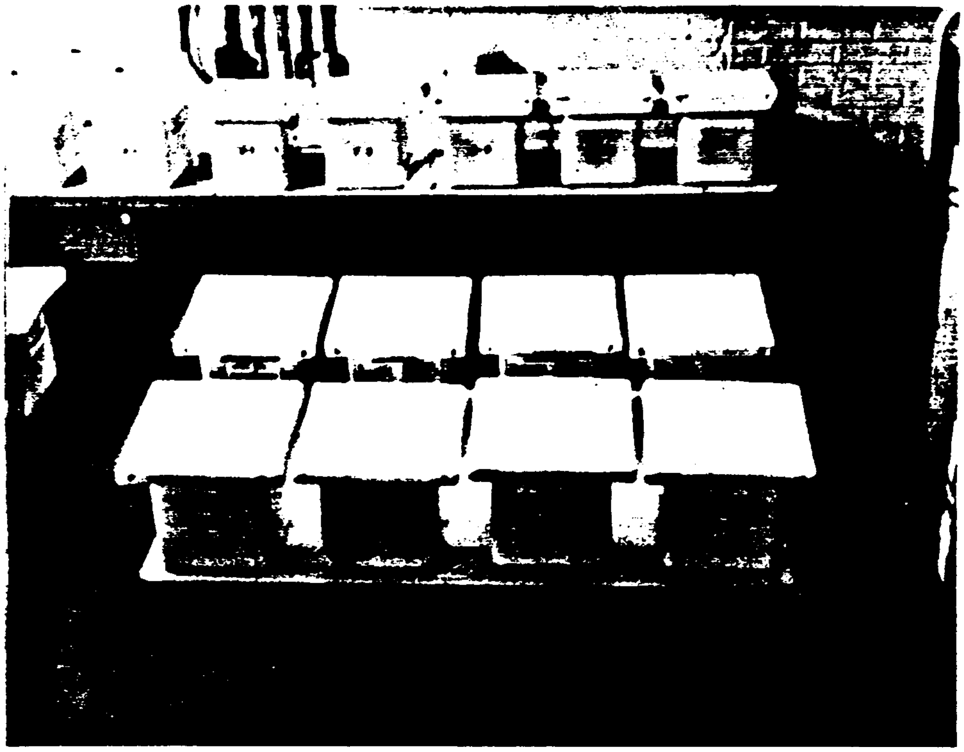
Code B	=	Galfan-coated	-	1.15	oz.
C	=	"	-	2.0	"
D	=	Galvanize	-	2.6	"
E	=	"	-	2.0	"
F	=	"	-	1.15	"
G	=	Aluminum-coated	-	1.0	"

These codes were followed by the pH level at which they were tested. For example, any Galfan-coated panels with a 2.0 oz. coating tested at pH-3 are indicated by the code "C-3"; aluminum-coated panels tested at pH-9 are indicated by the code "G-9", etc.

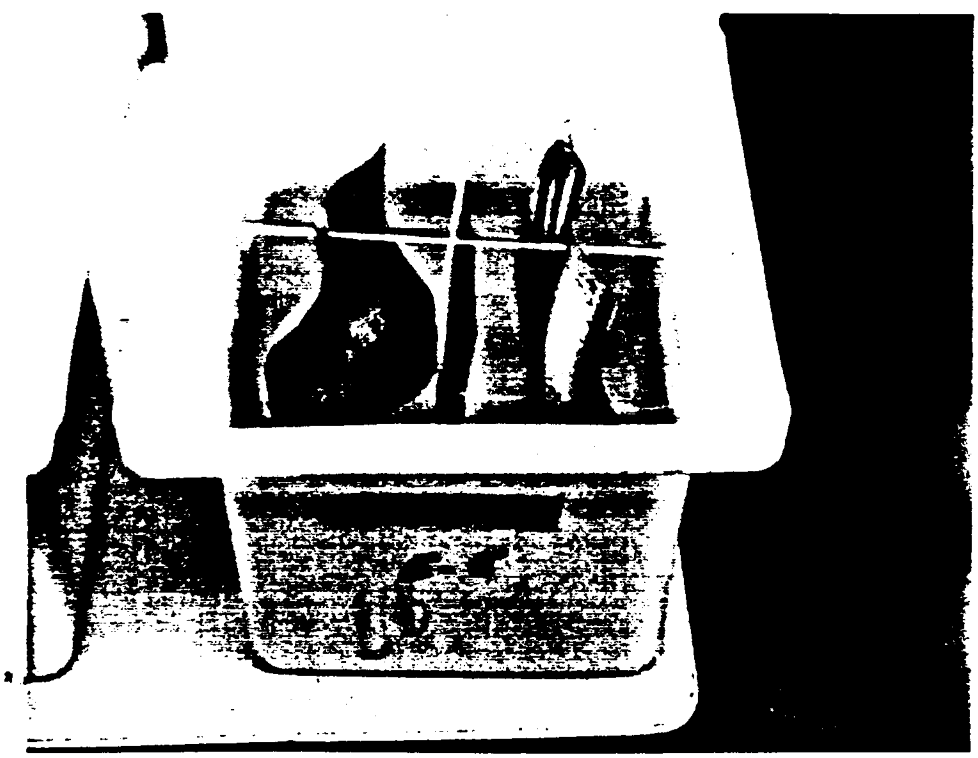
Flat, formed and painted panels from the same material tested at the same pH level have the same code. Identification of the flat or painted panel is obvious. The corrugated panel is identified by the diagonal lockseam; the reformed panel by the vertical lockseam.

TABLE OF CONTENTS

IMMERSION TEST LAYOUT



Partial View of Immersion Test Set-Up



View of Sample Arrangement in Test Container

IMMERSION CORROSION TESTING

COATING PROTECTION CHARACTERISTICS

A continuous metallic coating presents a physical barrier to a corrosive atmosphere, providing a certain protection to the base metal substrate. In general, the degree of this protection is relative to the coating thickness. Beyond this point, various metallic coatings have unique characteristics which give them corrosion resistance capabilities in addition to simple barrier-type protection. Applicable protective coating mechanisms for the three types of metallic coatings involved in this test program are discussed below.

Galvanize Coating

There are two important characteristics which make zinc coatings effective for corrosion protection of a steel substrate. Its natural corrosion resistance is due to its reactive nature and subsequent ability to form a protective surface film of zinc oxide or other corrosion products depending on the type of environmental exposure. This further enhances the corrosion resistance of the coating.

Seldom is the coated product free of coating discontinuities. When this product undergoes severe forming operations such as in culvert production, the coating is also subject to abrasions, scratches and crazing/flaking. These potential corrosion sites become less of a concern because of the electro-chemical nature of the zinc coating. Zinc provides cathodic protection to the steel substrate, sacrificing itself in lieu of the substrate. The zinc corrosion products resulting from this sacrificial action become themselves protective of the substrate by sealing the discontinuities or other defects from which the activity began. Cathodic protection will continue as long as zinc coating is present and the distance between the exposed steel substrate and remaining coating is not too remote.

Because of its reactive nature, zinc is susceptible to dissolution at extreme pH conditions such as pH-3 and pH-12 employed in this program. The more aggressive reaction occurs at the acidic pH-3 condition and can result in total coating dissolution. Cathodic protection is active but of relatively short duration under this condition.

Aluminize Coating

It should be noted that because of the difference in density of aluminum and zinc, a 1.0 oz. aluminum coating provides a total coating thickness (free aluminum and alloy) greater than either a 2.0 oz. Galfan or galvanize coating.

As with zinc coatings, the protection of the steel substrate by the aluminum coating depends on the physical barrier associated with oxidation products and its sacrificial ability. Whereas the sacrificial property of the zinc coating was most effective in this program, it was the physical barrier characteristic of the aluminum coating which appeared more effective.

Aluminum is a reactive metal with a high affinity for oxygen. As a result, a protective, inert oxide surface film develops quickly providing a barrier resistant to most atmospheres. However, this barrier proved ineffective against aggressive corrosion of the upper test panel areas. Corrosion developed in areas of poor coating adhesion and at cut edges where the steel substrate was exposed and aggressively penetrated beneath the protective surface barrier.

In the immersed condition, sacrificial protection occurs in a less dramatic fashion than for a zinc coating. Exposed substrate initially develops corrosion staining but then remains virtually unchanged. Little sacrificial corrosion product is formed but corrosion progress is limited by the surrounding coating.

Another similarity to zinc is its susceptibility to dissolution at the extreme pH-3 and pH-12 conditions. Their dissolution at pH-3 is somewhat comparable but at pH-12 the aluminum coating is more readily attacked and dissolved.

A factor which is an important consideration in any product requiring significant forming operations is the susceptibility to flaking of the coating. In the coating of steel with aluminum, there is a tendency to develop a rather thick iron-aluminum alloy layer. This layer is relatively brittle and during forming is subject to flaking, exposing bare substrate.

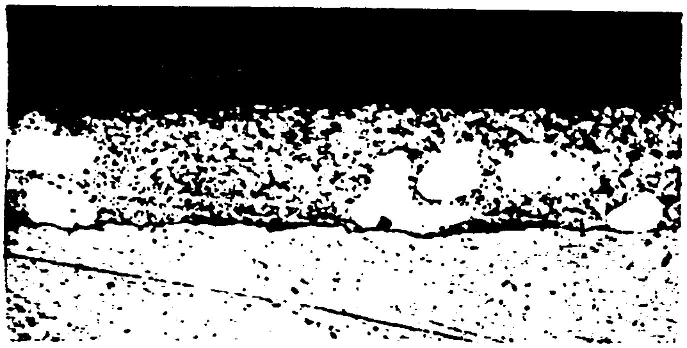
Galfan Coating

The following reflects observations of this coating performance relative to the performance of the other coatings involved in this test program. In general, the Galfan coating (95% Zn - 5% Al) appears to combine the best protection characteristics of both the galvanize and aluminize coatings.

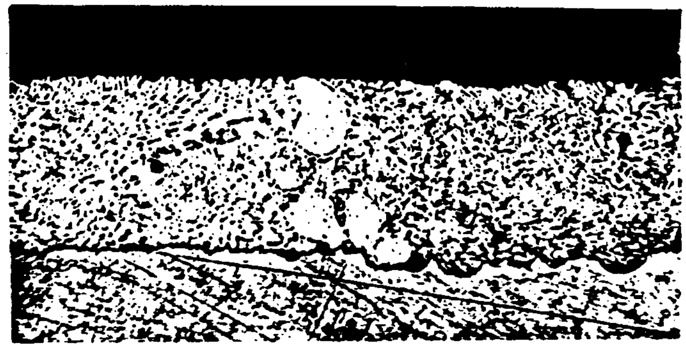
The sacrificial protection typical for galvanize coatings, was active and effective for this coating as well. Sacrificial corrosion protection was evident at exposed cut edges and at various locations on the immersed panel areas.

Reaction to the various test conditions was less, with one exception, than that of galvanize or aluminize of comparable coating weight. At the pH-3 condition, the Galfan coating (2.0 oz.) resisted coating loss more effectively than galvanize or aluminize. At the pH-12 condition, the Galfan coating showed virtually no attack while galvanize attack was moderate and aluminize attack was severe. The one exception noted was for pH-3 condition, 1.15 oz. coating for which coating loss occurred more rapidly than the other comparable coatings.

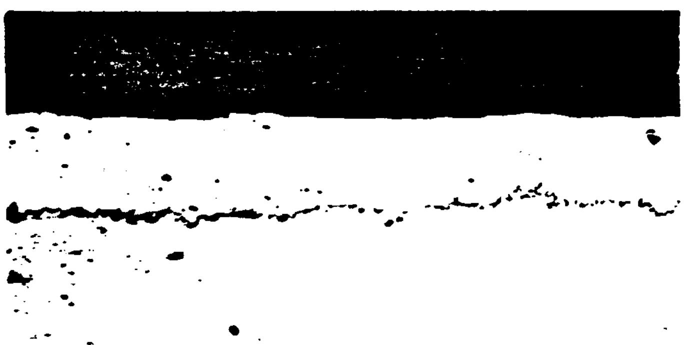
TYPICAL COATING STRUCTURES PRIOR TO TESTING



Galfan 1.15 oz. X-500

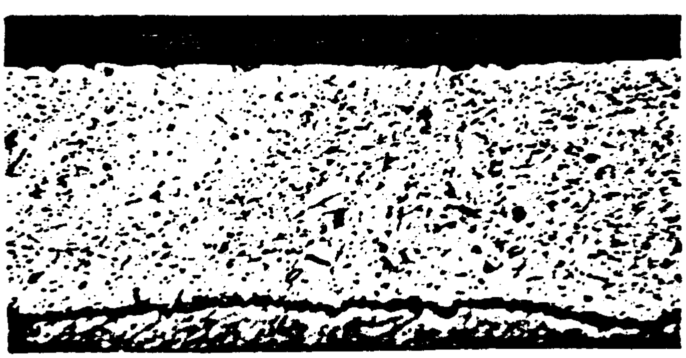


Galfan 2.0 oz. X-500

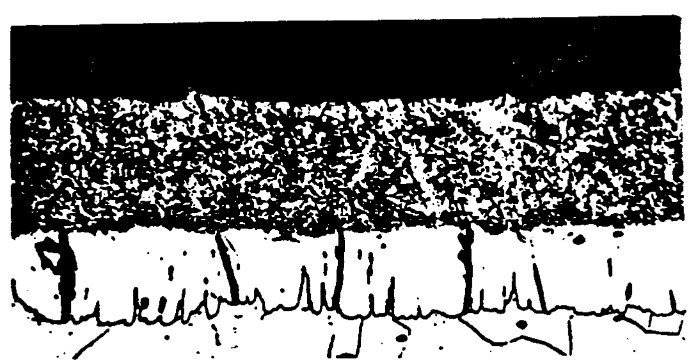


Galvanize 1.15 oz. X-500

Galvanize 2.0 oz. X-500



Galvanize 2.6 oz. X-500



Aluminized Type II 1.0 oz. X-500

IMMERSION CORROSION TESTING

CORROSION PERFORMANCE COMPARISON

Galfan - 2.0 oz. vs. Aluminized Type II - 1.0 oz.

The overall performance of the Galfan product was superior to the aluminized product under the conditions of this test program. Performance of the product test panels was to be based upon the ability of the coating to resist failure as indicated by red rust formation on the immersed areas exposed to the corrosive media. However, other performance characteristics of the aluminized product contributed to its overall questionable performance.

Performance comparison of the two products, based only on the immersed test panel areas, showed similar base metal protection at the intermediate test conditions of pH-5 and pH-9. At the more aggressive conditions of pH-3 and pH-12, the aluminized product was unable to protect the base metal from red rust formation while the Galfan product exhibited minor red rust formation, only at the pH-3 condition.

Contributing to the overall poor performance of the aluminized product was the unsatisfactory coating adhesion which resulted from the culvert-forming process. This product exhibits a thick alloy layer which apparently results in flaking and/or crazing of the coating, reducing its effectiveness. These areas then become sites of red rust attack. Those in the immersed panel area are limited in area while those on the upper panel area are aggressive and expansive.

Also involved in the coating failure on the upper panel area is the apparent susceptibility toward red rust initiation at the waterline - panel edge interface. Flat panels, which exhibit no flaking problem, are subject to this upper panel attack as well as the formed panels. Throughout the test period, the upper panel areas involved, continually increased.

The Galfan product showed no evidence of poor adhesion or similar coating failure as noted for the aluminized product. Some minor "white rust"-like corrosion was noted on upper panel areas. Immersed panel areas exhibited deposits similar to the sacrificial deposits common to a galvanized product.

Galfan - 2.0 oz. vs. Aluminized Type II - 1.0 oz.

PERFORMANCE AT pH-3

Galfan - 2.0 oz. - Fig. 1A

Week 3 - Minor sacrificial corrosion product on immersed panel surface and base metal exposed edges.

Week 11 - First indication of red rust corrosion on immersed panel surface.

Week 14 - Minor red rust corrosion on immersed panel area.

Micro - Above Waterline- Fig. 1B

Metallic coating above the waterline is essentially unaffected. Heavy sacrificial coating loss near the waterline is also shown at the right edge of the micro.

Micro - Below Waterline - Fig. 1C

There is complete loss of the metallic coating with some minor base metal attack. A protective "coating", possibly sacrificial corrosion product, is visible as a dark layer on the base metal in place of the original metallic coating.

Aluminized Type II - 1.0 oz. - Fig. 2A

Week 3 - Some aggressive red rust corrosion on upper area of formed panels where coating flaked. Flat panel showed beginning of corrosion at waterline - panel edge interface.

Week 5 - Increase in above-noted conditions. Light red rust indication across waterline.

Week 6 - Reformed immersed panel area dark, other panels had a mottled (dark and light) surface. Increase in above-noted conditions.

Week 9 - Immersed panel areas uniformly covered with a red rust coating.

Week 14 - Immersed panel areas uniformly dark with red rust coating. Heavy upper panel red rust corrosion; flat panel - 50%, reformed panel - 100%.

Micro - Above Waterline - Fig. 2B

Near total loss of the free aluminum layer. Attack of the alloy layer is in progress. The fissured alloy layer provides access to the base metal. Heavy upper panel corrosion appears to involve attack of the free aluminum and alloy layers and minimal base metal involvement.

Micro - Below Waterline - Fig. 2C

Total loss of free aluminum layer and most of alloy layer. Significant base metal attack and dissolution is evident.

GALFAN - 2.0 OZ. | pH - 3 | ALUM TYPE II - 1.0 OZ.

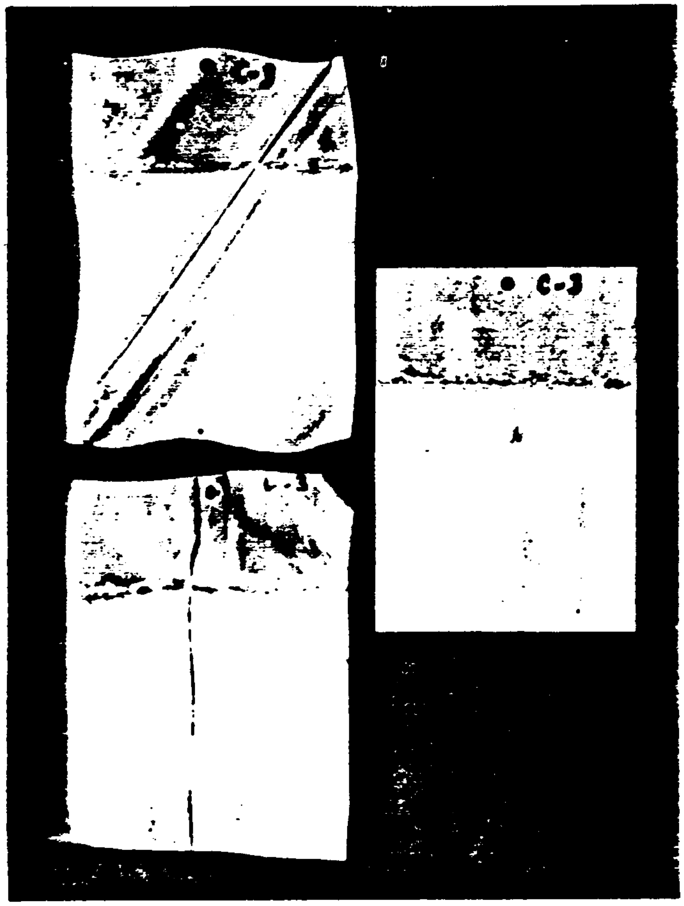


Figure 1A

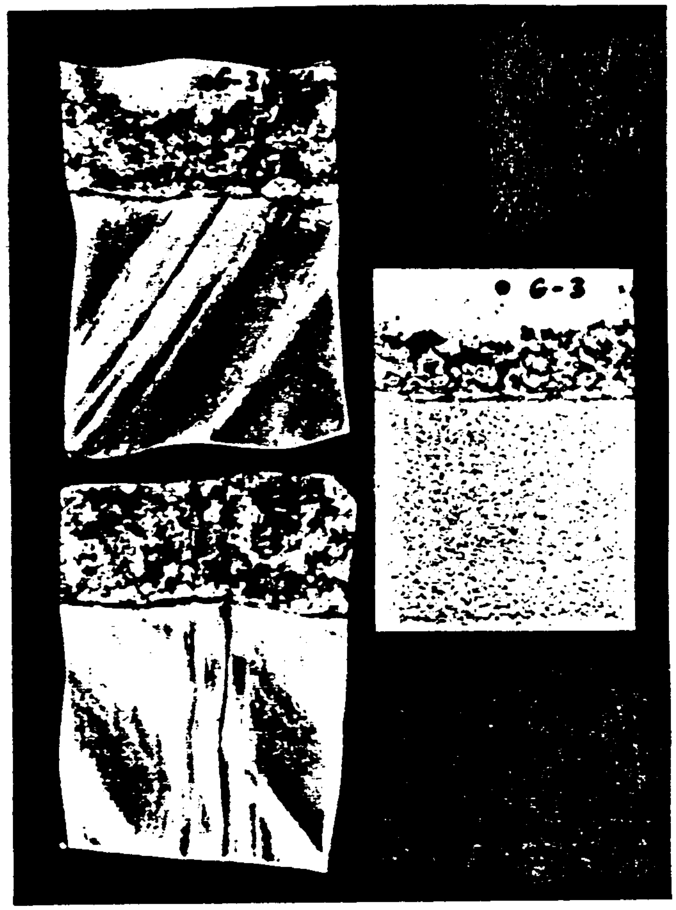


Figure 2A

Photograph of cleaned test panels at 14 weeks

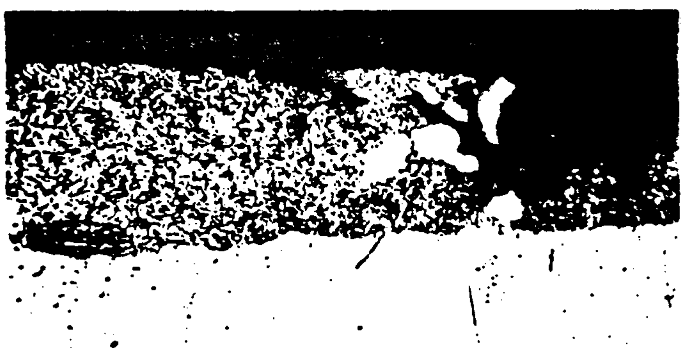


Figure 1B 500X

Figure 2B 500X

Photomicrograph - above the waterline

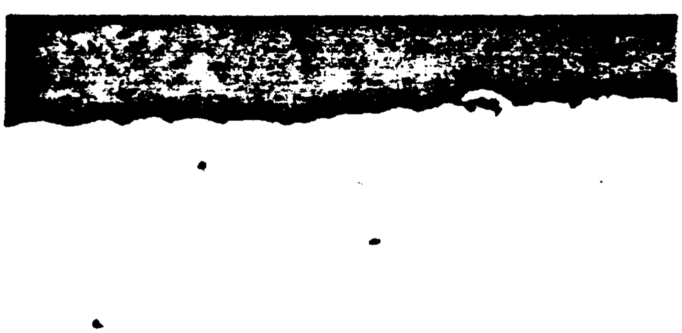


Figure 1C 500X

Figure 2C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-5

Galfan - 2.0 oz. - Fig. 3A

Week 3 - Scattered light sacrificial corrosion product on the immersed panel areas. Also light accumulation across water line. Base metal exposed edges coated with sacrificial corrosion product.

Week 14 - Conditions noted above increased only slightly through the test period. No indication of coating failure.

Micro - Above Waterline - Fig. 3B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 3C

A significant amount of coating attack and loss has occurred. No penetration to or attack of base metal.

Aluminized Type II - 1.0 oz. - Fig. 4A

Week 3 - Formed panels exhibited flaking/crazing of the coating with that on the reformed panel being more extensive. Red rust corrosion both above and below the waterline was evident on the reformed panel.

Week 6 - Extensive red rust corrosion on upper panel area of reformed panel where flaking occurred; some was evident on the corrugated panel. Corrosion at the waterline - panel edge interface in progress.

Week 10 - Aggressive upper panel corrosion continued. Reformed upper panel area - 100%.

Week 14 - Upper panel red rust corrosion heavy. Red rust sites on the immersed panel areas remained unchanged through test period. Scattered coating loss on immersed areas but no indication of coating protection failure.

Micro - Above Waterline - Fig. 4B

There is almost total loss of the free aluminum layer. There also appears to be some alloy layer attack. Base metal remains protected.

Micro - Below Waterline - Fig. 4C

Some minor attack of the free aluminum layer. Base metal protection is satisfactory.

pH - 5

GALFAN - 2.0 OZ.

ALUM TYPE II - 1.0 OZ.

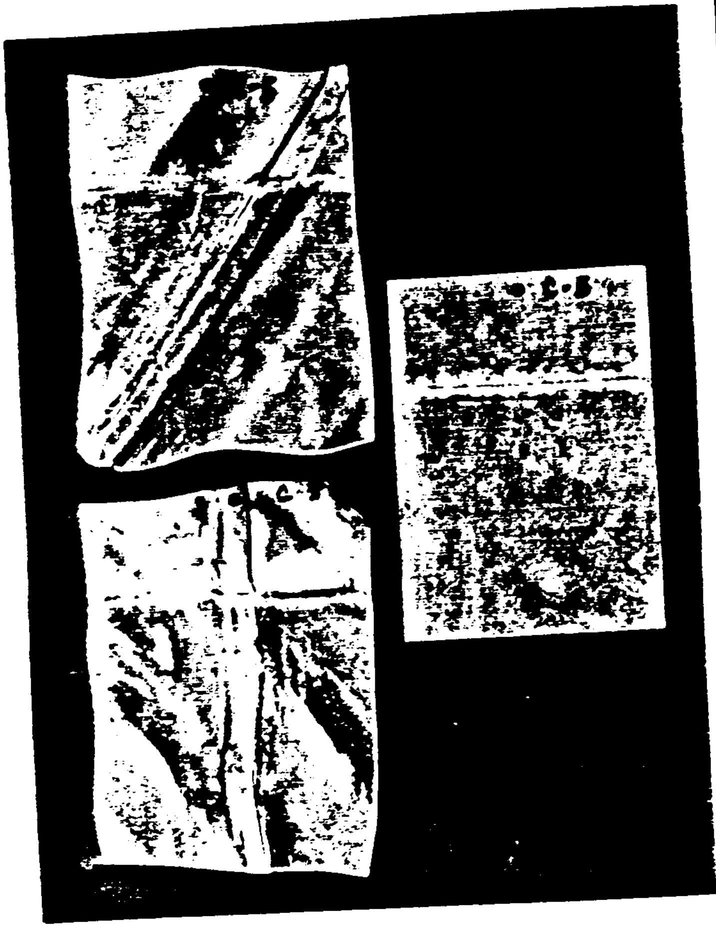


Figure 3A

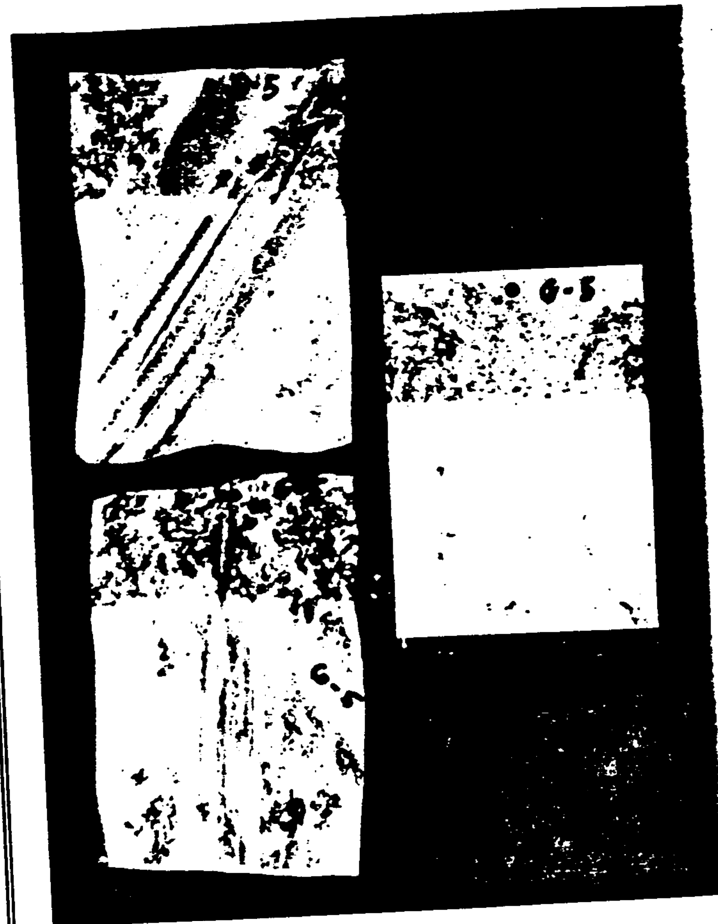


Figure 4A

Photograph of cleaned test panels at 14 weeks

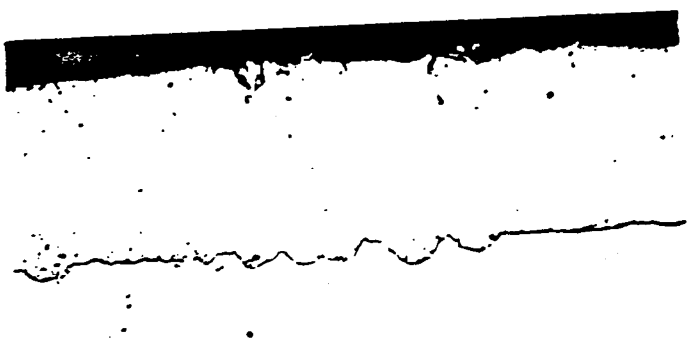


Figure 3B

500X

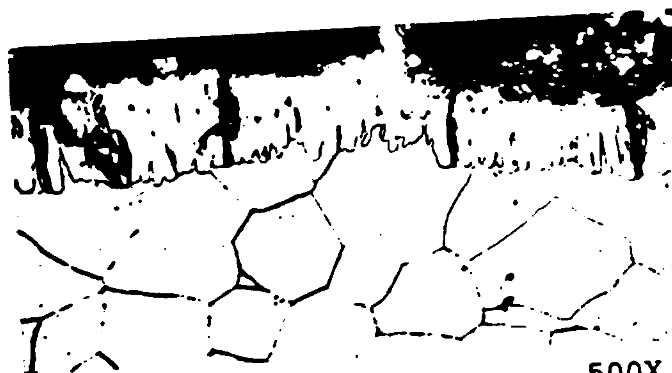


Figure 4B

500X

Photomicrograph - above the waterline

Figure 3C

500X

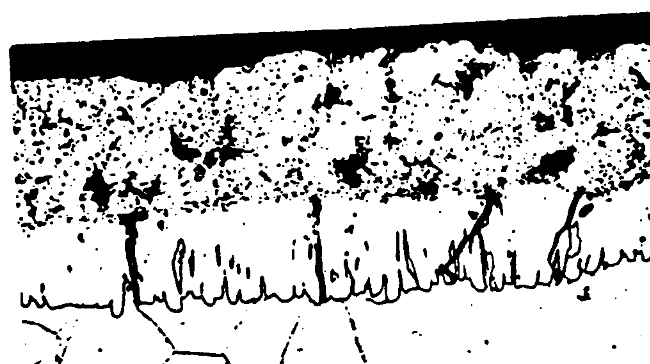


Figure 4C

500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-9

Galfan - 2.0 oz. - Fig. 5A

Week 3 - Scattered light sacrificial corrosion product at the waterline and on the immersed panel area.

Week 6 - Some increase in accumulations noted in the above areas, particularly at the waterline. Some coating loss beneath immersed panel area accumulations.

Week 14 - Continued increase in conditions noted above. Areas involved were scattered and less than 10% of immersed panel area. No failure of coating protection.

Micro - Above Waterline - Fig. 5B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 5C

The coating shows a typical, unaffected surface.

Aluminized Type II - 1.0 oz. - Fig. 6A

Week 3 - Formed panels exhibited flaking/crazing of the coating with that on the reformed panel being more extensive. Red rust corrosion occurred above the waterline on the reformed panel.

Week 9 - Formed panels showed increased heavy red rust corrosion in the lockseam area and along the edges of the upper panel area. A white corrosion product had formed on the immersed panel area, along the waterline and at the waterline - edge interface.

Week 14 - Upper panel areas showed a varying extent of corrosion involvement. Immersed areas showed large patches of white corrosion product. There was no evidence of red rust due to coating protection failure.

Micro - Above Waterline - Fig. 6B

The free aluminum layer appears to be uniformly reduced in this area. Base steel remains protected.

Micro - Below Waterline - Fig. 6C

The rough coating surface indicates some attack and dissolution of the free aluminum layer. Most of the free aluminum layer is intact, providing protection.

pH - 9

GALFAN - 2.0 OZ. | ALUM TYPE II - 1.0 OZ.

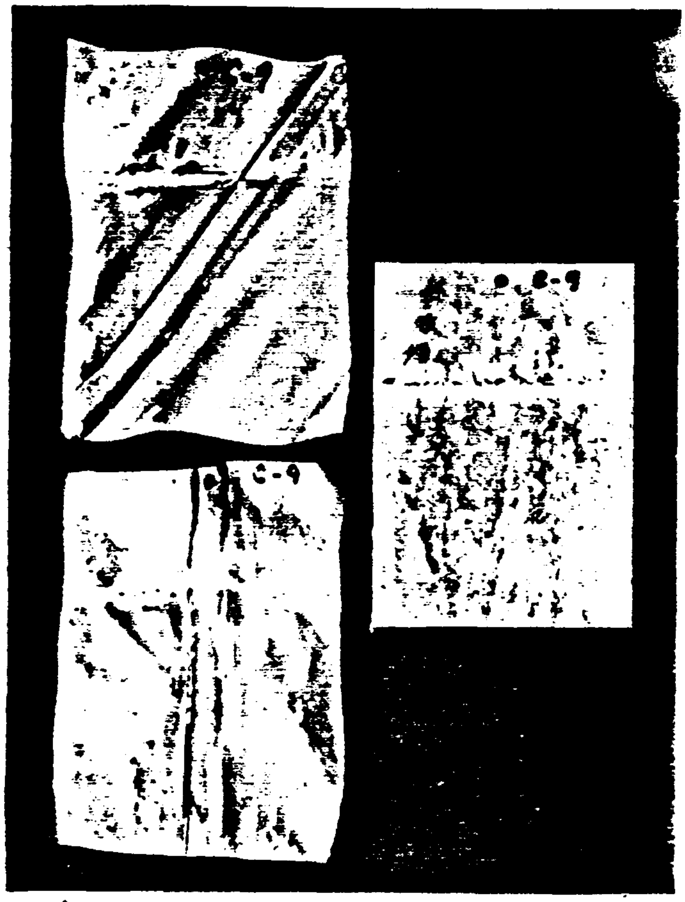


Figure 5A

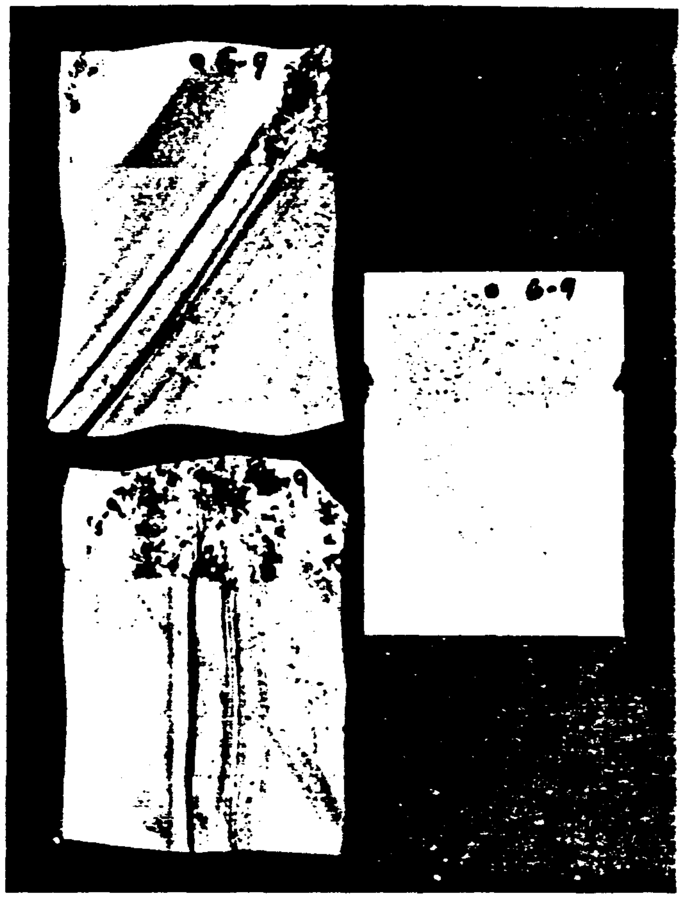


Figure 6A

Photograph of cleaned test panels at 14 weeks

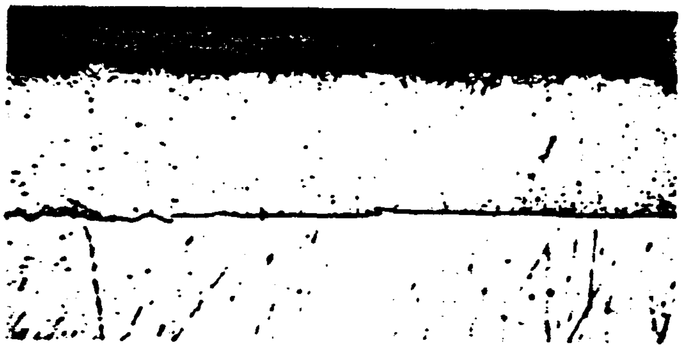


Figure 5B 500X

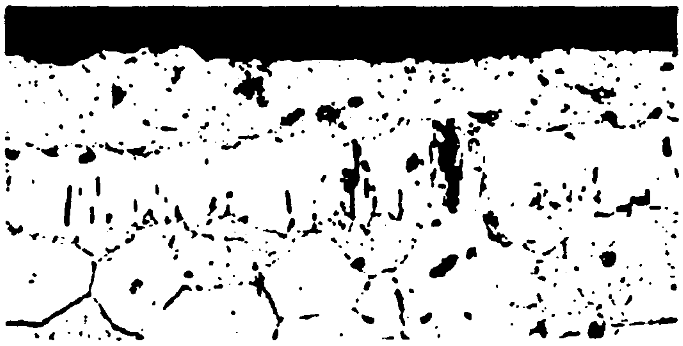


Figure 6B 500X

Photomicrograph - above the waterline

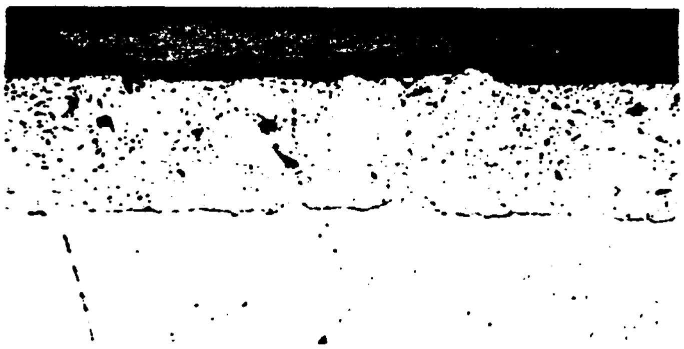


Figure 5C 500X

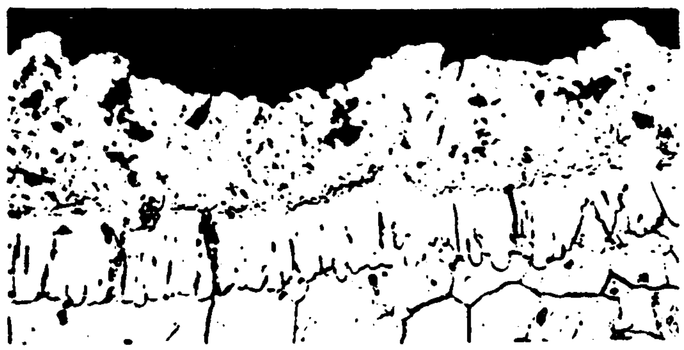


Figure 6C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-12

Galfan - 2.0 oz. - Fig. 7A

Week 3 - Crevice-type attack within the immersed lockseam indicated by heavy sacrificial corrosion product in that area. Some waterline accumulation also present.

Week 6 - Heavy sacrificial corrosion accumulation at the waterline and a few scattered areas on the immersed panel. No coating loss in these areas was apparent.

Week 14 - There was some additional increase in above-noted areas coated with sacrificial corrosion product, then remained unchanged through the test period. There was no indication of coating protection failure.

Micro - Above Waterline - Fig. 7B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 7C

The coating surface shows some minor coating dissolution.

Aluminized Type II - 1.0 oz. - Fig. 8A

Week 1 - The aluminum coating on the immersed panel area reacted vigorously with the test media the first 2 to 3 days of testing. The immersed panel area took on a dark appearance with some scattered light areas. This condition remained unchanged through the test period.

Week 6 - A white accumulation developed in a band across the panel width immediately above the waterline. Coating loss and base metal corrosion were evident under the accumulation. The reformed panel exhibited coating flaking/crazing in the upper lockseam area. Red rust corrosion in that area was in progress.

Week 14 - Upper panel red rust corrosion increased in the above-noted areas through the test period. Panel edge areas also became involved. Cleaned panels showed extensive red rust corrosion above and below the waterline.

Micro - Above Waterline - Fig. 8B

The free aluminum layer is totally absent and attack of the alloy layer is evident. Access to the base metal is apparent but no indication of base metal attack is shown.

Micro - Below Waterline - Fig. 8C

The free aluminum layer was completely removed by dissolution. The alloy layer was also affected; its thickness appears partially reduced. A protective "coating" appears as a thin dark layer, possibly alloy corrosion product, on the remaining alloy layer, restricting base metal access through the alloy fissures. No base metal attack is apparent.

GALFAN - 2.0 OZ. **pH - 12** ALUM TYPE II - 1.0 OZ.

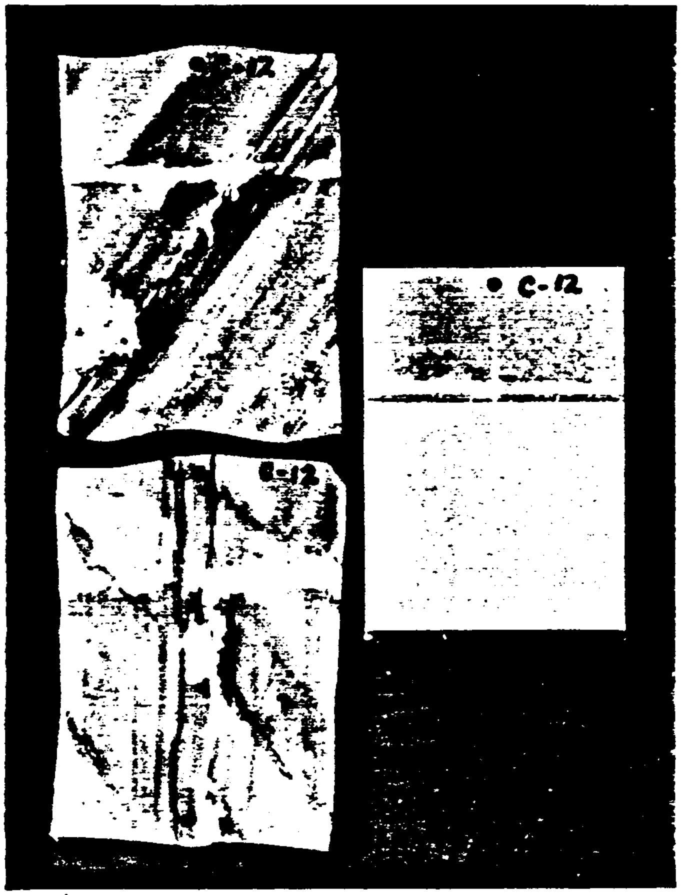


Figure 7A

Figure 8A

Photograph of cleaned test panels at 14 weeks

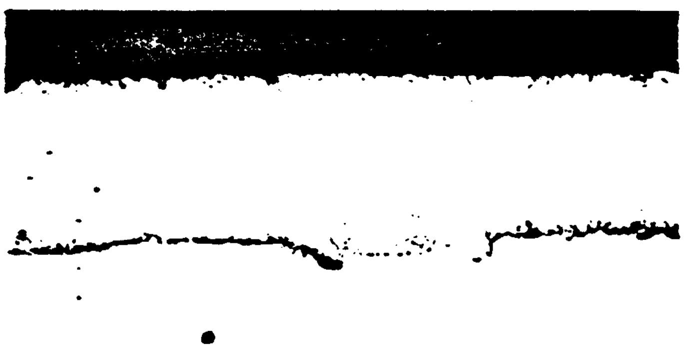


Figure 7B 500X

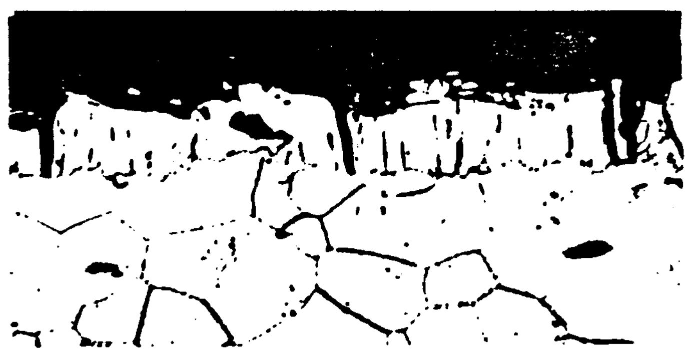


Figure 8B 500X

Photomicrograph - above the waterline

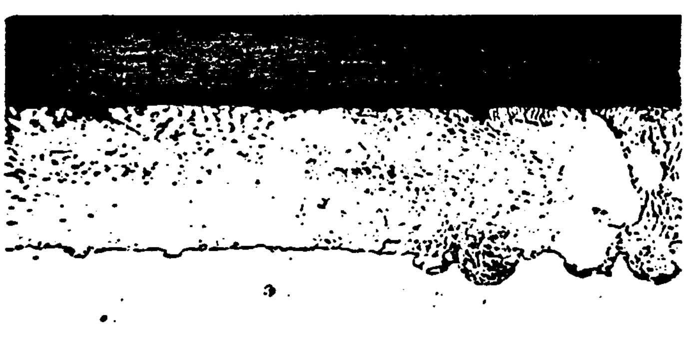


Figure 7C 500X

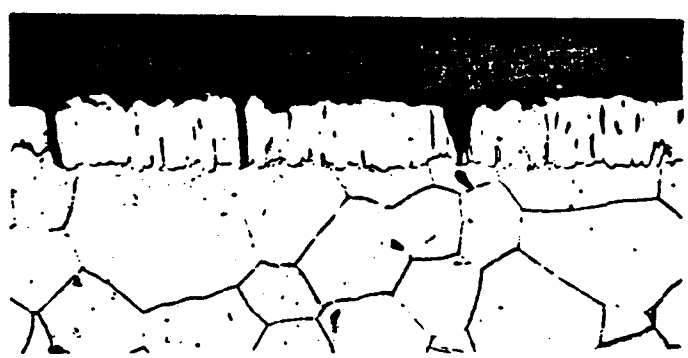


Figure 8C 500X

Photomicrograph - below the waterline

IMMERSION CORROSION TESTING

CORROSION PERFORMANCE COMPARISON

Galfan - 2.0 oz. vs. Galvanize - 2.0 oz.

As was noted previously, this galvanize product was compared successfully with the aluminized Type II product in the 1980 immersion corrosion test program. Because of the possible introduction of Galfan-coated material as a culvert pipe product, a performance comparison of these two coated materials is of interest.

In the current test program, the overall performance of the Galfan product was superior to the galvanize product at each test condition. The only failure, in terms of significant red rust formation, occurred with the galvanize panels at the more aggressive pH-3 condition. While performance was satisfactory at the other pH levels for both coated materials, the Galfan panels appeared to provide a greater resistance to the test media. At each test condition, the Galfan panels exhibited considerably less sacrificial corrosion product than the corresponding galvanize panels. The Galfan test panels appear to have fewer coating discontinuities by which the test media can contact the base metal. With less base metal exposure, there is less need for sacrificial loss of coating. This, in turn, should provide extended service performance.

Galfan - 2.0 oz. vs. Galvanize - 2.0 oz.

PERFORMANCE AT pH-3 - Fig. 9A

Galfan - 2.0 oz.

Week 3 - Minor sacrificial corrosion product on immersed panel surface and base metal exposed edges.

Week 11 - First indication of red rust corrosion on immersed panel surface.

Week 14 - Minor red rust corrosion on immersed panel area.

Micro - Above Waterline - Fig. 9B

Metallic coating above the waterline is essentially unaffected. Heavy sacrificial coating loss near the waterline is also shown at the right edge of the micro.

Micro - Below Waterline - Fig. 9C

There is complete loss of metallic coating with some minor base metal attack. A protective "coating", possibly sacrificial corrosion product, is visible as a dark layer on the base metal in place of the original metallic coating.

Galvanize - 2.0 oz. - Fig. 10A

Week 3 - Immersed panel areas showed some coating loss, particularly in areas stressed during forming. Some sacrificial corrosion product at the waterline.

Week 9 - Coating loss on immersed panel areas appeared to be complete. Some light red rust on formed panels, extensive on flat panel. Heavier sacrificial corrosion product at and extended above the waterline. Some "white rust" corrosion on upper panel areas.

Week 12 - Heavy red rust coating on immersed panel areas. Other conditions noted above continued to progress.

Week 14 - Red rust on upper portion of immersed panel area easily removed. The heavy corrosion band adjacent to the waterline appeared to provide sacrificial protection for some distance, preventing more vigorous base metal attack.

Micro - Above Waterline - Fig. 10B

The galvanize coating above the waterline has been totally sacrificed to protect the lower panel area. Corrosion product in this area is shown as a dark non-metallic layer. Base metal attack is indicated by the uneven surface.

Micro - Below Waterline - Fig. 10C

Total dissolution of the galvanize coating has occurred. Base metal attack is indicated by the uneven surface.

pH - 3

GALFAN - 2.0 OZ. | GALVANIZE - 2.0 OZ.

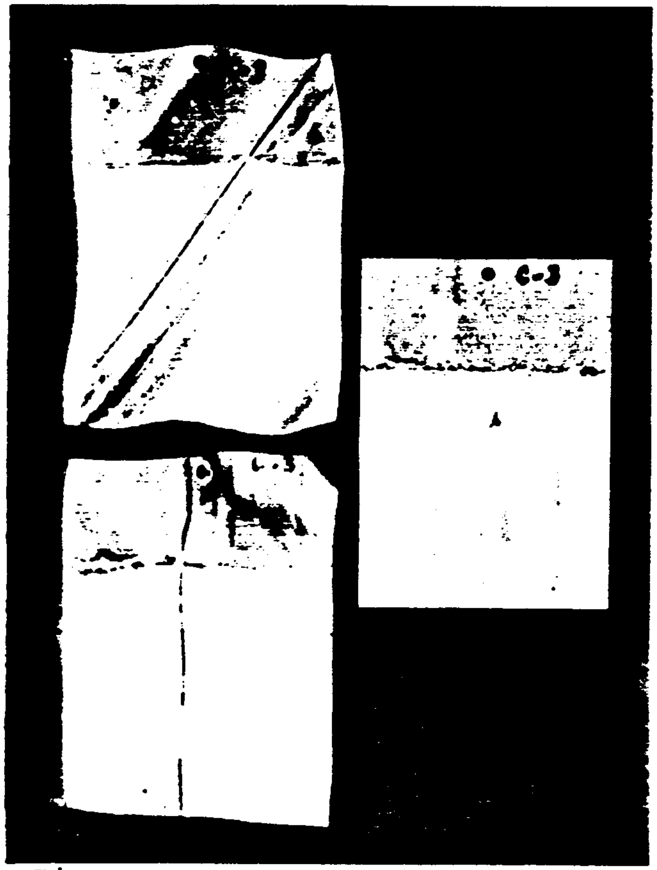


Figure 9A

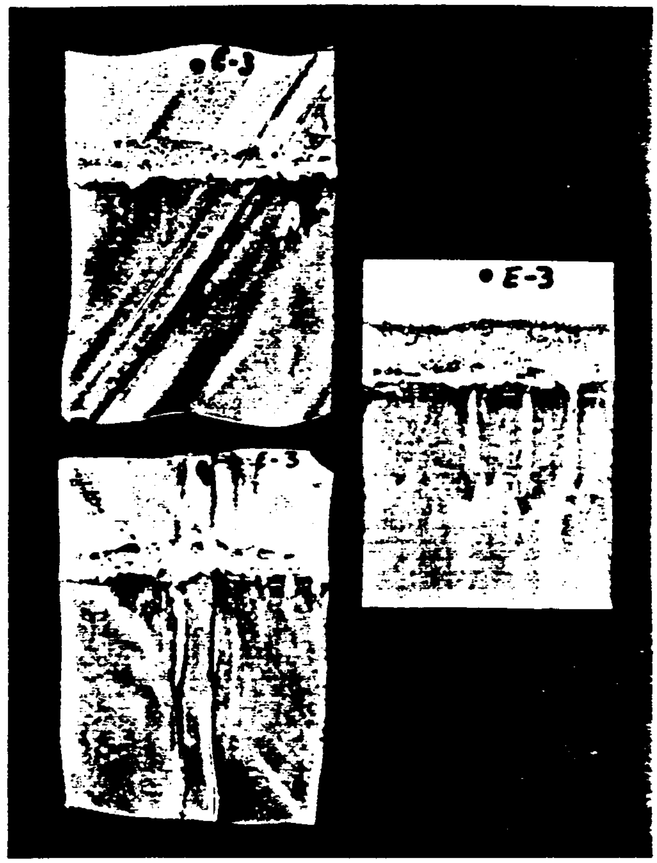


Figure 10A

Photograph of cleaned test panels at 14 weeks

Figure 9B 500X

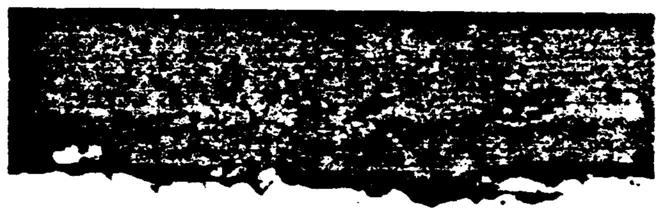


Figure 10B 500X

Photomicrograph - above the waterline

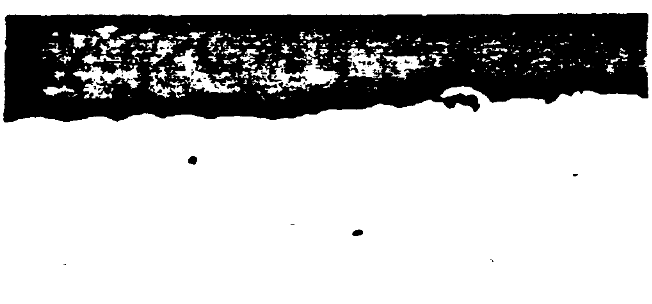


Figure 9C 500X

Figure 10C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-5

Galfan - 2.0 oz. - Fig. 11A

Week 3 - Scattered light sacrificial corrosion product on the immersed panel areas. Also light accumulation across water line. Base metal exposed edges coated with sacrificial corrosion product.

Week 14 - Conditions noted above increased only slightly through the test period. No indication of coating failure.

Micro - Above Waterline - Fig. 11B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 11C

A significant amount of coating attack and loss has occurred. No penetration to or attack of base metal.

Galvanize - 2.0 oz. - Fig. 12A

Week 3 - Light sacrificial corrosion product was present along the waterline and on the immersed cut edges where base metal was exposed.

Week 6 - Increased waterline accumulation. Some apparent coating loss, particularly in the stressed area associated with lockseam forming. Increased sacrificial corrosion product in these areas.

Week 14 - Heavy sacrificial corrosion product accumulation at the waterline, along the lockseam area and in some corrugated areas. No indication of red rust failure.

Micro - Above Waterline - Fig. 12B

Some selective attack of the galvanize coating is shown. Most of the coating remains unaffected and provides substantial base metal protection.

Micro - Below Waterline - Fig. 12C

Much of the galvanize coating has been removed. Some selective attack of the base metal is evident. The remaining coating continues to provide sacrificial protection against red rust formation.

pH - 5

GALFAN - 2.0 OZ. | **GALVANIZE - 2.0 OZ.**

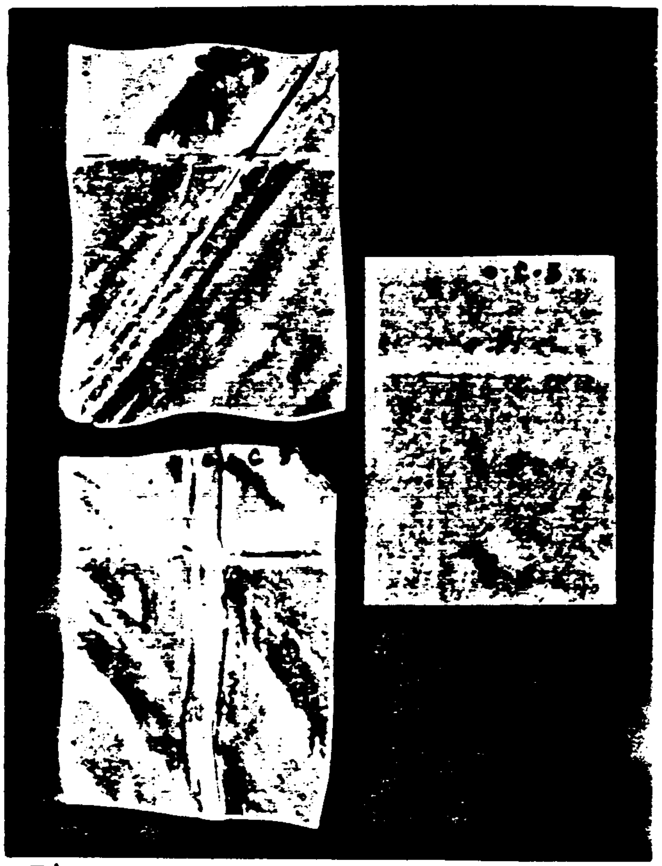


Figure 11A

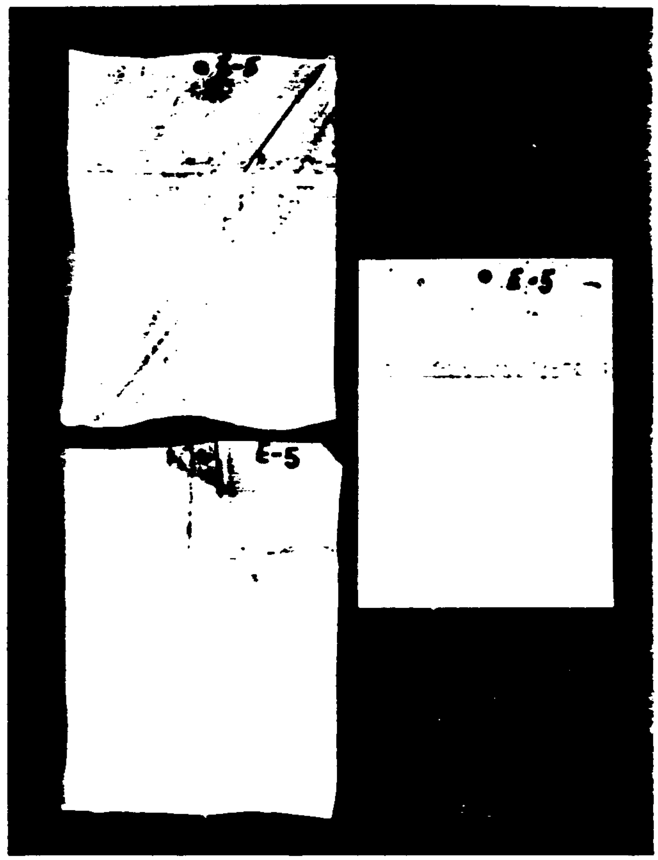


Figure 12A

Photograph of cleaned test panels at 14 weeks

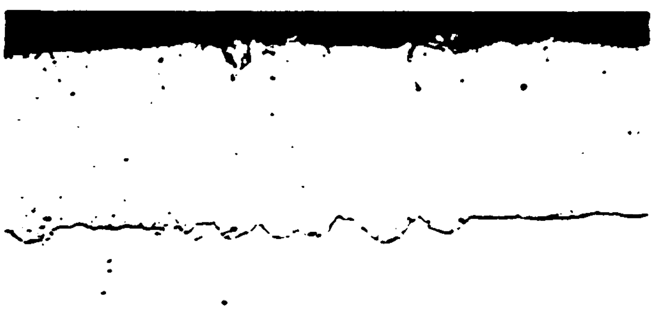


Figure 11B 500X

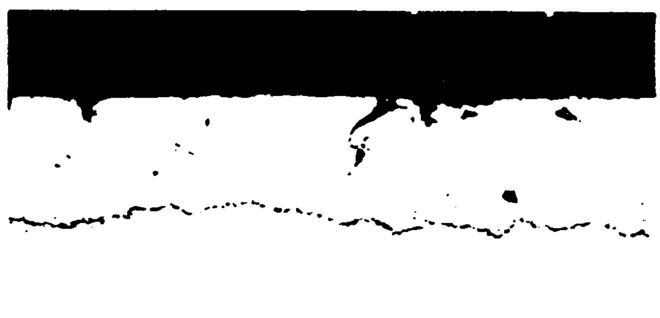


Figure 12B 500X

Photomicrograph - above the waterline

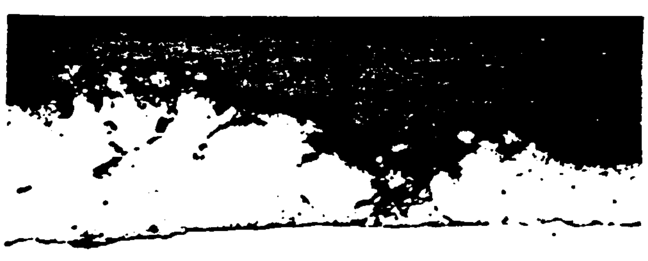


Figure 11C 500X

Figure 12C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-9

Galfan - 2.0 oz. - Fig. 13A

Week 3 - Scattered light sacrificial corrosion product at the waterline and on the immersed panel area.

Week 6 - Some increase in accumulations noted in the above areas, particularly at the waterline. Some coating loss beneath immersed panel area accumulations.

Week 14 - Continued increase in conditions noted above. Areas involved were scattered and less than 10% of immersed panel area. No failure of coating protection.

Micro - Above Waterline - Fig. 13B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 13C

The coating shows a typical, unaffected surface.

Galvanize - 2.0 oz. - Fig. 14A

Week 3 - Heavy sacrificial corrosion product on immersed panel areas. Accumulations scattered in large and small patches.

Week 6 - Continued increase in above-noted condition.

Week 14 - Panel areas having sacrificial corrosion product coverage were extensive. Unaffected areas presented a shiny, spangled surface. There was no indication of red rust failure.

Micro - Above Waterline Fig. 14B

The galvanize coating surface is slightly uneven suggesting minor attack. Remaining coating provides substantial base metal protection.

Micro - Below Waterline - Fig. 14C

The galvanize coating shows a varied degree of attack with some loss complete to the base metal. Some minor base metal attack appears to have occurred at these locations. Considerable coating remains to provide continuing base metal protection against red rust failure.

GALFAN - 2.0 OZ. | pH - 9 | GALVANIZE - 2.0 OZ.

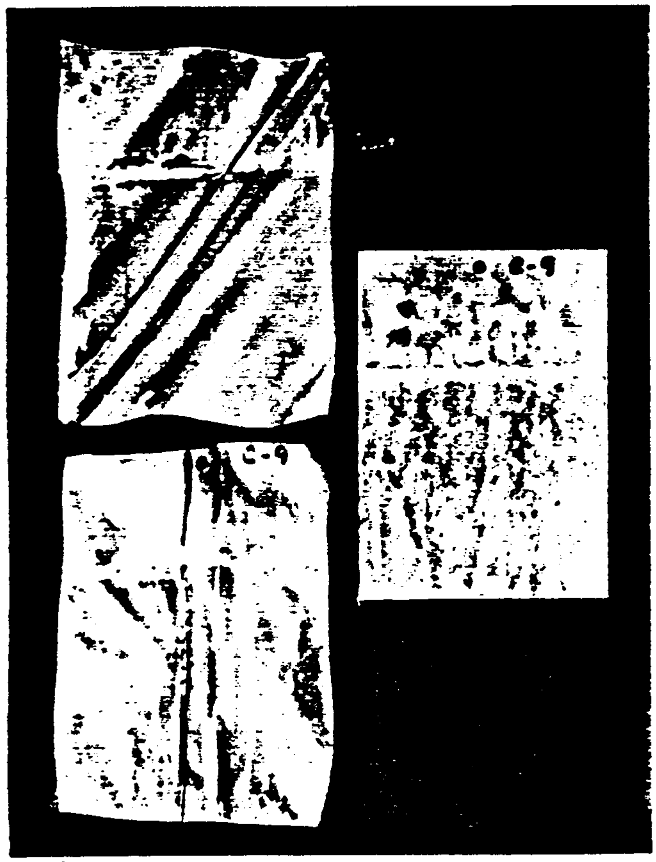


Figure 13A

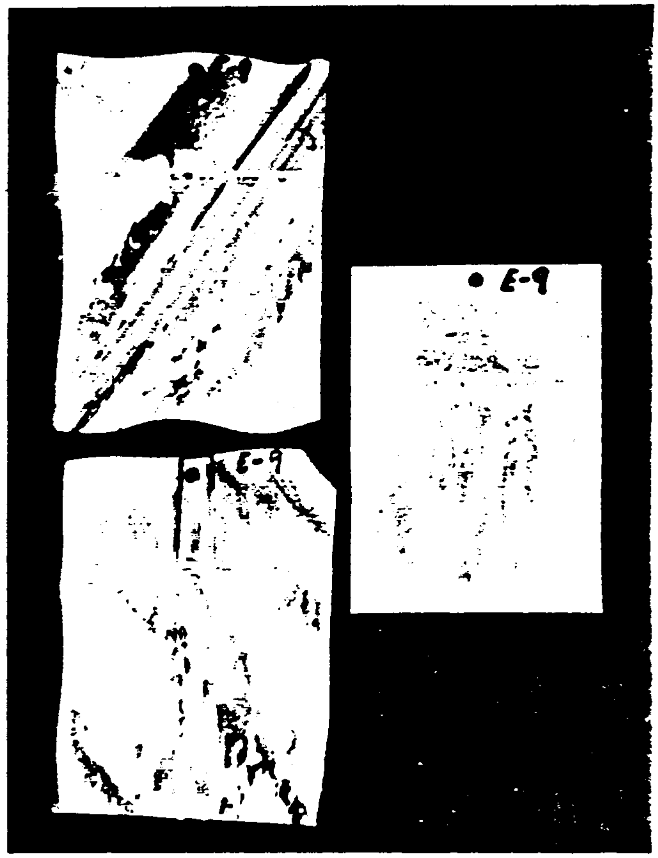


Figure 14A

Photograph of cleaned test panels at 14 weeks

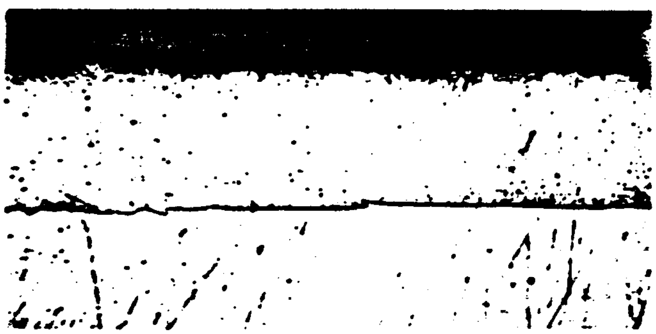


Figure 13B 500X

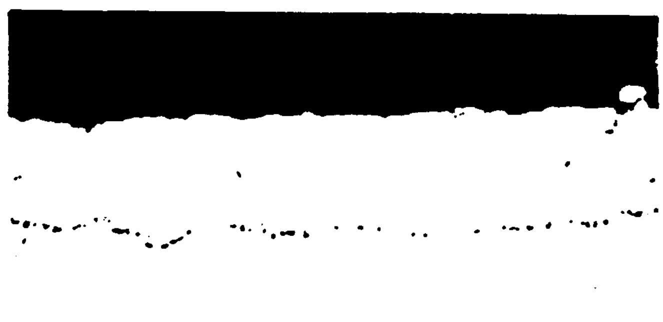


Figure 14B 500X

Photomicrograph - above the waterline

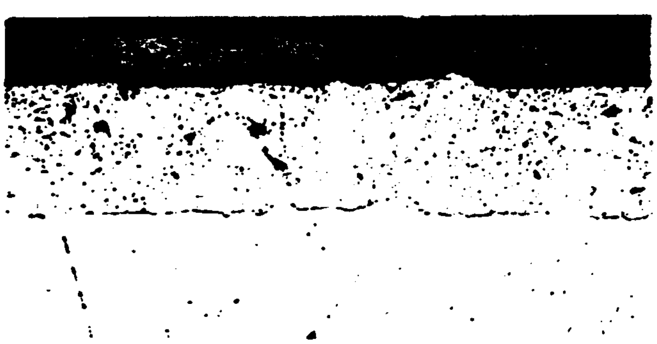


Figure 13C 500X

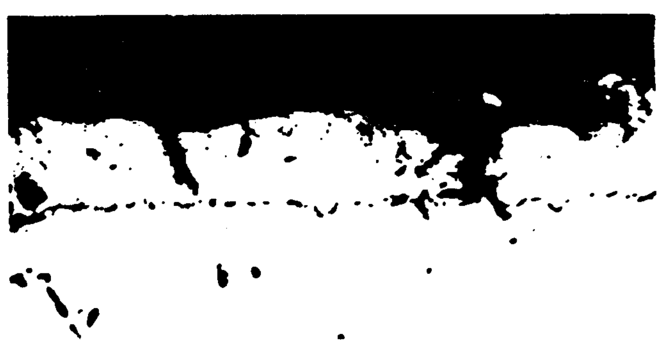


Figure 14C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-12

Galfan - 2.0 oz. - Fig. 15A

Week 3 - Crevice-type attack within the immersed lockseam indicated by heavy sacrificial corrosion product in that area. Some waterline accumulation also present.

Week 6 - Heavy sacrificial corrosion accumulation at the waterline and a few scattered areas on the immersed panel. No coating loss in these areas was apparent.

Week 14 - There was some additional increase in above-noted areas coated with sacrificial corrosion product, then remained unchanged through the test period. There was no indication of coating protection failure.

Micro - Above Waterline - Fig. 15B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 15C

The coating surface shows some minor coating dissolution.

Galvanize - 2.0 oz. - Fig. 16A

Week 3 - Heavy sacrificial corrosion product at the waterline and at scattered locations on the immersed panel areas. On the formed panels, this condition primarily involved the lockseam area.

Week 6 - Increased heavy accumulation in above-noted locations and involved larger panel areas.

Week 14 - Involved areas noted above remained unchanged from Week 6. Areas under sacrificial corrosion product showed aggressive galvanize coating attack. Remaining coating provided adequate protection against red rust failure.

Micro - Above Waterline - Fig. 16B

The galvanize coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 16C

The galvanize coating shows a feather-like surface condition. This appears to be caused by partial coating dissolution by the highly alkaline test media. Most of the galvanize coating shows no adverse effect and provides adequate base metal protection.

pH - 12

GALFAN - 2.0 OZ. | GALVANIZE - 2.0 OZ.

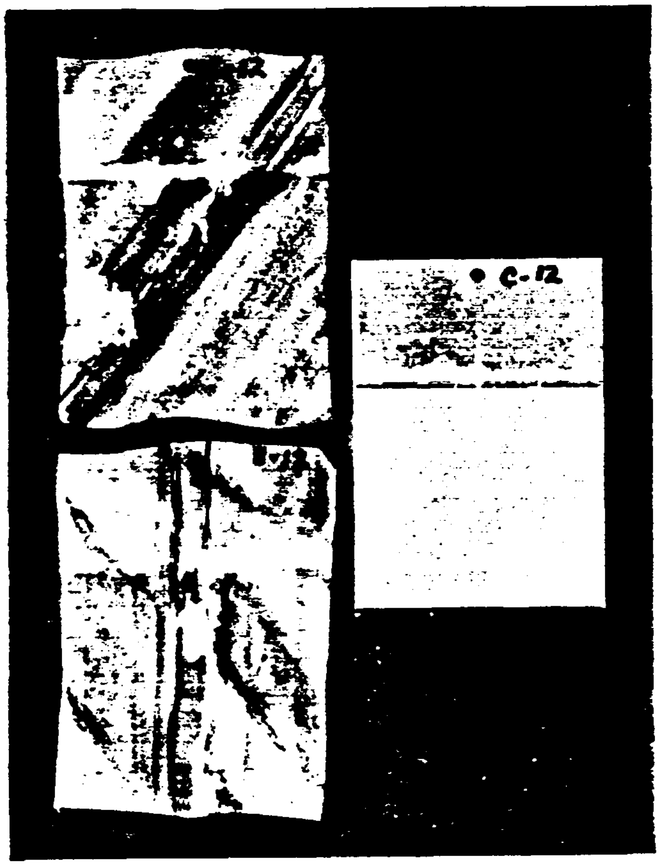


Figure 15A

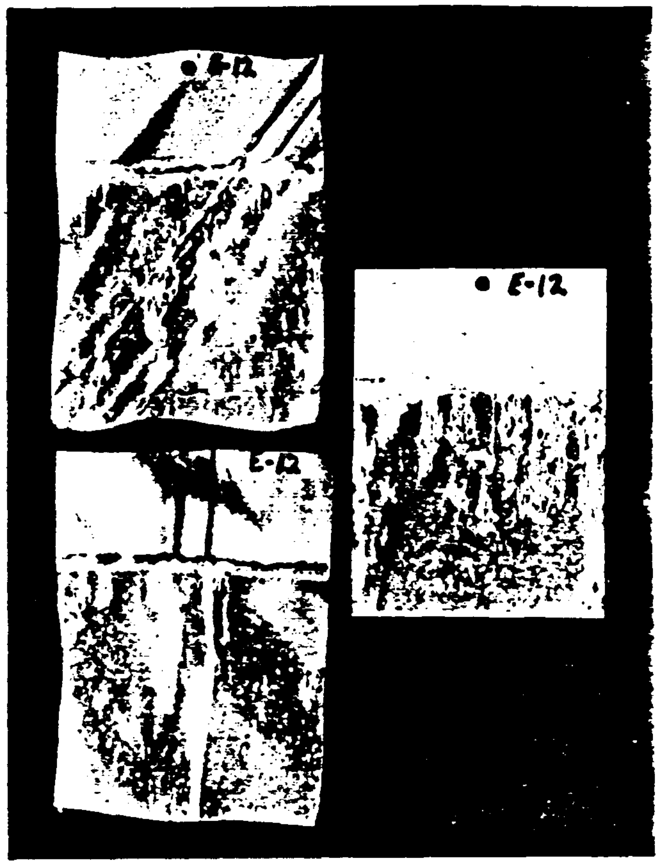


Figure 16A

Photograph of cleaned test panels at 14 weeks

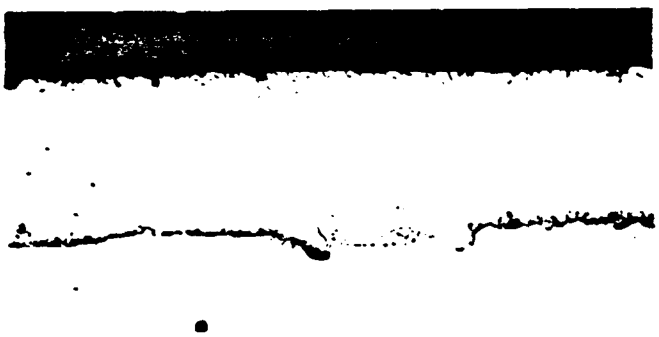


Figure 15B 500X

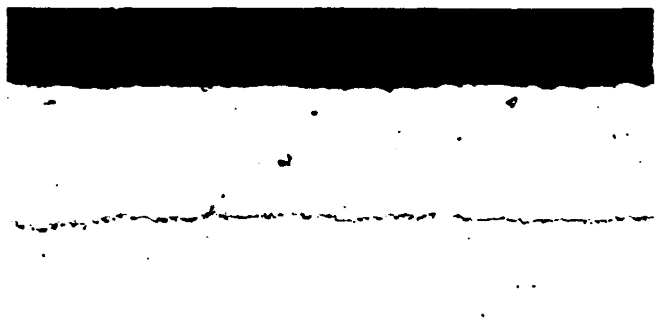


Figure 16B 500X

Photomicrograph - above the waterline

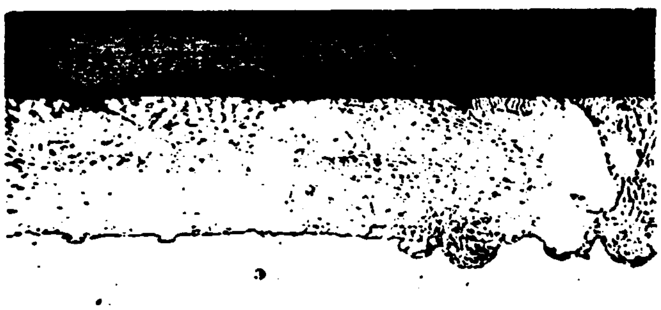


Figure 15C 500X

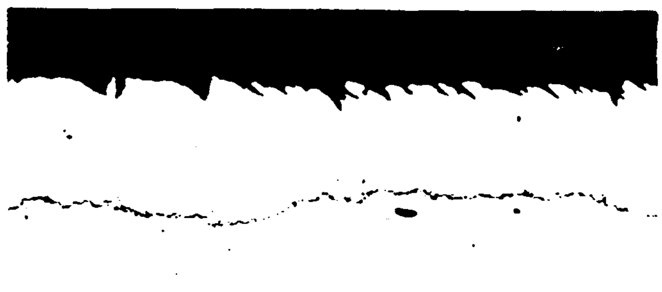


Figure 16C 500X

Photomicrograph - below the waterline

IMMERSION CORROSION TESTING

CORROSION PERFORMANCE COMPARISON

Galfan - 2.0 oz./Painted vs. Aluminized Type II 1.0 oz./Painted

It was expected that corrosion performance for each test condition would be dependent on paint performance at that test condition. Once barrier protection by the paint coating is adversely affected, corrosion performance of the metallic coating should be comparable to that for the unpainted panel. Painted panel performance was similar to that of the unpainted panels described previously. However, the rate of panel change was reduced because of the additional barrier-type protection afforded by the paint coating.

Addition of a paint coating was beneficial to the aluminized product in two ways: (1) upper panel corrosion, which was significant on the unpainted panels, was avoided; (2) areas exhibiting flaking/crazing were adequately protected through the test period. Regardless, the overall performance of the painted Galfan product was superior to the painted aluminized product under the conditions of the test program.

At test conditions of pH-3, pH-5 and pH-9, the paint coatings appeared virtually unaffected. However, penetration of the paint coating by the test media and attack of the underlying metallic coating was indicated by increasing paint bubble formation and subsequent paint delamination. At the pH-12 test condition, both penetration and deterioration of the paint coating occurred, resulting in exposure of considerable metallic coating.

The Galfan panels exhibited varying amounts of metallic coating exposure and sacrificial corrosion. None of the panels gave any indication of red rust corrosion failure. The aluminized panels exhibited a light red rust condition at pH-3 and a more severe red rust condition at pH-12. Test panels at the pH-9 test condition were virtually unaffected.

Galfan 2.0 oz./Painted vs. Aluminum Type II 1/0 oz./Painted

PERFORMANCE AT pH-3

Galfan - 2.0 oz./Painted - Fig. 17

Week 3 - Some scattered fine blistering of paint on immersed panel area. Very light waterline sacrificial corrosion product.

Week 6 - Some paint loss along upper panel edges.

Week 10 - Some increase in blistering condition. Increased waterline accumulation, especially in the waterline - crevice area.

Week 14 - Paint was easily removed by cleaning from approximately 30% of the immersed panel area. The underlying metallic coating showed some attack but no indication of red rust corrosion.

Aluminized Type II - 1.0 oz./Painted - Fig. 18

Week 3 - Some scattered blistering of paint on the immersed panel area.

Week 6 - Increased blistering, more widespread.

Week 10 - Immersed panel area had a fine white coating, heavier near the waterline. Some paint loss immediately above the waterline around the lockseam area.

Week 14 - Blistered surface extensive. Paint easily removed. Underlying surface heavily pitted. Areas near the waterline showed light red rust corrosion.

PERFORMANCE AT pH-5

Galfan - 2.0 oz./Painted - Fig. 17

Week 3 - Some sacrificial corrosion product on the immersed panel area.

Week 6 - Some increase in above panel surface condition.

Week 10 - Extensive sacrificial corrosion coating on immersed panel area. Some paint loss along upper panel edges.

Week 14 - Paint was easily removed by cleaning from approximately 50% of the panel surface. The underlying metallic coating showed some areas of attack while other areas retained a shiny surface.

Aluminized Type II - 1.0 oz./Painted - Fig. 18

Week 3 - Some scattered light blistering on the immersed panel area.

Week 6 - Increased blistering condition. Some specific areas involved, especially on the lockseam.

Week 14 - Paint easily removed from affected areas. Underlying aluminum coating was severely pitted. Some light red rust corrosion was evident on the lockseam in the waterline area.

PERFORMANCE AT pH-9

Galfan - 2.0 oz./Painted - Fig. 17

Week 6 - Some minor paint blistering and scattered sacrificial corrosion product on immersed panel area.

Week 10 - Some increase in above conditions but still relatively minor. Some coating loss on upper panel edges.

Week 14 - Paint removed by cleaning from about 10% of immersed panel area. Underlying coating surface was shiny.

Aluminized Type II - 1.0 oz./Painted - Fig. 18

Week 6 - Blistering limited to the back of panel in the lockseam area both above and below the waterline.

Week 10 - Increase in condition noted above.

Week 14 - Paint in blister area (back lockseam) easily removed by cleaning. Coating attack was evident both above and below the waterline. Front of panel was virtually unaffected.

PERFORMANCE AT pH-12

Galfan - 2.0 oz./Painted - Fig. 17

Week 1 - Deterioration and dissolution of the paint was evident from the amount of sediment in the bottom of the test container. Some areas of exposed metallic coating visible.

Week 6 - Some minor sacrificial corrosion product at the waterline and on the immersed panel area. Continued paint deterioration.

Week 14 - After cleaning, the paint coating was almost completely removed. Underlying Galfan coating was generally shiny. A tightly bound waterline corrosion product remained as well as a few scattered areas on the immersed panel.

Aluminized Type II - 1.0 oz./Painted - Fig. 18

Week 1 - The same conditions of paint deterioration noted above also occurred with this panel. By the end of this week, foaming occurred across the waterline indicating vigorous attack of the aluminum coating by the test media.

Week 6 - There were a few dark areas which had neither a paint nor aluminum coating. Much of the immersed area remained paint covered although the characteristics of the paint had changed.

Week 14 - Upon cleaning, approximately 20 - 25% of the immersed metallic coating was removed. The exposed areas, varying from pinpoint size to large continuous areas, were covered with red rust corrosion.

IMMERSION TEST PANELS - PAINTED

Figure 17 GALFAN - 2.0 oz.

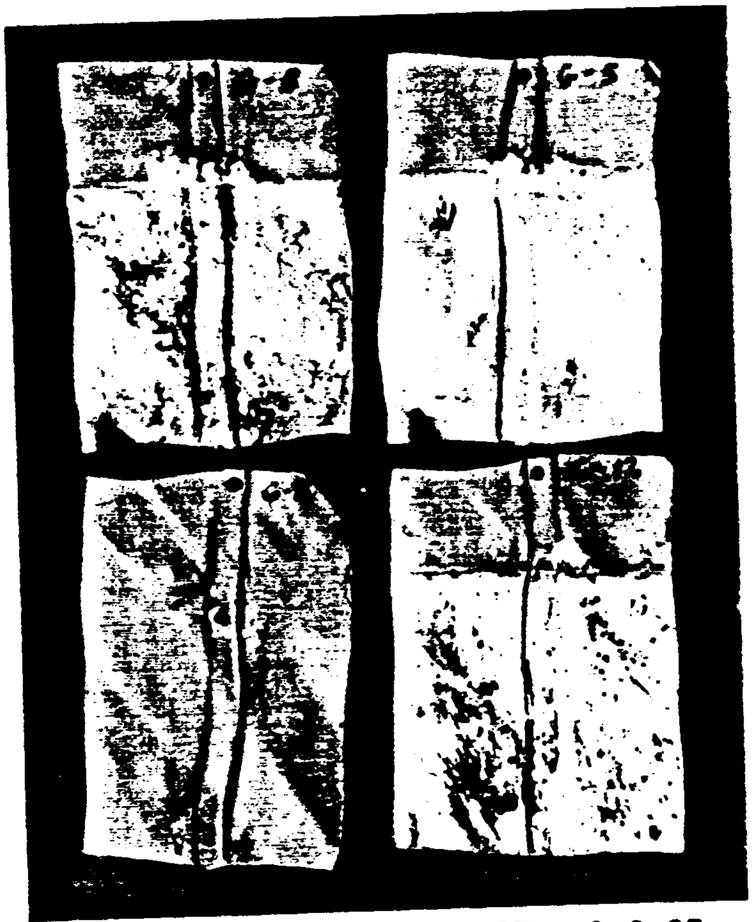


Figure 18 ALUM TYPE II - 1.0 OZ.

IMMERSION CORROSION TESTING

CORROSION PERFORMANCE

Galvanize - 1.15 oz.

Coating performance under the corrosive conditions at pH-3 was poor, exhibiting red rust failure before the mid-point of the test period. Performance at the other three test conditions was satisfactory. Sufficient sacrificial protection was available to prevent red rust failure through the test period.

PERFORMANCE AT pH-3 - Fig. 19A

Week 3 - Significant coating loss was evident, especially on the formed panels in the lockseam area. Waterlines were marked with sacrificial corrosion product.

Week 6 - Indication of light red rust on the immersed panel areas, particularly on the flat panel. Heavier waterline accumulations. Some "white rust" corrosion on the upper areas of the formed panels.

Week 9 - Immersed panel areas completely covered with red rust corrosion. Some of the corrosion product was loosely bound and easily removed. Waterline band showed a wider sacrificial corrosion area.

Week 14 - Most of red rust corrosion was easily removed by cleaning. Underlying surface appeared to have total coating loss. Over half of the upper panel areas showed heavy sacrificial corrosion product and some "white rust" condition.

<u>Micro - Above Waterline</u> - Fig. 19B

Total coating loss has occurred by sacrificial action. Some minor uniform base metal attack.

<u>Micro - Below Waterline</u> - Fig. 19C

Total coating loss has occurred by dissolution. Base metal surface shows uniform attack.

<u>PERFORMANCE AT pH-5</u> - Fig. 20A

Week 3 - Scattered sacrificial corrosion product on the immersed panel areas and light waterline accumulation. Immersed cut edges, where base metal was exposed, also showed sacrificial corrosion protection.

Week 6 - Heavy waterline accumulation. Some increase in scattered sacrificial corrosion product on the immersed panel areas. Some coating loss apparent in the lockseam areas.

Week 14 - Dark appearance of the immersed panel areas appeared to be due to significant coating loss. Final panel condition showed a light sacrificial corrosion coating over most of the surface; the remaining areas, such as the lockseam and the waterline, showed a heavier corrosion accumulation. There was no indication of red rust failure.

<u>Micro - Above Waterline</u> - Fig. 20B

The slightly uneven coating surface suggests some minor attack. Coating is providing adequate base metal protection.

<u>Micro - Below Waterline</u> - Fig. 20C

The coating shows considerable attack and dissolution with some areas having coating loss to the base metal. Remaining coating continues to provide protection against red rust corrosion.

pH - 3

GALVANIZE 1.15 OZ.

pH - 5

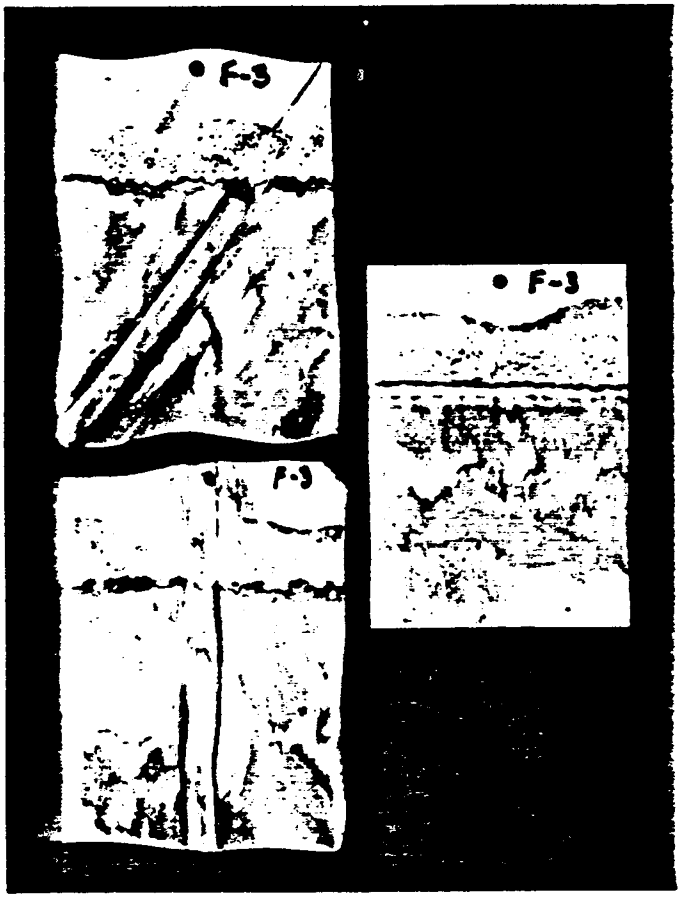


Figure 19A

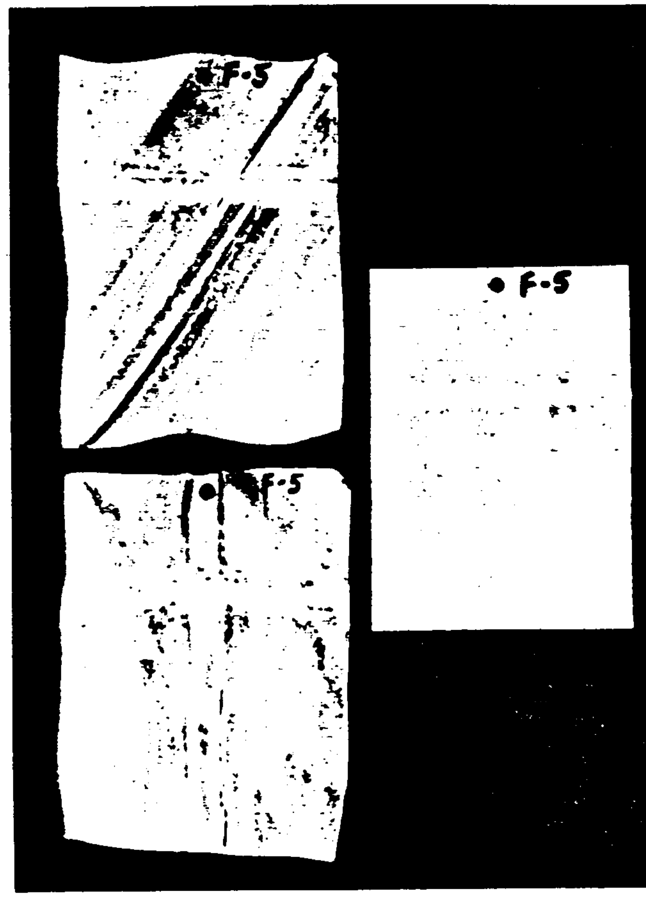


Figure 20A

Photograph of cleaned test panels at 14 weeks

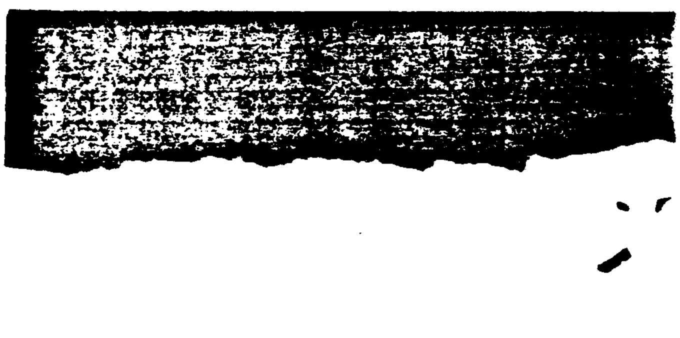


Figure 19B 500X

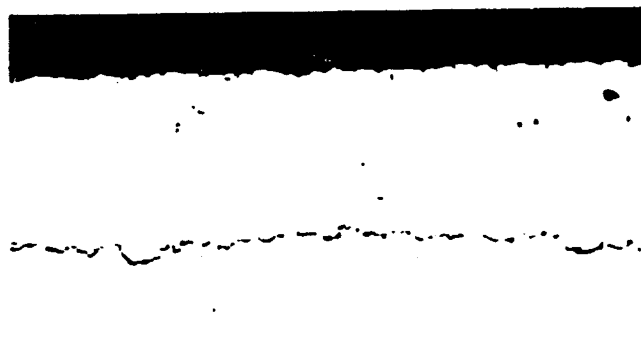


Figure 20B 500X

Photomicrograph - above the waterline

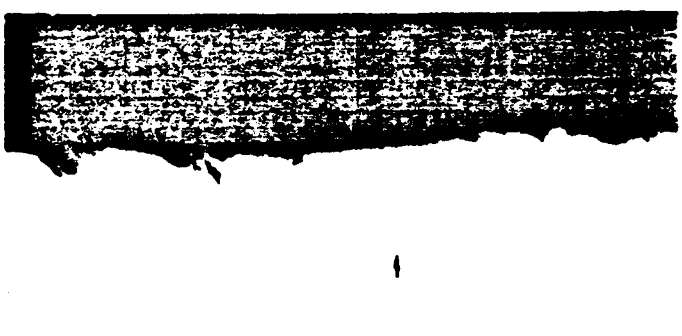


Figure 19C 500X

Figure 20C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-9 - Fig. 21A

Week 3 - Considerable sacrificial corrosion sites had developed along the waterline and on the immersed panel areas.

Week 6 - Continual progress in conditions noted above involving heavier corrosion product accumulation and increased area coverage.

Week 14 - Panel area involvement continued to increase during the test period. The reformed panel had approximately 90% of the immersed area covered with sacrificial corrosion product. Unaffected immersed areas continued to show a shiny, spangled surface. There was no indication of red rust failure.

Micro - Below Waterline - Fig. 21C

Some minor surface attack is evident. However, the original coating is intact, providing protection to the base metal.

Micro - Above Waterline - Fig. 21B

The coating shows a typical, unaffected surface.

PERFORMANCE AT pH 12 - Fig. 22A

Week 3 - Scattered heavy sacrificial corrosion accumulations developed rapidly. Corrosion sites were primarily in the waterline - lockseam area and along the lockseam crevice.

Week 6 - Some increase in the amount of sacrificial corrosion product in areas noted above. Also, an increase in the amount of area involved.

Week 14 - The conditions noted above remained unchanged through the test period. However, aggressive coating loss occurred in the original corrosion sites. While there was some shiny, spangled coating present, much of the immersed panel areas appeared to be coated with a fine sacrificial corrosion product. There was no indication of red rust failure.

Micro - Above Waterline - Fig . 22B

The coating shows a typical, unaffected surface.

Micro - Below Waterline Fig. 22C

The coating surface shows a feather-like appearance indicative of the aggressive coating attack and dissolution by the corrosive media. Coating thickness appears significantly reduced as well as having some deep penetration. Base metal protection is still provided by an adequate coating layer.

pH - 9

GALVANIZE 1.15 OZ.

pH - 12

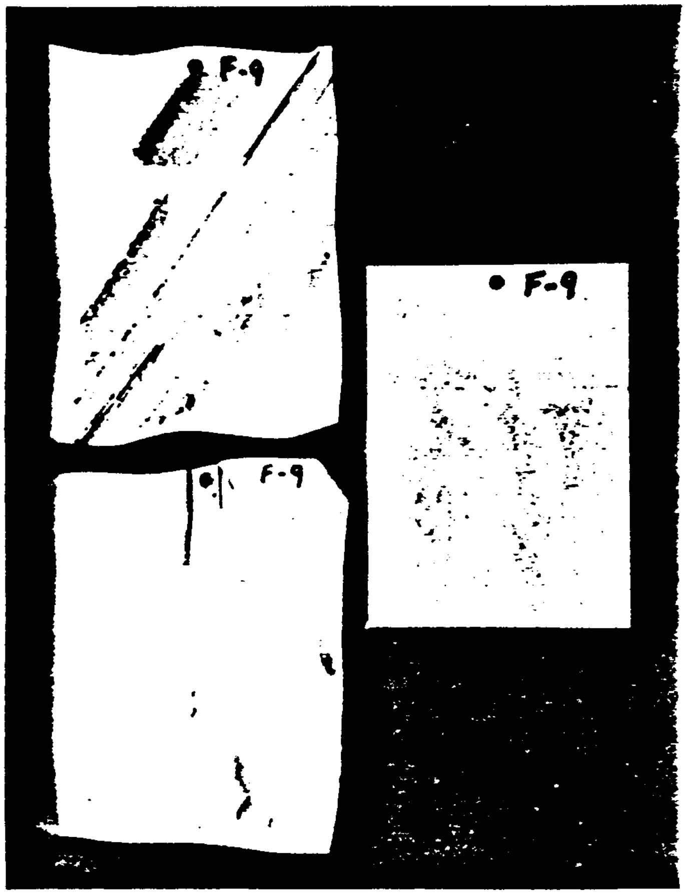


Figure 21A

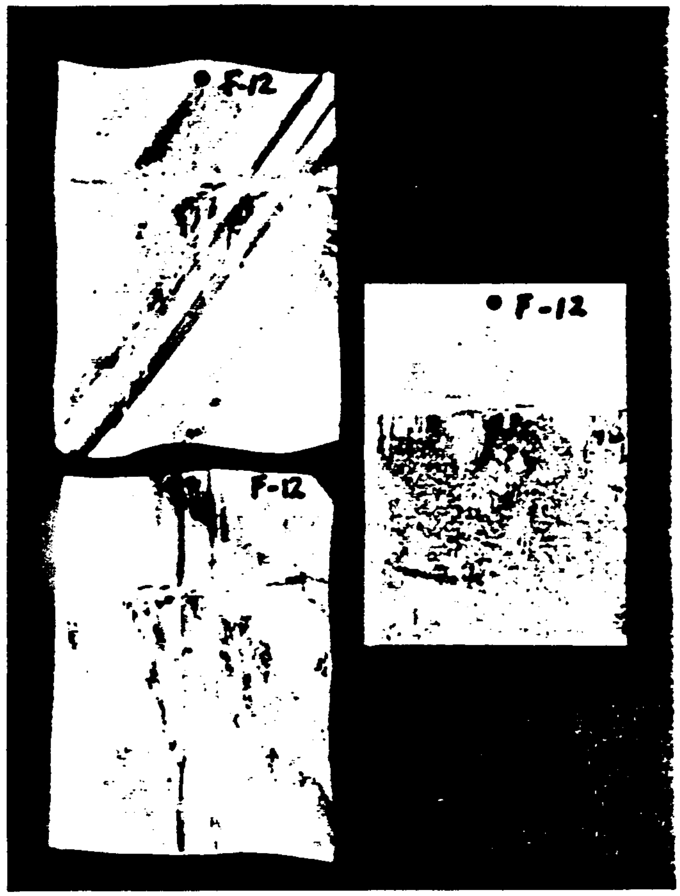


Figure 22A

Photograph of cleaned test panels at 14 weeks

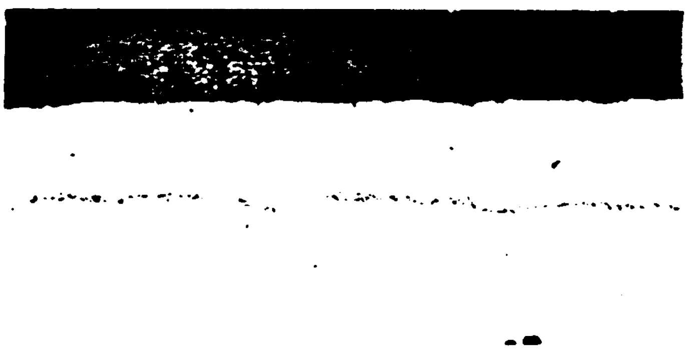


Figure 21B 500X

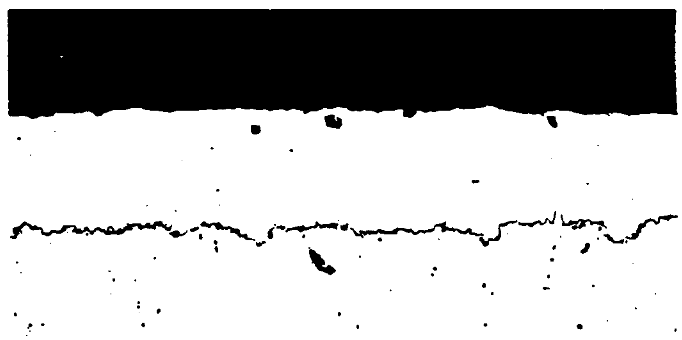


Figure 22B 500X

Photomicrograph - above the waterline

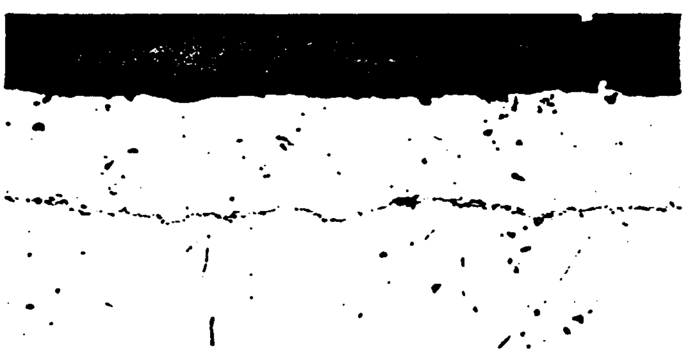


Figure 21C 500X

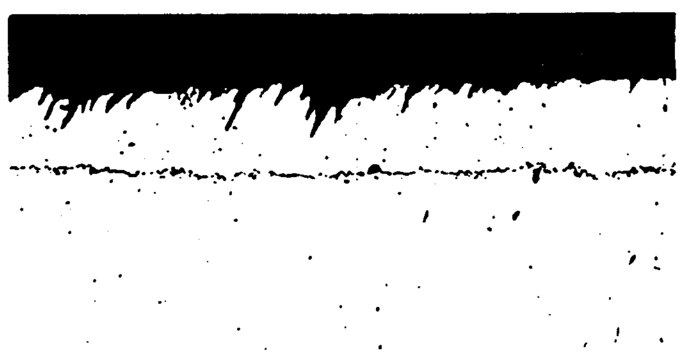


Figure 22C 500X

Photomicrograph - below the waterline

Galfan - 1.15 oz.

Coating performance under the corrosive conditions at pH-3 was poor, exhibiting red rust failure early in the test period. At the other three test conditions, performance was satisfactory. With increasing pH levels, more of the immersed panel areas were involved with heavier sacrificial corrosion accumulations but adequate protection was provided against red rust failure.

PERFORMANCE AT pH-3 - Fig. 23A

Week 3 - Coating dissolution was evident. Considerable coating loss on the immersed panel areas during this period.

Week 6 - Immersed panel areas uniformly covered with a light red rust coating. A waterline band across the panel showed coating loss and sacrificial corrosion product.

Week 14 - The waterline band noted above showed heavy sacrificial corrosion product in a wider area. The immersed panel areas were totally covered with heavy, tightly bound red rust.

Micro - Above Waterline - Fig. 23B

There is complete loss of the metallic coating. The base metal surface shows minor uniform attack. A protective "coating", possibly sacrificial corrosion product, is visible as a dark non-metallic layer in place of the original metallic coating.

Micro - Below Waterline - Fig. 23C

There is complete loss of the metallic coating. Uneven surface shows extent of base metal attack. Red rust corrosion product is visible as a dark non-metallic layer on the base metal.

PERFORMANCE AT pH-5 - Fig. 24A

Week 3 - Immersed cut edges where base metal was exposed was protected by a heavy sacrificial corrosion coating. Some light waterline accumulation present.

Week 6 - Some increase in the waterline accumulation. Some light, scattered sacrificial corrosion product on the immersed panel areas.

Week 14 - Some increase of conditions noted above. Some scattered "white rust" corrosion on upper panel areas. No red rust failure indicated.

Micro - Above Waterline - Fig. 24B

Most of the coating shows a typical, unaffected surface. Uneven surface at the left side of the micro appears to show some minor attack.

Micro - Below Waterline - Fig. 24C

Most of the coating shows a typical, unaffected surface. A level coating line extends across the micro. The darkened coating layer at the left appears to be either coating undergoing sacrificial conversion or corrosion product imbedded in unaffected coating during micro polishing.

pH - 3

GALFAN 1.15 OZ.

pH - 5

Figure 23A

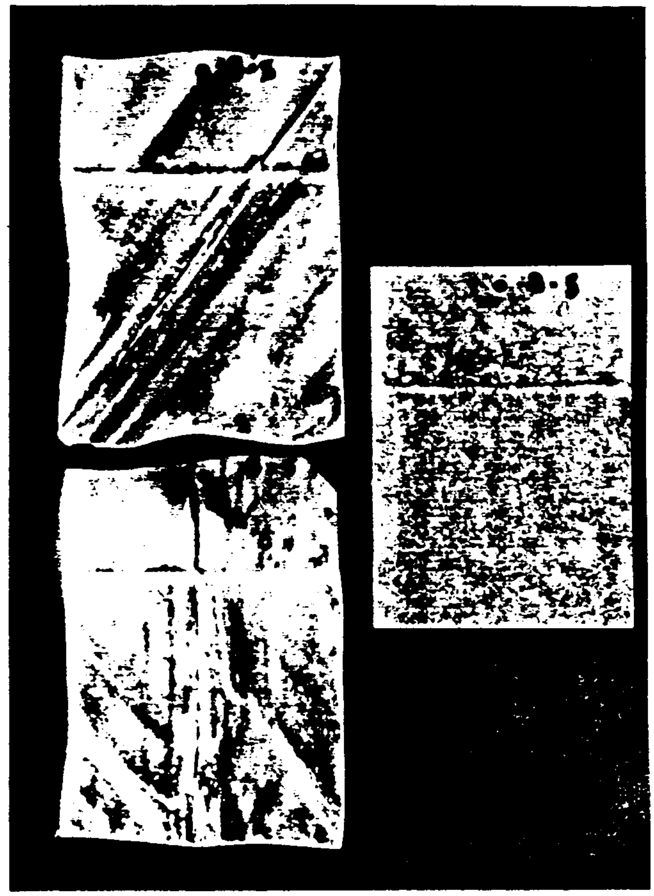


Figure 24A

Photograph of cleaned test panels at 14 weeks

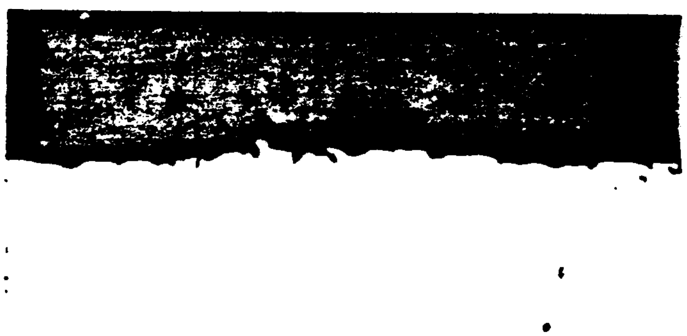


Figure 23B 500X

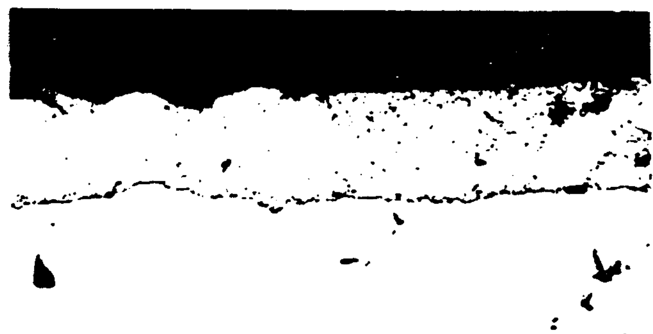


Figure 24B 500X

Photomicrograph - above the waterline

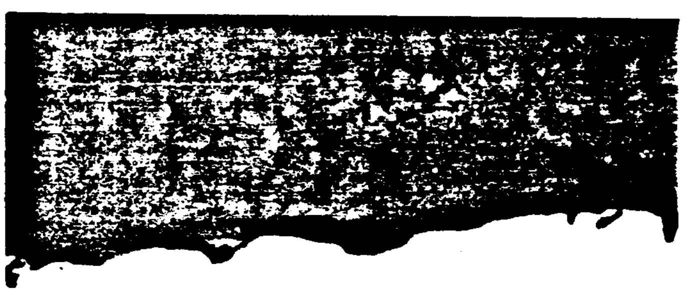


Figure 23C 500X

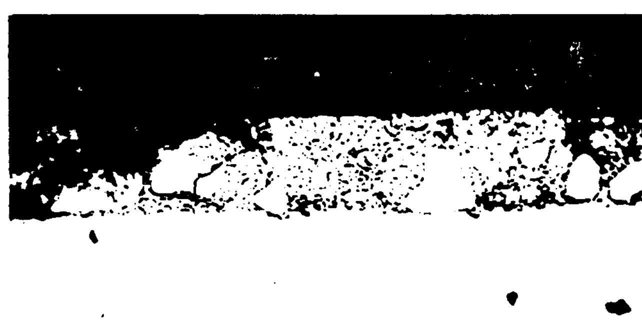


Figure 24C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-9 - Fig. 25A

Week 3 - Some scattered sacrificial corrosion product at the waterline and on the immersed panel areas. The reformed panel exhibited a few streak-like areas in which aggressive coating loss appeared to have occurred.

Week 9 - There was some increase in the areas involved and the amount of sacrificial corrosion product accumulation. The formed panel back areas were more extensively involved than the front areas.

Week 14 - Most of the panel changes involved heavier accumulations. Much of these accumulations were tightly bound. Beneath them, the coating showed some aggressive loss similar to the streak-like areas noted earlier, but there was no indication of red rust failure.

Micro - Above Waterline - Fig. 25B

Coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 25C

Coating shows a typical, unaffected surface.

PERFORMANCE AT pH-12 - Fig. 26A

Week 3 - Sacrificial corrosion product was concentrated primarily at the waterline and in the immersed panel lockseam crevice area.

Week 6 - Heavier accumulations and rapid expansion of involved areas.

Week 9 - Continued expansion of the areas involved with sacrificial corrosion product. Accumulations were heavy.

Week 14 - Sizable patches of tightly bound sacrificial corrosion product on the immersed panel areas. Underlying coating loss appeared to have occurred but there is no indication of red rust failure.

Micro - Above Waterline - Fig. 26B

Coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 26C

Coating shows a typical, unaffected surface.

pH - 9

GALFAN 1.15 OZ.

pH - 12

Figure 25A

Figure 26A

Photograph of cleaned test panels at 14 weeks

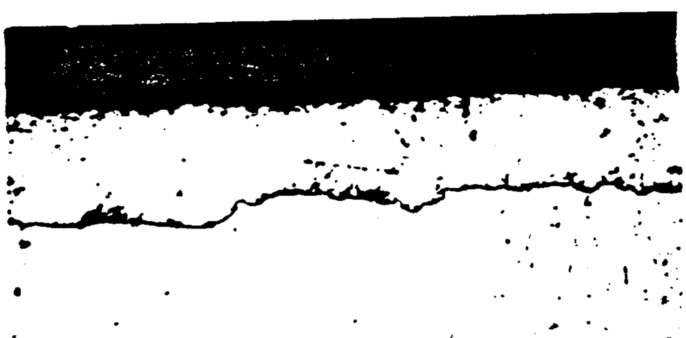


Figure 25B 500X

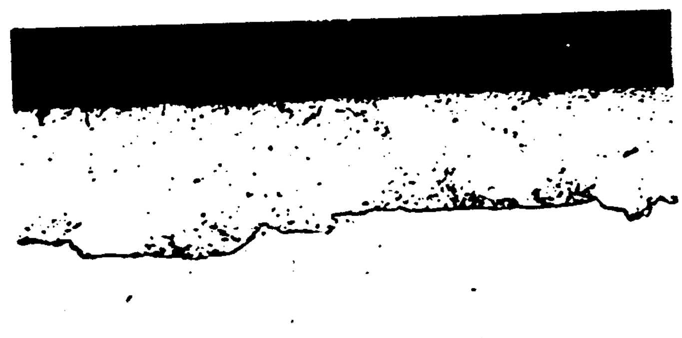


Figure 26B 500X

Photomicrograph - above the waterline

Figure 25C 500X

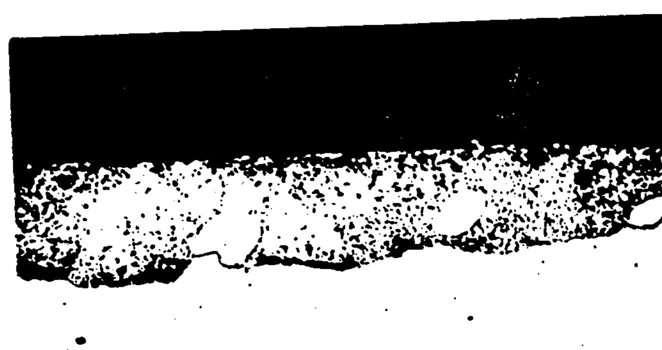


Figure 26C 500X

Photomicrograph - below the waterline

Galvanize - 2.6 oz.

Under the corrosive conditions at pH-3, coating loss on the immersed panel areas appeared to be total. There was a light tint of the sacrificial coating product along the lockseam suggesting some crevice-type red rust corrosion occurring. With this exception, there was no other indication of red rust failure. Test panels, exposed to the other pH conditions, showed varying degrees of sacrificial corrosion but all panels were adequately protected against red rust failure.

PERFORMANCE AT pH-3 - Fig. 27A

Week 3 - Coating loss was evident in various locations on the immersed panel areas. Sacrificial corrosion product at the waterline. Some light "white rust" corrosion on upper panel areas.

Week 6 - There was noticeable increase in the above-noted conditions, heavier .water line accumulations, heavier "white rust" corrosion, more severe coating loss. Formed sample coating loss was more pronounced along the lockseam.

Week 12 - Coating loss on the immersed panel areas appeared to be near total. Some sacrificial corrosion accumulation on the formed panels, primarily in the immersed lockseam area.

Week 14 - Coating loss on the immersed panel areas appeared to be total. Waterline areas also showed coating loss. Scattered sacrificial corrosion on all immersed panel areas. Lockseam corrosion product showed light red tint suggesting some crevice-type red rust corrosion. Some heavy "white rust" corrosion on upper panel areas. No indication of red rust failure.

Micro - Above Waterline - Fig. 27B

Coating shows some minor surface attack. Most of the coating remains, providing substantial base metal protection.

Micro - Below Waterline - Fig. 27C

Total coating loss has occurred by dissolution. Uneven base metal surface shows extent of attack.

PERFORMANCE AT pH-5 - Fig. 28A

Week 3 - A light sacrificial corrosion coating on most of the immersed panel areas. A waterline accumulation had also formed on the panels.

Week 6 - Some immersed panel areas, particularly along the lockseams, showed heavier sacrificial corrosion product. The waterline accumulation was heavier and wider.

Week 14 - Conditions noted above have increased through the test period. The waterline and lockseam areas particularly, developed a heavy sacrificial corrosion coating. A band above the waterline appeared to show coating loss. There was no indication of red rust failure.

Micro - Above Waterline - Fig. 28B

Some minor attack of the coating surface is evident but overall coating thickness provides adequate base metal protection.

Micro - Below Waterline - Fig. 28C

Significant coating loss has occurred in some areas, very little in others. Base metal protection is still being provided.

pH - 3

GALVANIZE 2.6 OZ.

pH - 5

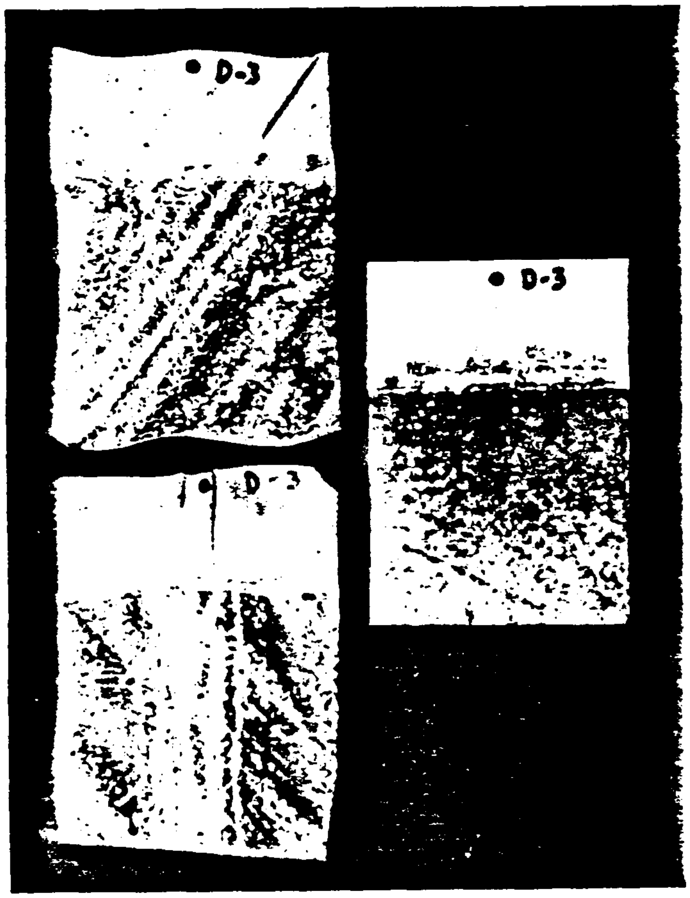


Figure 27A

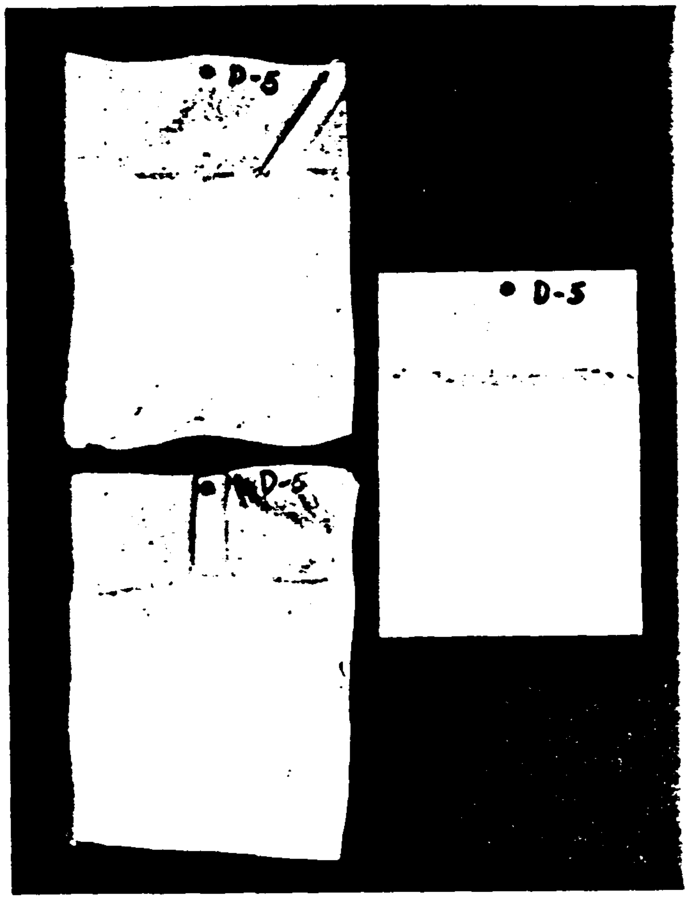


Figure 28A

Photograph of cleaned test panels at 14 weeks

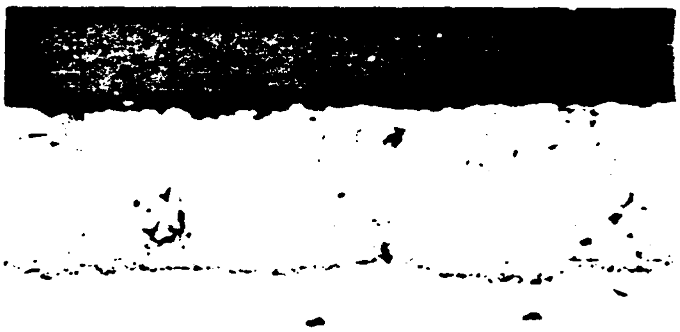


Figure 27B 500X

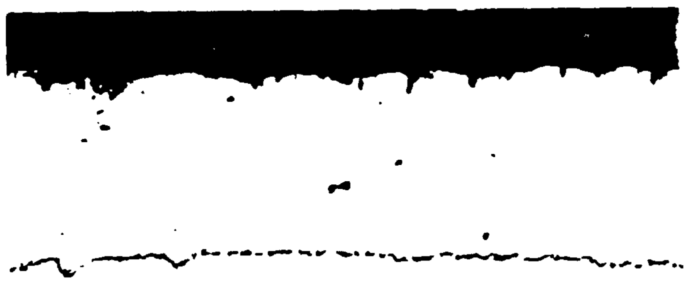


Figure 28B 500X

Photomicrograph - above the waterline

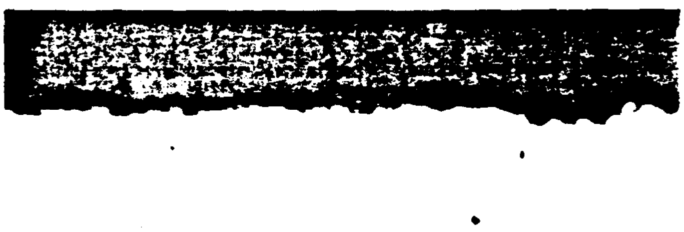


Figure 27C 500X

Figure 28C 500X

Photomicrograph - below the waterline

PERFORMANCE AT pH-9 - Fig. 29A

Week 3 - A light sacrificial corrosion accumulation developed at the waterline. Some scattered sacrificial corrosion product on the immersed panel areas.

Week 6 - There was an increase in the number of scattered sacrificial corrosion areas and in the amount of corrosion product in those areas. Some "white rust" corrosion evident on the upper panel areas.

Week 14 - Scattered sacrificial corrosion areas, some small in size, others more extensive. Accumulations in those areas were heavy. Unaffected areas showed a shiny, spangled surface. There was no indication of red rust failure.

Micro - Above Waterline - Fig. 29B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 29C

The uneven coating surface shows the extent of attack. Coating thickness appears reduced by approximately half. The remaining coating is adequately protecting the base steel.

PERFORMANCE AT pH-12 - Fig. 30A

Week 3 - Some scattered areas at the waterline and on the immersed panel, particularly in the lockseam and lockseam crevice areas, showed sacrificial corrosion product accumulation.

Week 6 - Sacrificial corrosion was limited to the sites established during the early phase of testing. Accumulations were only slightly heavier.

Week 14 - Original sacrificial corrosion sites showed little change through the test period. Areas beneath the corrosion product showed aggressive coating loss. Overall, the immersed panel areas appeared to have a very fine coat of sacrificial corrosion product. There was no indication of red rust failure.

Micro - Above Waterline - Fig. 30B

The coating shows a typical, unaffected surface.

Micro - Below Waterline - Fig. 30C

The coating surface shows the typical feather-like feature seen in all galvanize coatings at this pH level. Coating thickness does not appear to be significantly reduced nor has there been any coating penetration causing base metal exposure.

pH - 9

GALVANIZE 2.6 OZ.

pH - 12

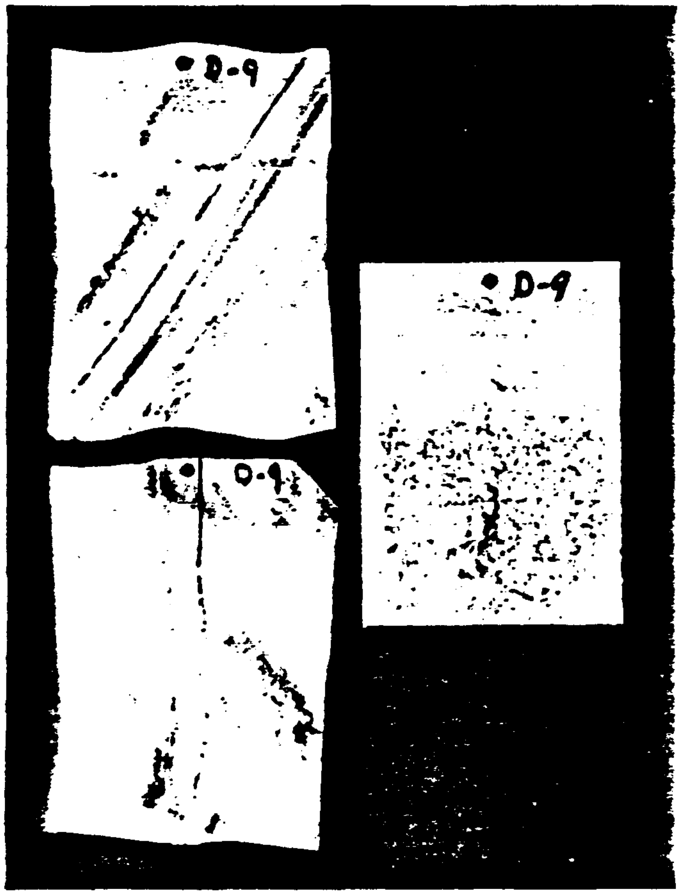


Figure 29A

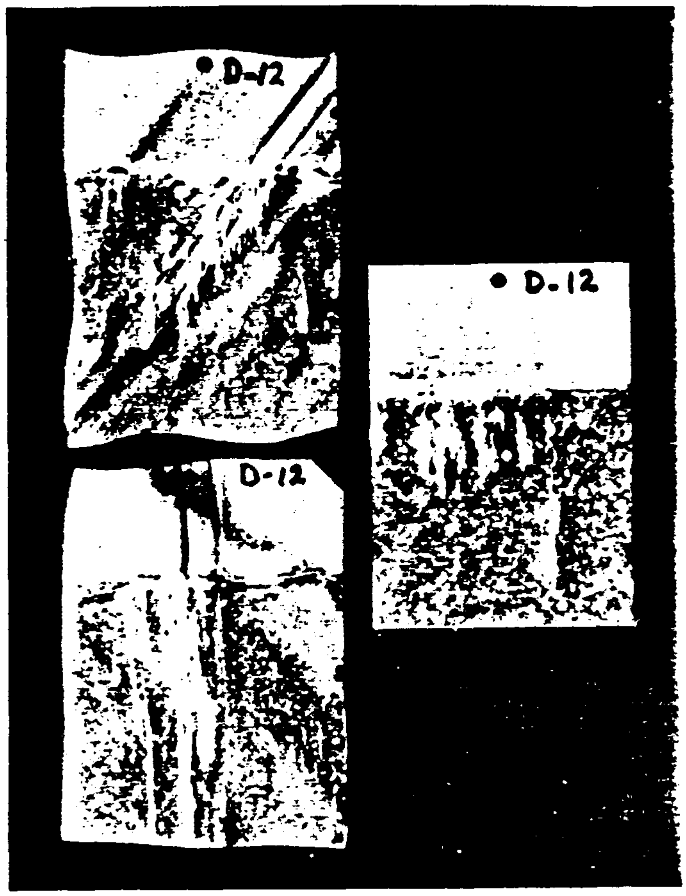


Figure 30A

Photograph of cleaned test panels at 14 weeks

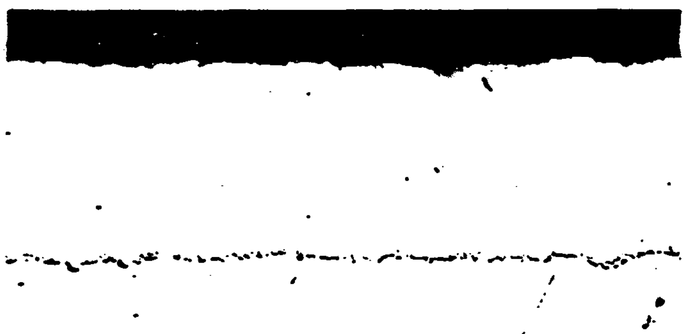


Figure 29B 500X

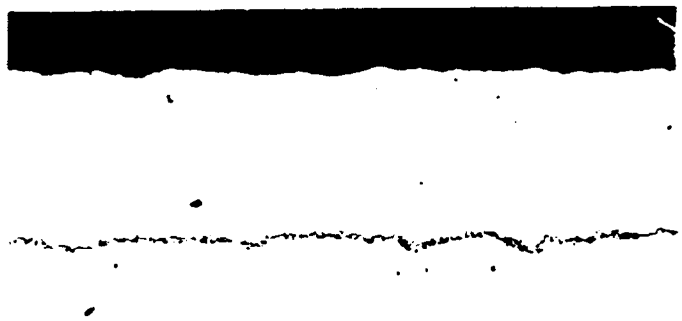


Figure 30B 500X

Photomicrograph - above the waterline

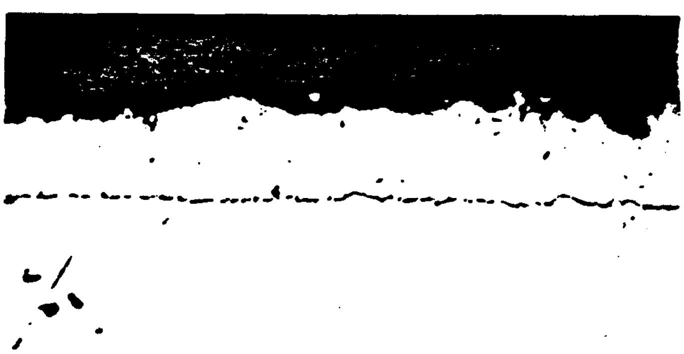


Figure 29C 500X

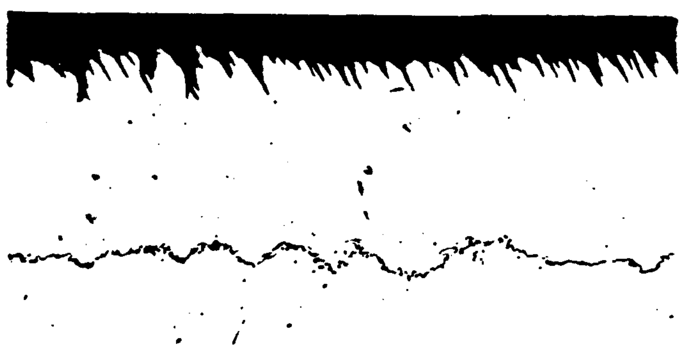


Figure 30C 500X

Photomicrograph - below the waterline

SALT SPRAY TESTING

TEST CONDITIONS

Flat and reformed samples, 6" x 12", from each type of coating were subjected to salt spray testing in a chamber maintained according to ASTM B-117. Test conditions were 95°F. with a fallout rate of 1 to 2 ml. per hour of 5% salt solution in a standard collector.

The edges of all panels were coated with paraffin to prevent them from affecting the results. The flat panels were diagonally scribed through the coating to evaluate undercutting.

Reformed panels of Galfan 2.0 oz. and Aluminized Type II 1.0 oz. were painted and tested with the regular coatings to evaluate the adherence of paint to these coatings during salt spray testing.

The duration of the testing was 90 days with visual observations daily for the first week and weekly thereafter. All panels were tested the full length of time even though they may have already failed. Photographs of each panel were taken at approximately 30-day intervals. No cleaning of the panels was done before, during or after the test.

Conditions evaluated were white rust, red rust and undercutting. White rust indicates the coatings were corroding but protecting the base metal. Red rust indicates the coating has been corroded through and the base metal is being attacked. Undercutting evaluates the ability of coatings to prevent corrosion from spreading between the coating and the steel and causing coating liftoff.

Results of all the materials tested are shown on page 71.

Salt Spray Test Results

		Days				
Flats		1	15	30	60	90
Galfan 1.15	White Rust	10%	50%	100%		
	Red Rust				10%	75%
Galfan 2.0	White Rust	10%	50%	100%		
	Red Rust				10%	75%
Galv. 1.15	White Rust	50%	100%			
	Red Rust			10%	100%	
Galv. 2.0	White Rust	50%	100%			
	Red Rust			10%	75%	100%
Galv. 2.6	White Rust	50%	100%			
	Red Rust			10%	50%	100%
Alum 1.0	White Rust	10%				
	Red Rust					10%
Reformed						
Galfan 1.15	White Rust	10%	100%			
	Red Rust		10%	25%	100%	
Galfan 2.0	White Rust	10%	50%	100%		
	Red Rust			10%	50%	100%
Galv. 1.15	White Rust	50%	100%			
	Red Rust			10%	75%	100%
Galv. 2.0	White Rust	50%	100%			
	Red Rust		10%	50%	100%	
Galv. 2.6	White Rust	50%	100%			
	Red Rust				10%	50%
Alum 1.0	White Rust			50%		
	Red Rust		5%	10%	25%	50%
Painted Reformed						
Galfan 2.0	White Rust		10%	50%	100%	
	Red Rust					5%
Alum 1.0	White Rust		10%	50%	100%	
	Red Rust					5%

SALT SPRAY TESTING

CORROSION PERFORMANCE COMPARISON

Galfan - 2.0 oz. vs. Aluminized Type II - 1.0 oz.

Coating failure in a salt spray test occurs when about 10% red rust is evident. The protection provided by the coating is no longer available and the base metal begins to corrode (red rust).

The Galfan coating provided this protection 60 days on the flat panel and 30 days on the reformed panel. The aluminized coating protection lasted 90 days on the flat panel and 30 days on the reformed panel.

Flat Panels (see page 74)

Both materials had about 10% white rust after one day. The white rust continued to form on the Galfan panel but very little change occurred on the aluminized panel.

Red rust occurred on the Galfan panel at 60 days (10%) and continued to form throughout the test period. The aluminized panel showed red rust at 90 days (10%) when the test was terminated.

Reformed Panels (see page 75)

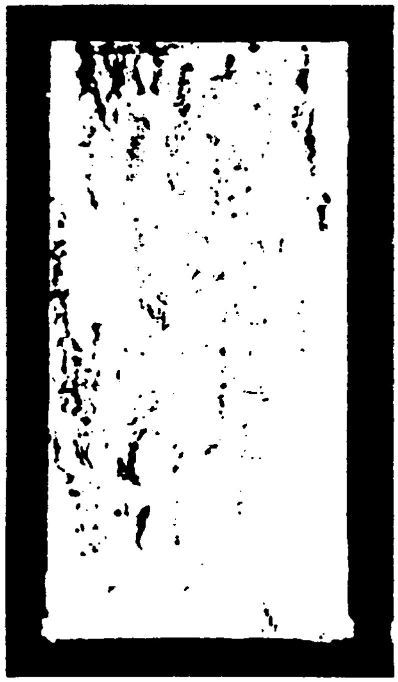
The Galfan reformed panel performed similar to the Galfan flat panel. White rust started on day 1 and by day 30 the panel showed 100% white rust. The aluminized panel had about 50% white rust at day 30.

Red rust on the Galfan panel was slightly more severe on the reformed panel than the flat one. Red rust failure on the aluminized panel occurred at 30 days.

SALT SPRAY TEST PANELS

GALFAN 2.0 oz. - Flat Panels

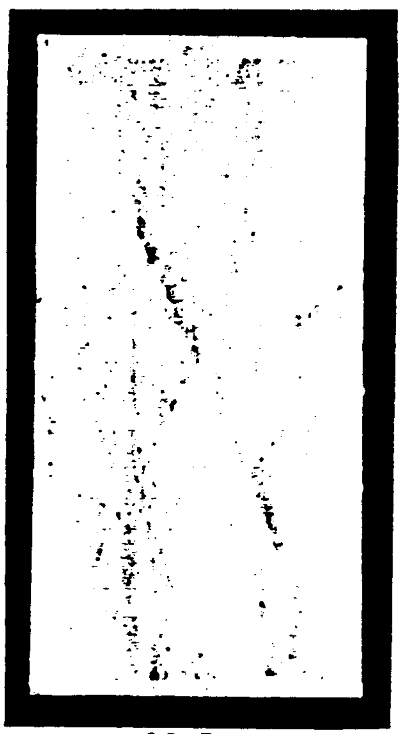
30 Days



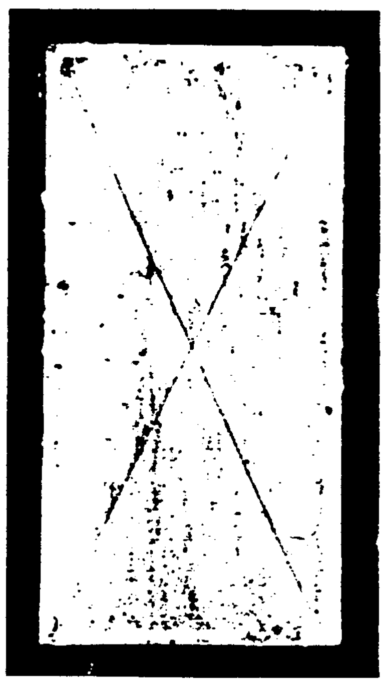
60 Days

90 Days

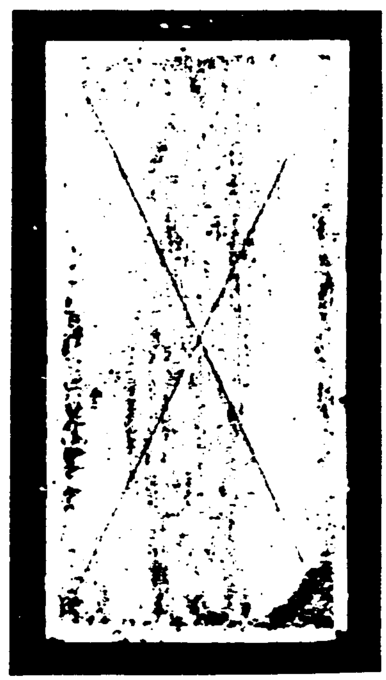
ALUM TYPE II 1.0 oz. - Flat Panels



30 Days



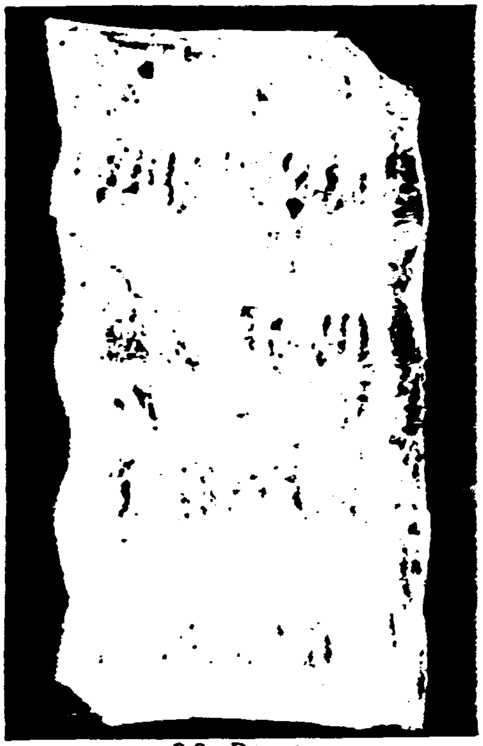
60 Days



90 Days

SALT SPRAY TEST PANELS

GALFAN 2.0 oz. - Reformed Panels

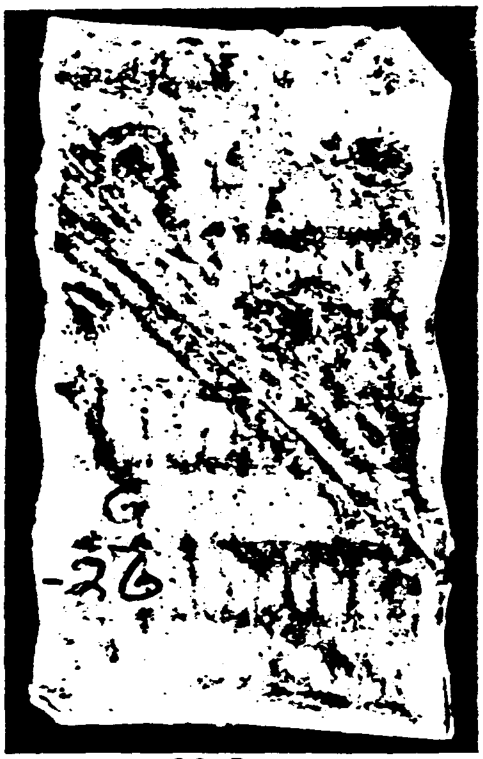


30 Days

60 Days

90 Days

ALUM TYPE II 1.0 oz. - Reformed Panels



30 Days

60 Days

90 Days

SALT SPRAY TESTING

CORROSION PERFORMANCE COMPARISON

Galfan - 2.0 oz. vs. Galvanize - 2.0 oz.

Red rust failure on the Galfan flat panel occurred at 60 days vs. 30 days for the galvanize panel. The Galfan reformed panel failed at 30 days vs. 15 days for the galvanize panel.

Flat panels (see page 77)

White rust occurred more rapidly on the galvanize panel. At 30 days both were covered with white rust.

Red rust on the Galfan panel started at 60 days compared to 30 days for the galvanize panel.

Reformed Samples (see page 78)

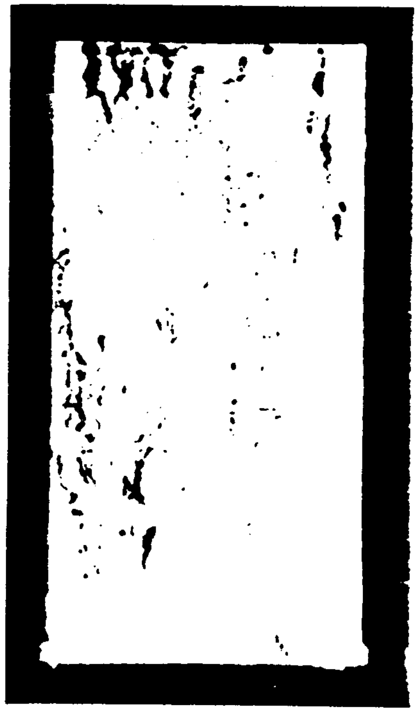
White rust was similar to the flats with the Galfan coating giving more protection than the galvanize coating.

Red rust started at 30 days on the Galfan panel and 15 days for the galvanize panel.

SALT SPRAY TEST PANELS

GALFAN 2.0 oz. - Flat Panels

30 Days



60 Days

90 Days

GALVANIZE 2.0 oz. - Flat Panels

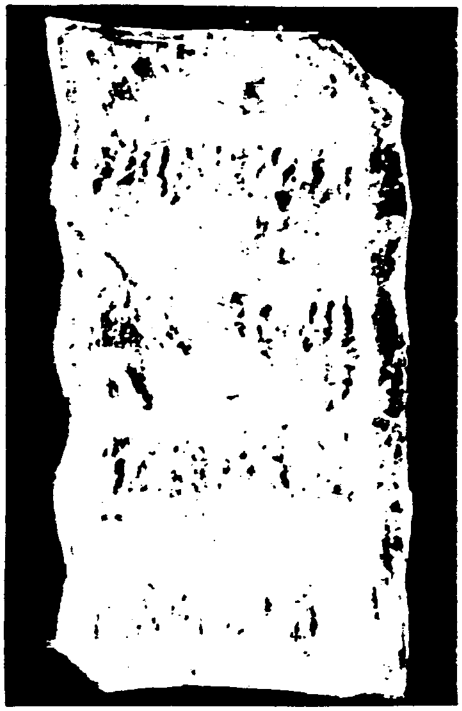
30 Days

60 Days

90 Days

SALT SPRAY TEST PANELS

GALFAN 2.0 oz. - Reformed Panels



30 Days

60 Days

90 Days

GALVANIZE 2.0 oz. - Reformed Panels

30 Days

60 Days

90 Days

SALT SPRAY TESTING

CORROSION PERFORMANCE COMPARISON

Galfan - 2.0 oz./Painted vs. Aluminized Type II 1.0 oz./Painted (see page 80)

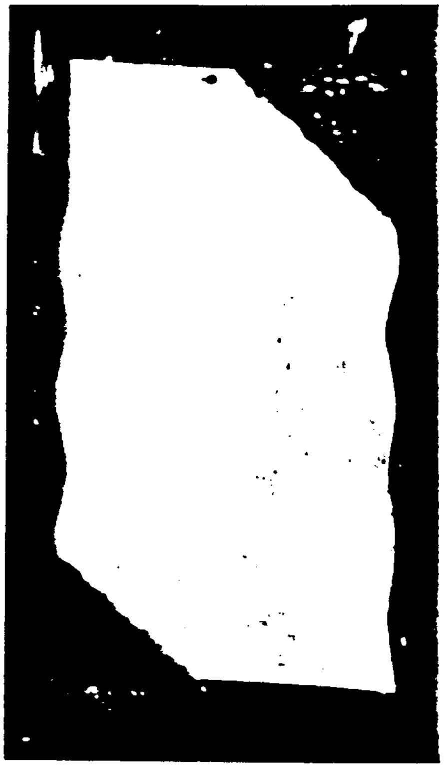
White or red rust would be the failure mode for painted panels. The paint provides protection to the coating and any type of rust under the paint indicates the paint has failed. This condition occurred on both reformed panels at about 15 days into the test and progressed similarly on both types of material to 100% white rust in 60 days. By the end of the test period both materials also showed red rust was starting.

NOTE: The lower group of panels on Page 80 are incorrectly identified. The correct title should read "Aluminized Type II 1.0 oz. - Reformed Panels/Painted".

SALT SPRAY TEST PANELS

GALFAN 2.0 oz. - Reformed Panels - Painted

30 Days



60 Days

90 Days

GALVANIZE 2.0 oz. - Reformed Panels - Painted

30 Days

60 Days

90 Days

SALT SPRAY TESTING

CORROSION PERFORMANCE

Three other coating weights were tested along with the comparisons already presented.

Galvanize - 1.15 oz. (see page 83)

Flat Panel

White rust developed on the panel on day 1 and progressed to 100% by 15 days. Red rust failure (10%) occurred at 30 days.

Reformed Panel

White rust developed on the panel on day 1 and progressed to 100% by 15 days. Red rust failure (10%) occurred at 30 days.

Galfan 1.15 oz. (see page 84)

Flat Panel

White rust developed on the panel on day 1 and progressed to 100% by 30 days. Red rust failure (10%) occurred at 60 days.

Reformed Panel

White rust developed on the panel on day 1 and progressed to 100% by 15 days. Red rust failure (10%) occurred at 15 days.

Galvanize - 2.6 oz. (see page 85)

Flat Panel

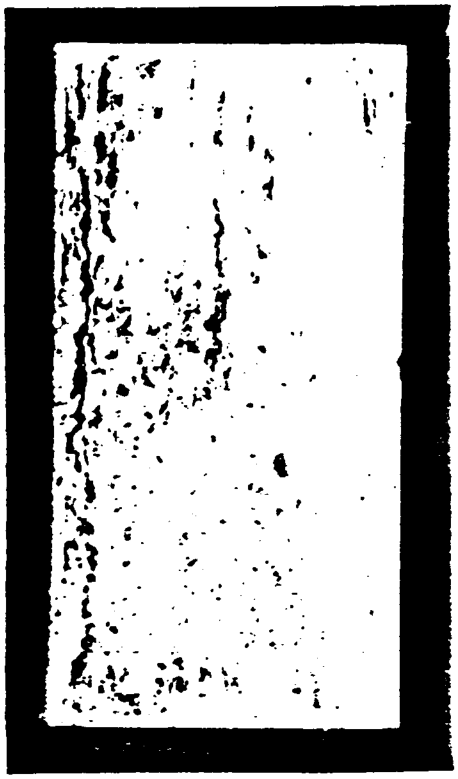
White rust developed on the panel on day 1 and progressed to 100% by 15 days. Red rust failure (10%) occurred at 30 days.

Reformed Panel

White rust developed on the panel on day 1 and progressed to 100% by 15 days. Red rust failure (10%) occurred at 60 days.

SALT SPRAY TEST PANELS

GALVANIZE 1.15 oz.



30 Days

60 Days

90 Days

Flat Panels

30 Days

60 Days

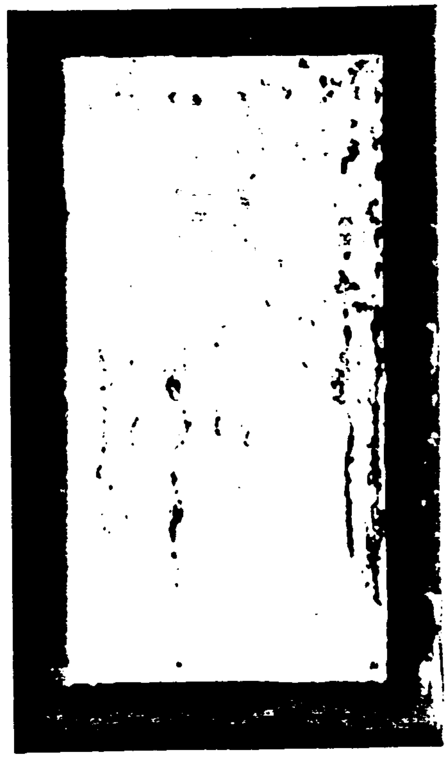
90 Days

Reformed Panels

SALT SPRAY TEST PANELS

GALFAN 1.15 oz.

30 Days



60 Days

90 Days

Flat Panels

30 Days

60 Days

90 Days

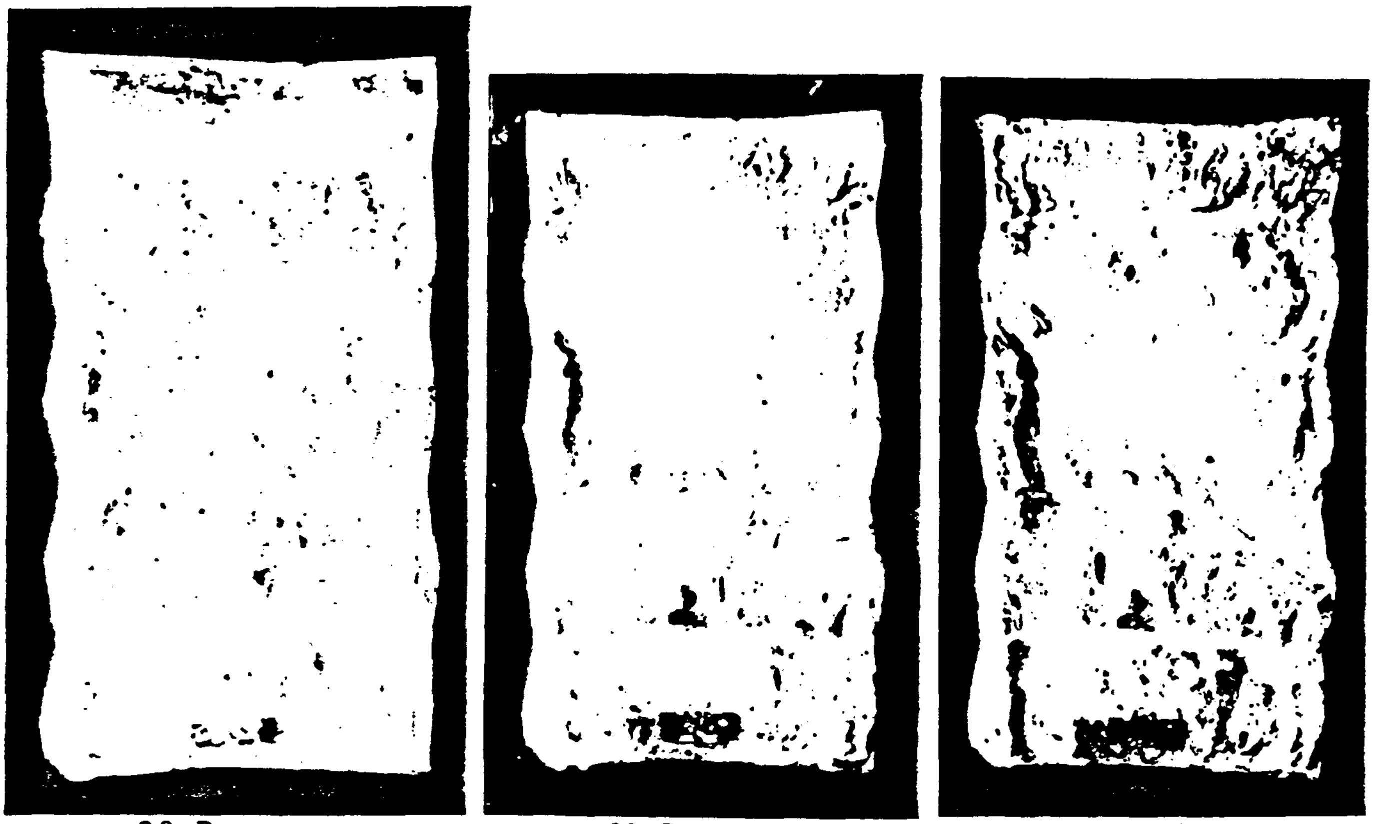
Reformed Panels

SALT SPRAY TEST PANELS

GALVANIZE 2.6 oz.

30 Days 60 Days 90 Days

Flat Panels



30 Days 60 Days 90 Days

Reformed Panels

SAMPLE IDENTIFICATION

Samples provided for this corrosion performance study consisted of 2' x coil width sections, 12" diameter culvert pipe sections and reformed culvert end pieces.

The following tabulation describes and identifies the six (6) material types involved in this program.

Type	Coil No.	Coating Classification	Beech Bottom Coil No.	Culvert Pipe Identification (2) (3)
Galfan(1)	300625	GF-1.15 oz./sq.ft.	7195	B-13 thru B-24
	300628	GF-2.0 "	7196	C-13 " C-24
Galvanize	146042	G -1.15 "	7199	F-13 " F-25
	146106	G -2.0 "	7198	E-13 " E-25
	600446	G -2.6 "	7197	D-13 " D-25
Aluminum Type II	912523	AL-1.0 "	7258	G-23 " G-37

(1) Coils were coated at Weirton Steel Corporation.

(2) Culvert pipe was produced at Lenexa, Kansas.

(3) The alpha codes used for culvert pipe identification were used as sample identification throughout testing.

SAMPLE PREPARATION

A single flat coil width section, from each of the six (6) material types to be tested, was selected. A six (6) inch coil width section was sheared from each flat sample to provide the triple spot coating weight test samples. The balance of the flat sample provided all other test samples - tensile (L, T), bend (B), micro (M), chemical (C), salt spray (6" x 12"), immersion corrosion (5" x 7") - as shown on the following sample layout. All test samples noted above were sheared.

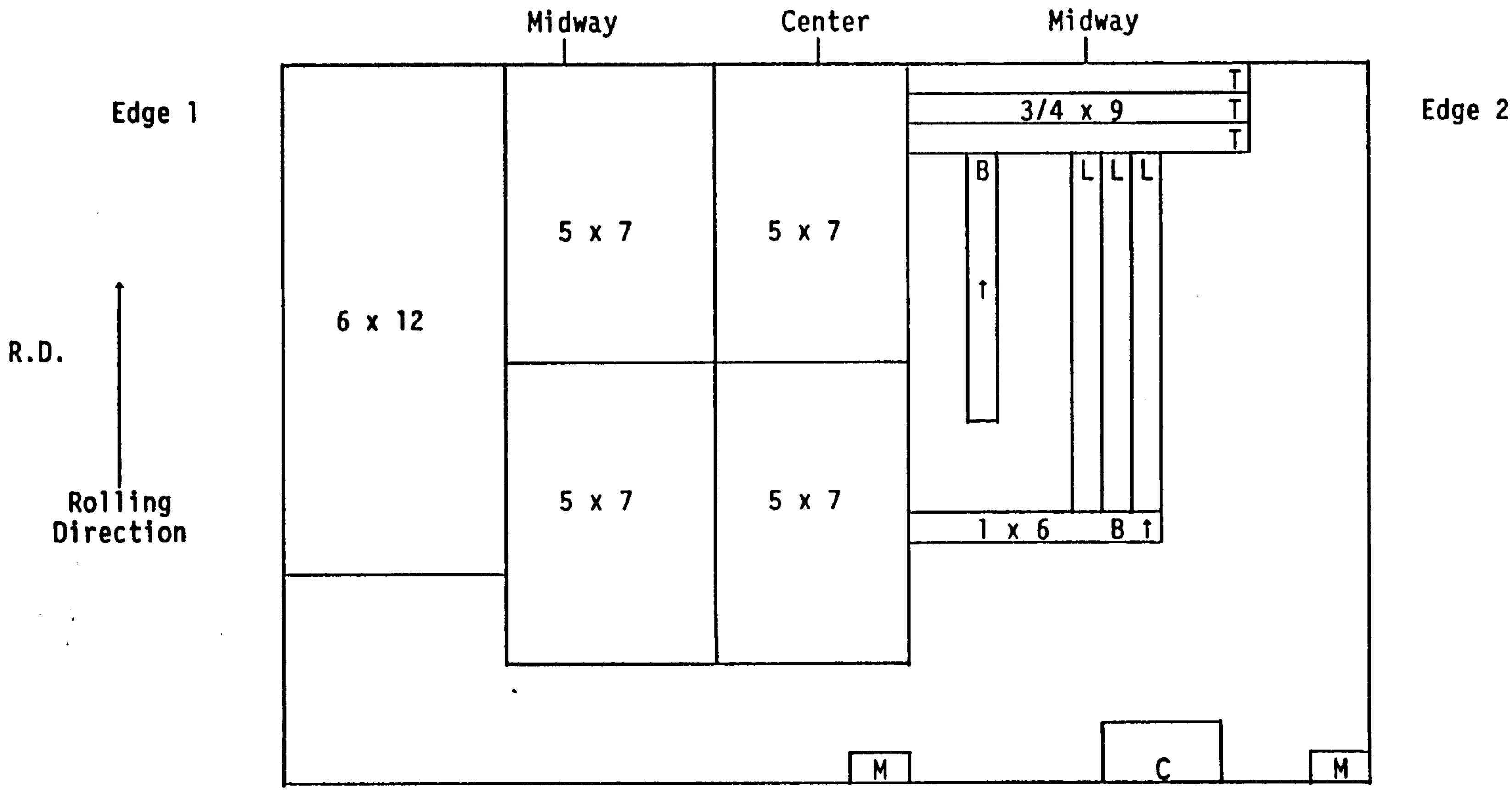
Formed test panels, for salt spray and immersion corrosion testing, were obtained from the culvert pipe sections and reformed culvert end pieces. These samples required cutting with a band saw and light removal of the resulting burr. The corrugated immersion corrosion panels are distinguished by a diagonal lockseam while the reformed immersion corrosion panels have a vertical lockseam.

Immersion corrosion test panels had ¼" holes drilled near the top center in order to suspend the panels. They were then degreased and cleaned with organic solvents prior to testing.

Salt spray test panels were edge protected with a paraffin coating.

All other test samples were processed according to routine laboratory procedures.

Photomicrographs of the final test panel conditions (94 days) were taken from a selected position on the flat panels. The area examined was 1½" from the left panel edge and spans the waterline ½" above and below.



Layout of individual sample positions on flat coil width section.

CHEMICAL COMPOSITION

Base steel chemical analysis was obtained for each material type involved in this testing program. The following tabulation presents that data.

	Code B 300625 Galfan 1.15	Code C 300628 Galfan-2.0	Code D 600446 Galvanize-2.6	Code E 146106 Galvanize-2.0	Code F 146042 Galvanize-1.15	Code G 912523 Aluminize-1.0
Carbon	.048	.045	.038	.051	.042	.038
Manganese	.28	.27	.28	.32	.29	.26
Phosphorus	.003	.002	.003	.006	.006	.005
Sulfur	.008	.008	.010	.008	.011	.014
Silicon	.014	.014	.013	.013	.016	.004
Copper	.016	.020	.011	.021	.009	.013
Tin	.010	.009	.009	.009	.009	.010
Nickel	.019	.026	.017	.018	.017	.019
Chromium	.027	.031	.024	.025	.023	.022
Molybdenum	.012	.013	.011	.011	.011	.012
Aluminum	.050	.039	.039	.043	.047	<.005
Vanadium	<.005	<.005	<.005	<.005	<.005	<.005
Titanium	<.005	<.005	<.005	<.005	<.005	<.005
Columbium	<.005	<.005	<.005	<.005	<.005	<.005
Nitrogen	.0064	.0043	.0044	.0034	.0032	.0023

COATING WEIGHT/IRON-IN-COATING

Sample I.D.	Edge 1		Center		Edge 2		Average	
	Coating Weight	Iron	Coating Weight	Iron	Coating Weight	Iron	Coating Weight	Iron
Code B - 300625-GF-1.15	1.15	51	1.32	66	1.25	57	1.24	58
Code C - 300628-GF-2.0	1.54	74	1.89	93	2.30	91	1.91	86
Code D - 600446-G-2.6	2.15	168	2.49	382	2.31	165	2.32	238
Code E - 146106-G-2.0	2.08	193	1.98	185	2.00	184	2.02	187
Code F - 146042-G-1.15	1.40	189	1.50	190	1.42	263	1.44	214
Code G - 912523-AL-1.0	1.08	6700	1.07	7400	1.15	9000	1.10	7700

NOTE:

Coating Weight - oz./sq. ft. sheet

Iron-in-Coating - mg.Fe./sq. ft. sheet

METALLOGRAPHIC EXAMINATION (BASE STEEL)

Code		Microcleanliness ASTM Inclusion Rating	Microstructure ASTM Grain Size
B	Galfan 1.15	Type D Thin #1	#10 Equiaxed
C	Galfan 2.0	Type D Thin #1	#10 Equiaxed
D	Galvanize 2.6	Type D Thin #1	#10 Equiaxed
E	Galvanize 2.0	Type D Thin #1	#10 Equiaxed
F	Galvanize 1.15	Type D Thin #1	#10 Equiaxed
G	Aluminize 1.0	Type D Heavy #4	#8 Equiaxed

PHYSICAL AND MECHANICAL PROPERTIES

Code	Base Steel Gauge (inches)	Hardness (HRB)		Yield Point ksi (MPa)	Ultimate Strength ksi (MPa)	Percent Elong. in 2" (50mm)	Percent Uniform Elong.	Percent Yield Point Elong.	Yield/ Ult. Ratio	Bend Test
B	.0562	68	L	44.6 (307)	57.7 (398)	31.5	19.5	1.0	.77	ØT
(GF 1.15)			T	47.2 (326)	58.3 (402)	29.0	18.0	2.5	.81	ØT
C	.0575	69	L	47.4 (327)	60.2 (415)	32.0	18.5	1.0	.79	ØT
(GF 2.0)			T	49.6 (342)	60.2 (415)	31.0	17.5	2.0	.82	ØT
D	.0553	66	L	47.7 (329)	56.8 (391)	37.0	22.0	4.5	.84	ØT
(GALV 2.6)			T	53.0 (366)	56.8 (391)	35.0	21.5	6.0	.93	ØT
E	.0557	64.5	L	45.7 (315)	57.9 (399)	33.0	20.0	2.0	.79	ØT
(GALV 2.0)			T	50.4 (348)	57.3 (395)	31.5	18.0	3.5	.88	ØT
F	.0554	66	L	45.7 (315)	56.0 (386)	36.0	21.5	3.5	.81	ØT
(GALV 1.15)			T	53.7 (370)	56.4 (389)	33.0	20.5	5.5	.95	ØT
G	.0547	64.5	L	49.9 (344)	60.4 (416)	21.5	13.0	1.0	.82	ØT
(AL 1.0)			T	47.3 (326)	61.4 (423)	20.5	11.5	1.0	.77	ØT

BERGISCHE UNIVERSITÄT
GESAMTHOCHSCHULE WUPPERTAL

GAUSS-STRASSE 20
POSTFACH 100127
5600 WUPPERTAL 1
TELEX 8592262 ghw
TELEFON (0202) 439-1

Fachbereich 14
SICHERHEITSTECHNIK
Werkstoffe und Korrosionsschutz

Prof. Dr.-Ing. R. Nünninghoff

New Test Results - GALFAN Wire and Small Pieces

(Referat on October 3rd 1991 at ILZRO GALFAN LICENCEES MEETING 2. - 4. October 1991 in Pittsburgh, PA)

Contents

Ladies and Gentleman,

since the last ILZRO-meeting in Liege we made some new developments in GALFAN, I will show you some examples:

1. Short-time corrosion tests

The corrosion behaviour of aluminized, electro-galvanized, hot-dip-zinc-coated and galfan-coated steel wires coated with the douple-dip process, has been tested once again in SO_2-atmosphere (Kesternich-Test according to DIN 50 018 KFW 2,0 S) as well as in NaCl-atmosphere (salt spray mist test according to DIN 50 021 SS)in comparative studies. During the well known GALFAN-douple-dip process with TrefilARBED/Luxemburg, steel wire is zinc-coated in the first bath (first dip) and galfan-coated in the second bath (second dip). The hard zinc layer, built up in the first bath, is totally transformed to a Zn/Al/Fe-alloy in the second bath. In chapter 4 I will show some new results.

1.1 Short-time corrosion tests in SO_2-atmosphere

All tests were carried out according to DIN 51 018 KFW 2,0 S. Already after 1 cycle the electro-galvanized specimen, and after 2 cycles the aluminized specimen show first signs of red rust. After 22 cycles there is no more layer on the electro-galvanized wire (cf. fig. 1 and 2). The aluminium layer has been partially lifted from the basic material (cf. fig. 3) and a heavy corrosion attack right down to the basic material can be seen (cf. fig. 4) because there is no cathodic protection of the aluminium. In some areas the pure zinc-layer of the hot-dip-zinc-coated specimen is totally reduced (cf. fig. 5, 20th cycle), the hard-zinc layer is in some areas heavily attacked and the corrosion attack goes straight down to the basic material (cf. fig. 6). In contrast the galfan-coated wires show a completely uniform reduction after 20 cycles (cf. fig. 7 and 8). Delamination heavy corrosion attacks can not be noticed.

In summerizing all test results, one can say that the galfan-coated steel wire, as already known from various other investigations, has a 2-3 times better lifespan in SO_2-atmosphere as a comparable hot-dip-zinc-coated steel wire. In contrast to the hot-dip-zinc-coated and the aluminized wire the corrosion attack of the galfan-coated wire is totally uniform.

1.2 Short-time corrosion tests in NaCl-atmosphere

The tests were carried out according to DIN 50 021 SS. The aluminized wire already showed a first corrosion attack after 240 h, and after 260 h heavy loss of the layer down to the basic material could be noticed. After 520 h great areas of delamination can bee seen. In some areas the aluminized layer is totally lifted up (cf. fig. 9). The corrosion attack goes partly through the aluminium layer down to the basic material (cf. fig. 10). The electro-galvanized wires show a corrosion attack only after 900 h, but this attack is very non-uniform (cf. fig. 11) and partly going down to the basic material (cf. fig. 12). The standard galvanized wire (one dip) shows testing a totally non-uniform corrosion attack after 480 h testing (cf. fig. 13). The pure zinc-layer often is solved. In some areas the hard-zinc layer is already attacked (cf. fig. 14). The galfan-coated wire shows a totally uniform corrosion attack after 520 h (cf. fig. 15). Just as with the galvanized wire the basic material is not attacked (cf. fig. 16). From the test results one can conclude that an aluminized layer seems to be a really bad corrosion protection for this medium due to delamination and a very early corrosion attack. In the same way as a result of the non-uniform corrosion attack the electro-galvanized wire is only partially suitable. The galfan-coated wire shows similar loss rates to the hot-dip-zinc-coated wire, but because of the essentially more uniform corrosion attack of the hot-dip-zinc-coated wire, the galfan corrosion protection can be considered superior.

2. Lead content in the Galfan-layer

According to CRM already less lead-content lead to grain boundery corrosion in the galfan-layer of sheets with thin coatings, produced in the sendzimir process.

For steel wires high thickness of the coating is required. Usually the double-dip process is used with TrefilARBED for this quality. As has often been pointed out in several previous presentations, the hard zinc-layer is transformed into eutectic texture in the process.

Lead in the galfan-layer could not always be avoided, because of processing lead annealed or lead patenting steel wires, which take in traces of lead in the zinc bath or in the galfan bath respectively.

In spite of intensive short-time and long-time corrosion tests it is extremely rare that galfan-coated wires demonstrate grain boundary corrosion, and this only after a very long time of testing (about 1300 h salt mist spray test). But at this time the galfan-coated wires have already a 2-3 times longer lifespan in opposite when compared to the hot-dip-zinc-coated wires (cf. fig. 17). The mass reduction is uniform in spite of a lead content of 200 - 500 ppm in the galfan-layer (cf. fig. 18).

3. Cooling tests

To get an optimal corrosion behaviour and technological characteristics of the galfan-coated wires, it is more necessary to have an eutectic texture of the galfan-layer. Wrong cooling can result in a zinc rich galfan texture with a dendritic primary proeutectic (cf. fig. 19) beside a galfan texture rich in zinc with a globular primary proeutectic (cf. fig. 20 and 21). These unequal textures could possible promote grain boundary corrosion. With an optimized cooling it is possible today to get an eutectic texture of the galfan-layer on the steel wire in large scale production (cf. fig. 22). In extremely cases grain boundary corrosion can very rarely be established at this texture and then only after a very long time of exposition, which exceed the exposition time of hot-dip-zinc-coated wires by a factor of about 2-3.

4. Scanning electron microscope investigation

To prove the total transformation of the hard zinc-layer (built up in the zinc bath), into a Zn/Al/Fe-layer in the galfan bath, a lot of extensive scanning electron microscope investigations using a microprobe have been carried out at the TrefilARBED Recherches in Esch-sur-Alzette/Luxembourg. During the investigation the distribution of the particular chemical elements Zn, Fe and Al of the texture has been detected in the thickness of the galfan-layer. The following figures and diagrams (cf. fig. 23 - 26, digram 1 - 4) of the Trefil ARBED Recherches are to be regarded as a pre-publication of a doctoral dissertation of V. Hagebölling at the Bergische Universität GH Wuppertal, Germany.

4.1 Wires produced at TrefilARBED/Luxemburg

Fig. 23 shows the typical texture of a hot-dip-zinc-coated wire with distinctive pure zinc-layer and a clearly visible hard zinc- layer at the transition to the steel. In contrast, the texture of a galfan-coated wire, coated in a double-dip process, shows a significant eutectic corrosion protection layer (cf. fig. 24). The Fe-proportion of the Zn/Fe-alloy of the hot-dip-zinc-coated wire decreases over the cross section towards the edge (cf. diagram 1), whereas the Zn-proportion increases correspondingly. The aluminium of the galfan-coated wire has diffused down to the basic material (cf. diagram 2) that is to say that the hard zinc-layer has been totally transformed into eutectic. The Fe-proportion decreases towards the edge. The little shifting of each of the distribution diagrams of the Zn, Al and Fe can be attributed back to insignificant surface effects.

4.2 Small pieces

In the process of batch galvanizing of small pieces we have only a hard zinc-layer (cf. fig 25). Galfan-coated small pieces (double-dip process) show a significant eutectic texture (cf. fig. 26). As is clearly visible, the zinc texture with the hard zinc-layer has been transformed into a uniform texture (eutectic). The distribution diagrams of each corrosion protection layer confirm the light microscopical view. The Fe-proportion of the galvanized specimen decreases towards the edge (cf. diagram 3). The Al-proportion of the galfan-coated specimen has diffused down to the basic material (cf. diagram 4) which demonstrates the total transformation of the hard zinc-layer. With about 4 - 8 % over the whole cross section of the layer the Fe-proportion corresponds approximately with the aluminium distribution. As the corresponding complement to 100 % the Zn-proportion fluctuates in dependence of the each Fe-proportion and Al-proportion respectively over the thickness of the layer. The little shifting of the distribution diagrams of Zn, Al and Fe to themselves can be attributed to insignificant surface effects.

5. Galfan piece coating

During the development of galfan coated surfaces it is now possible to galfan-coat several small pieces (cf. fig. 27). Further research deals with piece galfan-coating of structural parts, such as screws and rivets.

5.1 Screws

During the first experimental stage short-time corrosion tests are currently being conducted with piece galvanized screws (460 °C, cf. fig. 28) high-temperature piece galvanized (560 °C, cf. fig. 29) and piece galfan-coated screws (fig. 30) as well in SO_2-atmosphere as in NaCl-atmosphere (DIN 50 018 KFW 2,0, respectively DIN 50 021 SS). The results after 35 cycles at the SO_2-test already show that there is a distinctively smaller corrosion sensibility (smaller decreasing of thickness of layer, equal attack of corrosion) of the piece galfan-coated screws compared to both variants of the piece hot-dip-zinc-coated screws (normal temperature and high-temperature, fig. 31 - 33). The tests will be continued in the future. Similar tests in NaCl atmosphere have up to now shown no significant differences between the specimen, which is substantiated in the smaller corrosive environment. The course of the tests will still be observed.

The test of the technological properities of piece galfan-coated screws compared to piece hot-dip-zinc-coated variants (normal and high temperature) research is going on at the Technical University of Hamburg/Harburg.

5.2 Rivets

With piece galfan-coated and sherardized rivets short-time corrosion tests have been conducted both in SO_2-atmosphere and in NaCl-atmosphere. Already in the fitting process the galfan-coated rivets show some advantages in comparison to the sherardized rivets visible. The galfan-coated rivets are more ductile so that the corrosion protection layer will not peel off which can be observed in some areas of the sherardized rivets.

Even in the SO_2-atmosphere (DIN 50 018 KFW 2,0 S) the galfan-coated rivets are better than the sherardized rivets both separated (cf. fig. 34 after 8 cycles) and riveted (cf. fig. 35 after 8 cycles). The sherardized rivets already show red rust after 2 cycles whereas the first red rust can be recognized at the piece galfan-coated rivets only after 23 cycles. In order to optimize the piece coated process further tests are planned.

6. New Applications

6.1 GALFAN as a substitute of PVC-layers

Because of environmental reasons the Galfan-Chain-Link-Fence will be used more and more as a substitute for the Chain-Link-Fence with PVC-coating (disposal problems).

6.2 Rigging of radio masts

Currently several radio masts in Germany (Hessischer Rundfunk (HR), SüdWestfunk (SWF) and Norddeutscher Rundfunk (NDR)) are rigged by galfan-coated wires because of the considerable longer down time (cf. fig. 36 and 37). Some of the radio masts are located at the broadcasting stations: Würzberg (HR), Göttingen (NDR), Hardtkopf/Mosel (SWF) and Aurich (NDR). The same can be reported from skandinavia (Bridon-rope).

6.3 Transformation of wires

Because of the good ductility and good adhesion of the corrosion protection layers galfan wires are suitable for transformed wires in various kinds of applications.

6.4 CORE WIRE and core strands for Aluminium conductors (ACSR)

Scandinavia wishes to substitute hot-dip-galvanized wire and strands for Aluminium conductors with GALFAN. Zinc has only a life-span of 4 years in the strong Sodium-chlorid atmosphere of Scandinavia.

Figure 1: 100:1

Electro-galvanized wire after 22 cycles in SO_2-atmosphere without significant zinc layer

Fig 2: 500:1

Electro-galvanized wire with a heavy corrrosion attack after 22 cycles in SO_2-atmosphere

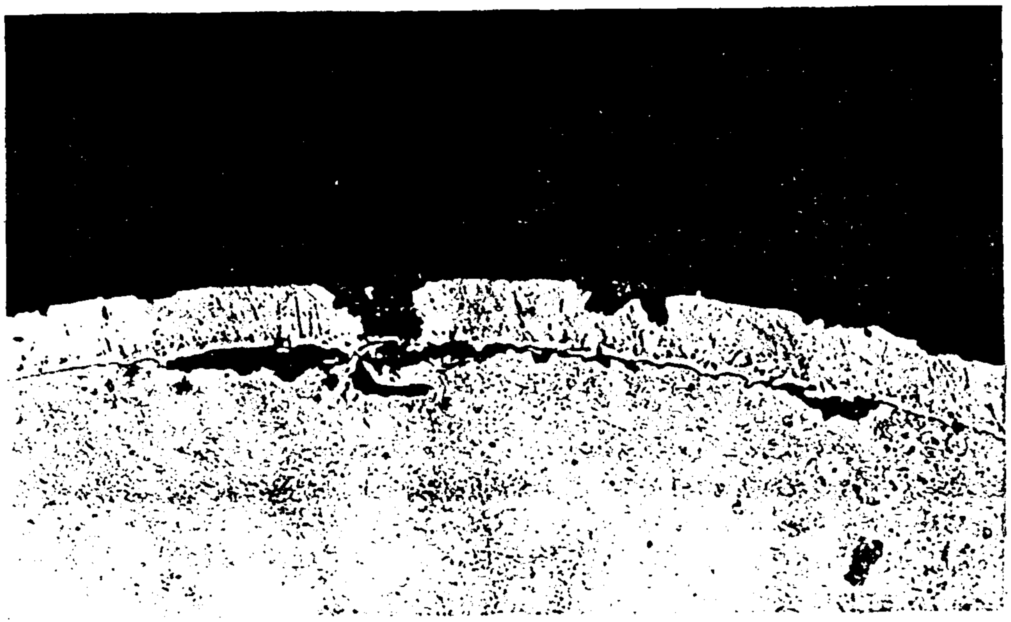


Figure 3: 100:1

Heavy delamination of the aluminium layer in some areas; aluminized wires after 15 cycles in SO_2-tests

Figure 4: 500:1

Aluminized wire after 15 cycles So_2-test; heavy corrosion attack down to the basic material

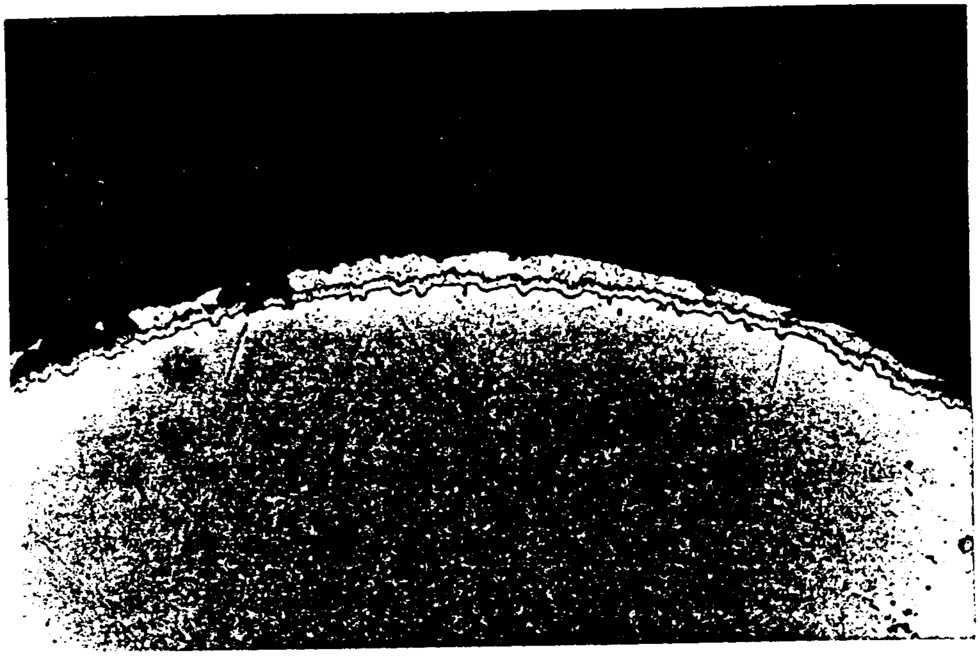


Figure 5: 100:1

Partly totally solved pure zinc layer of a zinc-coated wire after 20 cycles SO_2-atmosphere

Figure 6: 500:1

Zinc-coated wire after 20 cycles SO_2-test; non-uniform corrosion attack, partly down to the basic material

Figure 7: 100:1

Galfan-coated wire after 20 cycles in SO_2-atmosphere; total uniform corrosion attack

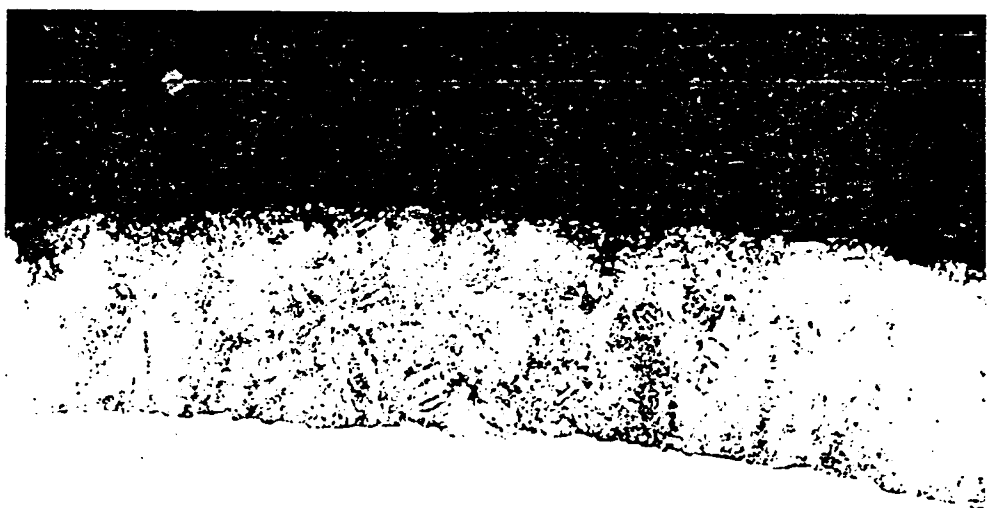


Figure 8: 500:1

Galfan-coated wire after 20 cycles SO_2-test; uniform reduction of the layer

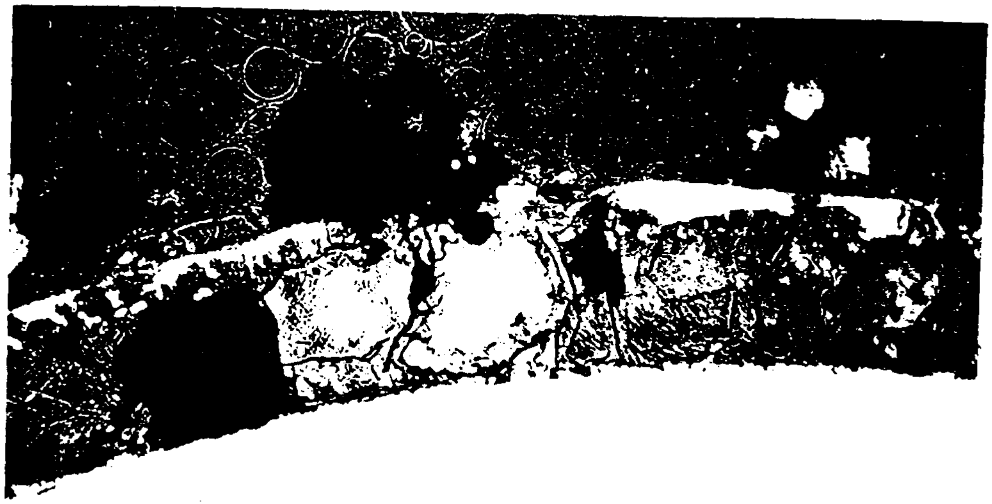


Figure 9: 200:1

Aluminized wire after 520 h in NaCl-atmosphere; big areas with delamination, heavy corrosion attack

Figure 10: 500:1

Aluminized wire after 520 NaCl-test; locally corrosion attack down to the basic material

Figure 11: 100:1

Electro-galvanized wire after 900 h NaCl-test; very non-uniform corrosion attack

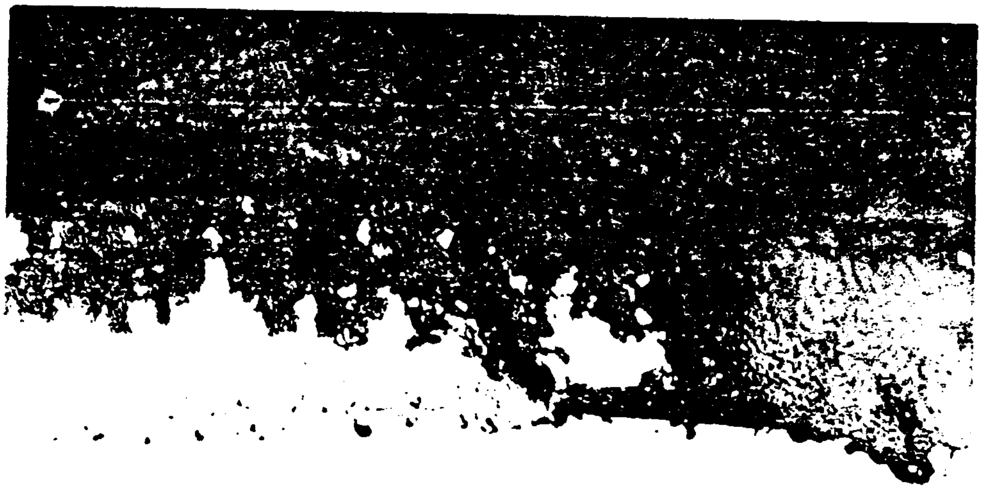


Figure 12: 500:1

Electro-galvanized wire after 900 h NaCl-test; heavy corrosion attack in some areas down to the basic material

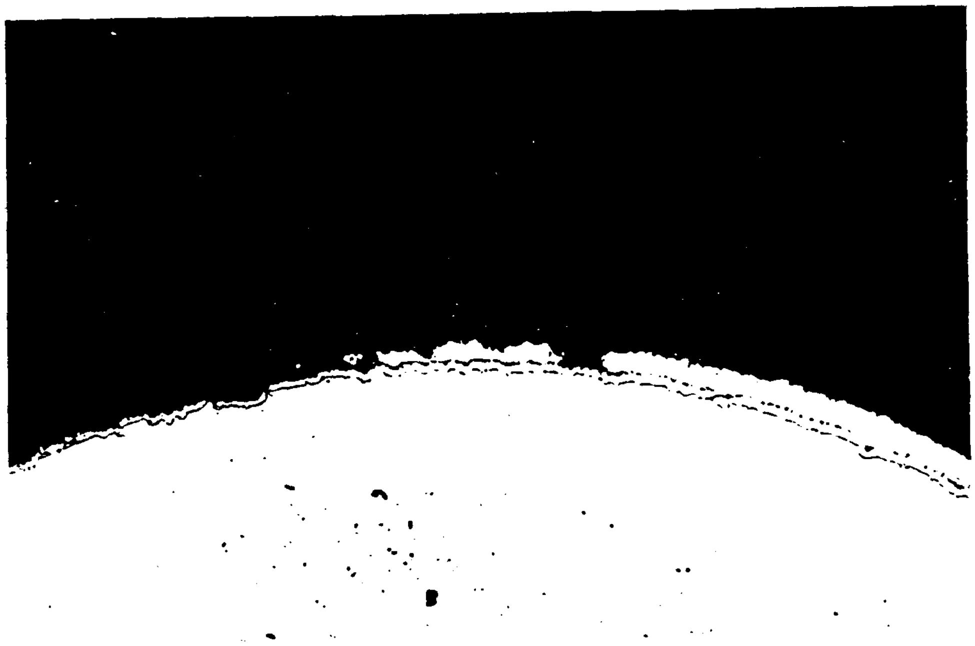


Figure 13: 100:1

Zinc-coated wire after 480 h NaCl-test; non-uniform corrosion attack, partly solved pure zinc layer

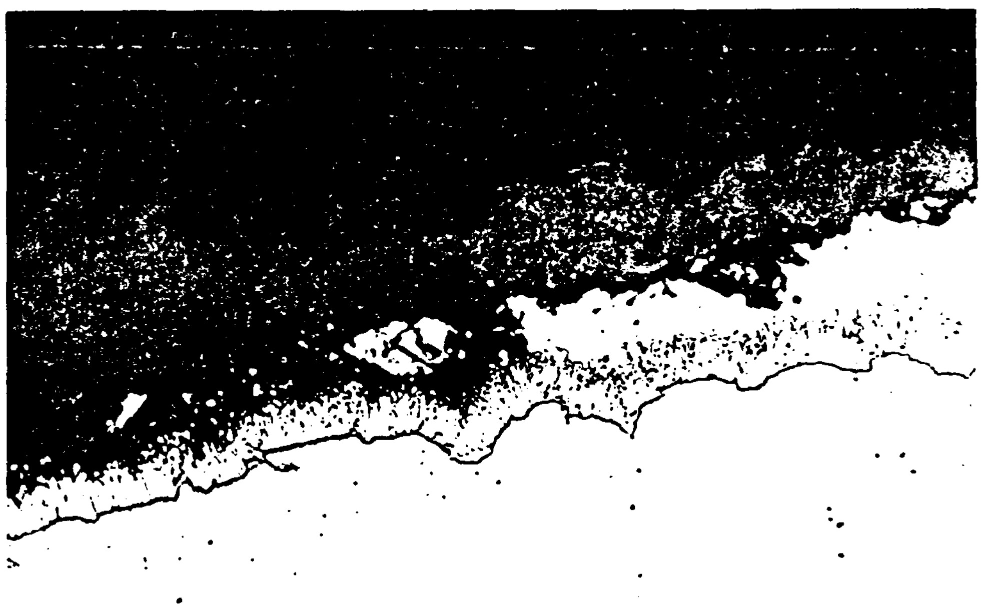


Figure 14: 500:1

Zinc-coated wire after 480 h NaCl-test; locally attacked hard zinc layer

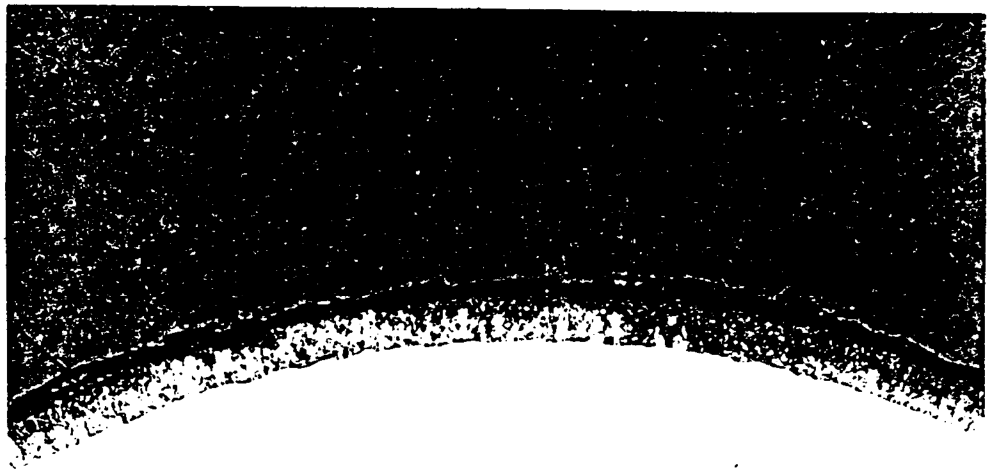


Figure 15: 100:1

Galfan-coated wire after 520 h NaCl-test; uniform corrosion attack

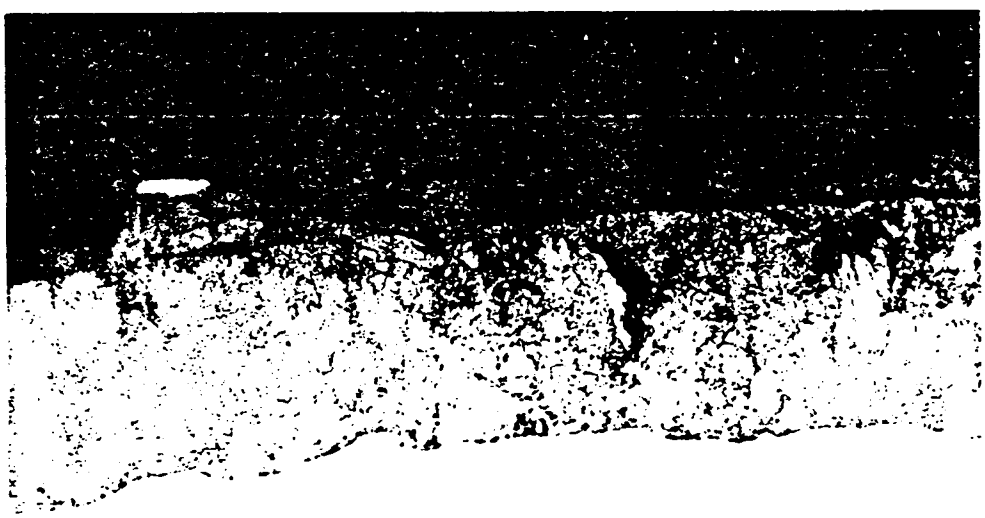


Figure 16: 500:1

Galfan-coated wire after 520 h NaCl-test; uniform corrosion without attack of the basic material

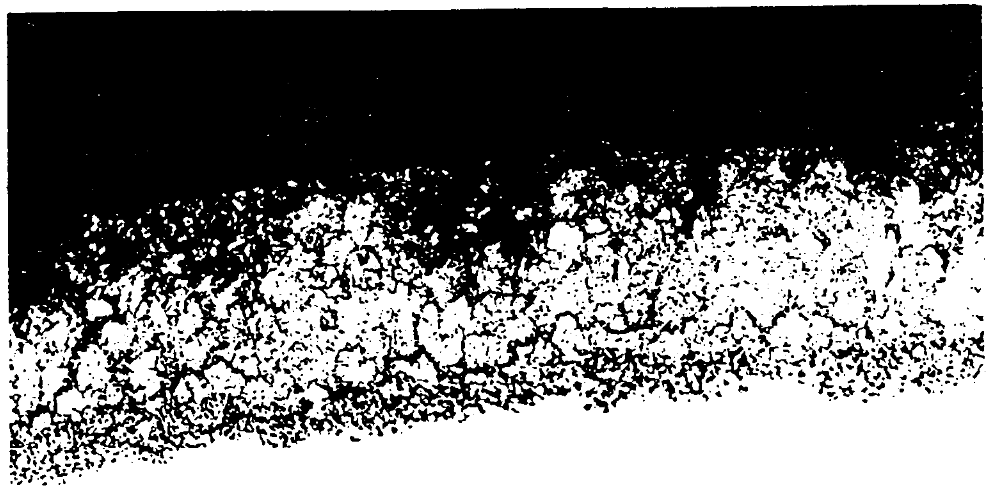


Figure 17: 500:1

Galfan-coated wire after 1300 h NaCl-test; beginning grain boundary corrosion

Figure 18: 500:1

Galfan-coated wire after 1300 h NaCl-test; uniform corrosion attack in spite of 200 - 500 ppm lead

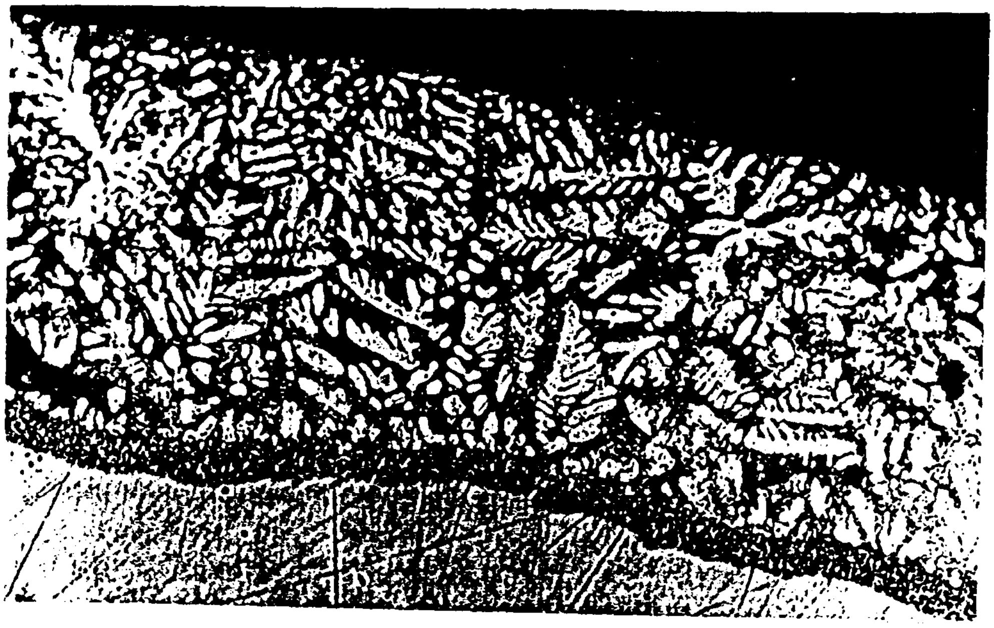


Figure 19: 500:1

Zinc rich galfan texture with dendritic primary proeutectic due to wrong cooling

Figure 20: 500:1

Zinc rich galfan texture with globular primary proeutectic due to wrong cooling

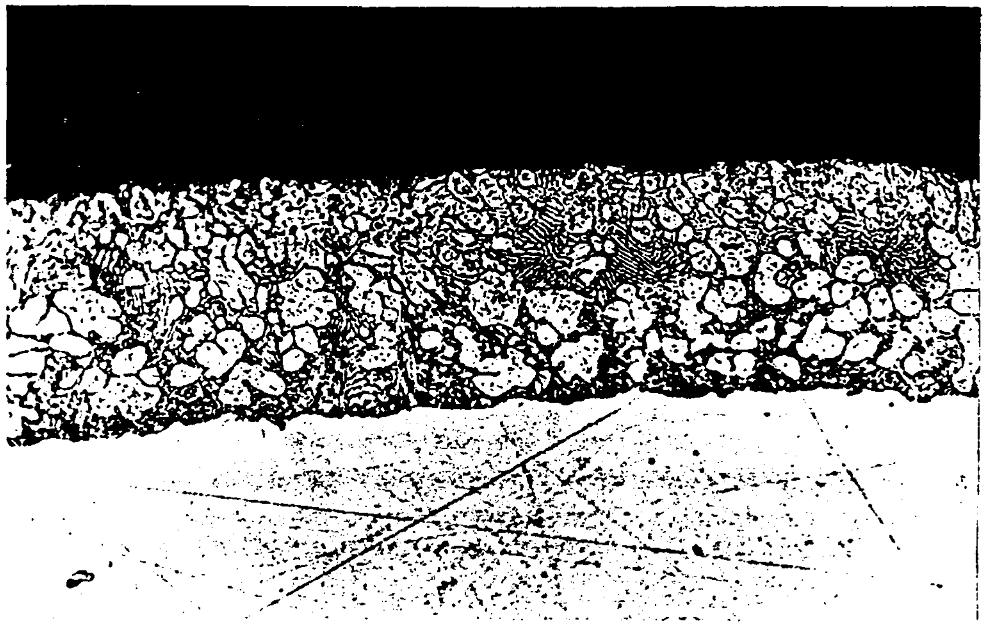


Figure 21: 500:1

Zinc rich galfan texture with globular primary proeutectic due to wrong cooling

Figure 22: 500:1

Eutectic texture of a galfan-coated wire due to optimized cooling

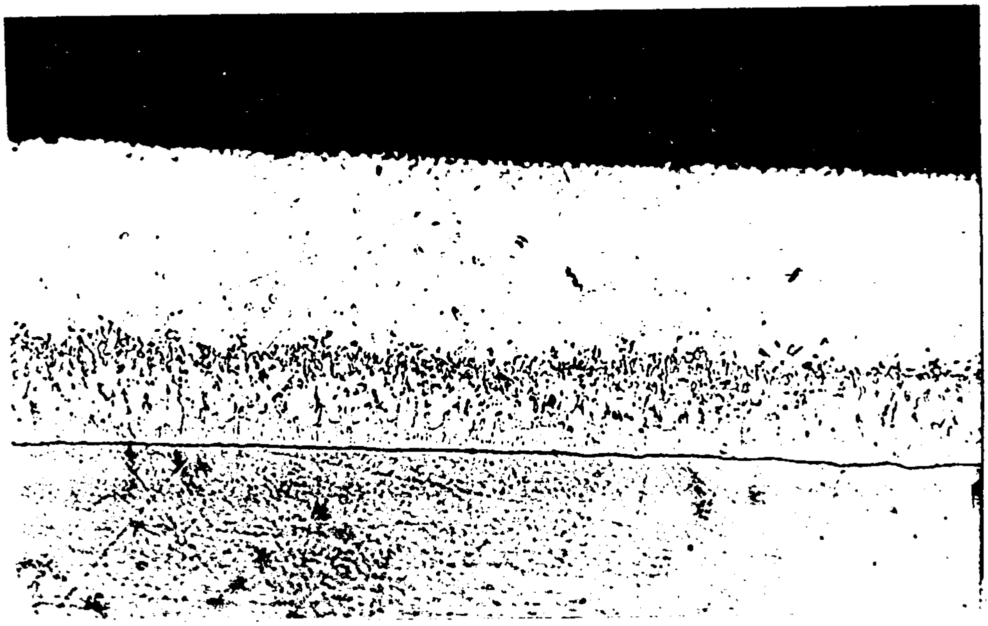


Figure 23: 500:1

Zinc-coated wire; texture at the transition basic material/ zinc-layer (cross section)

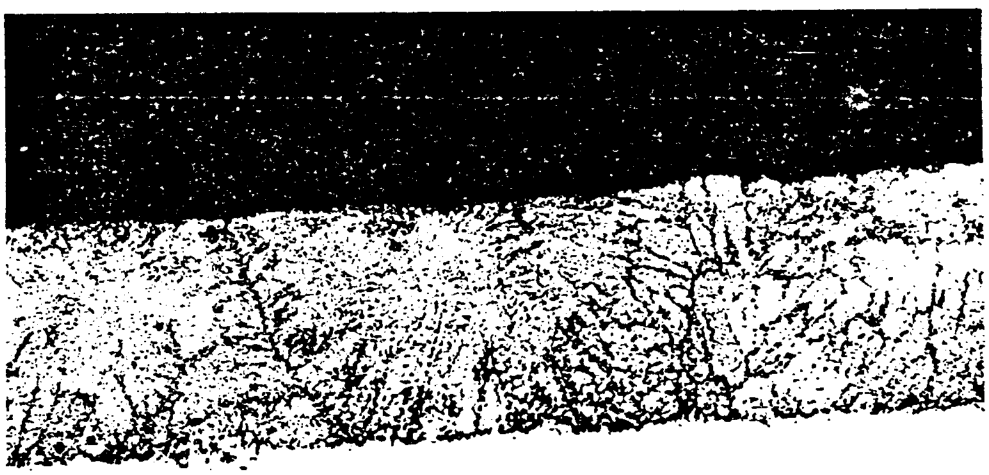


Figure 24: 500:1

Galfan-coated wire; texture at the transition basic material/ Zn-Al-layer (cross section)

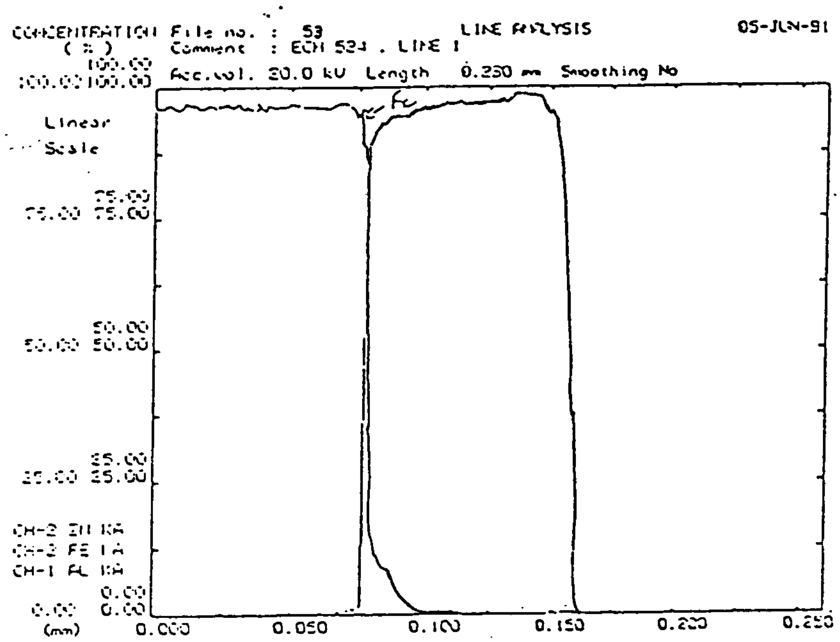
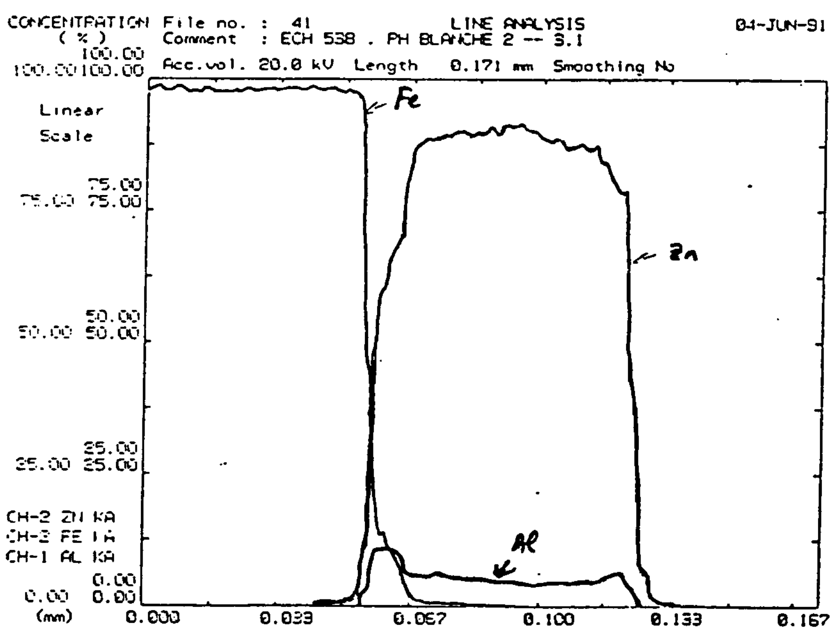


Diagram 1:

Distribution of the texture proportions of a zinc-coated wire at the transition basic material/zinc-layer



Digram 2:

Distribution of the proportions of a galfan-coated wire at the transition basic material/Zn-Al-layer

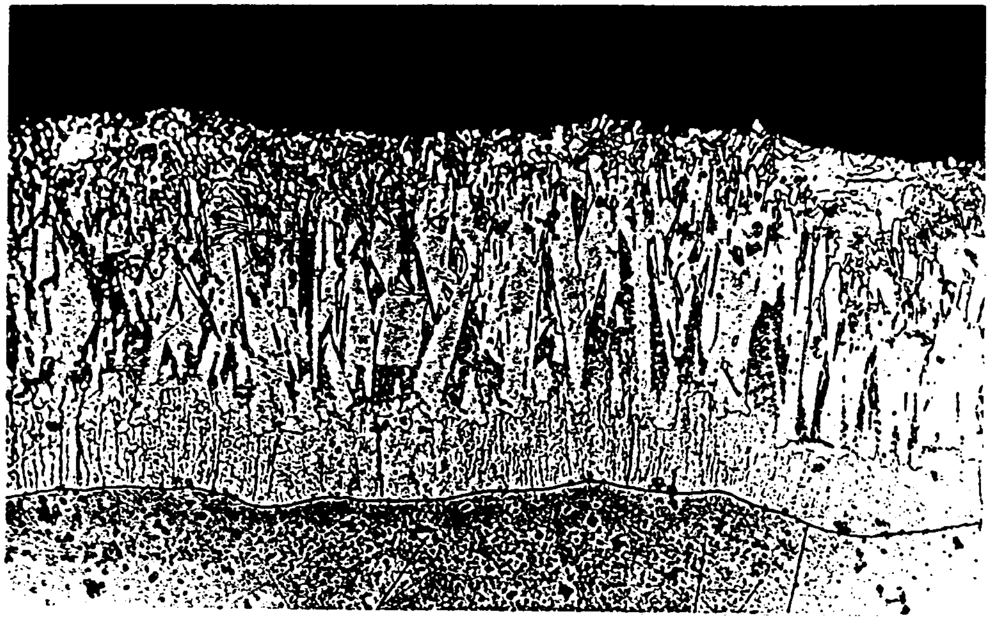


Figure 25: 500:1

Texture of a batch galvanized, high stresses resistance screw at the transition basic material/zinc-layer (cross section)

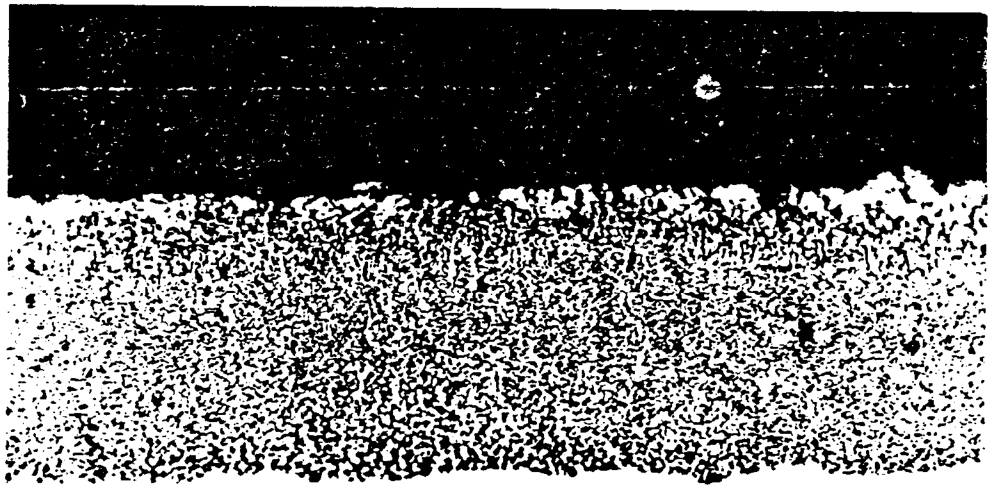


Figure 26: 500:1

Texture of a galfan-coated, high stress resistant screw at the transition basic material/Zn-Al-layer (cross section)

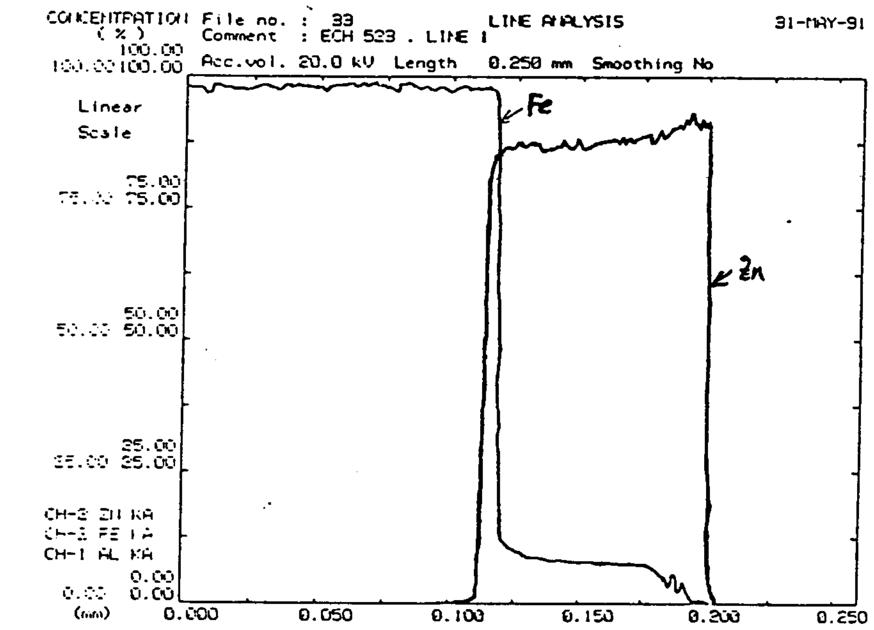


Diagram 3:

Distribution of the texture proportions of a batch galvanized, high stress resistant screw at the transition basic material/zinc-layer

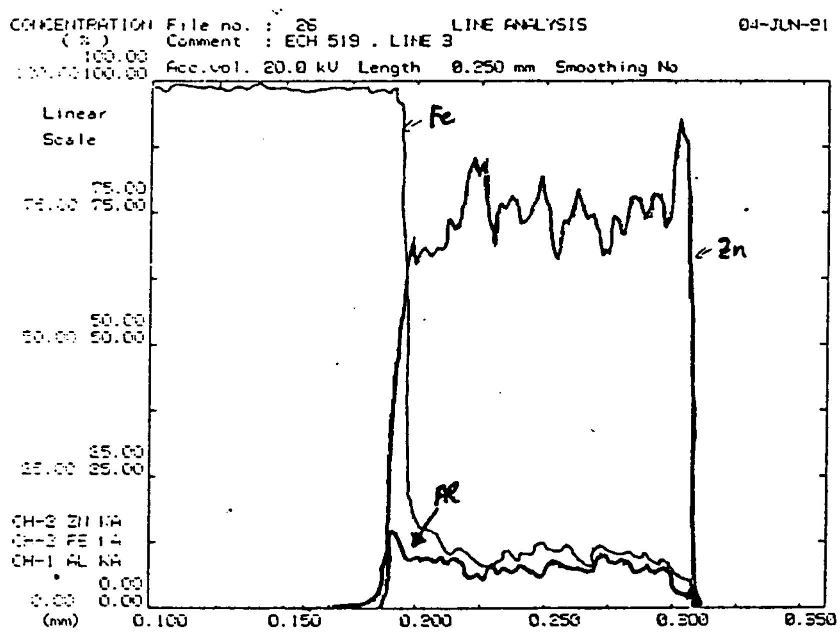


Diagram 4: Distribution of the texture proportions of a galfan-coated, high stress resistant screw at the transition basic material/Zn-Al-layer

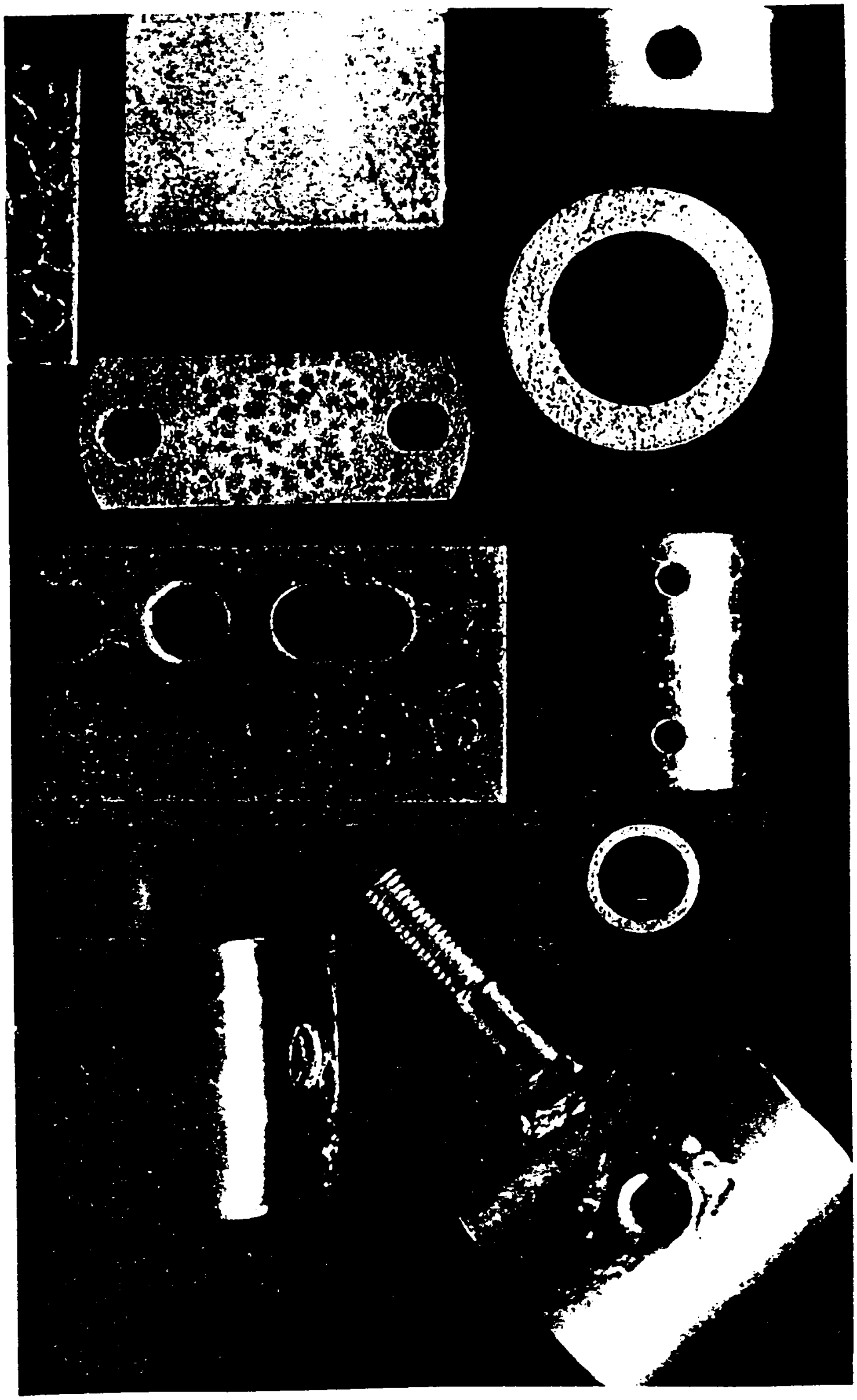


Figure 27: Galfan-coated small pieces

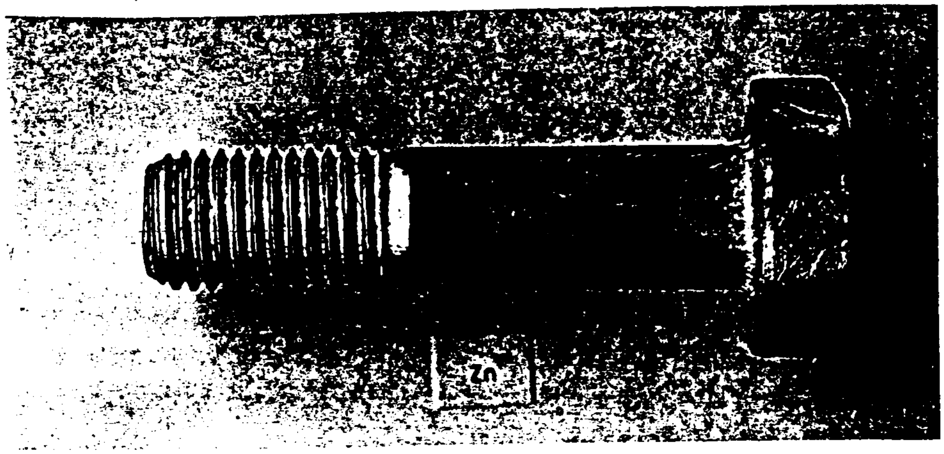


Figure 28: 1,5:1

Galvanized, high stress resistant screw (460 °C)

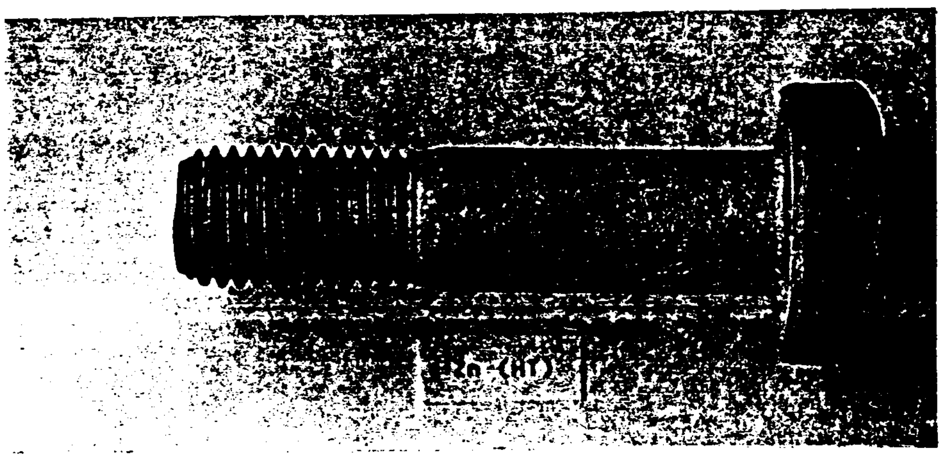


Figure 29: 1,5:1

Hightemperature zinc-coated, high stress resistant screw (560 °C)

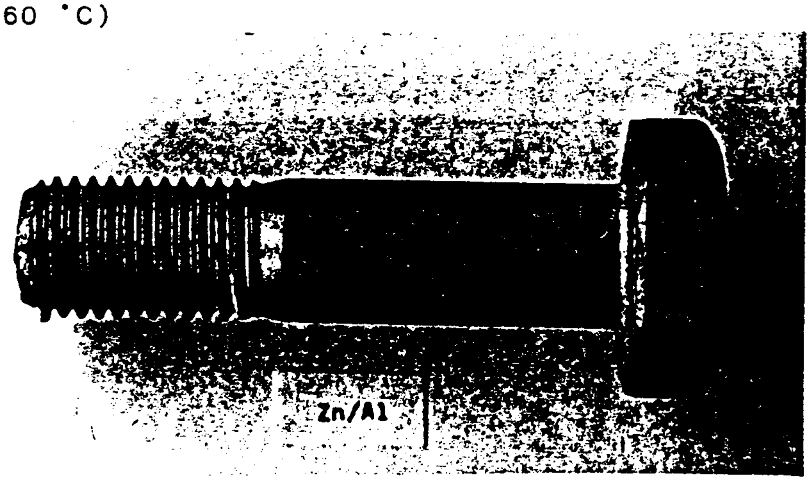


Figure 30: 1,5:1

Galfan-coated high stress resistant screw

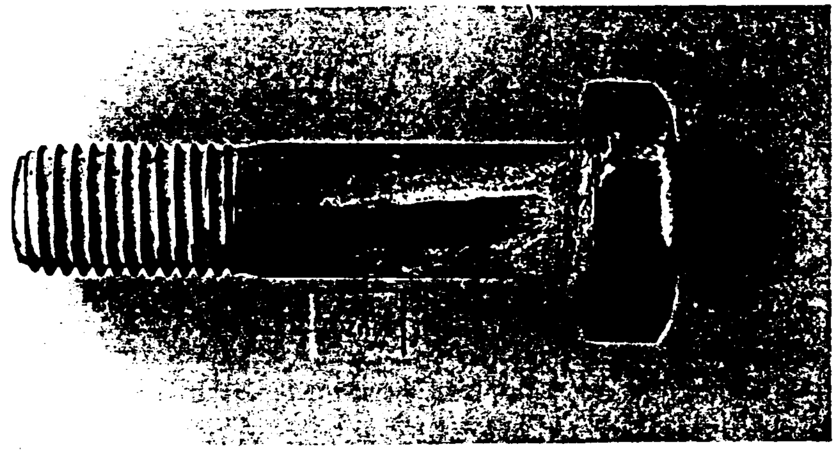


Figure 31: 1,2:1

Galvanized, high stress resistant screw after

35 cycles SO_2-test

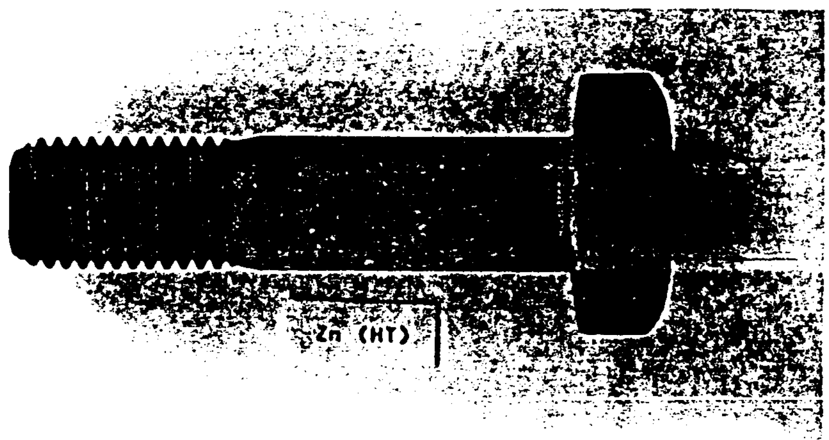


Figure 32: 1,2:1

Hightemperature zinc-coated, high stress resistant

screw after 35 cycles SO_2-test

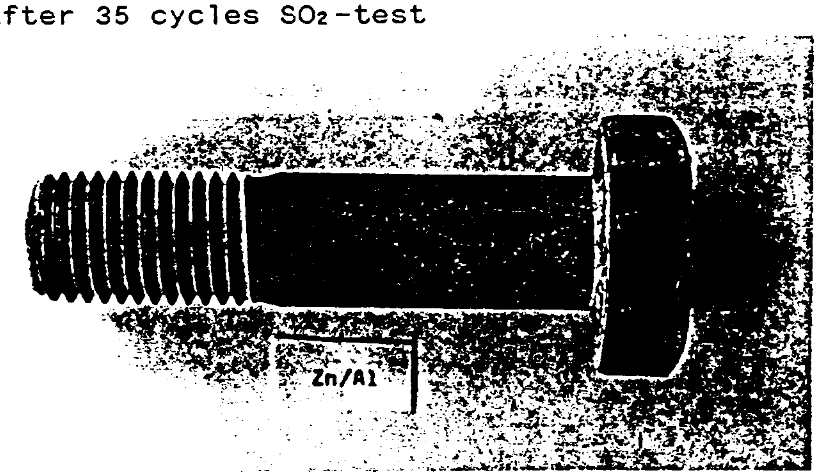


Figure 33: 1,2:1

Galfan-coated, high stress resistant screw (35 cycles)

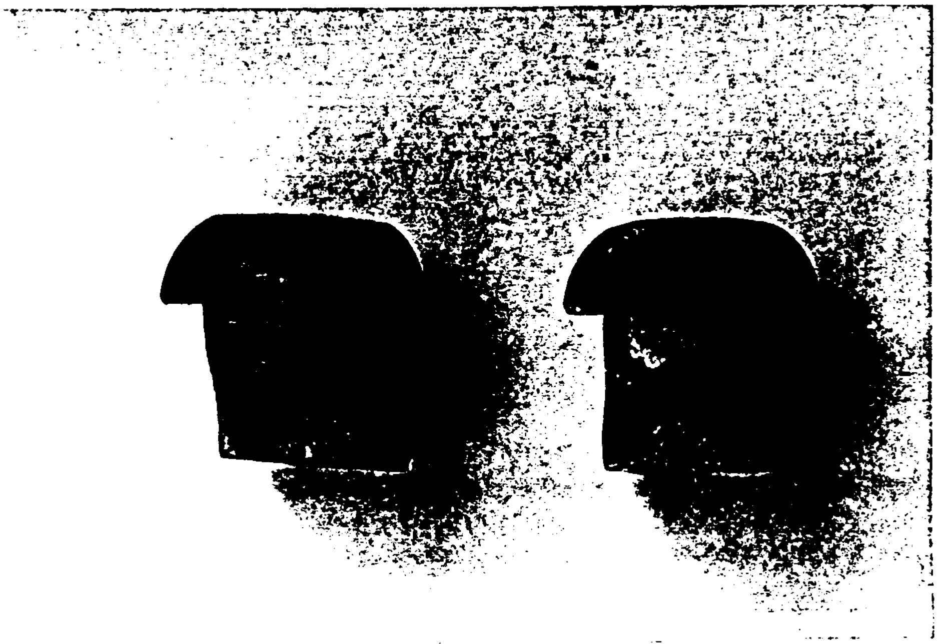


Figure 34: 0,5:1

Zinc-coated rivet (left) and galfan coated rivet (right) after 8 cycles in SO_2-atmosphere

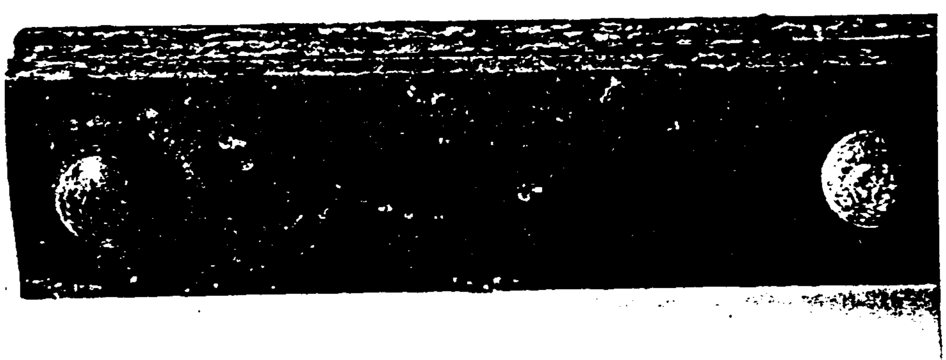


Figure 35: 0,5:1

Riveted steelplates, left the zinc-coated rivet and right the galfan coated rivet, each after 8 cycles SO_2-test

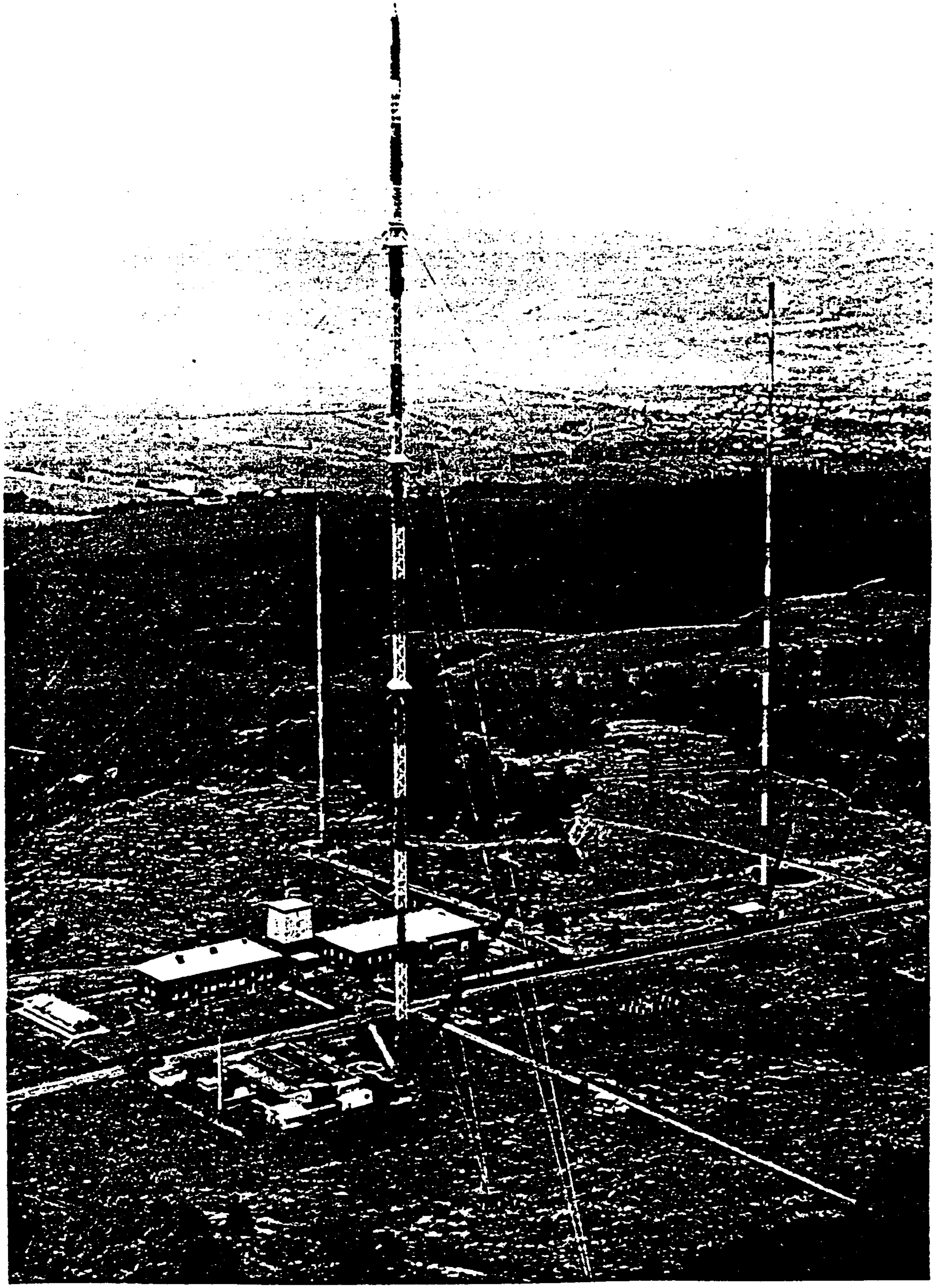


Figure 36: Radio mast with rigging ropes

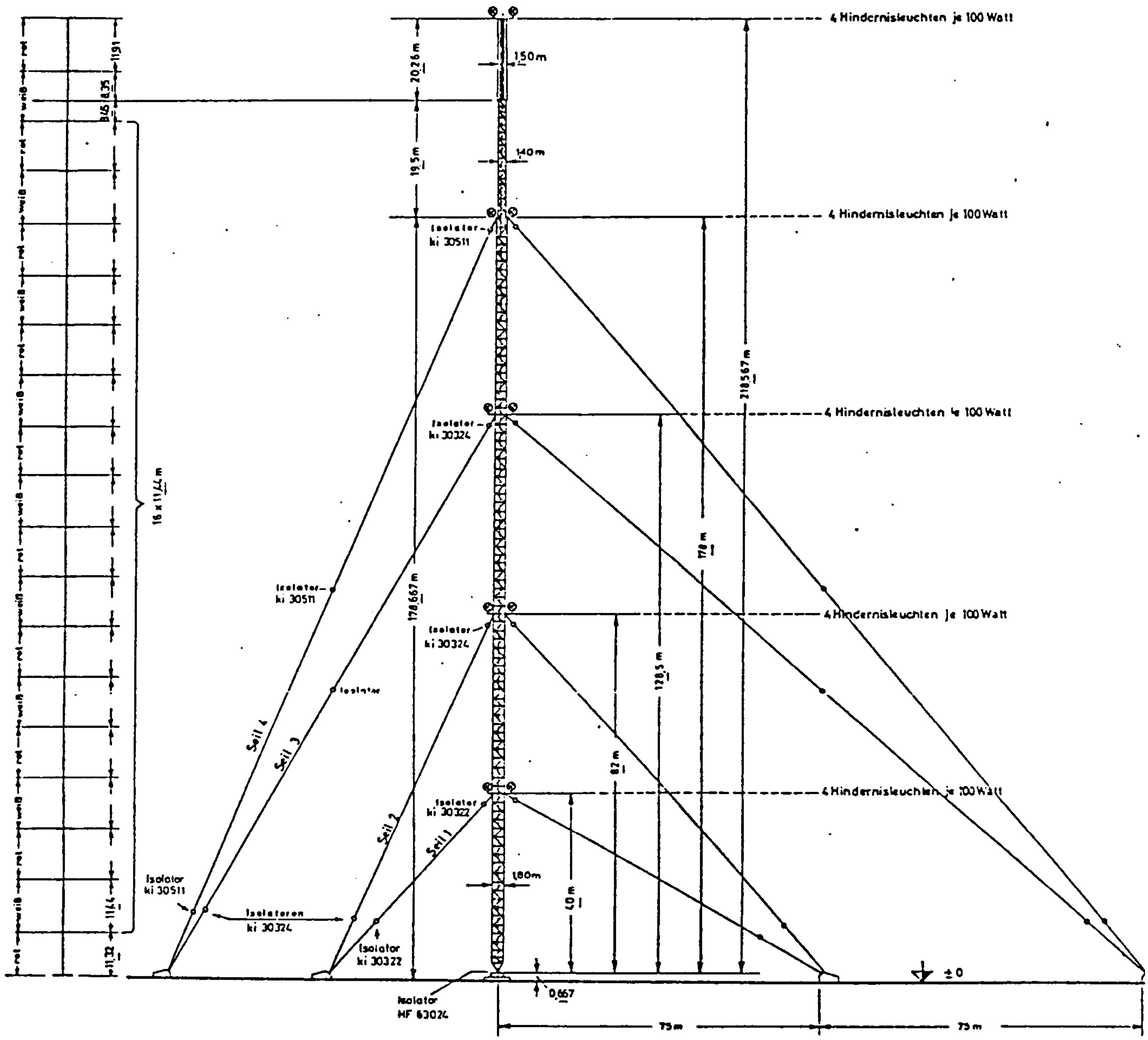


Figure 37: Sketch of positioning of rigging ropes of a radio mast

Inhibition of Black Patina Development on Galfan Coated Steel Sheets by Spray Treatment of Cobaltous Solution

by

Yusuke Hirose, Nisshin Steel Co., Ltd.

For presentation at the 16th Galfan Licensees' Meeting,
to be held on October 3, 1991

1. Introduction

Galfan coated steel sheets have superior corrosion resistance to that of conventional galvanized steel sheets, but have a problem of premature darkening. This surface darkening is due to the formation of thick black patina which is composed of the mixture of non-stoichiometric zinc oxide and chromium oxide [1].

We find that this phenomenon is effectively retarded by spraying aqueous solutions which contain iron group metal ions, especially cobalt ion, onto the molten coating surface just after gas wiping. The spray treatment is now put into operation at Ichikawa Works of Nisshin Steel.

This report shows the effect of the spray treatment and the role of cobalt ion in darkening inhibition.

2. Experimental Procedure of preliminary examination

Experimental procedure and conditions of each treatment are shown in Fig. 1. In this examination, specimen, cut from commercial product, was hot-dip coated in atmosphere again, and followed spray treatment.

Acceleration test for black patina formation was carried out in high humidity condition (HCT). Before and after this testing, surface structure was investigated by various surface analytical methods to clarify the effect of cobalt ion. Conditions of surface analyses are shown in Table 1.

3. Operating condition

After several line trial, the spray treatment is now used in No.2 and

No.3 CGL of Ichikawa Works. Standard operating conditions are as follows,

(i) solution

cobaltous nitrate ($Co(NO_3)_2 \cdot 6H_2O$) : 20±2 g/l : room temperature

weight of cobalt deposited : 1 - 3 mg/m^2 (as Co metal)

(ii) spraying

- water pressure 40 - 50 kg/cm^2 (for dull appearance)
- water pressure 3.0 - 4.0 kg/cm^2 and air pressure 3.5 - 5.0 kg/cm^2 (for bright appearance)

4. Results

4.1 Effect of Spray Treatment

The lightness of coating surface decreased rapidly during HCT without metal ion spray treatment. The spray treatment of metal ion, such as Co, Ni and Fe, -containing solution retarded the decrease in lightness. Among these cations, cobalt ion showed the most excellent effect for darkening inhibition.(Fig.2) The inhibitive action of cobalt increased with volume of sprayed cobalt salt solution. (Fig.3)

Fig.4 shows the result of indoor exposure test of trial product which was produced in No.2 CGL with high pressure type spraying. Without cobalt treatment, surface darkening occured only after one month indoor exposure, but cobalt treated surface kept its clear appearance after 13 months. In the case of low pressure type (air-mixed) spray treatment, similar result was obtained.

4.2 Structure of Cobalt Compound Deposited on Coating Surface

In transmission electron microscopic (TEM) image of chemically peeled surface oxide film after the spray treatment, a large number of island-like Co_3O_4 deposits were observed. The structure of these deposits was identified with selected area HEED pattern and EDX analysis. (Photo.1) The thicknessof cobalt oxide deposits was 0.1 - 0.2 μm as determined by a direct observation of the ultramicrotomed cross section of the coating layer. (Photo.2) The HEED pattern of deposits did not change after a chromate treatment. (photo.3)

Differential thermal analysis (DTA) curve of $Co(NO_3)_2 \cdot 6H_2O$ showed several endothermic peaks. (Fig.5) The peak around 250℃ was attributed to NO_2 evolving reaction. Above this temperature, $Co(NO_3)_2 \cdot 6H_2O$ altered to Co_3O_4. It is reasonable to consider that the same reaction takes place on the Galfan coating surface immediately after the spray treatment in conventional CGL.

4.3 Changes in Surface Structure of Galfan during Acceleration Test

After 20 days of a HCT, the presence of cobalt oxide was detected by ESCA analyses. (Fig.6) ESCA analyses also showed that the spray treatment of cobalt salt retarded surface oxidation of zinc in the coating layer. (Fig.7) Namely, the presence of cobalt oxide had inhibitive action to the black patina (ZnO_{1-x}) formation.

SAM depth analysis of Al-rich phase of the eutectic showed that oxidation reaction was extremly suppressed beneath the cobalt oxide deposit. (Fig.8) This means that cobalt oxide deposit has a kind of barrier effect to oxidation. SAM analysis of β-Zn phase showed, however, surfase oxidation was also retarded at the area where spotty dispersed cobalt oxide was not obsaerved in SAM image. (Fig.9) In cross-sectional TEM images of Al-rich phase, the suppression of oxidation was also observed at the area without cobalt oxide deposit. (Photo.4) Hence cobalt oxide has not only the barrier effect but also another inhibitive effect to oxidation reaction.

Spotty dispersion of cobalt oxide was also observed after 20 days of a HCT in IMA ion images obtained using thin Ga^+ primary beam. (Phot.5) From the area where cobalt oxide was not observed, very small amount of cobalt ion was detected by IMA (SIMS) measurements. (Fig.10) Co_3O_4 has finite solubility to water, then these cobalt ions were considered to be eluted into condensed water on the coating surface under the high humidity circumstance of HCT.

It is well known that the presence of small amount of cobalt ion on the zinc surface improves its corrosion resistance markedly [2,3]. This means the decrease in rate of oxidation. Proposed mechanisms by these authors are both based on inhibition of electrochemical reaction. Considering thin and small surface coverage of cobalt oxide deposits, this electrochemical inhibitive effect might be dominant. Fig.11 shows the schematic explanation of inhibition mechanism of black patina development by cobalt oxide.

Reference

1) Y.Hirose : presented at the 6th Galfan Licensees' Meeting, (1985)
2) H.Okada et al. : Proc. Internl. Congr. Metallic Corrosion, (1972) p.662
3) H.Leidheiser,Jr. et al. : J. Electrochem. Soc., 128 (1981) p.242

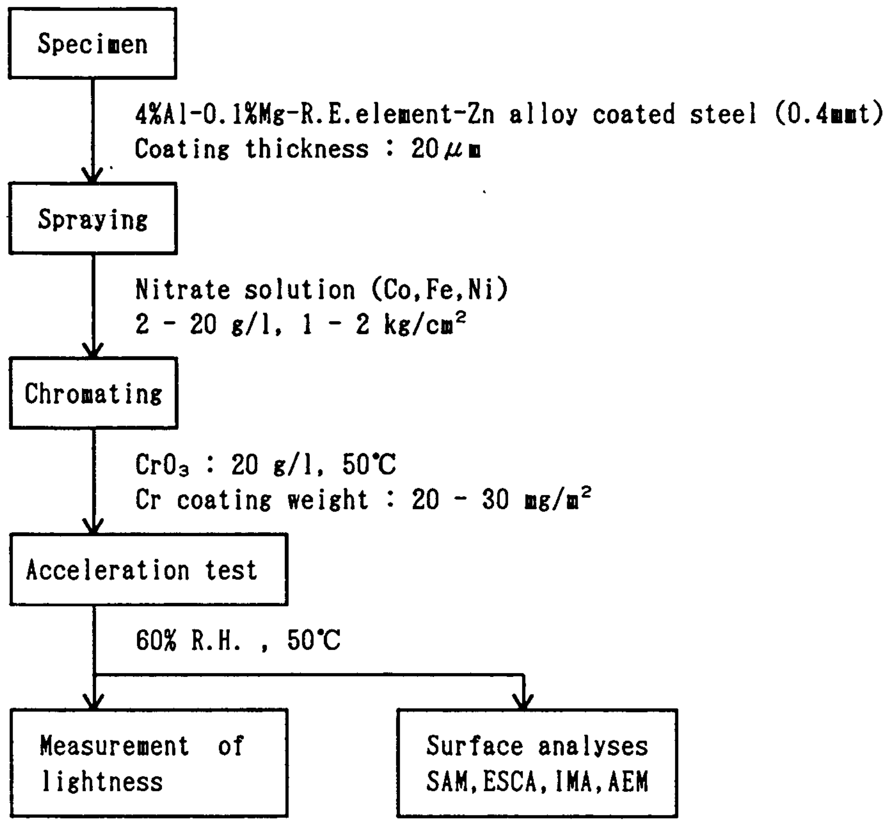


Fig.1 Experimental procedure

Table 1 Conditions of surface analyses

Equipment		Condition
SAM	PHI-610	5kV - 4μA
ESCA	PHI-5100	Al : 15kV - 20mA
IMA	HITACHI IMA-3	Ga^{+} : 17kV - 0.1nA
AEM	HITACHI H700-H	200kV, camera length : 1m

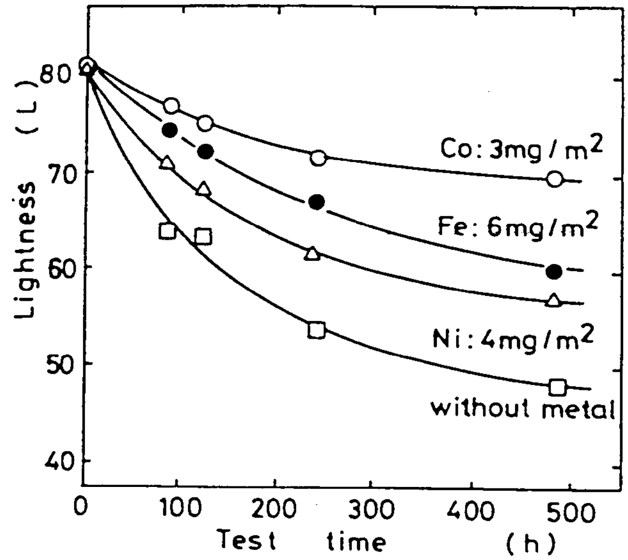


Fig.2 Changes in the lightness of the coating surface treated by various nitrate solutions in a humidity cabinet test. The weights of deposited oxides (as metal) are indicated.

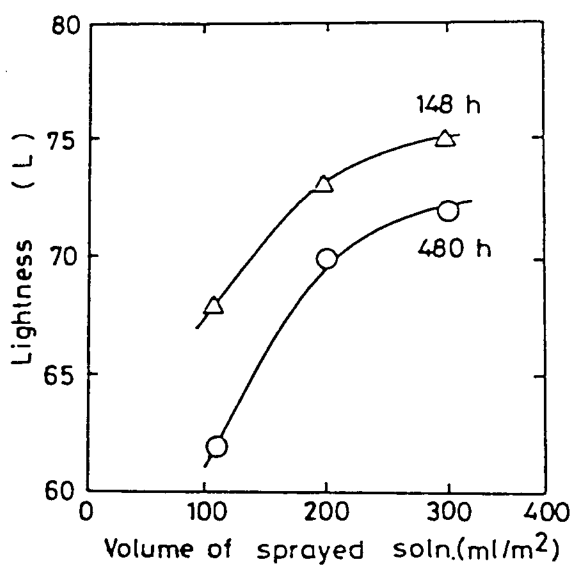


Fig.3 Relationship between the lightness of Co treated coating surface after 148 and 480 hours of a humidity cabinet test and volume of sprayed Co salt solution.

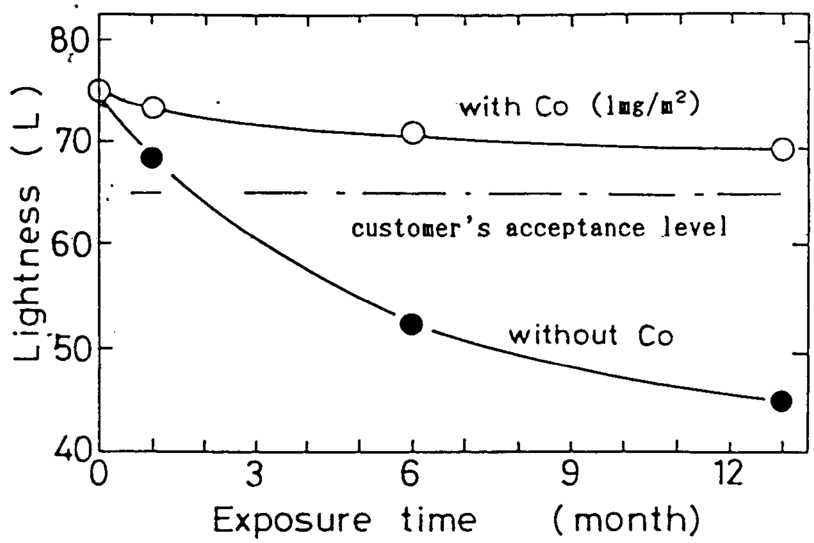


Fig.4 Changes in the lightness of the coating surface with and without Co treatment in an indoor exposure test.

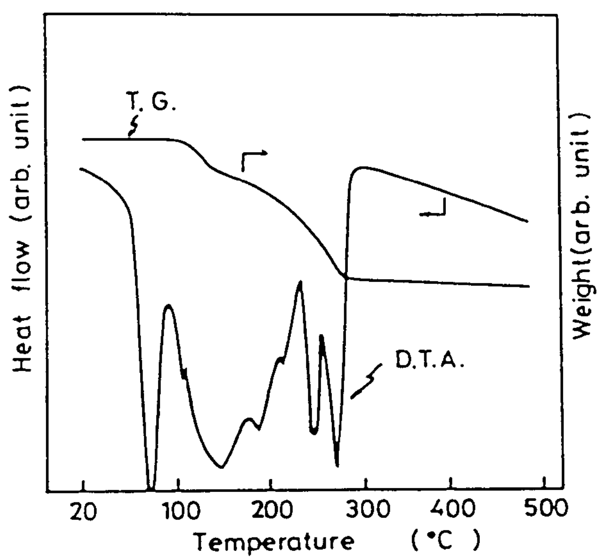


Fig.5 Thermogravimetry(T.G.) and differential thermal analysis (D.T.A.) curves of $Co(NO_3)_2 \cdot 6H_2O$.
(temperature increasing rate:10℃/min)

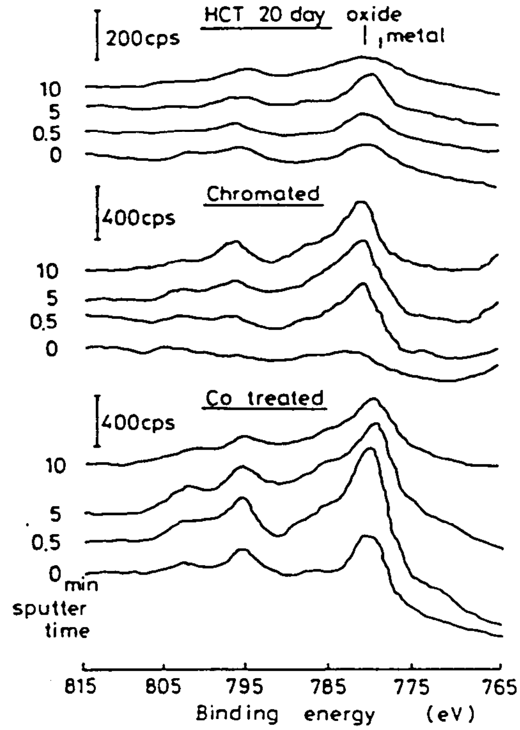


Fig.6 Co 2p ESCA spectra of Co treated coating surfaces.

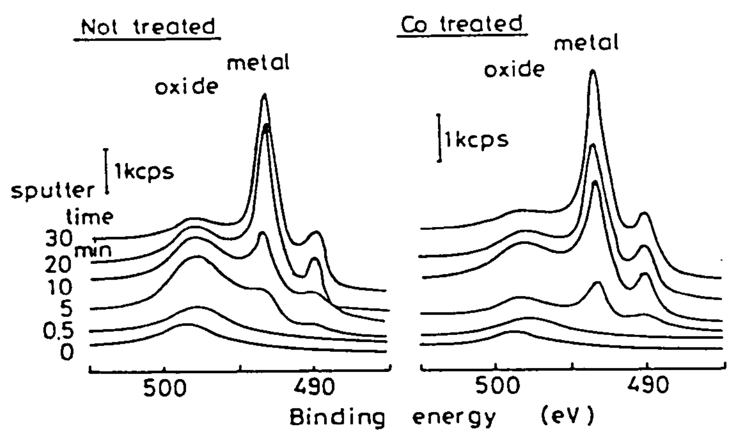


Fig.7 Zn LMM Auger spectra of the coating surface with and without Co treatment after 20 days of a humidity cabinet test.

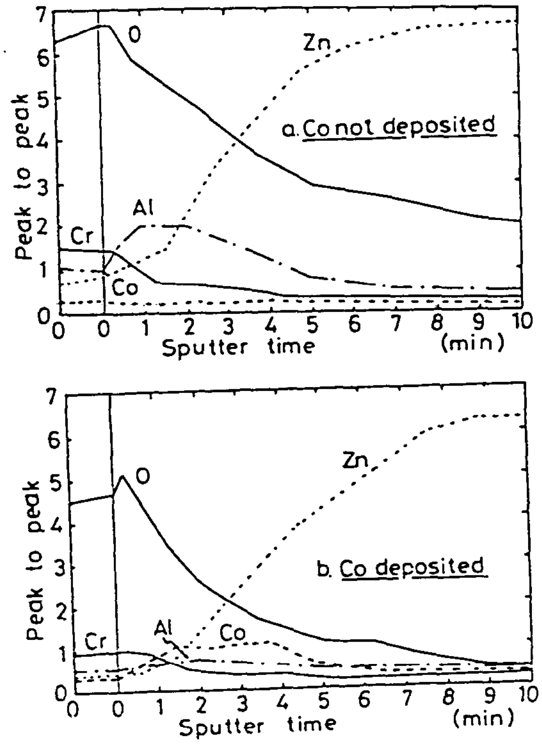


Fig.8 SAM depth profiles of the Co treated coating surface of a Al-rich phase after 20 days of a humidity cabinet test.
(sputter rate:200nm/min as Zn)

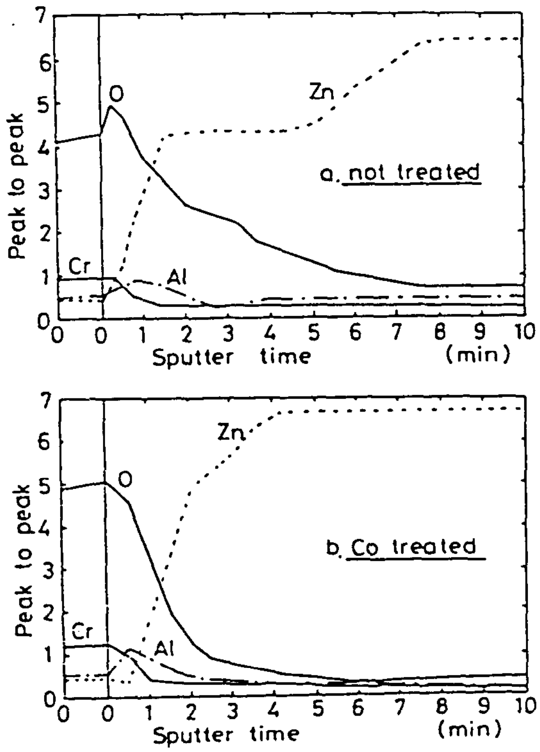


Fig.9 SAM depth profiles of the coating surface of β-Zn phase after 20 days of a humidity cabinet test. On Co treated specimen, measured area is where spotty dispersed deposition of Co oxide was not observed in SAM image.
(sputter rate:200nm/min as Zn)

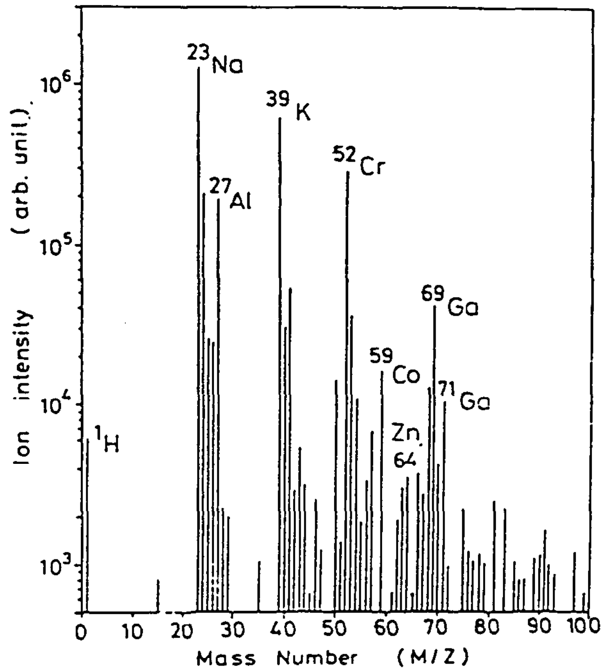


Fig.10 Mass spectrum obtained from the area on the Co treated surface where spotty dispersed deposition of Co oxide was not observed.

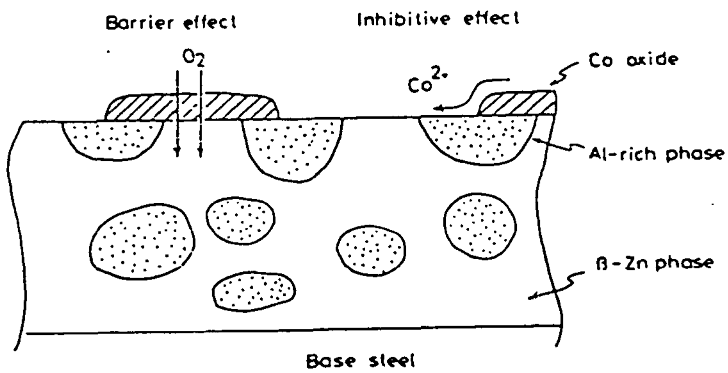
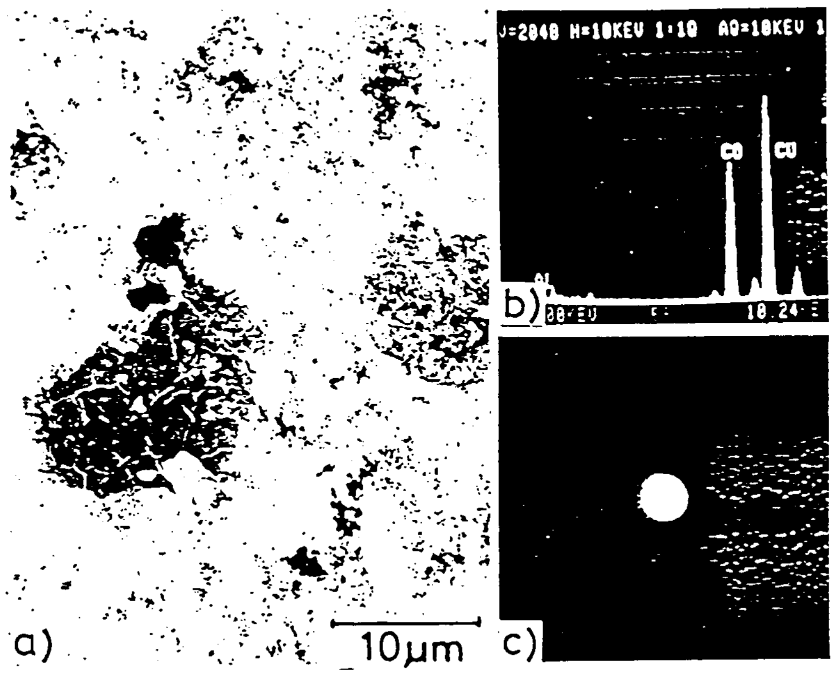
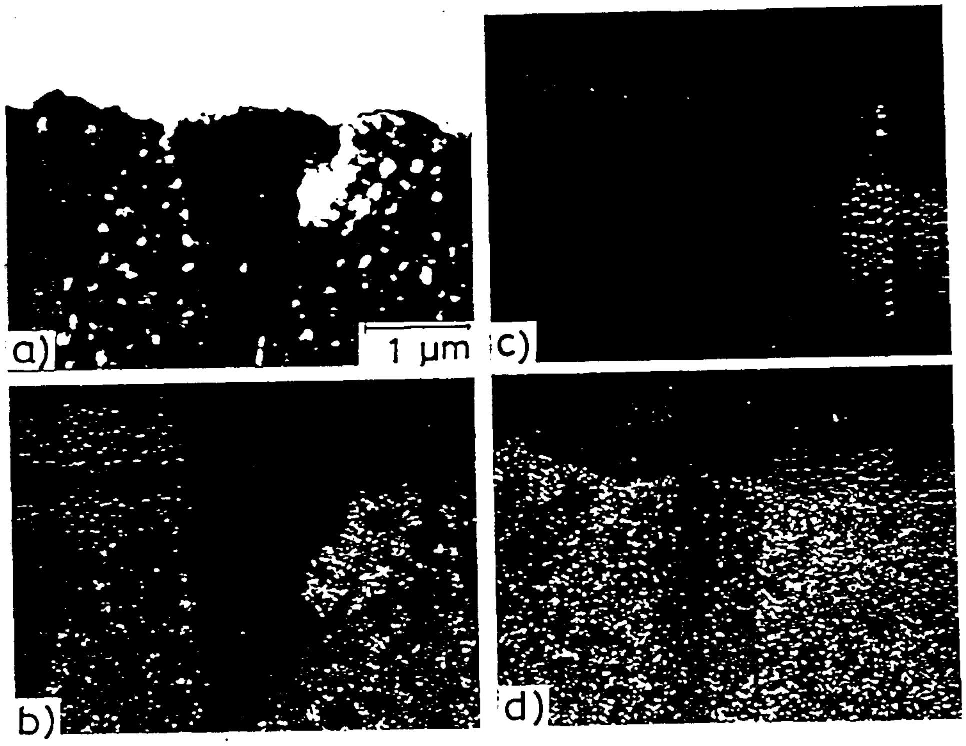


Fig.11 A schematic model explaining inhibition mechanism of the black patina development on a Zn-Al alloy coating by Co oxide.



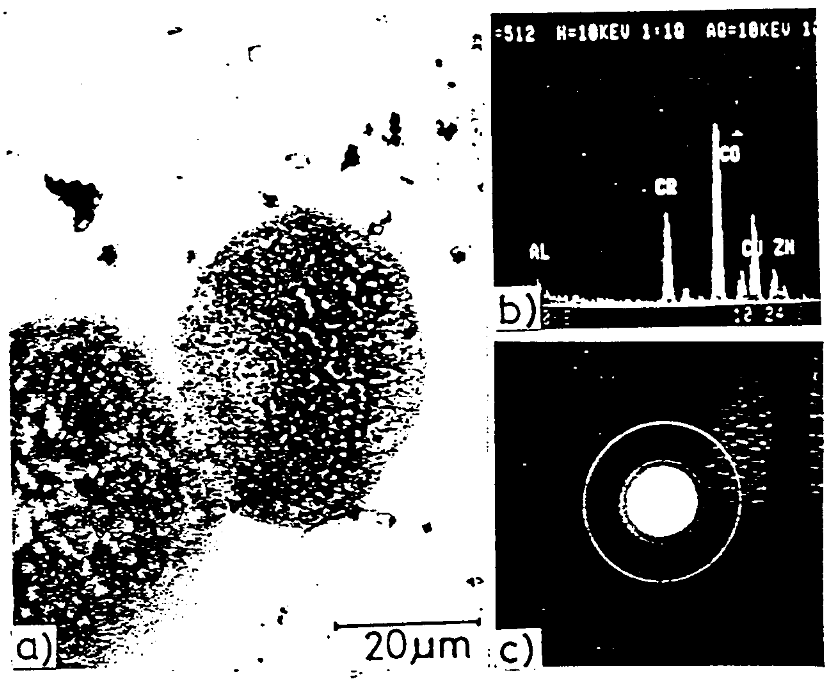
a) TEM image
b) EDX spectrum
c) HEED pattern

Photo.1 TEM image, EDX spectrum and HEED pattern of the deposited Co oxide.



a) TEM image
b) Al X ray image
c) Co X ray image
d) Zn X ray image

Photo.2 Cross-sectional TEM image and characteristic X ray images of Co treated coating surface.

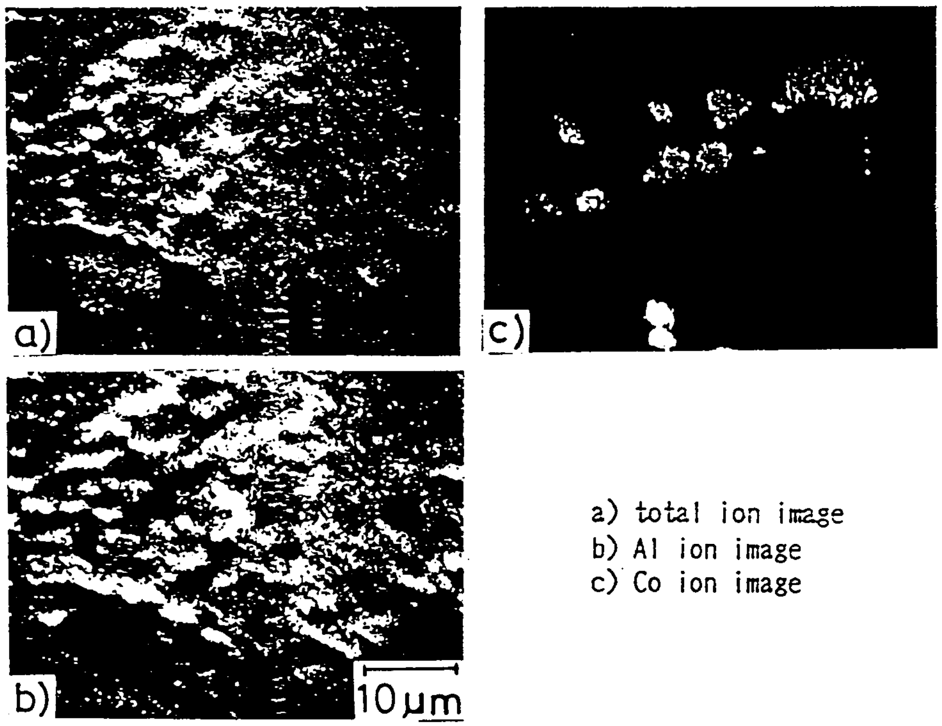


a) TEM image
b) EDX spectrum
c) HEED pattern

Photo.3 TEM image, EDX spectrum and HEED pattern of deposited Co oxide after chromate treatment.

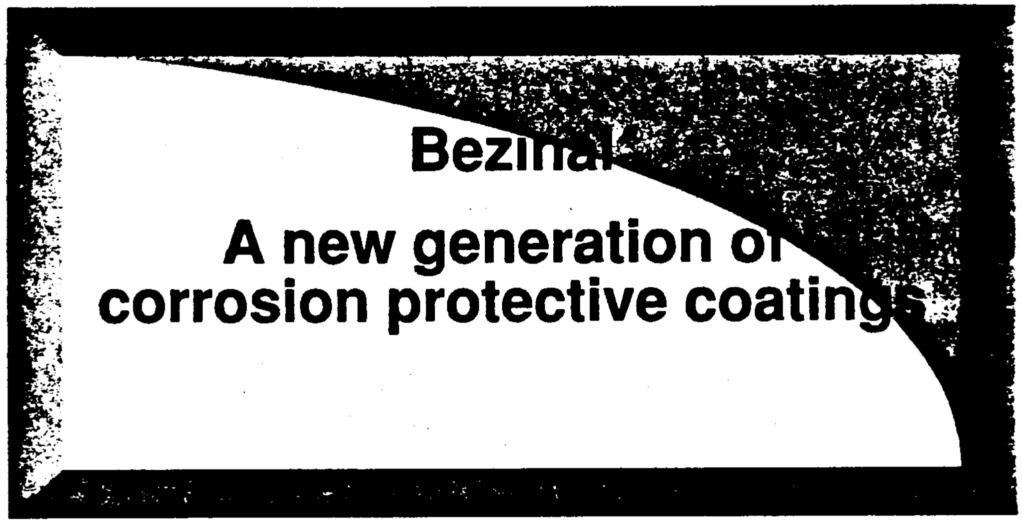
a) not treated
b) Co treated

Photo.4 Cross-sectional TEM images of the coating surface with and whithout Co treatment after 20 days of a humidity cabinet test. TEM images show the Al-rich phase of the coating.



a) total ion image
b) Al ion image
c) Co ion image

Photo.5 IMA ion images of the Co treated coating surface after 20 days of a humidity cabinet test.



M. Dewitte
Coating Technology Manager
N.V. Bekaert S.A., Belgium

J. Vanhoutte
Market Manager Mechanical Spring Wire
N.V. Bekaert S.A., Belgium

Introduction

The search for an efficient corrosion protection of steel is, - needless to say - a complicated one. Firstly there is the basic need to prevent the steel from corroding, preferably for extended periods of time. Secondly, one has to consider the specific conditions to which the coating-steel compound is subjected and which have a big impact on efficiency. Thirdly and not least important there is the question of economics. Fortunately for the scientists we have an extremely challenging world. Today, corrosion-protected steel components are never expected to corrode, even under the worst environmental and mechanical conditions and, should one wonder, nobody is willing to pay for it.

Galfan

In this constellation, it was undoubtedly to the credit of the ILZRO (International Lead-Zinc Research Organization) to focus research into more durable metallic coatings on the eutectic Zn-Al alloy. Two elements readily available in industry easily to be combined in an alloy.

In 1979, the CRM (Centre de Recherches Métallurgiques) started research, sponsored by IZLRO, on the eutectic 95 % Zn 5 % Al alloy which rapidly showed fantastic corrosion protection properties. This led researchers to the brand name GALFAN, which stands for "Galvanisation Fantastique".
This 95 % Zn/5 % Al alloy with La-Ce addition rapidly gained acceptance in industry due to its unique combination of formability and superior corrosion resistance.

BEZINAL

Bekaert, the world's largest independent steel wire producer, was amongst the first companies to take the Galfan licence and use it on an industrial scale. Extensive research and valuable experience gained on wire from large scale production have led to substantial improvements in the Galfan-coating process. On several products, one of which is spring wires, this coating process is now marketed under the brand name BEZINAL (**BE**kaert **ZIN**c **AL**uminium).

Laboratory testing of these BEZINAL products consistently proves that corrosion resistance is at least two to three times higher than that of conventional galvanized steel wire. These results have been gradually confirmed by production application and field tests.

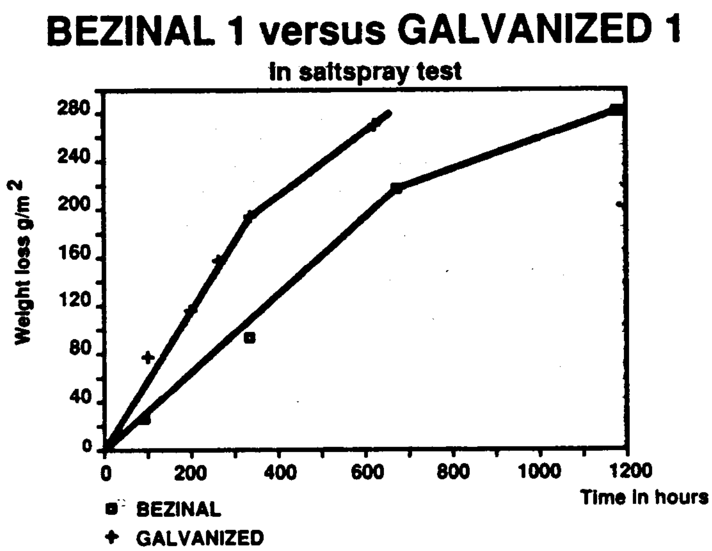


Fig. 1.a. ASTM B117 saltspray corrosion test for "as coated" wire

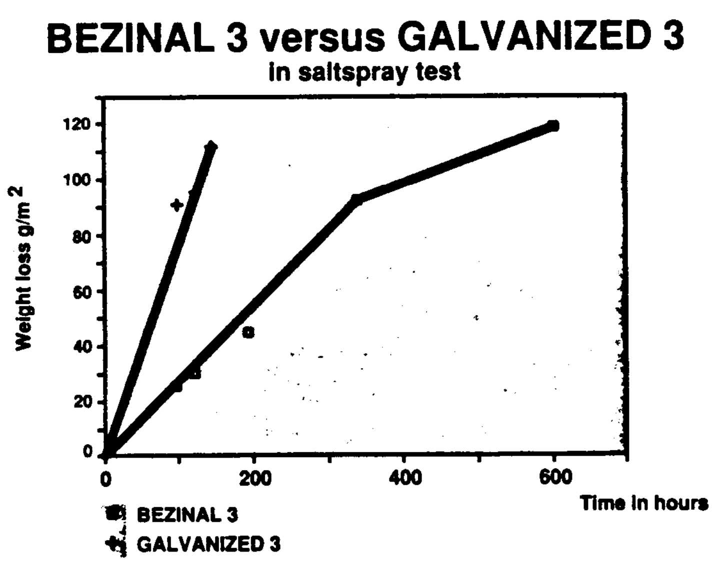


Fig. 1.b. ASTM B117 saltspray corrosion test for redrawn wire

Corrosion Testing

Both standard accelerated tests such as Salt Spray and SO_2 tests and tailor-made tests such as herbicide slurry and animal food slurry tests have been used for the evaluation of corrosion properties of BEZINAL products.

A brief comparison of corrosion results merits our attention. As Bekaert manufactures products for different applications, Salt Spray Testing data on "as coated" wires and on redrawn wires are available for BEZINAL-wire and for regular galvanized wires. For reasons of precision spring wires are always redrawn.

Table 1 gives the coating data on the sample wires used for corrosion testing. Lots 1 & 2 are "As coated". Lot 3 is redrawn from.

Sample	Ref.	Diam.(mm)	Coating weight (g/m^2)	Type
Bezinal 1	B1	1.95	323	as coated
Galvanized 1	G1	1.95	386	as coated
Bezinal 2	B2	3.60	300	as coated
Galvanized 2	G2	3.60	342	as coated
Bezinal 3	B3	1.39	124	redrawn
Galvanized 3	G3	1.39	148	redrawn

Table 1: Wire samples, coating data

Figure 1 shows ASTM B 117 Salt Spray testing results. These curves clearly show that the rate of coating loss is remarkably lower for BEZINAL than for regular Zinc. The time to initial red rust of BEZINAL is about 3 to 4 times that of corresponding galvanized wires (even with slightly heavier coating weight). The same goes for the K-value (time to initial red rusting divided by initial coating weight).

BEZINAL redrawn : K = 4,7 Galvanized redrawn K = 0,9. Moreover, the distinct form of the BEZINAL weight-loss curve clearly shows a decelerating process, whereas the slope of the "galvanized" curve remains virtually constant. From different experiments corrosion rates can be calculated in the initial and final stages of the corrosion process (gr/m^2 per 100 hrs).

The values in table 2 show that the initial corrosion rates for BEZINAL fall back to about 1/3 of their initial rates in as coated wires whereas as coated galvanized still continues at about 1/2 its initial rate.

gr/m² per hrs	**initial**	**final**
BEZINAL as coated	28	9
BEZINAL redrawn	28	10
Galvanized as coated	57	24
Galvanized redrawn	127	127

Table 2 : corrosion rates from weight loss experiments.

Redrawing apparently does no structural harm to the corrosion behaviour of BEZINAL wires, the relative corrosion rates are virtually the same as for "as coated wires". The same cannot be said of redrawn galvanized wire, which displays no fall-back in corrosion rate.

A further measure for corrosion protection, especially for galvanic protection, is the ability of the protecting metal to overcome local defects in the protecting coating (the remote zinc effect). One can evaluate this ability by measuring the coating residue on the steel at the moment during Salt Spray testing where 5 % surface red oxide is measured.

The figures in table 3 show that a BEZINAL coating works efficiently even with much less residual coating.
1 µm BEZINAL coating protects as efficiently as 6 µm of Zinc.

	original coating		**residual coating**
	intermetallic layer (µm)	**pure alloy layer (µm)**	**at 5% red oxide (µm)**
BEZINAL	2	20	1
Zinc	3	25	6

Table 3 : coating data before and after (5 % red rust) Salt Spray Testing.

A tentative explanation of this can be that the basic protection for BEZINAL coated steel wire is given by the bulk Al-Zn alloy. Once this is corroded, the intermetallic Fe-Al-Zn layer is revealed. This intermetallic layer, which acts more noble than Al-Zn, prevents penetrating and focuses corrosion further to the remaining Al-Zn ; causing this layer to be "consumed" to a greater extent before "offering" itself for corrosion.

Part of the explanation surely lies in the absence of a marked radial texture of the intermetallic crystals in the case of Bezinal coating. This phenomenon is very pronounced in the Fe-Zn layer formed between the pure surface Zn and the steel substrate of hot-dip galvanized wire. Here, the brittle radially-grown crystals easily form cracks through which electrolytes can penetrate to the bare steel ; this, in turn, leads to stress-corrosion or corrosion-fatigue failure.

Sulphur Dioxide Accelerated Tests

The extremely aggressive environment of the Kesternich test (SFW 2,0 S DIN 50018) allows only negligible differentiation in corrosion resistance between classic galvanized and BEZINAL coated wire. Therefore, a second series of tests was conducted using 1 litre of SO_2 instead of 2. Figure 2 shows the coating loss of BEZINAL and Zinc coating during SO_2 corrosion testing. The results clearly indicate a weight loss of BEZINAL only half of that of Zinc. This leads to the conclusion that, in more realistic SO_2 environments, BEZINAL coated wires will resist roughly twice as well as zinc coated wires. In these conditions (1 l SO_2) a passivation layer can indeed establish whereas this is impossible in the more severe Kesternich environment (2 l SO_2).

Other Corrosion Tests

For more specific applications such as vineyard wire and fox and mink netting, additional corrosion tests were conducted using slurries containing chemical substances such as herbicides or animal food. The purpose was to compare the coating resistance in the most appropriate environment. In these tests too, though less representative of the spring industry, BEZINAL scored far better than did the equivalent zinc coatings.

BEZINAL 1 versus GALVANIZED 1
in SO_2 - test (1 l SO_2)

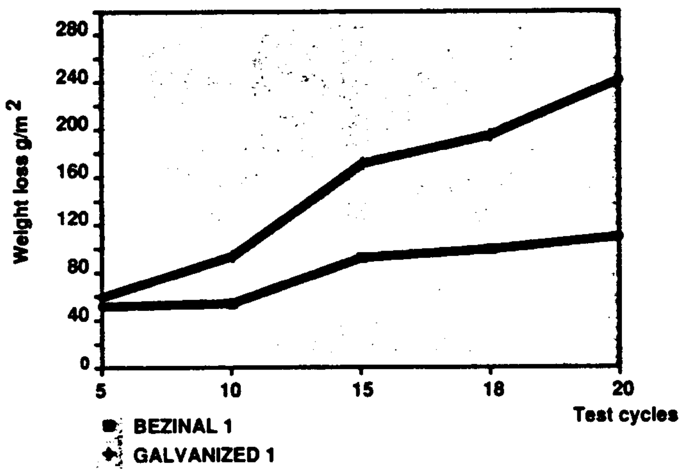


Fig. 2.a. SO_2-corrosion test on "as coated" wire

BEZINAL 3 versus GALVANISED 3
in SO_2 - test (1 l SO_2)

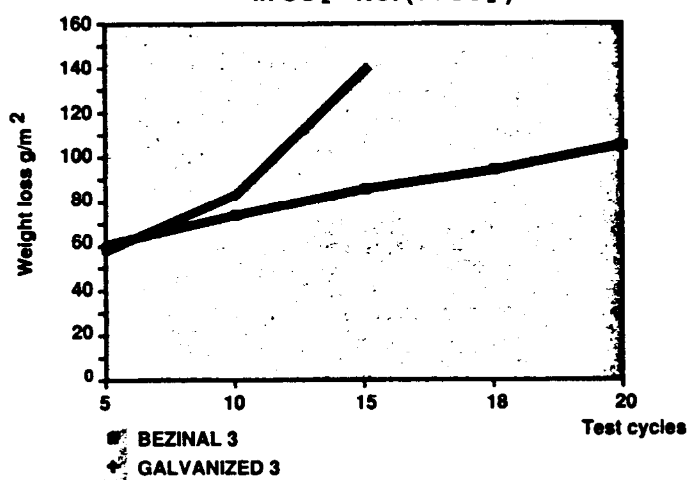


Fig. 2.b. SO_2-corrosion test on redrawn wire

Corrosion Mechanism

Bezinal's excellent anti-corrosion properties are clearly related to the effect of decelerating corrosion speed (figs. 1 and 2).

The weight loss curves of BEZINAL show remarkable comparison to those of pure zinc in the early stages of corrosion. Later in the process, Bezinal's weight loss clearly slows down indicating a passivation phenomenon, whereas pure zinc layers continue to lose weight at very much the same rate as during the early stage of the corrosion attack.

Passivation can be evidenced by Auger Spectroscopy of the BEZINAL surface after a period of corrosion (Fig. 3). Apparently, the original 5 % Al in the alloy is enriched in the surface layer. As if the zinc simply dissolves from the alloy leaving the aluminium behind and thus leaving a surface that gradually acts more like an aluminium surface. The real advantage of BEZINAL is, however, that this passivation readily takes place again when the Al-enriched surface is accidently severed. This reduces the risk of pitting from aluminium-rich alloys.

Al enrichement in the outer layers of a corroded Bezinal surface

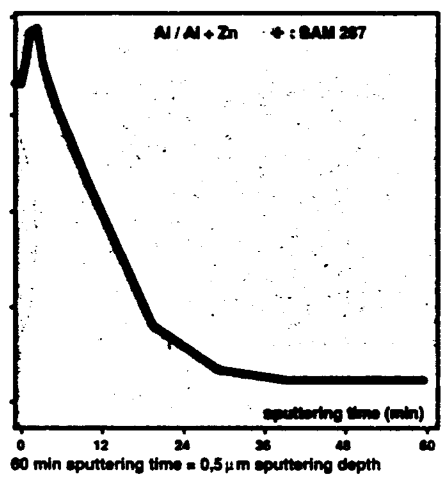


Fig. 3: Auger spectroscopy in-depth chemical analysis (Al %)

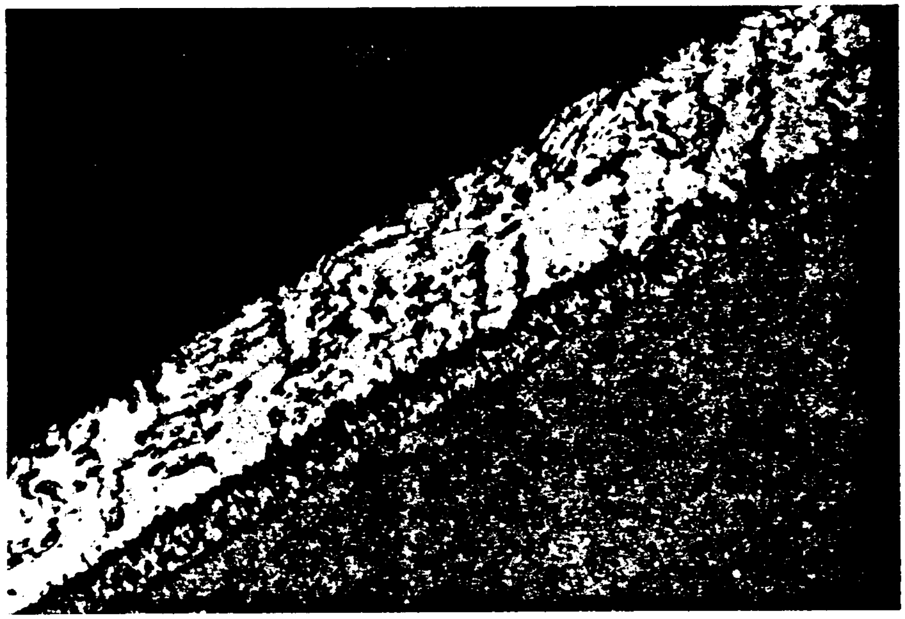


Fig. 4: Microstructure of hot-dip galvanized spring wire

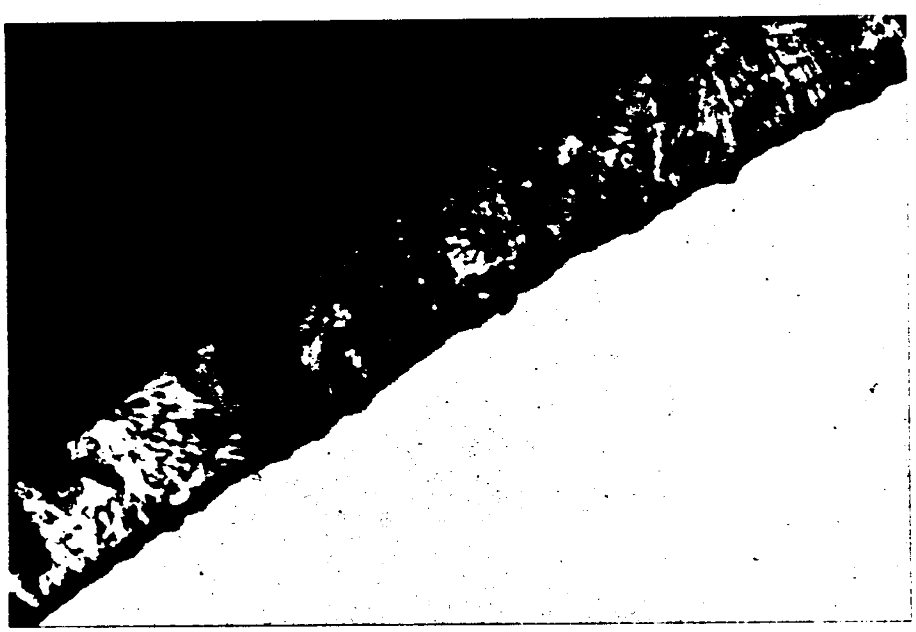


Fig. 5: Microstructure of hot-dip Bezinal-coated spring wire

Mechanical Properties

The superiority of BEZINAL is not limited to its corrosion behaviour, also its ability for plastic deformation is far better than conventional galvanized wire.

To understand the underlying mechanisms, one should refer to the marked differences between the microstructure of hot-dip Zinc coatings and that of hot-dip BEZINAL coatings. Figures 4 and 5 give photographs of both microstructures. The relatively thick layer of Fe-Zn intermetallic alloy between the outer Zinc layer and the steel substrate is easy to see. In the case of BEZINAL-coated steel wire one can see the same phenomenon, only, this time, the alloy-layer is much thinner and consists of an Fe-Al alloy with traces of Zn. The advantages of this phase versus the Fe-Zn phase are :

Fe-Al-(Zn) is far more ductile than Fe-Zn

BEZINAL and steel adhere far better to Fe-Al-(Zn) than does zinc to Fe-Zn (as clearly illustrated in wrapping tests).

The Fe-Al-(Zn) layer microstructure shows no coarse and, radially-oriented crystals such as the Fe-Zn, and will therefore not interfere with corrosion-fatigue performance.

Bezinal's advantages also include the intrinsically higher ductility of the fine eutectic structure.

These properties make BEZINAL-coated steel wire an interesting alternative especially in cases where the wire needs to withstand severe cold work. A good example is the production of flat windshield-wiper-arm wire where the coating is still intact even after most severe bending. Other examples also related to the car industry are light-bulb retainer springs, several types of door springs, brake springs and many others where the wire is heavily deformed during the spring coiling process.

Again due to their differing microstructure, BEZINAL-coatings tend to have better lubricity than conventional hot-dip Zinc. The relatively hard, even though more ductile, eutectic structure has an even, fine surface texture that accommodates lubricants. This further advantage of BEZINAL has consistently been proved in comparative friction tests.

Conclusion

It has been adequately proven that the eutectic Zn-Al alloy has substantial advantages over pure zinc as regards corrosion resistance and formability.

Superiority in all accelerated corrosion tests where BEZINAL offers an interesting combination of passivation and cathodic protection.

Superior formability thanks to higher bulk ductility and the beneficial properties of the intermetallic alloy, which prevents BEZINAL from chipping or flaking.

The superiority of BEZINAL corrosion resistance becomes even more pronounced as the coated product undergoes mechanical deformation, thus proving that the structural properties of the coating strongly contribute to its corrosion resistance after forming.

Bekaert, one of the first industrial users of the Galfan licence is convinced of the intrinsic qualities of this alloy.

Bekaert also believes that the advantages are the result of the rigorous control of many factors, such as chemical analysis, microstructural elements and processing technology.

BEZINAL is thus the result of many years of laboratory research and several thousand tonnes of manufacturing experience. All this is now embodied in precise manufacturing procedures and the most advanced coating equipment ever realized.

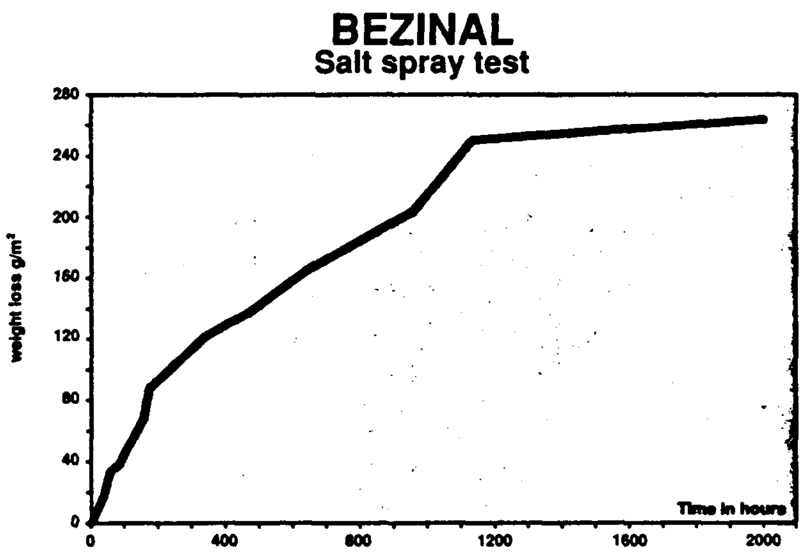


Fig. 6: Superior Bezinal protection in extreme conditions (2 000 hrs)

GALFAN GALVANIZING O.D. OF SMALL DIAMETER TUBING

by

John L. Hostetler, P.E.
Director, GALFAN Technical Resource Center
International Lead Zinc Research Organization, Inc.

For Presentation at

16th GALFAN Licensee Meeting
October 2-4, 1991
Pittsburgh, PA, U.S.A.

INTRODUCTION:

The use of GALFAN-coated tubing has grown rapidly in North America since 1989. GALFAN is a hot-dip galvanizing alloy containing 5% aluminum, 0.1% mischmetal, with the balance being zinc. The mischmetal is present in the form of naturally occurring mixtures of the lanthanum and cerium rare earth elements. GALFAN has been commercially marketed as an improved hot-dip galvanizing coating for steel strip and wire since 1981. There are now five tubing galvanizers in North America who are licensed by ILZRO to produce steel tube coated with GALFAN.

The demand for GALFAN-coated tubing has grown out of the desire to increase corrosion resistance on North American vehicles. Until now, the standard product used for such tube applications as brake lines, power steering lines, transmission cooling lines, and other similar applications has been a hot-dip terne (Pb <10% Sn) coating, however this coating shows relatively low corrosion resistance lasting only a few hundred hours in the ASTM B117 salt spray test before massive amounts of red rust appear. This product was improved by topcoating it with a zinc-rich paint which allowed approximately 400 hours before showing rust in the salt spray.

In addition to the problem of low corrosion resistance, the former product was insufficiently formable. Severe bends are necessary in many automotive tubing applications as well as in other applications such as refrigerant coils. In order to provide reliable protection, the coating must bend without cracking or compromising its protective capabilities.

In their search for improved protection, automakers evaluated several new alloy electro-deposited coatings for tube which held promise for increased corrosion protection. These were further improved to several thousand hours in salt spray by the addition of a layer of organic top coat over them, but these coatings are relatively expensive. In the last few years, the use of GALFAN-coated tubing with an aluminum-rich top coat has come to be the preferred choice in applications for tube when superior corrosion resistance is desired.

This paper will provide a general description of the continuous GALFAN tube coating technology for tubing in North American automotive applications. Chrysler, Ford, and General Motors have all published specifications for GALFAN-coated tubing.

GALFANIZED TUBING

The current standard for corrosion protection of the outside diameter of on automotive hydraulic lines, oil cooler lines, fuel lines, and brake line tubing is a duplex system consisting of:

(1) a hot dip Zn-5%-mm alloy (GALFAN®), and
(2) an aluminium-rich epoxy top coat.

A GALFAN coating provides an effective sacrificial coating to protect the steel tubing by cathodic action; the aluminium rich epoxy provides an excellent passive barrier which keeps the elements of corrosion away from the GALFAN coating. Whereas the old system (terne coat with zinc-rich top coat) provided 300-400 hours protection against red rust in a salt fog spray, the new system exceeds 3000 hours and often more than 4000 hours.

A GALFAN coating thickness of 5 microns (35 g/m^2 or.12 oz/ft^2) covered with an aluminium-rich epoxy such as Magni's PT9ZE is flo-coated and heat-cured to a thickness of about 10 microns on top of one of several common pretreatments used to passivate the GALFAN surface is sufficient to provide 3000 hour salt spray resistance and is applied by a simple hot dip application.

The coating section may be in-line with the tube mill or it may be a stand-alone line where the tubing is processed from coils or in cut-to-length pieces. Typically, fuel lines are done in coils; brake tubing, because it is generally brazed in 100 foot long furnaces, is done in cut-to-length sections.

The pre-coat processing steps are similar to the older terne coat lines but with more demanding cleaning, pickling, and fluxing standards.

GALFAN alloy is not highly reactive with iron, therefore the tube surface must be very clean. Oils from the cold rolling mill and from the tube mill and other smut must be completely removed or else the pickling will be moderated. Thus, hot caustic, high density or ultrasonic cleaning is recommended, followed by a high pressure water rinse prior to pickling.

The cleaned tubing is then pickled in warm hydrochloric acid, removing scale and oxides from the steel surface and again thoroughly rinsed with water so as not to contaminate the flux solution with acid or iron.

Fluxing the tubing to be coated with GALFAN is accomplished with a patented electroflux process.[1] In this process, an anode is placed inside the flux solution while the tubing to be plated/fluxed is connected in the circuit as a cathode. As the tubing passes through the zinc-containing flux solution, zinc ions from the flux are electrodeposited on the tubing. Thus, a very thin layer of zinc covers the tubing surface and, it in turn is covered with the flux, preventing any oxidation from taking place. One company, Mid-Western Processes, Inc. of Detroit, has designed a combined pickle-rinse-electroflux process in one piece of equipment using a bi-polar arrangement needing no contact rolls.

The flux solution should be circulated at a generous rate and passed through a filter efficient enough to remove iron and small foreign particulate matter. It should also be heated. It is important to remove all excess flux and to thoroughly dry the flux film left on the tube before it enters the coating bath. Zinc chlorides in the flux can react adversely with the aluminum in the GALFAN bath necessitating addition of inhibitors to the flux to prevent this reaction. Proprietary Zaclon and Dolphin Chemical fluxes both include such inhibitors.

The GALFAN bath is generally operated between 425° and 450°C (800°-850°F) in the area where the tubing is coated. Molten GALFAN alloy is much more reactive with normal bath hardware than terne or even conventional galvanizing alloy, therefore the pot holding the alloy should be ceramic or at the least, a chemical and heat resistant alloy such as 316ELC. The ideal arrangement utilizes a ceramic pot with immersion tube heaters such as those provided by Burns Energy Systems, Ltd.

Care must be exercised if the same pot has been used for another coating alloy so that the GALFAN is not contaminated with left-over elements such as lead, tin, antimony, cadmium, etc. The lead in the alloy should be limited to less than 50 ppm. All other trace elements should not exceed a combined total of 100 ppm. The alloy composition should be analyzed before every campaign to assure that the composition falls within the ASTM specifications.[2]

Unlike conventional hot dip galvanizing, GALFAN does not form a brittle binary Fe-Zn alloy layer at the interface. Instead, a relatively thin interface consisting of a ternery Fe-Zn-Al alloy is formed which is not brittle, thus GALFAN maintains its ductility and will not crack or fail even when severely formed or crimped.

Excess GALFAN is gas-wiped from the tubing after leaving the bath, to control the final desired thickness. The gas may be air, exothermic gas, or nitrogen, heated or at ambient temperature. Heated nitrogen produces the smoothest and most uniform coating and produces the thin coatings at lower pressures. Some GALFAN licensees have developed their own knife design, others have used designs by Decktec, Inc.

After the tubing passes through the coating knife, it should be cooled as rapidly as possible to achieve the maximum eutectic fraction in the microstructure. A cooling rate of about 30°C/sec from 400° to 300°C will form such microstructures containing small zinc-rich globules in a eutectic matrix which provide optimum surface characteristics, maximum corrosion resistance and maximum formability. The initial cooling should be done with air so as not to crater or disturb the molten coating; then followed with a water quench as soon as the coating is solidified.

The GALFAN surface should be conditioned to assure the best possible paint adhesion by mechanical abrasion or with chemical conversion such as chromating or phosphating. Several pre-treatments by Parker Am-Chem or Betz Chem are available for this conversion.

Magni Group's thermosetting epoxy with aluminium flake paint can then be flo-coated on the tubing and cured to produce an exceptionally corrosion resistant, severely formable tube. It is also able to provide other protection against stone chipping, physical abuse, thermal extremes, etc. It is easily prepared for fittings, connectors, swaging or collaring.

GALFAN coatings can be applied using line speeds from 100 to 600 feet per minute, the optimum being 150-300 fpm. It is compatible with existing and planned auto recycling systems and, with normal waste water treatment facilities, the process is environmentally friendly.

Each step of the GALFAN tube coating process includes several variables which should be statistically monitored and controlled. A fully packaged SPC system including all hardware, Major Micro software, and customization for the line shown in Fig. 1 is available from Decktec, Inc.

REFERENCES:

1. ILZRO U.S. Patent No.4,448,748
2. ASTM Specification No. B-750-85.

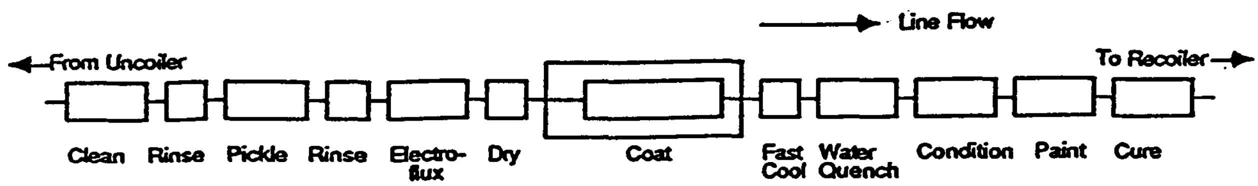


Figure 1 - Diagram of Line Layout

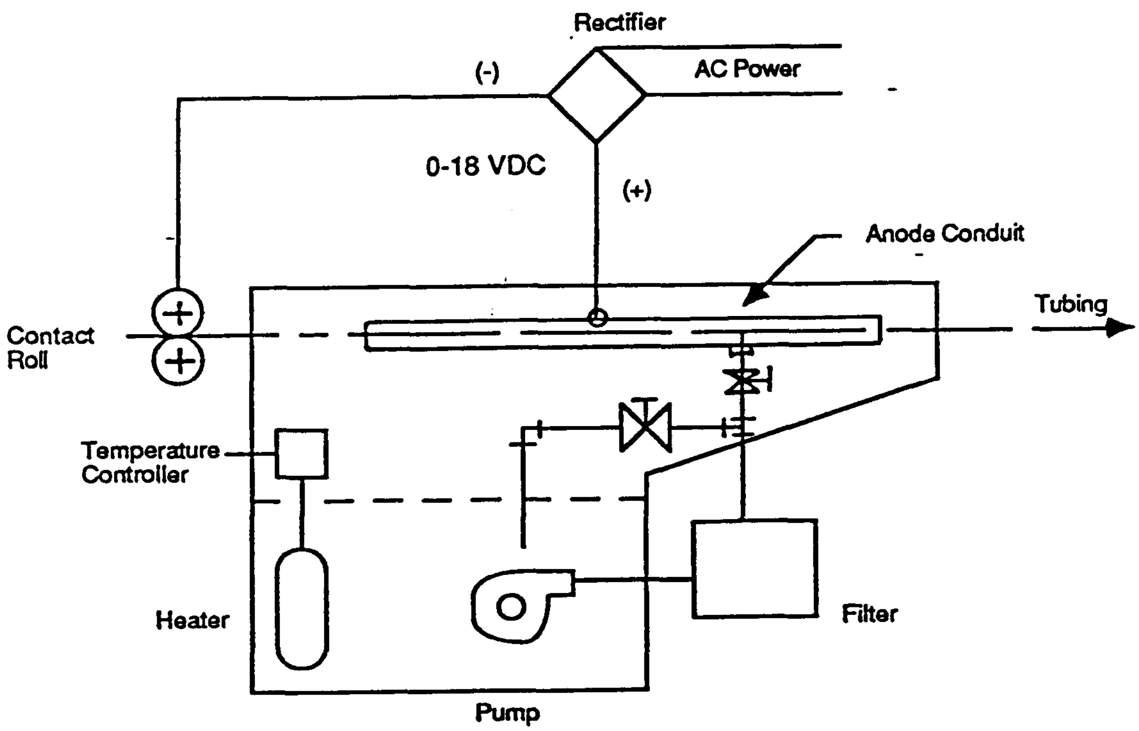


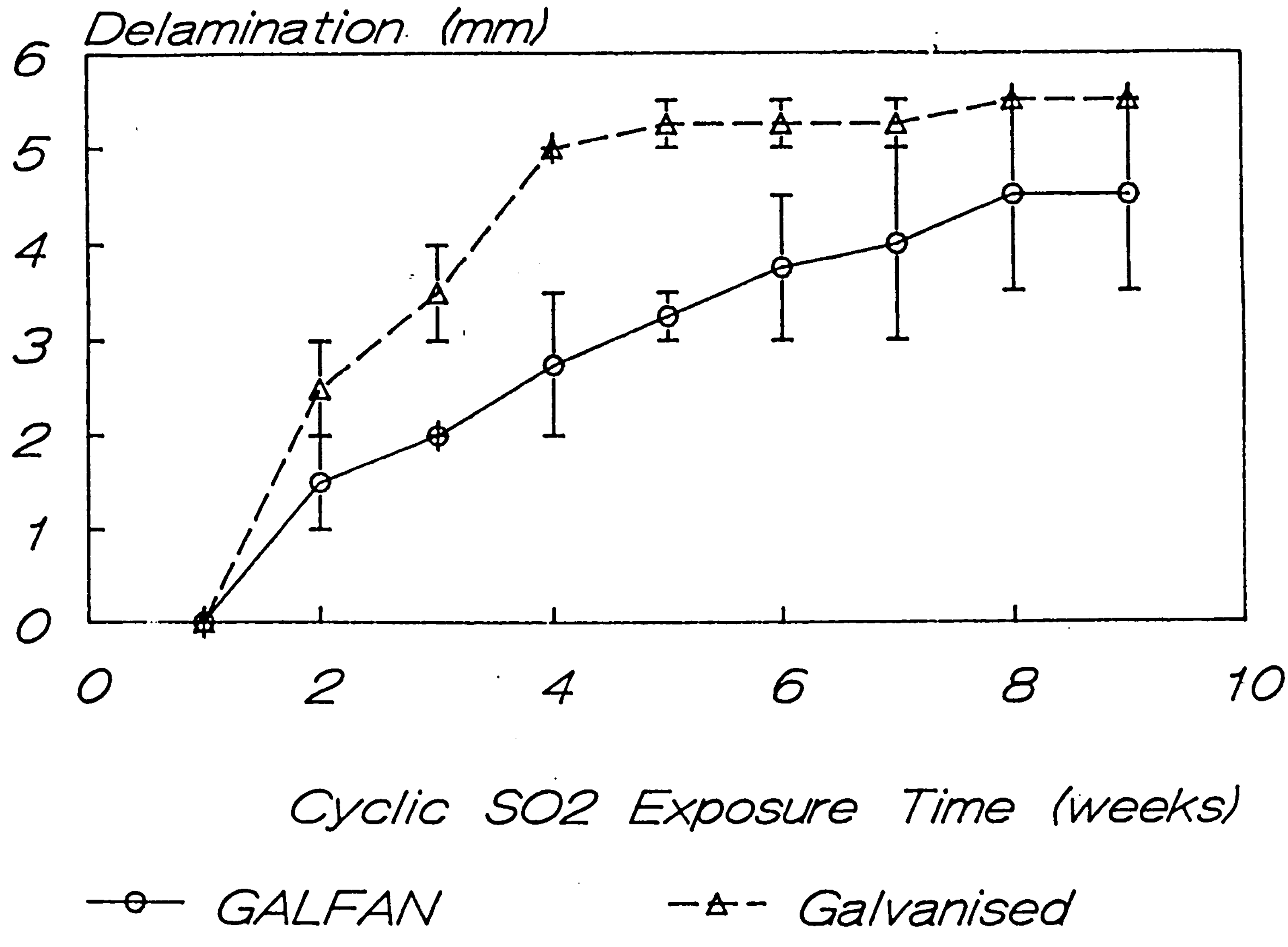
Figure 2 - Schematic of Electroflux System

Coil Coated GALFAN

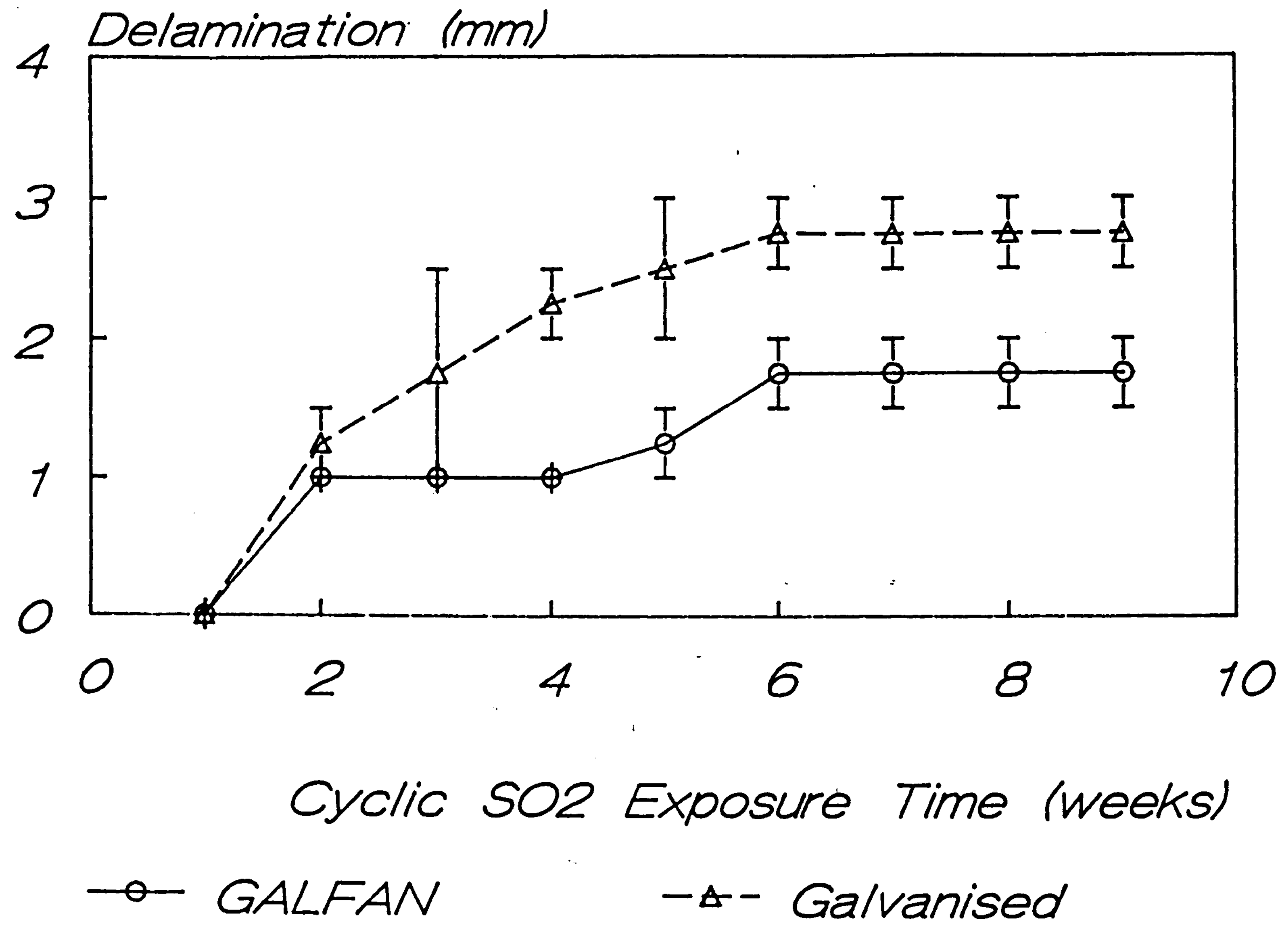
Advantages

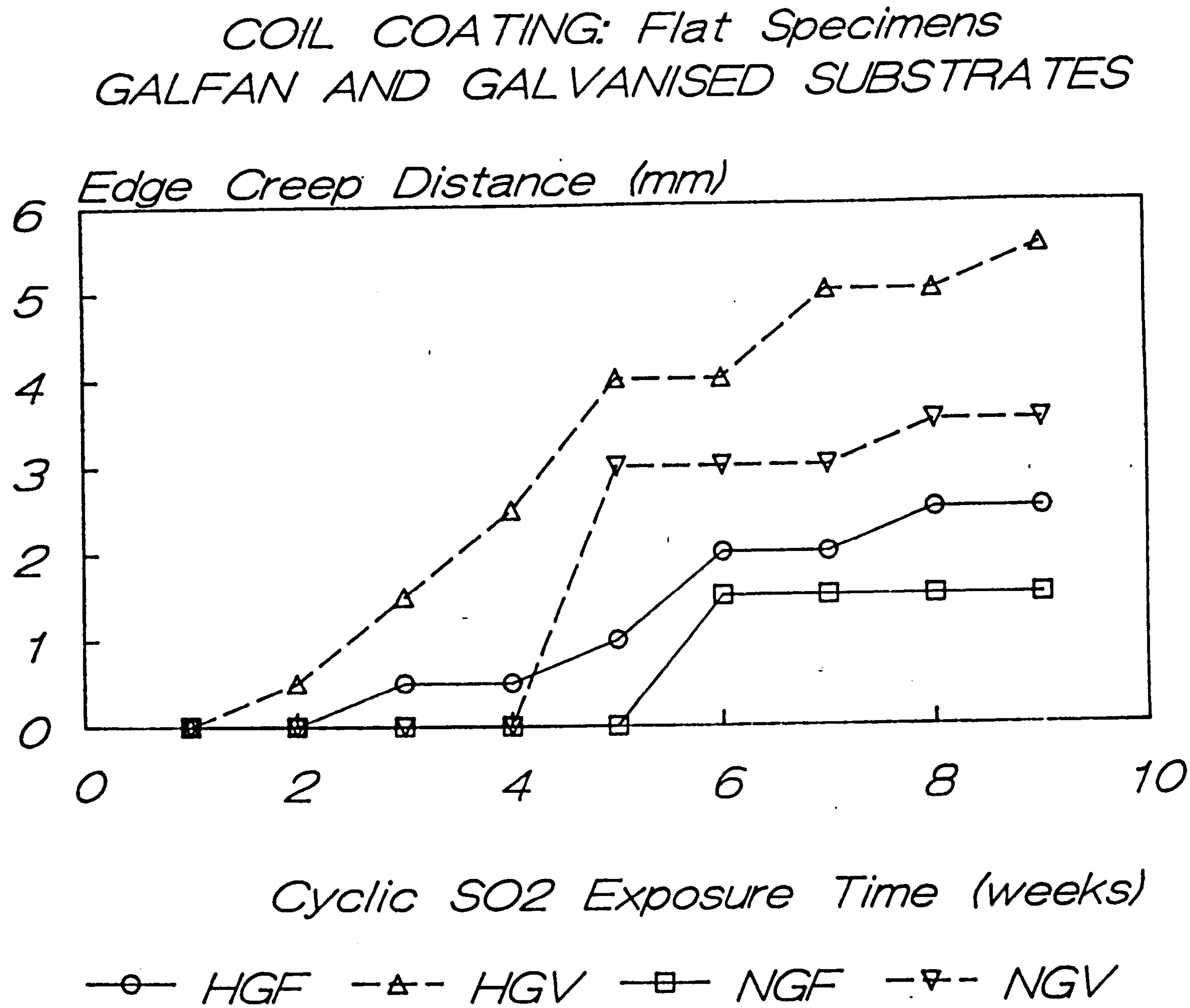
- Compatibility with pretreatments and paints commonly used with conventional galvanizing.
- Lower coating corrosion rate, allowing use of lighter coating weights to maintain acceptable life.
- Good passivation characteristics, slowing paint delamination.
- Excellent formability - a fine, dense network of cracks upon severe bending.

COIL COATING: 1mm Wide Scratch to Steel
GALFAN AND GALVANISED SUBSTRATES



COIL COATING: Cross-Scratched Specimens
GALFAN AND GALVANISED SUBSTRATES



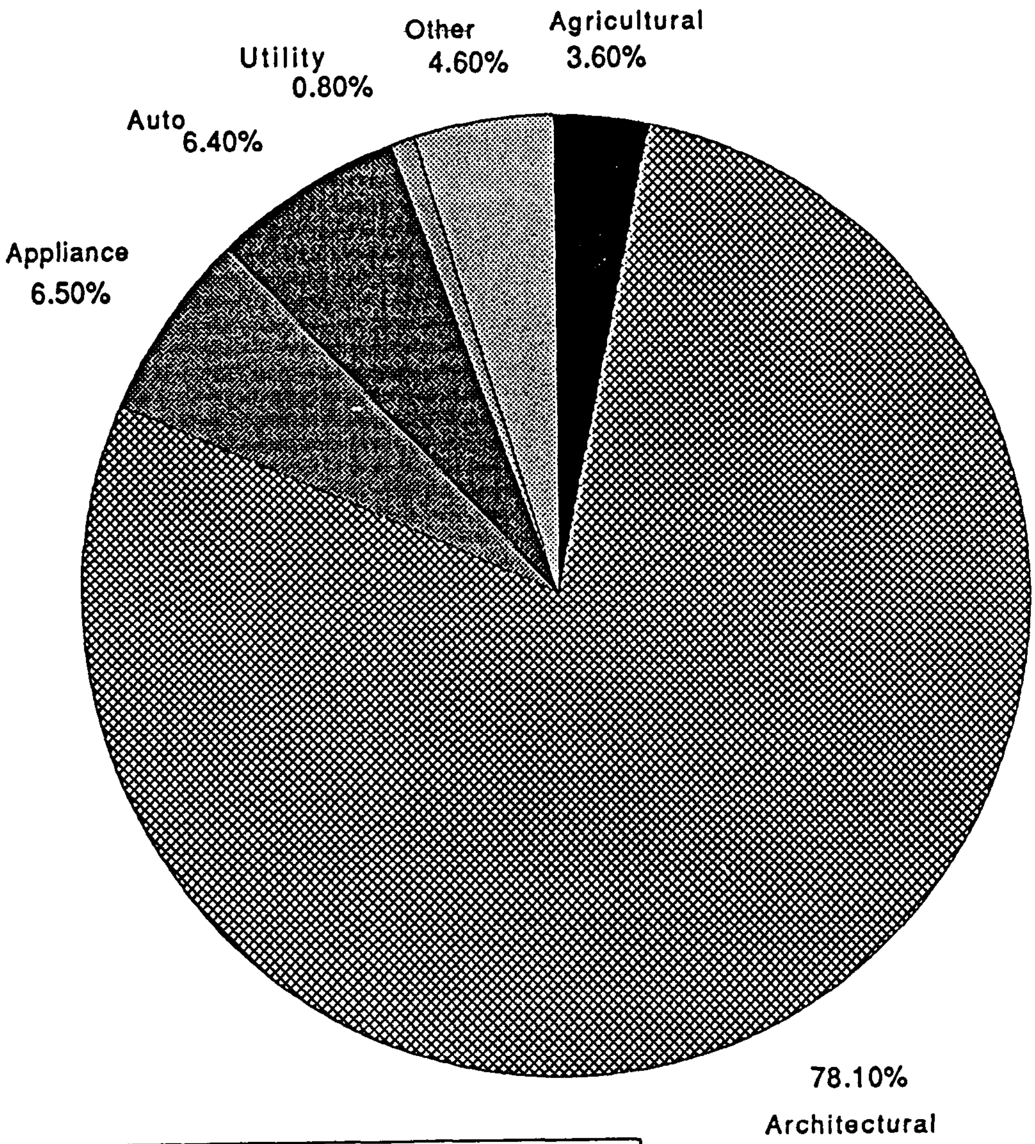


COIL COATING: Flat Specimens
GALFAN AND GALVANISED SUBSTRATES
Edge Creep Distance (mm)
0
1
2
3
4
5
6
0
2
4
6
8
10
Cyclic SO2 Exposure Time (weeks)
HGF
HGV
NGF
NGV

Realized projects :

- Dish-washers
  - improved detergent resistance : ZA better than Z, ZE
  - aesthetic appearance : structured paint systems
- Freezers/Refrigerators
  - bend diameters $\geq$ 1 T without cracks : achieved by reduced coating masses (ZA 50)

Figure 6	Prepainted GALFAN for Domestic Appliances	HOESCH



1991 GALFAN PRODUCT APPLICATIONS

a)

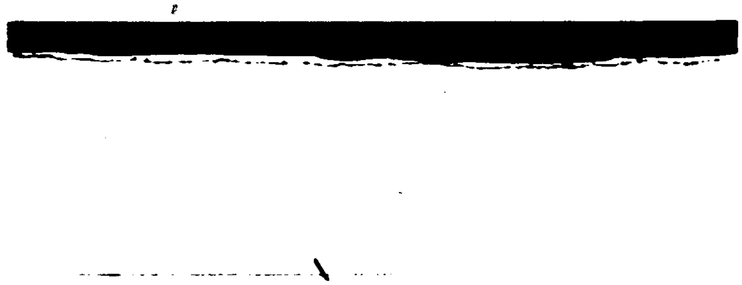
20:1

b)

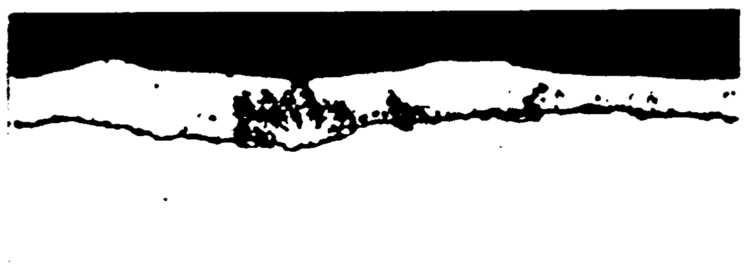
20:1

Figure 1	surface condition of the weld a) Galfan- sheet b) hot dipped galvanized sheet	THYSSEN

a)

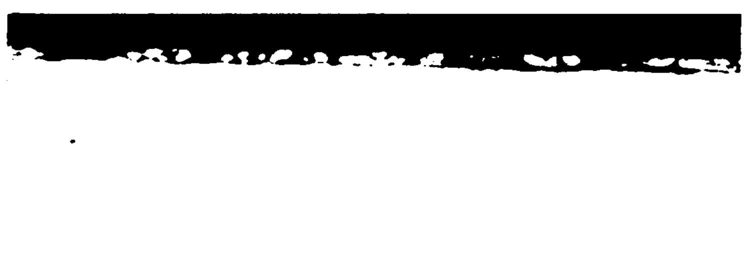


etched (0.5% HN03) 200:1

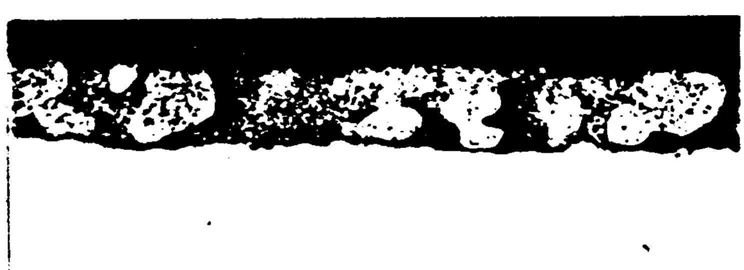


etched (0.5% HNO3) 1000:1

b)

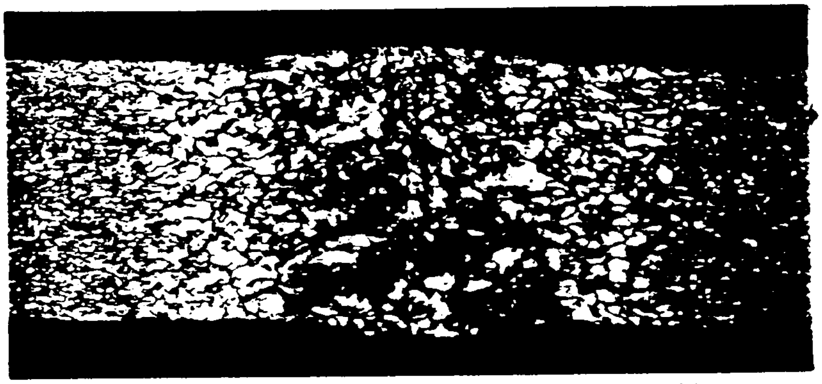


etched (0.5 % HNO3) 200:1



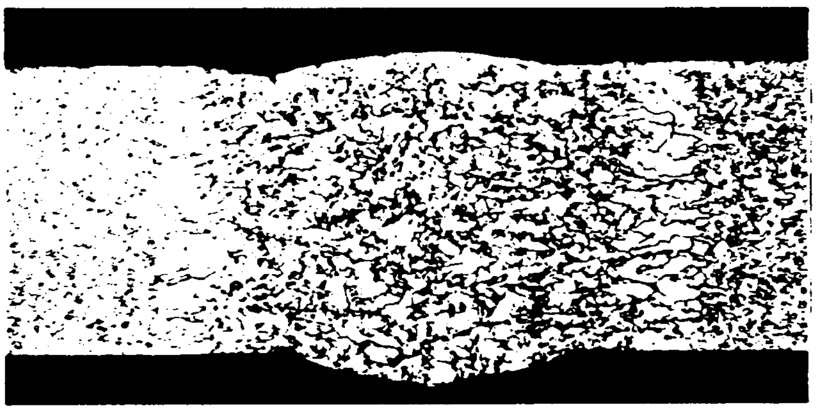
etched (0.5% HNO3) 1000:1

Figure 2	microstructure of the coating a) Galfan- sheet b) hot dipped galvanized sheet	THYSSEN



a)

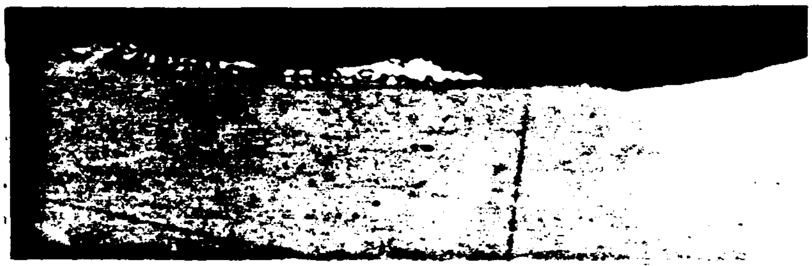
etched (0.5% HNO_3) 50:1



b)

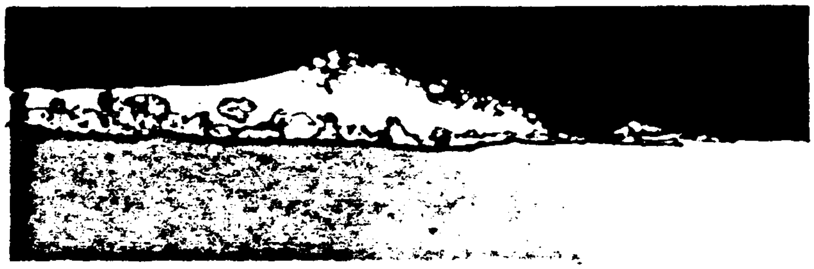
etched (0.5% HNO_3) 50:1

Figure 3	cross-section of the weld a) Galfan- sheet b) hot dipped galvanized sheet	THYSSEN

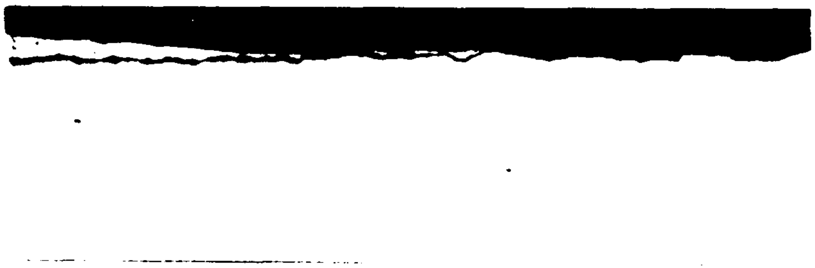


a)

etched (0.5% HNO_3) 200:1

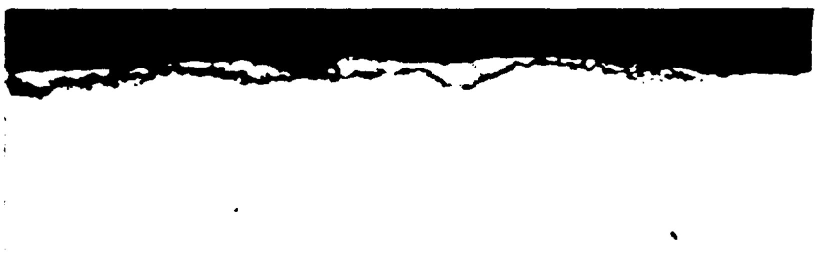


etched (0.5% HNO_3) 500:1



b)

etched (0.5 % HNO_3) 200:1



etched (0.5% HNO_3) 500:1

Figure 4	microstructure of coating (HAZ) a) Galfan- sheet b) hot dipped galvanized sheet	THYSSEN

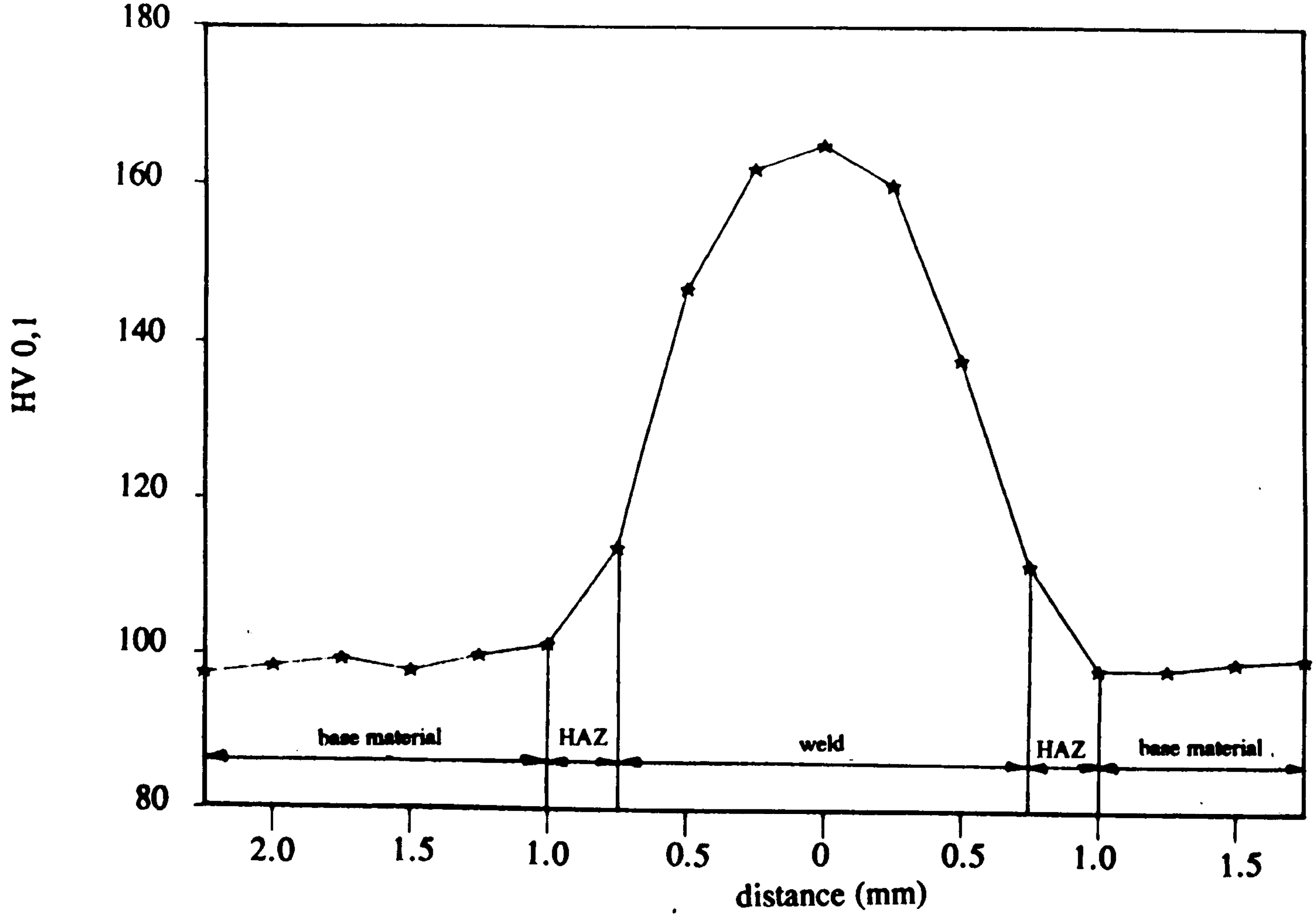


Figure 5	microhardness of the welded Galfan-sheet	THYSSEN

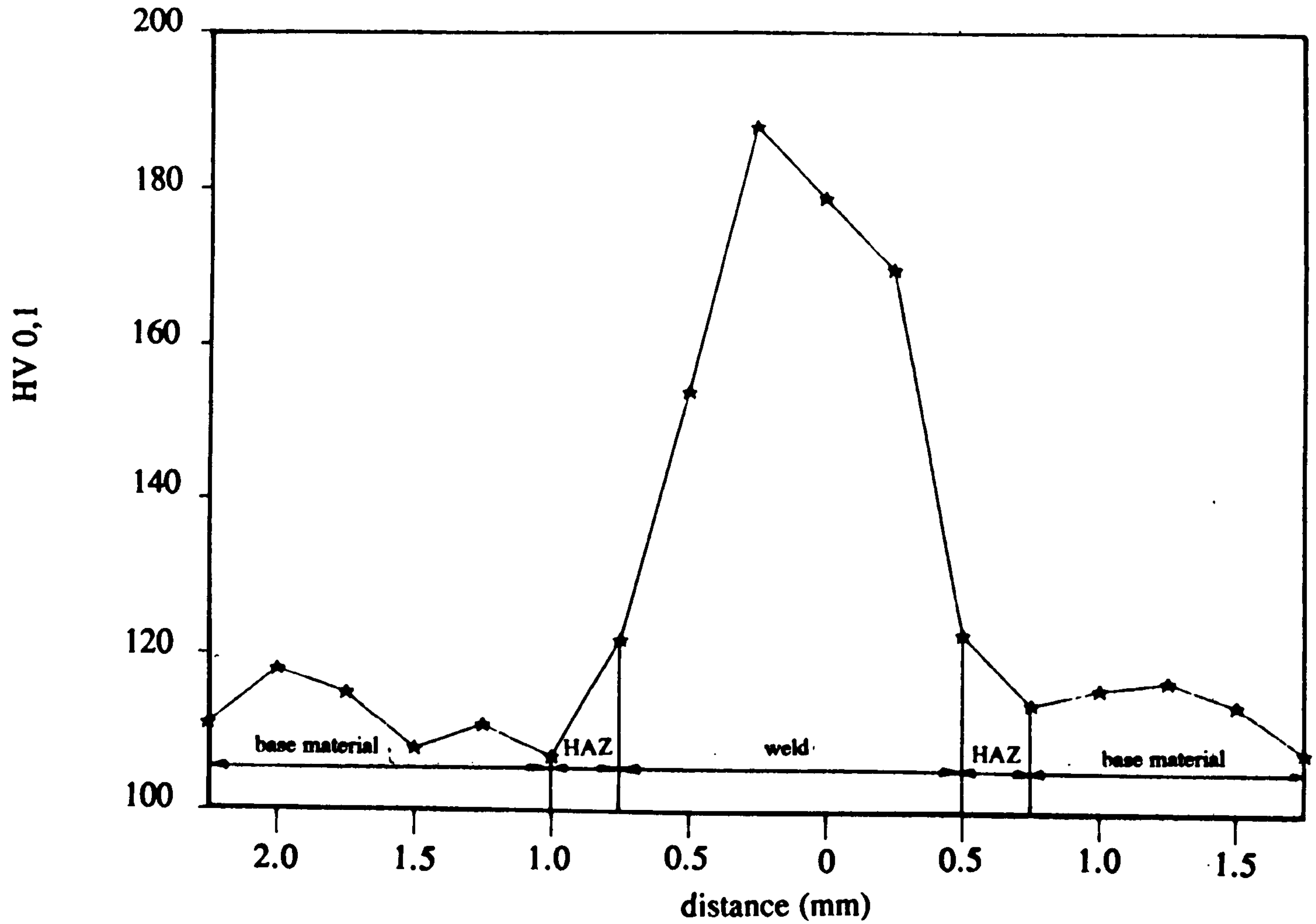


Figure 6	microhardness of the welded hot dipped galvanized sheet	THYSSEN

	Galfan	HDG
Steel thickness [mm]	0,75	0,77
Coating mass [g/m²]	160	140
Laser capacity [KW]	5,1	5,1
Welding speed [m/min]	4,6	5,2
Argon consumption [l/min]	25	25

Figure 7

Laser-welding parameters

THYSSEN

ASTM Specifications for Galfan Sheet Products

B750-88	Zinc-5% Aluminum-Mischmetal Alloy (UNS Z38510) in Ingot Form for Hot-Dip Coatings
A875/ A875M-88	Steel Sheet, Zinc-5% Aluminum Alloy Metallic-Coated by the Hot-Dip Process
A755/ A755M-89	Steel Sheet, Metallic Coated by the Hot-Dip Process and Prepainted by the Coil-Coating Process for Exterior Exposed Building Products *Substrate supplied to Specification A 875/A 875M is an acceptable material.*
F1234-90a	Standard Specification for Protective Coatings on Steel Framework for Fences *Substrate supplied to Specification A 875/A 875M is an acceptable material.*

Revisions and New ASTM Specifications for Galfan Sheet Products

1. A742/A742M-86 Specification for Steel Sheet, Metallic Coated and Polymer Precoated for Corrugated Steel Pipe

   STATUS: Concurrently on A05 Main Committee and A05.11 Subcommittee ballots to include Zinc-5% Aluminum-Mischmetal Alloy-Coated Steel Sheets as an acceptable material for this specification.

2. A762/A762-86 Specification for Corrugated Steel Pipe, Polymer Precoated for Sewer and Drain

   STATUS: Concurrently on A05 Main Committee and A05.11 Subcommittee ballots to include Zinc-5% Aluminum-Mischmetal Alloy-Coated Steel Sheets as an acceptable material for this specification.

3. A760/A760M-91 Specification for Corrugated Steel Pipe, Metallic coated for Sewers and Drains

   STATUS: Concurrently on A05 Main Committee and A05.17 Subcommittee ballots to include Zinc-5% Aluminum-Mischmetal Alloy-Coated Steel Sheets as an acceptable material for this specification.

4. A849-90 Post-Applied Coatings, Pavings, and Linings for Corrugated Steel Sewer and Drain Pipe

   STATUS: Revisions have been proposed in ASTM Subcommittee A05.17 to include Zn-5% Al-MM as an acceptable material for this specification:

5. New Standard Specification for Steel Sheet, Zinc-5% Aluminum-Mischmetal Alloy-Coated by the Hot-Dip Process for Storm Sewer and Drainage Pipe

   STATUS: Currently on A05 Main Committee ballot

ASTM WIRE SPECIFICATIONS

A817 - Metallic-Coated steel wire for chain-link fence fabric

A855 - Zinc-5% Aluminum-Mischmetal Alloy-Coated steel wire strand

A856 - Zinc-5% Aluminum-Mischmetal Alloy-Coated carbon steel wire

B802 - Zinc-5% Aluminum-Mischmetal Alloy-Coated steel core wire for Aluminum Conductors, steel reinforced (ACSR)

B803 - High-Strength Zinc-5% Aluminum-Mischmetal Alloy -Coated steel core wire for Aluminum and Aluminum-Alloy Conductors, steel reinforced

F1345 - Zinc-5% Aluminum-Mischmetal Alloy-Coated steel chain-link fence fabric

APPLICATIONS

Agriculture - vineyard support wire

Fencing - chain-link fencing and stock fencing

Ropes - fishing ropes and lifting ropes in high-corrosive environments

Strands - mast stays, guy strand, messenger strand, and as ACSR core strands

Automotive - springs, armor wire, and cable controls

Constructions - gabions, wire mesh

Klotzki
Thyssen Stahl AG

October 1, 1991

THYSSEN

Standardization of Galfan, ECISS/TC27

1. EN number 10214 has been allocated.

2. The lay out of EN 10214 will be aligned with that of EN 10215 concerning AZ (Galvalume).

3.1 Considered Grades, low carbon for cold forming

Steel Grades	R_e N/mm², max.	R_m N/mm², max.	A_{80} %, min.
Fe P02 ZA	--	500	20
Fe P03 ZA	320	420	24
Fe P04 ZA	280	380	30
Fe P05 ZA	240	350	36

3.2 Considered Grades, structural steels

Steel Grades	R_e N/mm², min.	R_m N/mm², min.	A_{80} %, min.
Fe E 250 ZA	250	330	19
Fe E 280 ZA	280	360	18
Fe E 320 ZA	320	390	17
Fe E 350 ZA	350	420	16
Fe E 550 ZA	550	560	--

4. Considered coating weights

Coating Designation	TST g/m²	SST g/m²
95	95	80
130	130	110
185	185	155
(200)*	200	170
255	255	215
(300)*	300	255

* special request by the French delegation

5. All other characteristics will be aligned with those of EN 10215.

GALFAN GROWTH STATISTICS

The use of GALFAN galvanizing in Europe and Japan has grown about 50% per year from 1984 (when the world's total was 25,000 tons) through 1990 (which was 296,270 tons). 1991 will end with about 410,000 tons for a grand total of 1,280,000 tons in the ten years since GALFAN was introduced in 1981.

Licensees' forecasts for GALFAN's growth through 1995 is a rate of about 25% per year, for a total of 950,000 tons in 1995; a cumulative total of 4,511,000 tons.

In 1991, 61% of the GALFAN was produced in Japan, 35% in Europe and 4% in North America. Forecasts show that in 1995 42% will be produced in Europe; 31% in Japan; 22% in North America and 5% in other parts of the world. Although its growth is worldwide, the forecasts show GALFAN will grow faster in North America and Europe.

More than 75% of GALFAN coated steel is used in architectural or construction applications, about half of it being pre-painted coil. Appliance applications and automotive accounted for 6.5% each with agricultural at 3.5%; utilities and other applications used the rest.

All market segments are expected to grow but automotive and painted appliance applications are expected to grow faster than the average. The North American automotive tubing market is expected to reach 65,000 tons/year by 1995. Fuel lines is the largest application of GALFAN automotive tubing active today but with Markin Tubing's recent entry as a GALFAN Licensee, refrigeration tubing will likely become a significant user market.

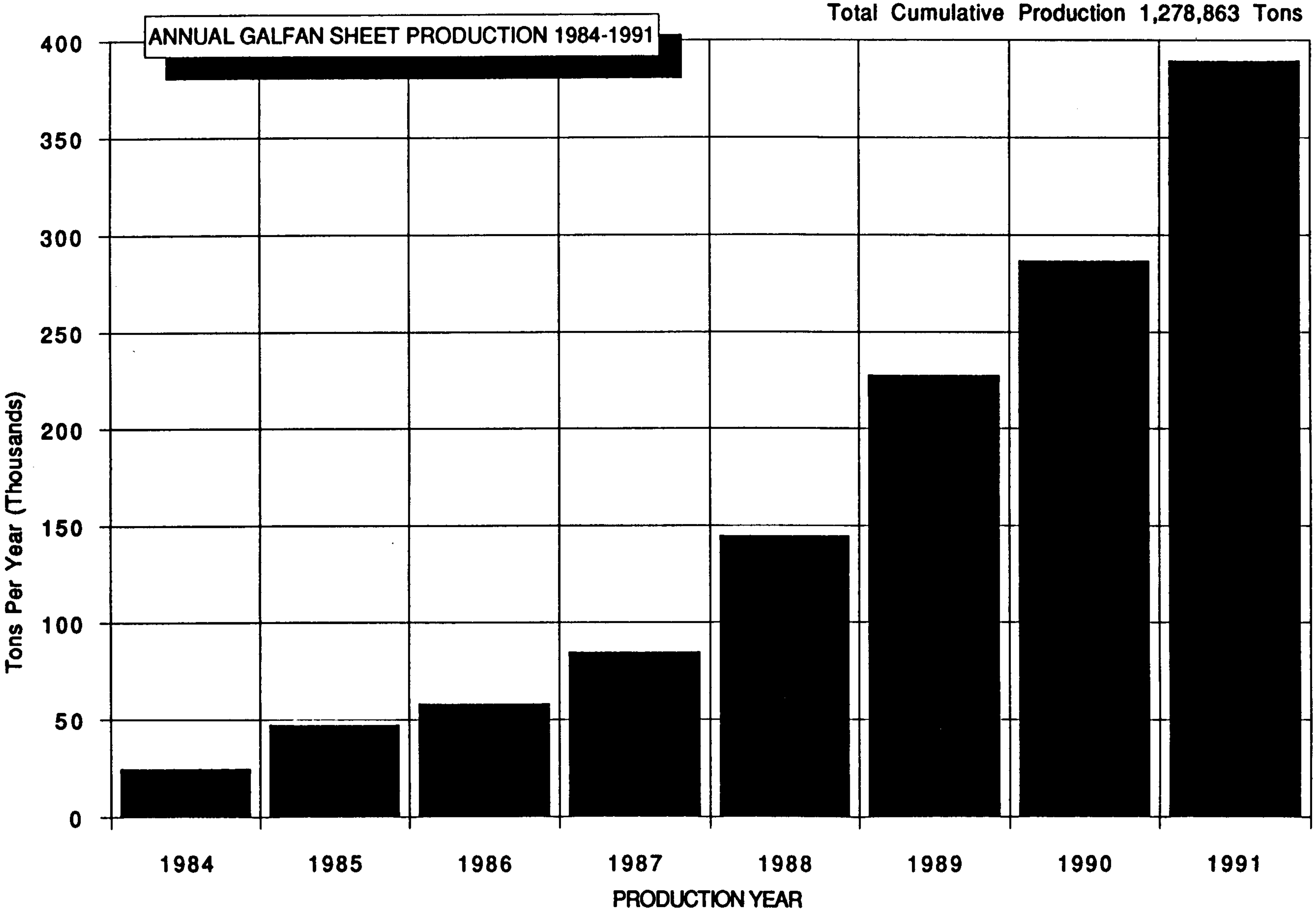
New coating technologies now under investigation by ILZRO's GALFAN Technical Resource Center will make it possible to coat larger diameter tubing with GALFAN for electrical thin wall tubing, furniture, fence posts, etc.

GALFAN wire will also grow rapidly as it finds more acceptance particularly in applications where its longer life saves expensive replacement. Some such applications include vineyard wire, high communication tower guy ropes, off shore oil drilling rigs, lobster traps, etc.

Indiana Steel and Wire has improved their GALFAN facility so they can produce larger quantities and a greater variety of wire grades and sizes.

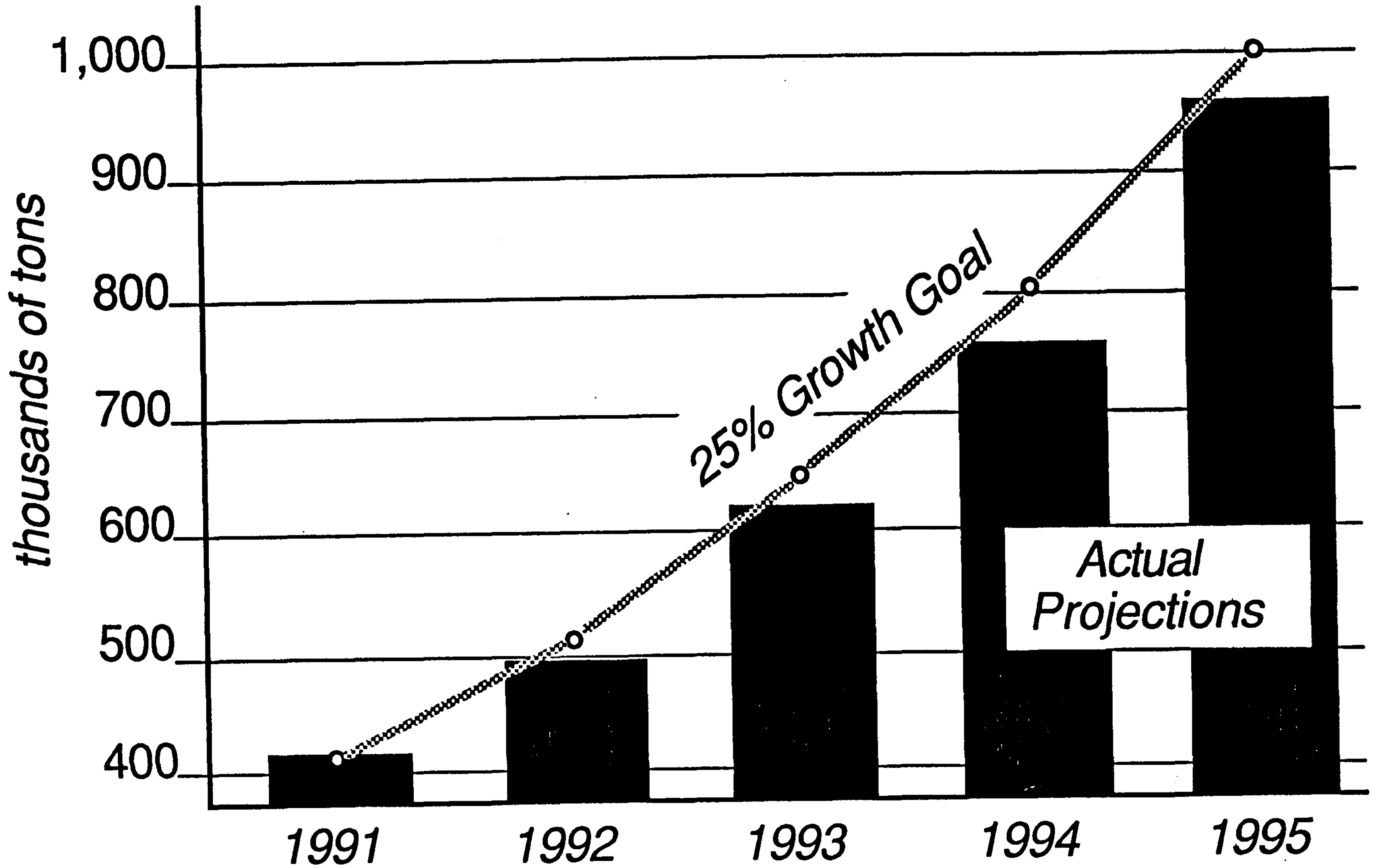
Wheeling-Pittsburgh Steel ran the first ever production of GALFAN strip on a flux-type line in late September with good results when it was coated on their painting line. Most of their GALFAN will be used in architectural panels and decking for construction and bridges but the other GALFAN sheet producer, Weirton Steel, is glad to see competitors in the business because many of their customers will not switch to GALFAN until there is more than one source for it.

John L. Hostetler, Director
GALFAN Technical Resource Center
November 4, 1991



Total Cumulative Production 1,278,863 Tons
ANNUAL GALFAN SHEET PRODUCTION 1984-1991
Tons Per Year (Thousands)
400
350
300
250
200
150
100
50
0
1984
1985
1986
1987
1988
1989
1990
1991
PRODUCTION YEAR

GALFAN Production (all types)
Licensee Forecast for Total Yearly Production



INTERNATIONAL LEAD ZINC RESEARCH ORGANIZATION, INC.

GALFAN TECHNICAL RESOURCE CENTER

2525 MERIDIAN PARKWAY
POST OFFICE BOX 12036
RESEARCH TRIANGLE PARK, N.C. 27709-2036
TELEPHONE 361-4647 (AREA CODE 919)
TELEX: 261533
FACSIMILE: (919) 361-1957

6 November 1991

SAMPLE

Sent to 13 Active Sheet Licensees

We are pleased to tell you that 13 of the active GALFAN Strip Licensees have asked to participate in the 1992 GALFAN Coil Characterization Program. Most have submitted general data concerning their coating line processes on the last questionnaire.

Additional suggestions were made during the Sheet Operator's Session at the Licensee Meeting in Pittsburgh, hence an enlarged Form has been designed. A copy is attached for you to use as your Entry Form. Use a separate sheet for each sample you want characterized.

Four pieces of each sample should be submitted. The sample size shall be one meter by the full width. Each piece should be labelled to indicate the top and bottom of the sheet and the direction of line travel.

Samples should be lightly oiled, tightly wrapped and crated. Samples shall not be chromated or coated with anything which will not rinse or wipe off. A slug of the GALFAN bath, taken near the sink roll at the time of the sample's production shall accompany the sample.

Please return your completed Entry Forms before November 30 so that we can compile the data and report back to all of the participants for final suggestions. Identification of the samples shall be coded so that the sample source is confidential and shall not be disclosed without the participant's written permission.

A shipping authorization tag and final Sample Data Form will be forwarded to you before December 31, 1991. Samples should then be shipped to arrive at C.R.M. between February 15 and March 1, 1992.

The Characterization Report to be prepared by CRM shall include:

1) Surface Characteristics

   Cell Size
   Defects
   Smoothness
   Paintability

2) Coating Profile

   Thickness
   Thickness Variation (edge-to-edge)

3) Coating Characteristics

   Microstructure
   Composition
   Intermetallics

4) Bath Composition

5) Corrosion Resistance

   Salt Spray Fog
   Sulfur Dioxide
   Humidity
   Outdoor

The program is funded for one sample from each participant. If you want to submit more than one sample, please complete an Entry Form for each one. We will then quote the additional cost if any, to include the extra samples.

Sincerely,

John L. Hostetler, Director
GALFAN Technical Resource Center

JLH/kd

Encls.

cc: M. Lamberigts/CRM

1992 GALFAN SHEET CHARACTERIZATION PROGRAM ENTRY FORM

GALFAN LICENSEE: ______________________________
Represented by: ______________________________

	Proposed	As Submitted
STEEL MAKING/SHAPING		
Steel Type		
Composition, % C		
S		
Mn		
P		
Si		
Al		
N		
Other (Specify)		
Hot Roll Finish Temp.°C		
Coiling Temp. °C		
Cold Rolling Mill Type		
Lubricant		
Reduction %		
CR Strip Gauge, mm		
Strip Width, mm		
Conditioning *(See Note 1)*		
GALVANIZE PROCESS		
Type Cleaning		
Furnace Type *(See Note 2)*		
Peak Annealing Temp. °C		
Soak Time, sec.		
Over-ageing, sec.		
Dew Point Temp °C		
Hydrogen %		
Cooling Rate, °C/min		
Strip Entry Temp. °C		
GALFAN Pot Temp. °C		
GALFAN Composition, % Al		
Mischmetal		
Fe		
Strip Residence, m		
Line Speed, MPM		
Knife Wipe Media		
Coating Weight, g/sq.m		
Cooling Media		
Cooling Rate, °C/sec.		
Skin Pass, %		
Levelling Elongation, %		
Chem Treat *(See Note 3)*		
Other (Describe)		

Note 1: Was any strip conditioning such as skin passing, side trimming, levelling, etc. done prior to the galvanizing process?
Note 2: Specify what type of furnace heating transfer is used; radiant tube, direct fire, induction, etc.
Note 3: Indicate type and method of post-coating chemical treatment used; chromate, oiled, etc.

16th GALFAN Licensee Meeting

Pittsburgh, PA, U.S.A.

October 2-4, 1991

GALFAN Constant Improvement Program

We are indeed heavily committed to the continuing and constant improvement of GALFAN. We have done it with the alloy and will continue but we now focus our attention to the processes which are involved from the making and shaping of the steel to the final fabrication of the GALFAN coated part.

Our involvement in some of these processes will be limited to the generation and/or distribution of knowledge; in some it will be an intimate involvement with the design or operation of the process; in the vast majority of cases, it will be somewhere between the two.

We will mainly concern ourselves with the **processes on the galvanizing line**. Our objective is not necessarily to become the source of all knowledge on the processes, but rather on how to diagnose problems within a process and find appropriate solutions. Solving problems for the GALFAN Licensee is GTRC's <u>first priority</u> . . . nothing else is more important. But we needed to develop a plan for how to do this effectively. We don't have all the answers so we had to find a way to get good answers quickly and get them back to the Licensee. We call this program The GALFAN Constant Improvement Program.

The term **constant improvement** is probably not new to you . . . it is the cornerstone of Edward Deming's philosophy; all other devices and techniques are tools to make constant improvement realistic and effective.

One of the techniques which has become an integral part of constant improvement is the involvement of those who actually perform the tasks *involved* in the process in such a way as to influence the process itself. Some call this involvement *quality circles* or by many other labels.

What you call it is not nearly so important as whether or not it works. It is admittedly a difficult program to initiate, execute and administer but the **results** from those times when it works, are so effective that it cannot be ignored.

The GALFAN Constant Improvement Program has as its aim the *continual and constant improvement* of the GALFAN product. Its method is the involvement of those who are performing the tasks on the galvanizing line.

The nominal setting for the Quality Circle is within a building where the process is operated. In our case, the contributors who are the operators, supervisors and engineers running the lines, are separated by continents and oceans.

This does not have to mean the performance of the group will be compromised. It may slow down the speed of the interactions but with the fax machine, even that is not a severe restriction.

The idea then is to create a pool of people who meet two requirements:

1) People who **want** to improve GALFAN products, and
2) People who have process know-how.

In addition to the pool of people with inputs, the system needs to have someone who directs activities to keep the focus on specific areas to be improved, accumulates the input from the operating Licensees and republishes it in efficient form. That is the GTRC's role. It is a never-ending system because there is always room for improvement . . . always a way to do it better.

The first problems were submitted in May and although we had the general idea in mind, I was not as ready to produce and publish it as I thought, so it was mid-August before the first Manual with 10 problems were released. Volume 2 will be issued when the next problem is ready for publishing.

The first 10 problems nominated (in ranked order) were:

1) Gray Patina
2) Intermetallic Layer (several aspects of)
3) Dents
4) Contaminated Coatings
5) Process Control
6) Welding and Soldering
7) Cooling
8) Sag Lines/Edge Build-up
9) Temper Rolling (Redrawing)
10) Strip Temperature Profile

Most times a problem statement starts out describing a symptom of the problem or is too vague and fuzzy to attack effectively so the first thing GTRC may do is to analyze the nominated problem statement and rewrite it so that it is stated as "How can (this thing) be made to work better?"

GTRC will then research the problem to the point where at least one apparent solution can be described. This is then published and distributed to the Registered Manual Holders as a new Section in the Manual.

If a Licensee has any experience with the problem or solution, a response should be sent to GTRC. It can include suggestions, references, critiques, ideas, etc. The response can be a compilation of all the Licensee's contributing personnel or it can be the individual responses.

The GTRC will review, edit, combine and comment on the responses in a Report to the Problem's Nominator which will be distributed to all Manual Holders. Licensees may wish to expand or comment further on the Report; the cycle is started again and may continue ad infinitum.

The process depends upon the willingness of the Licensees to participate both in nominating problems and in responding to other Licensee nominated problems. It will be as effective as your corporate commitment to it.

Manuals have been distributed to active producers only. Other Licensees may order a copy for $100/manual which includes the updating service.

In some cases, a GALFAN problem will not allow the normal time to solve it. In such cases, GTRC will pursue any resource at their disposal, including other Licensees. The procedure will be initiated in the same way and will be documented for further improvements and for future reference.

We ask three things of each Licensee:

1) **Take this program seriously**. It can solve your problem when one hits you . . . but <u>only</u> if you are part of the 'Round Robin'. Other Licensees may not feel like helping you if you have not been contributing to help others.

2) **Register the Manual** in the name of someone in your Operating department. Most of the problems to be handled will need hands-on type solutions.

3) **Nominate the Problems** to this program. Talking about the problem to the wrong people or at the wrong time or in the wrong setting will not get you solutions. Nominating it correctly will.

16th Galfan Licensee Meeting 2. - 4. Oct. 1991
General Session

Start-up and Operating report on GALFAN coated sheet production at VOEST-ALPINE Stahl Linz GmbH

J. Faderl, L. Schönberger, W. Suppan

---

1. Introduction

The strategie target of the brand new hot-dip galvanizing line No. 2 has been the production of best quality surface and product diversification. It has been decided to choose Galfan instead of Galvalume for ZnAl alloy coating.
One main reason for this decision has been, that Galfan should be a proper product for our coil coating line, which started operation in 1989.

2. Line Configuration

The typical line date are shown in table 1. On figure 1 you can see a schematic lay-out of the line. Before entering the entry-looper the strip passes the precleaning section consisting of an alkaline washing, electrolytically degreasing and brushing units. The selas type direct fired non-oxidizing vertical preheating furnace is followed by the vertical radiant tube heated annealing reduction furnace. After cooling down to Zn bath temperature the strip passes a short holding section - a space option for an overaging zone - before it dips into the melt. There are two inductively heated, moveable ceramic pots, each with a capacity of about 180 tons Zn. One is filled with "lead-free"-Zn, the other one with Galfan. Coating apperatus consists of a three roll design for the strip pass and a air knive with changeable nozzle profiles. A special sealing system (nitrogen purging) in the snout enables the change of the pots while maintaining the reducing atmosphere in the furnace. About 2 m above the bath surface a hot x-Ray floureszence measurement is located to minimise the response time for regulating the coating weight.

After this alternatively the inductively heated Galvannealing furnace or the "Heurtey" minspangle unit can be locked in. After the resistance heated holding zone of the galvannealing furnace the strip is cooled down and passes a coating profile measurement a final cooling stage, the skin-pass and tension leveller unit and the phosphating and chromating treatment unit.

3. Galfan start-up

3.1 Filling the Galfan pot

About 50 tons from total 130 tons of Galfan with 4,85 % Al have been premelted in an armco-iron steel pot and afterwards pumped into the ceramic pot. This was necessary to enable the further melting in the inductively heated ceramic pot. Due to extensive reaction of Galfan with the steel pot about 15 tons of dross formed and couldn't be pumped out. This dross showed a higher concentration of Al and MM. So the Al-content of the final melt was too low, the content of REE was negligable low. For the latter we could not find any explonation. Before starting the campaign MM's have been enriched using a master alloy 12 % Zn, 45 % La, 36 % Ce. The Al-content has been enriched during the campaign with help of master alloys containing 15 % Al (rest Zn).

3.2 Galfan Campaign alloys

In table 2 the main production data are shown. The Al-content of the melt varied from 3.8 up to 5.0 wt% (table 3). During the campaign we had no Galfan specific problems like blinkers, ripples, tears, uncoated areas (pin-wholes) ore something else. Most of production has been done with normal coating finish, about 40 tons have been skin-passed. A higher tendency to roll pick-up has been observed as already mentioned from NKK (15th Galfan Licensee Meeting).

An influence of the Al-content on the depth of the grain bourdary dents hasn't been observed optically. The cooling rate during solidification of Galfan couldn't be determined, natural cooling with and without additional cooling by mini-spangle unit was used.

4. Product-quality

Four coils with different Al-content in the coating have been investigated in more detail (table 5).

4.1 Cross sections

In figure 2 the cross sections of the 4 materials are shown. No correlation of the amount of Zn-primary phases with the Al-content could be observed.

4.2 SEM-images

General two regions can be observed (fig. 3). One region where the Al-rich lamellars are parallel to the surface and another one where they are in a right angle to the surface (fig. 4).

4.3 Corrosion behaviour

The results of the salt spray test are shown on table 6. It must be taken into account that all materials were chromated (Cr-layer about 20 mg/m^2). Therefore rather high values have been found even for the zinc-coatings. The time to 5 % red-rust has been found to be more than two times higher for Galfan in comparison to Zn. A correlation between Al-content and SS-result has not been found.

Outdoor exposure tests in industrial atmosphere are under way.

4.4 Cracking behaviour of the coating

In figure 5 the cross section of the bend-edge (2a) of material D is shown. A lot of cracks can be observed. These cracking behaviour has also been found for the other coils (figure 6). One of the greatest advantages of Galfan should be superior formability of the cooling, so we are not satisfied with our preliminary results.

5. Marketing activities

Galfan is sold under the market name Thervagal®ZnAl (Thervagal stands for thermic Voest-Alpine galvanized).

For promotion of Galfan technical brochures have been produced and technical presentations for our customers have been organized.

6. Technical Problems with Galfan

One of the most frequent question was about the problem of darkening of the surface and whether this has been solved (sometimes there was the meaning that Galfan gets really black).

30 tons of the Galfan production have been sold for roofing application in a bare state. Due to soldering problems this material has been rejected. Due to missing information from Galfan Technical Resource Center, we had to find a solution by ourselves. It has been found that an organic flux (type LW 2) in combination with CdZn(20 % Zn, rest Cd)- and SnZn(10 % Zn, rest Sn)-solders showed good results in terms of wetting behaviour and strength of the soldered seam (figure 7).

Line No. 1:

Start up 1973, several modifications and reconstructions aiming at capacity enlargement and quality improvement

Capacity:	220.000 t/yr
Line speed:	100 m/min
Strip dimensions:	0,45 - 3,0 mm thickness
	700 - 1520 mm width
Coatings:	Zn (regular spangle, mini spangle, skin passed)
Surface treatment:	chromated (C), oiled (O), chromated and oiled (CO)

Line No. 2:

Start up 1991

Capacity:	210.000 t/yr
Line speed:	150 m/min
Strip dimensions:	0,35 - 1,5 mm thickness
	750 - 1600 mm width
Coatings:	Zn (mini spangle, skin passed)
	Galfan (Zn-5 % Al-0,2 % MM)
	Galvannealed (ZnFe)
Surface treatment:	oiled (O), chromated (C), phosphated (P), and combinations

Production: 1050 to

Steel grade: Fe PO2 G (CQ)

Dimensions:

thickness: 0,6 - 1 mm
width: 1000 - 1330 mm

Coating mass: 255 g/m^2 (total, both sides)

Surface conditions:

normal finish (NA): share: 96 %
improved surface (MB): share: 4 %
(skin passed)

Operation parameters:

line speed: 58 - 92 m/min
bath temperature: 430 - 460 °C
strip temperature (snout): 465 - 505 °C ("VA")
$\Delta T_{max} = 58$ °C
$\Delta T_{min} = 21$ °C
$\Delta T_{average} = 40$ °C
wiping gas: air (ambient temperature)
ingots added: ~50000 kg Galfan alloy (4,85 % Al, 0,03 % MM)
~14000 kg Al-master alloy (15 % Al, rest Zn)
~50 kg MM-master alloy (12 % Zn, 45 % La, 36 % Ce)

FEP	**Production and operating parameters of the 1st VA-GALFAN campaign (24.5. - 26.5.1991)**	**SFO 2** Metallische Beschichtungen

23.9.1991

Table 3

date	time	Al in the melt (%) d = 300 mm	d = 800 mm	d = 1500 mm	Al in the coating (%)
24.5.91	16.00	3,8	3,9	4,0	
	21.00 (start)	3,7	---	3,9	4,2
	23.00	4,0	---	---	4,2
25.5.91	0.00	3,8	---	---	4,2
	3.00	4,3	---	---	4,3
	6.00	4,3	---	---	4,4
	9.00	4,1	4,3	4,4	4,7
	12.00	4,6	4,7	4,7	4,5
	18.00	4,7	4,8	4,4	4,7
	22.00	4,8	5,1	5,1	4,9
26.5.91	2.00	5,0	4,9	4,9	4,8
	6.00	4,9	5,0	5,1	4,8
	14.00 (end)	4,8	4,8	4,7	4,7

FEP

Al-content in the melt (different depths) and in the coating (coating weight 255 g/m² (sum of both sides)) during the first VA-Galfan campaign from 24.5. to 26.5.1991

SFO 2
Metallische Beschichtungen

date	time	depth								
		d = 300 mm			d = 800 mm			d = 1500 mm		
		Ce (ppm)	La (ppm)	Fe (ppm)	Ce (ppm)	La (ppm)	Fe (ppm)	Ce (ppm)	La (ppm)	Fe (ppm)
24.5.91	16.00	< 1	4	< 50	< 1	5/8	< 50	< 1	4/5	< 50
25.5.91	2.00*)	60	57	< 50	65	57	< 50	60	54	< 50
	9.00	60	86	70	40	54	50	80	112	50
	18.00	75	89	50	50	54	< 50	60	66	60
26.5.91	6.00	70	66	50	55	48	< 50	60	53	< 50
	14.00	65	52	< 50	60	51	< 50	60	52	< 50

*) Between 16.00 and the start of the campaign about 50 kg MM master alloy with 12 % Zn, 45 % La, 36 % Ce have been added to the melt.

FEP

Ce, La and Fe content in the melt during the first VA-Galfan trial

SFO 2
Metallische Beschichtungen

23.9.1991

Table 5

Sample	Coil No.	Spezification	sheet thickness (mm)	sheet temp. (snout) °C "VA"	bath temp. (°C)	ΔT (°C)	Al_{bath} (wt%)	$Al_{coating}$ (wt%)
A	704943	AK-ZA 255 NA C	0,75	502	439	63	3,8	4,2
B	704920	AK-ZA 255 NA C	0,60	491	453	38	4,6	4,5
C	704947	AK-ZA 255 NA C	0,60	484	442	42	5,0	4,8
D	704919	AK-ZA 255 MB	0,60	484	452	32	---	---
E	711199	AK-Z 275 NA C	0,80	---	---	---	---	---

FEP

Samples of the 1st VA-Galfan campaign for quality evaluation

SFO 2
Metallische Beschichtungen

sample	coating designation	time to 5 %*) redrust (h)	Al-content in the coating (wt%)	$\Delta T_{sheet/bath}$ (°C)
A	ZA 255	1900	4,2	63
B	ZA 255	1400	4,5	38
C	ZA 255	1500	4,8	42
E*)	Z 275	480	< 0,5	---

*) Remark: All samples tested are chromate passivated

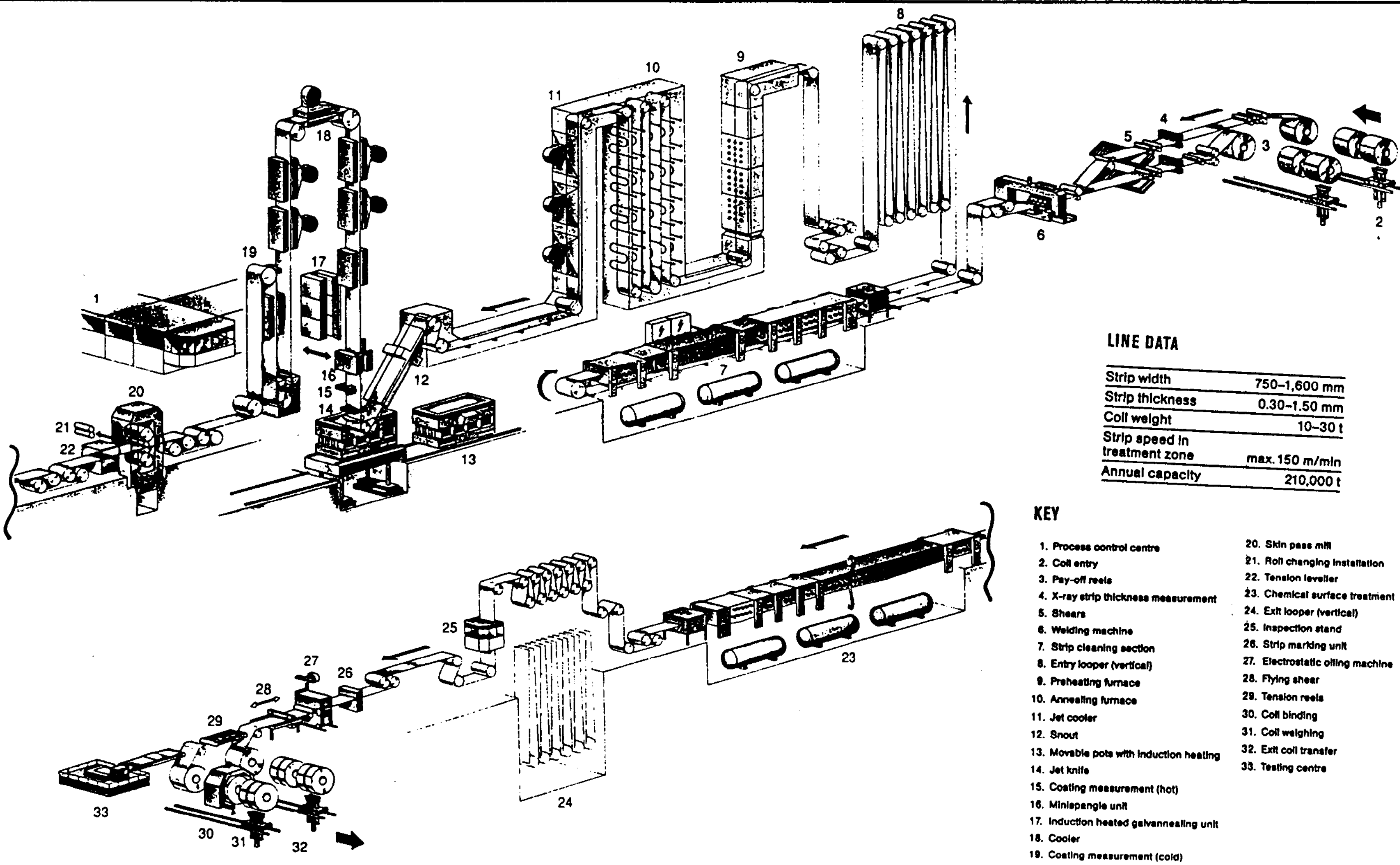
FEP

Time to 5 % redrust in the salt spray test of different samples from the 1st VA-Galfan campaign (24.5. - 26.5.1991)

SFO 2
Metallische Beschichtungen

24.9.1991

Fig. 1



LINE DATA

Strip width	750–1,600 mm
Strip thickness	0.30–1.50 mm
Coil weight	10–30 t
Strip speed in treatment zone	max. 150 m/min
Annual capacity	210,000 t

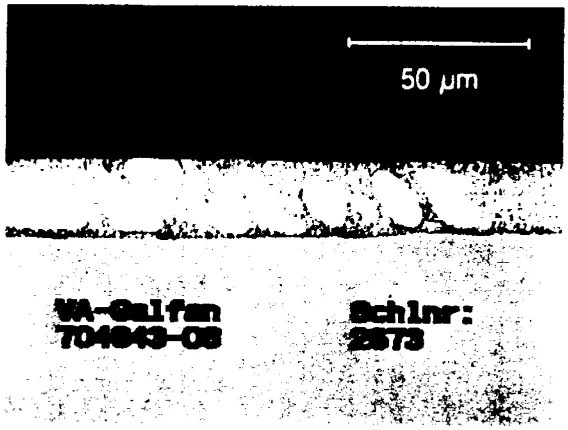
KEY

1. Process control centre
2. Coil entry
3. Pay-off reels
4. X-ray strip thickness measurement
5. Shears
6. Welding machine
7. Strip cleaning section
8. Entry looper (vertical)
9. Preheating furnace
10. Annealing furnace
11. Jet cooler
12. Snout
13. Movable pots with induction heating
14. Jet knife
15. Coating measurement (hot)
16. Minispangle unit
17. Induction heated galvannealing unit
18. Cooler
19. Coating measurement (cold)
20. Skin pass mill
21. Roll changing installation
22. Tension leveller
23. Chemical surface treatment
24. Exit looper (vertical)
25. Inspection stand
26. Strip marking unit
27. Electrostatic oiling machine
28. Flying shear
29. Tension reels
30. Coil binding
31. Coil weighing
32. Exit coil transfer
33. Testing centre

FEP

Hot-dip galvanizing line No. 2 at VOEST-ALPINE Stahl Linz GmbH

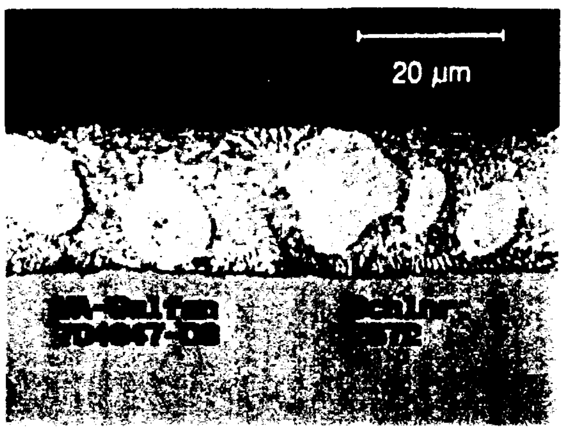
SFO 2
Metallische Beschichtungen



Sample A

Sample B

Galfan
VA-704920/A



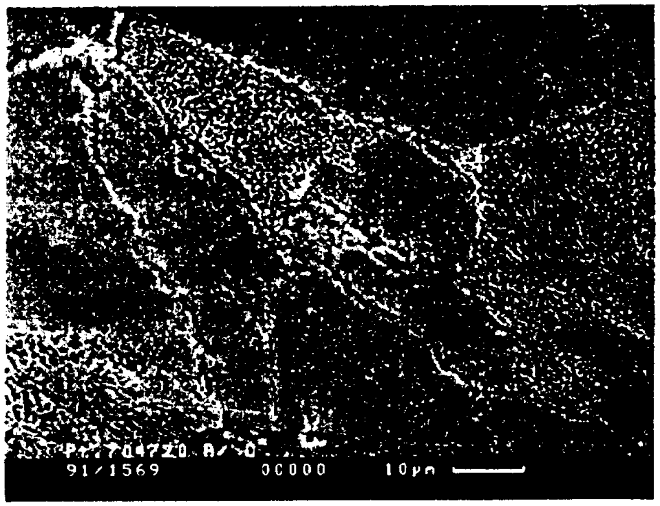
Sample C

FEP	**Cross sections of different samples from the 1st VA-Galfan campaign (24. 5. - 26.5.1991)**	**SFO 2** Metallische Beschichtungen

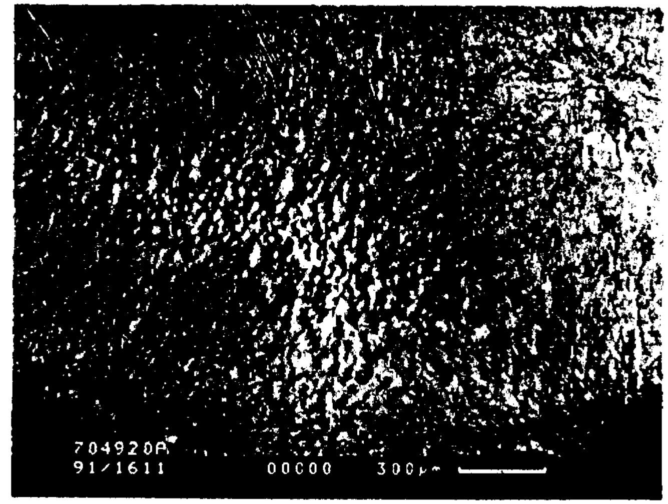
19.9.1991

Fig. 3

a) SE-image of the surface

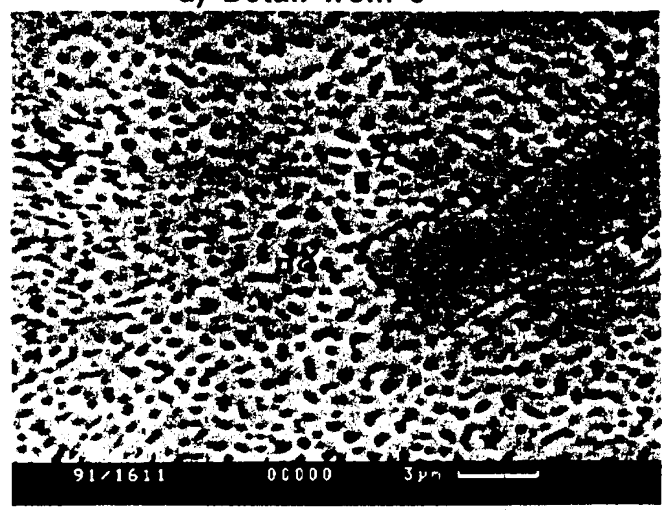


b) SE-image of a dent



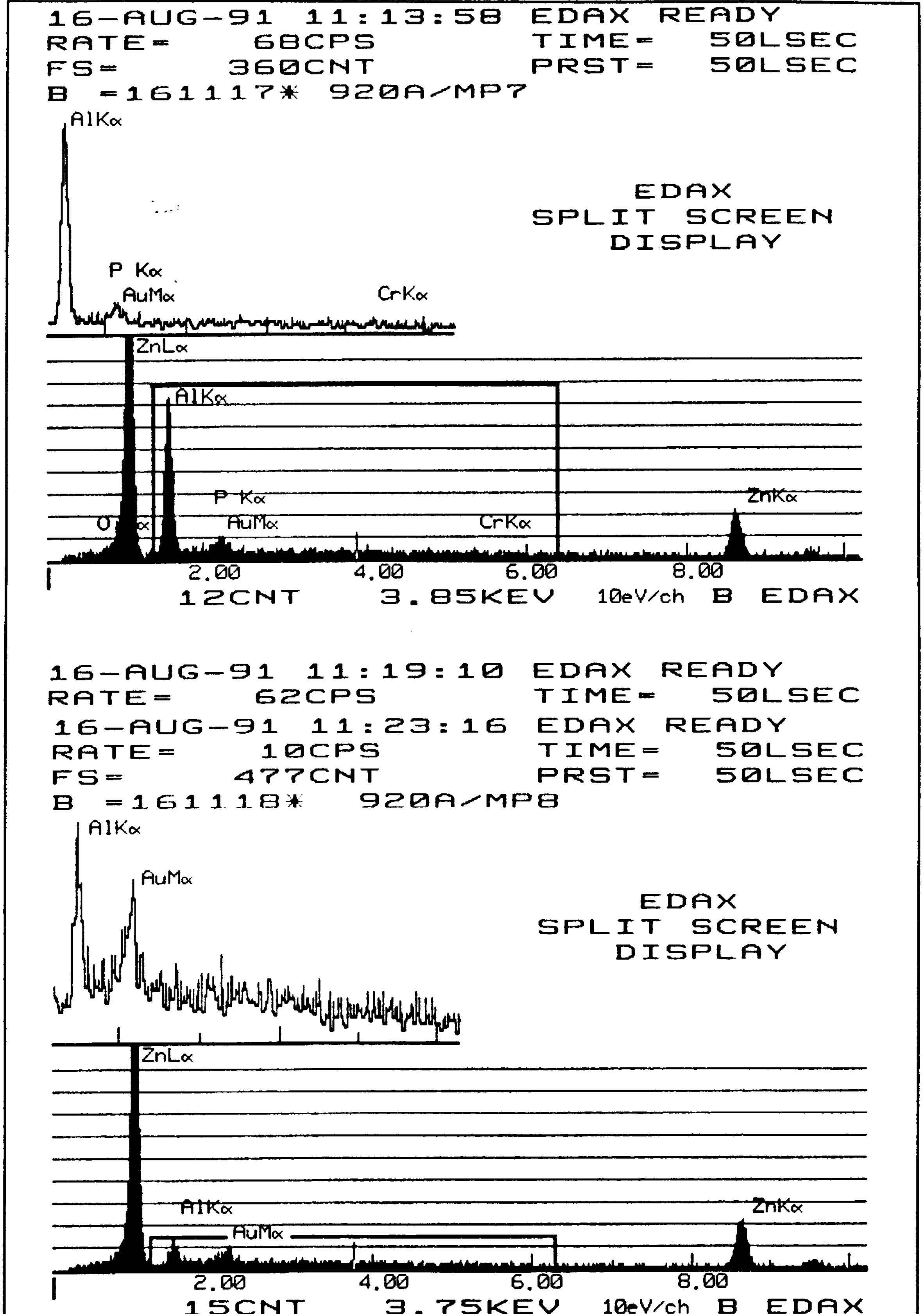
c) BSE-image of the surface

d) Detail from c



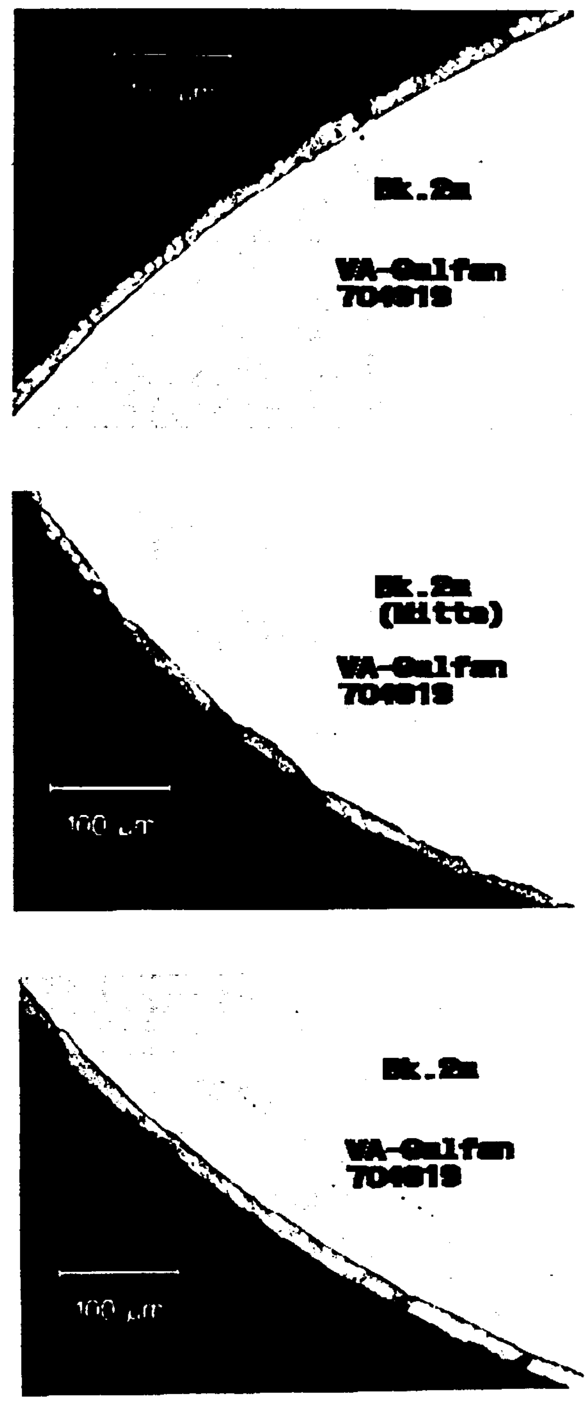
SEM-images of sample B from the 1st VA-Galfan campaign (24.5. - 26.5.1991)

SFO 2
Metallische Beschichtungen



EDX-spectra from point 7 (top) and point 8 (bottom) (see fig. 3/d)

SFO 2
Metallische Beschichtungen

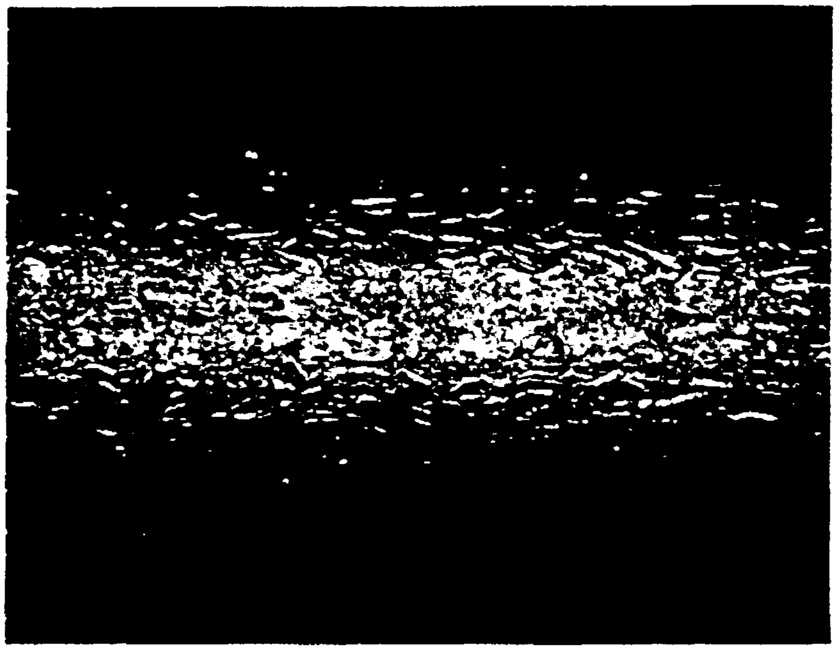


FEP

Cross-sections of the bend edge (2a) of sample D

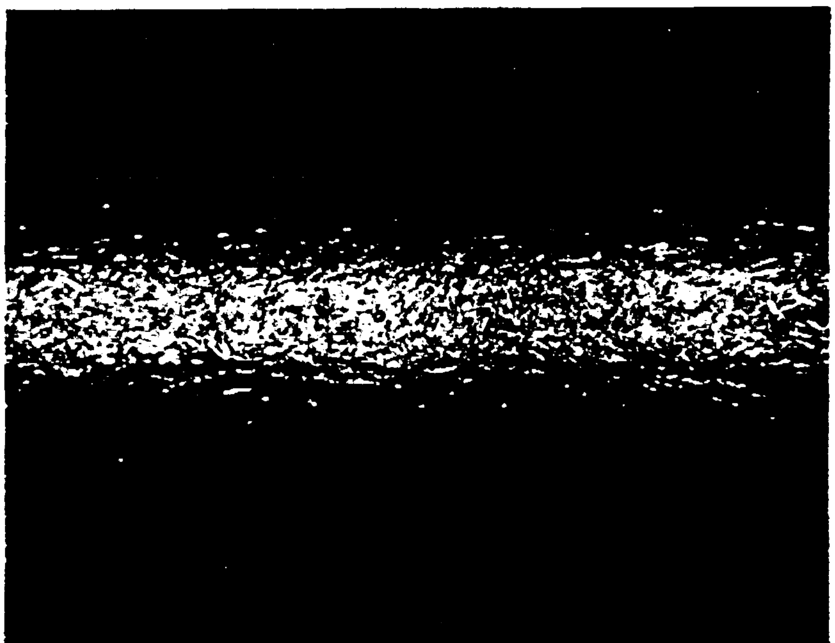
SFO 2
Metallische Beschichtungen

Sample A



M= x20

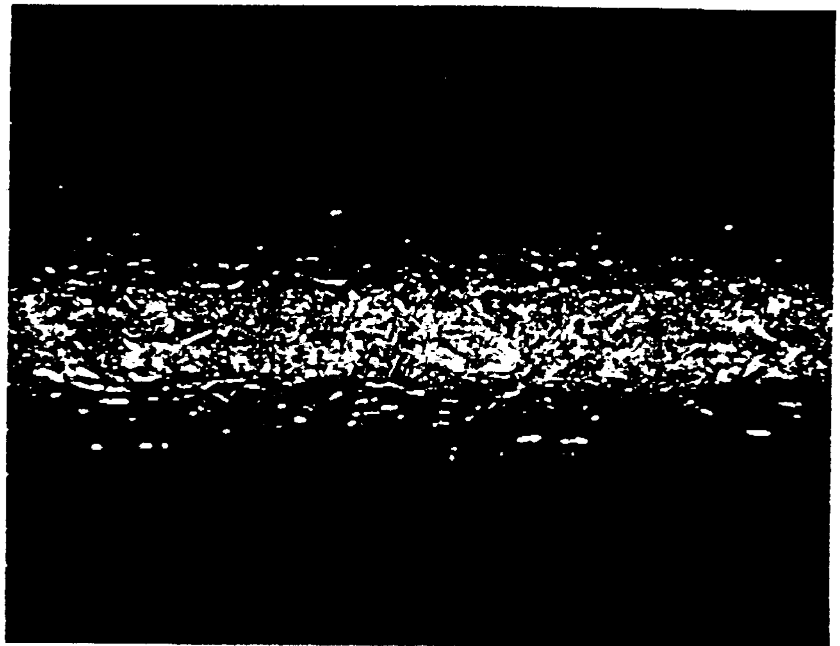
Sample B



M= x20

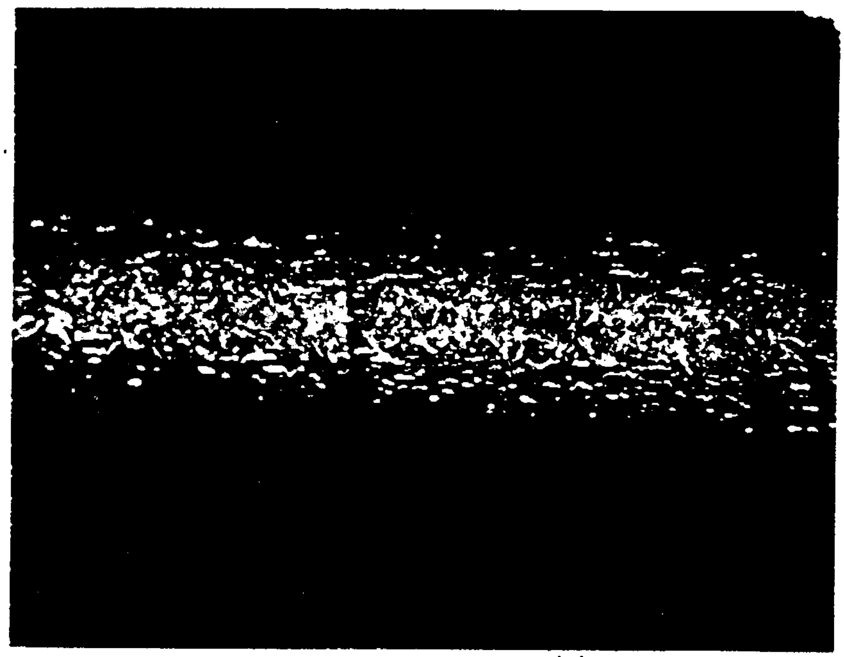
FEP	Top view of the bend edges (2a) of different samples from the 1st VA-Galfan campaign (24.5. - 26.5.1991)	SFO 2 Metallische Beschichtungen

Sample C



M= x 20

Sample D



M= x 20

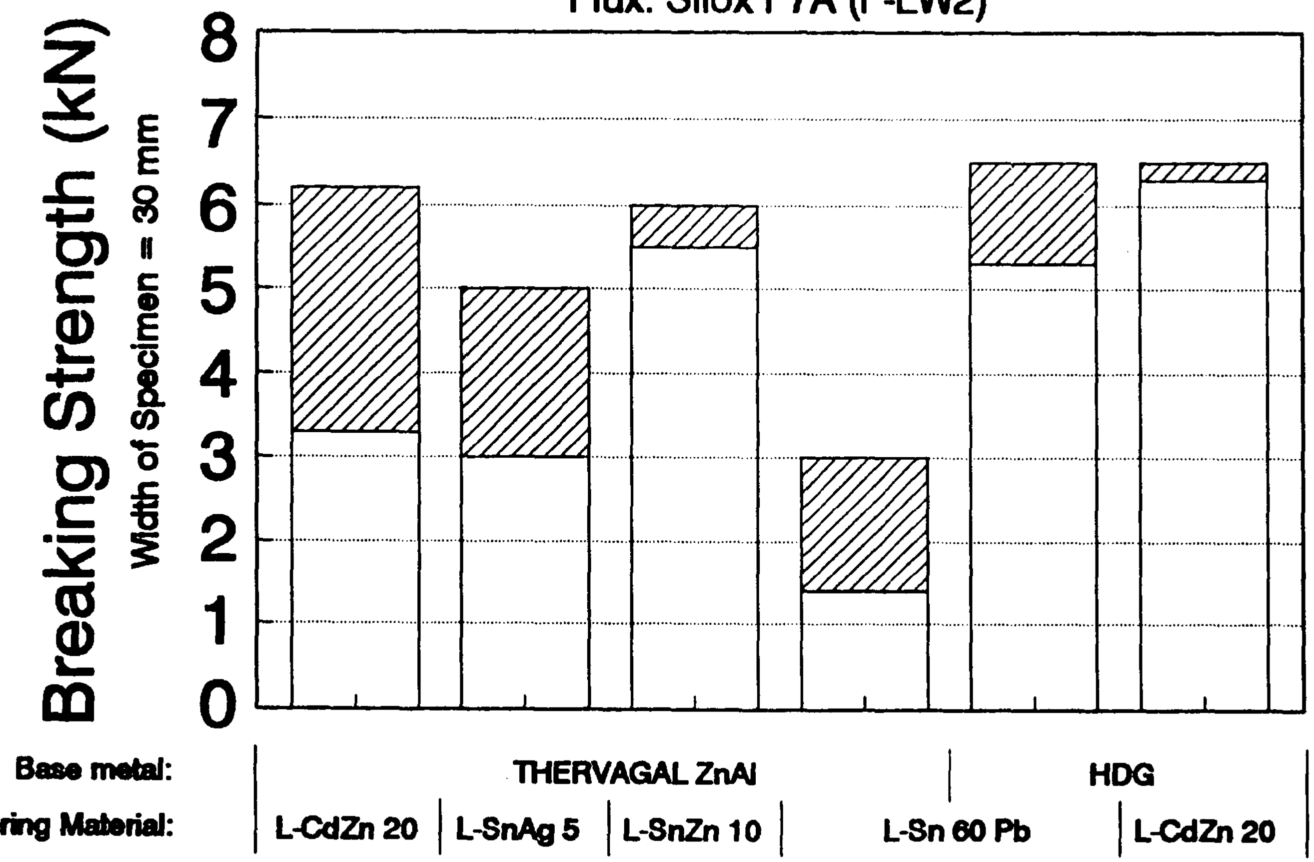
FEP

Top view of the bend edges (2a) of different samples from the 1st VA-Galfan campaign (24.5. - 26.5.1991)

SFO 2
Metallische Beschichtungen

Fig. 7

Shear Strength of Solder Joints
Flux: Silox F7A (F-LW2)



VOEST-ALPINE Stahl Linz

Soldering Test at Hot DIP Galvanized Sheet

THERVAGAL ZnAl

SFF 4

Schweißtechnik

VOEST-ALPINE Stahl Linz GmbH RESEARCH, DEVELOPMENT AND TESTING TECHNIQUES

GALFAN PRESENTATION

Austin Matthews

The Future of Galfan within the Total Coated Steels Market

SLIDE 1

1 Introduction

Coated steel output has increased dramatically since 1970 with applications expanding in many markets. This is attributed to market demand for longevity, colour, shape and cost. Zinc and the alloy Galfan impart excellent galvanic properties to steel which, together with improvements in surface, steel quality and prepaint provide excellent characteristics that enable the products to meet current market requirements.

The future will be about all of these qualities plus others. It is these 'others' - the 'plus factors', I wish to talk about today.

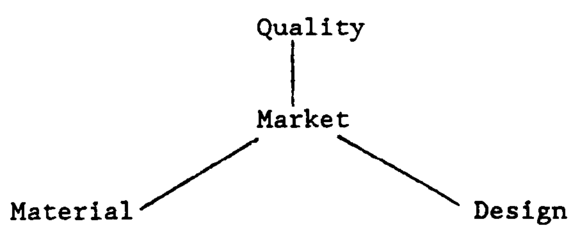
2 State of the Art

Since the late 1970's the demands for quality and reliability have paralleled higher standards of living and economic development. Closer to home, this has resulted in demand for high performance zinc coated products, particularly in the automotive, construction and domestic appliance markets.

New generation coatings such as Galfan are having an increasing influence on these market sectors. The excellent formability and corrosion resistance of this zinc - 5% aluminium alloy make it eminently suitable for a number of applications.

This can be exemplified by Figure 1.

SLIDE 2



Quality and reliability are the main factors behind the increased ratio of zinc coated steel products year on year. On the 'one-side' there is an opportunity for growth while on the 'other-side' there is the likelihood of increased competition and increased capacity to satisfy the markets. This is because at present 43 companies are licensed to produce Galfan coated steel products including steel sheet, wire and tubing. Only 18 of these are in commercial production at present. However, with increasing demands for zinc coated steels, the demand for Galfan will also improve. Thus a number of licensees will begin to produce Galfan as it becomes commercially expedient, increasing availability and competition within the market sector.

The single largest movement within the automotive industry since the 1940's took place during the period of change from cold reduced to zinc coated steel. With this change came all the attendant operational problems which were resolved through technology. Many product types, both via the hot dip or electroplating processes, are now being used.

Automotive usage of Galfan started in Europe and now includes a broad variety of deep drawn and stamped components used both bare and painted. At present Galfan is not used for exterior body panels due to its surface appearance, resulting in an orange peel effect when painted using traditional automotive paint systems.

The combination of a variety of zinc coated steels in the car coming off today's assembly line guarantees quality and reliability, and has resulted in the 10 year corrosion resistant vehicle.

In the construction market the need has grown for higher durability due to the move to prefabrication methods of building. Also, levels of atmospheric pollution giving rise to acid rain and corrosive smog demands products with greater rust resistance. There has been a significant move toward organic coated galvanised and zinc-aluminium coated steels for roofing and walling.

In the domestic appliance and office equipment markets there has been a move to prepainted steel. This has been bought about by a number of factors - cost reduction, design and environmental concerns at the point of production among others. Less expensive hot dipped products will only be favoured if their surface appearance is acceptable to these markets.

3 Future

There will be improvements made in the processing and manufacture of hot dip and electroplated zinc coated steel sheet. By taking advantage of present systems strengths and reinforcing them, technological advancement of new products will occur. However, the main questions will always be how little zinc can we use to meet the onerous corrosion resistance requirements coupled with the necessary forming, joining and painting properties.

SLIDE 3

Galfan, with its excellent corrosion resistance and thinner coating compared with traditional galvanised steel, has a number of advantages. Galfan has an unique combination of improved formability, enhanced corrosion resistance, cathodic edge protection, paintability and versatility. However, there are three problems associated with Galfan which have limited its use up to the present time:

SLIDE 4

a) Surface Appearance
b) Patina Effect
c) Alloy Composition

a) Surface Appearance

The surface of Galfan has a grain-like or orange peel appearance which is magnified by thin paint films. At present it is unsuitable for automotive applications or pre-paint applications where the dry film thickness is relatively thin (~25 microns).

Recent research by ILZRO (1), has stated that rapid cooling immediately after the strip exits the galvanising pot can improve surface appearance by reducing the depth of eutectic cell boundary depressions. Introduction of IF steel grades, justified by the ever increasing demands of present-day applications, alters the iron-aluminium interfacial reaction and modifies the coating solidification sequence, thus also improving surface appearance.

By improving the surface appearance the suitability of Galfan for automotive and some pre-paint applications is increased dramatically.

b) <u>Patina Effect</u>

The selective darkening of Galfan in storage has limited its suitability for use by stockholders/steel service centres, inhibiting the distribution of plain metallic Galfan. However, if increasing amounts of Galfan were used for prepaint, the material would be suitable for storage. The patina formation can be delayed, as described by Nisshin Steel, with the use of their patented cobalt-nitrate coating. However, the cost aspect must now come into play.

c) <u>Alloy Composition</u>

Until the present time there has been no exact specification for the makeup of Galfan. Recently this problem has been tackled. Production procedures and alloy composition are being determined to ensure that optimum operating parameters are utilised for the required material properties.

I should now like to turn to other important issues which will be happening in the next decade:-

SLIDE 5

1 Ecological Market Economy
2 EEC - 1992
3 Information Technology
4 Human Comfort

SLIDE 6

3.1 <u>Ecological Market Economy</u>

Elements of an 'ecological market economy' are beginning to enter legislation. The pollution of air, water and soil has a market price that motivates industries to use environmentally friendly materials and processes. As landfill is rapidly running out, the cost responsibility for non-recyclable materials will increasingly be assigned to those who decide material selection.

It is likely that, over the next decade, legislation will be enacted particularly in North America and Europe ensuring that products are designed and manufactured in an environmentally acceptable way.

As well as the ultimate disposal of the material, manufacturers are becoming controlled by increasing legislation. A number of manufacturers have moved away from post-painting practices to pre-paint in order to meet emission controls limiting atmospheric pollution.

Pre-painted systems have numerous applications from cladding for buildings to outer casings for washing machines. The system ensures that emissions of solvents and efficient waste disposal is tightly controlled by the steel manufacturer or toll coater.

Galfan, with its recyclable steel substrate and excellent corrosion resistance and formability, is eminently suitable for pre-paint applications. With the improved surface quality, Galfan would be suitable for thin solution coatings. Thus Galfan is likely to be in demand in the near future for pre-paint applications.

Due to the formability of Galfan, it would also be suitable as pre-prime for automotive applications if surface and low cost pre-treatments became available. If such a system could be developed then the automotive manufacturers could dispose of their electropaint systems whilst maintaining a similar surface quality and corrosion performance. Ultimately a pre-paint system could be developed which would meet all of the forming and joining requirements whilst eliminating, initially, the surfacer and then the top coat, removing the need for automotive paint shops. It will be a long time before a pre-prime system will be developed and operational. It will be sooner in the 'after' market, particularly for body components.

3.2 European Economic Community - 1992

SLIDE 7

The programme for the creation of the Single Internal Market in the EEC, 1992, seeks to address the issues of a genuine free market with non-intervention principles applying. The key thrust of the 1992 programme is to ensure freedom of enterprise across national frontiers. This could increase the demand for products which are, at present, only available to a limited market place such as Galfan. This could pressurise a number of licencees to begin to produce Galfan.

The manner in which the 1992 programme will directly affect steel producers is in the unification of product standards and specifications into Single European Standards to remove technical barriers to trade. Thus a specification identifying the composition of Galfan must be ensured in order to reduce confusion. As this is already underway it is possible that the specification will be agreed prior to the creation of the single market in the EEC.

Although North America is not included in this single market, in order to maintain sales levels as high as present, the specifications decided upon by the EEC will have to be met. This could result in a number of products disappearing from company's product ranges.

SLIDE 8

When the single market is implemented it will have far reaching implications which will increase trade and, with Eastern Europe. Converting to a market economy there will be even greater opportunities.

3.3 Information Technology

SLIDE 9

The single most important development affecting Information Technology for the 1990's is in the increasing integration within the business itself and between customers and the business.

Information technology will, in the near future, affect all aspects of trading. It will assist in the process of identifying appropriate suppliers or customers, it will streamline the process of matching specifications to requirements and it will facilitate the negotiation and agreement of a transaction. The combination of all three will transform a very wide range of markets. The benefits to the business will be felt in the ability to respond faster whilst making better use of available resources such as plant, stocks and cash. The benefits to the customer will be the setting of 'just in time' targets to accommodate their needs.

In economic terms, information technology will move many participants closer to the concept of a 'perfect market' - that is a market in which all participants are fully informed about all aspects of the market. The next few years will see three major manifestations of the concept of electronic market places:-

- Electronic marketing - use of information technology to make marketing/sales more effective.

- Electronic purchasing - use of information technology to increase purchase power.

- Electronic markets - linking together of multiple buyers and multiple sellers.

These developments will change the dynamics of markets, widening them and improving the availability of market information. They will also increase the responsiveness and, hence, the workability of markets. Senior managers of organisations affected by the development of electronic market places need to re-evaluate the basis on which they complete these functions during the 1990's, moving away from in house painters to fabrication and assembly with organic zinc coated steel.

3.4 Human Comfort

SLIDE 10

Due to the market activity in Japan, USA and Europe where there will be enforcement of noise levels to meet human comfort - noise reduction products will be in demand in the 1990's.

Counter measures against noise in automobiles include reinforcement of engine blocks, and the use of vibration damping and insulation material. Of these, vibration damping materials are attracting the most attention.

Vibration damping steel sheets are composites made by sandwiching a resin layer or organic film between two steel sheets primarily zinc coated. Galfan would need to be produced at 0.25/0.35mm to meet automotive standards in order to take advantage of this material. This will need to be developed in the 1990's. However, in machinery or in buildings Galfan could be used as the steel substrate for the vibration damping material. In these areas the thickness of the resultant material is not so important as weight reduction is not a primary requirement. Galfan would be suitable for such an application due to its formability, bonding abilities, corrosion resistance and other service performance properties.

Conclusion

SLIDE 11

I believe the key to future competitiveness and profitability is through the process of 'continuous technical challenges'. We must never be satisfied that we have got as far as we can. This is best illustrated by the improvements in surface texture recently obtained for Galfan. Management's willingness to keep extending technical boundaries lies at the root of endless progression.

Once the specifications for the Galfan alloy have been determined, with the relevant operating parameters to achieve the best performance, Galfan will become a major material. With its improved corrosion resistance and suitability for pre-paint it will go from strength to strength.

In line with this, suppliers will continue to aim to provide the highest level of support to customers and will establish new and innovative links through joint research ventures and joint technical and marketing initiatives. Emphasis will be placed on providing help and guidance at the conceptual design stage to ensure that the steels of tomorrow are tailored precisely to the needs of an ecologically conscious market place.

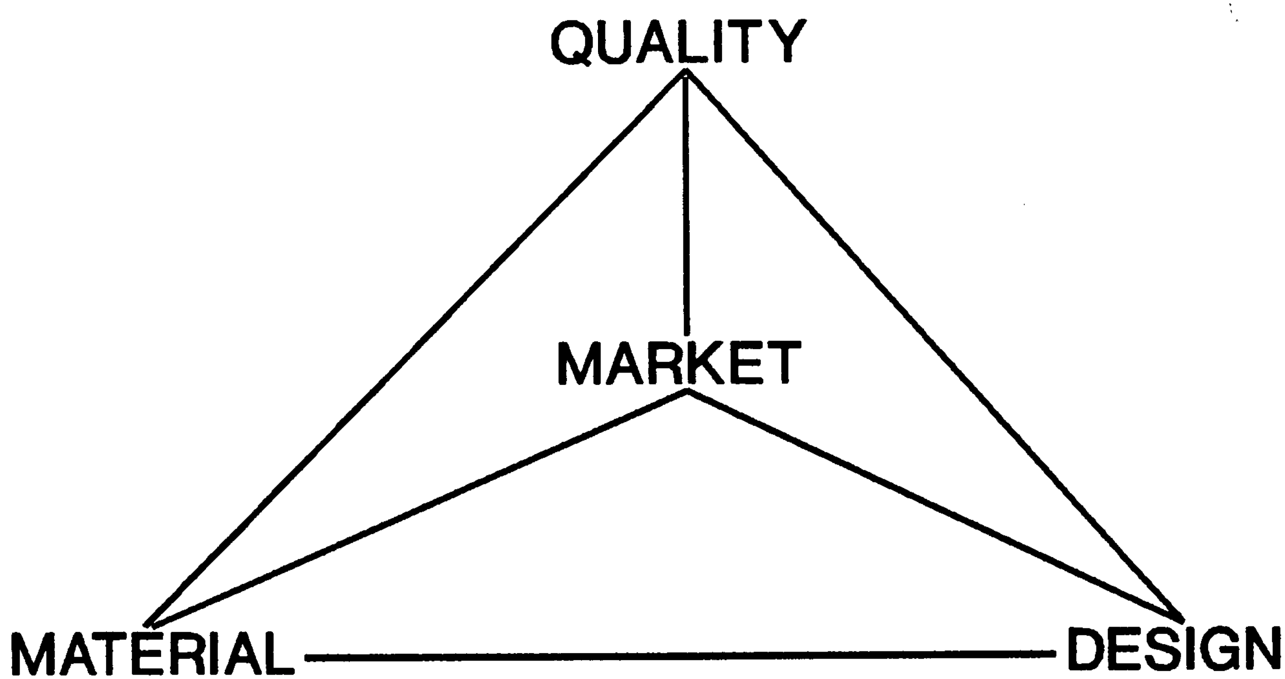
Ref.

(1) Galfan solidification control and associated effects on coating quality and microstructure, M Lamberigts, V Leroy and F E Goodwin, 1991.

TP/KAW
07089105

THE FUTURE OF GALFAN WITHIN THE TOTAL COATED PRODUCTS MARKET

BY AUSTIN MATTHEWS



SLIDE 2

FUTURE DIRECTION

IMPROVEMENTS IN -

FORMABILITY

WELDABILITY

SURFACE APPEARANCE

SLIDE 3

GALFAN

- SURFACE APPEARANCE
- PATINA EFFECT
- ALLOY COMPOSITION

SLIDE 4

- ECOLOGICAL MARKET ECONOMY
- EEC - 1992
- INFORMATION TECHNOLOGY
- HUMAN COMFORT

ECOLOGICAL MARKET ECONOMY

- ENERGY CONSERVATION
- BUILT IN RECYCLABILITY

SLIDE 6

EUROPEAN ECONOMIC COMMUNITY 1992

OPPORTUNITIES

- STANDARD GRADES ACROSS EUROPE
- COMMON TEST METHODS
- REDUCING RE-TESTING AT COUNTRY BORDERS

SLIDE 7

EUROPEAN ECONOMICS COMMUNITY 1992

IMPLICATIONS

- UNFAMILIAR GRADE CAPTIONS
- BREAK UP OF MULTI PRODUCT STANDARDS

SLIDE 8

INFORMATION TECHNOLOGY

- ELECTRONIC MARKETING
- ELECTRONIC PURCHASING
- ELECTRONIC MARKETS

SLIDE 9

HUMAN COMFORT

- NOISE REDUCTION

- USE OF VIBRATION DAMPING MATERIALS

SLIDE 10

CONCLUSION

IMPROVEMENTS OF GALFAN THROUGH

- SURFACE QUALITY
- OPPERATING PARAMETERS
- ALLOY SPECIFICATIONS

16th GALFAN Licensee Meeting
October 4, 1991

WHAT'S AHEAD FOR GALFAN?

by
John L. Hostetler, Director GTRC

The paper will also appear in the minutes as Austin Matthews wrote it but I will deliver it with some thoughts re-phrased, some sentences changed to an active voice and some words Americanized so that I can put emphasis where I want to be sure a point is made.

INTRODUCTION

The production of coated steel products has increased dramatically in the last 20 years. According to IISI, the growth of zinc coated sheet has been 9% per year since 1985, the biggest growth coming in hot dipped galvanizing which is forecast to grow from 3.3 million tpy in 1990 to 4.2 million tpy in 1995.

This exciting growth is market-driven, demanding products with longer life, brighter and more permanent color, creative shapes and competitive cost.

Hot dipped galvanized steel is a fast growing product because zinc's galvanic property is unbeatable in the fight against corrosion. Today's technology allows surface characteristics which are aesthetically pleasant and paint systems which make pre-painted and post painted coil a bargain in terms of beauty and versatility.

GALFAN, an **improved galvanizing** has all these attributes in greater degree and more!

- It is 2 to 3 times more **corrosion resistant** than all-zinc galvanizing.
- It is much more **ductile** so that severe profiling or deforming does not compromise corrosion resistance.
- It **paints over more easily** and with an even better interface.

These GALFAN strengths are well-known to you; they will **continue** to be the main characteristics we focus on when promoting GALFAN's use, and they need to be repeated again and again because they are **significant** and they are **true**. Over 1,250,000 tons of GALFAN product confirm that.

There are other reasons which also make GALFAN more attractive to all markets. It is those other **plus factors** I want to share with you today.

POSITIONING FOR GROWTH

Starting in the late 1970's the demand for more **quality** has paralleled higher standards of living and economic development. This is clearly what has driven this growth and will keep on demanding **continuous improvement** in the automotive, architectural, appliance and agricultural markets.

Are we positioned to take advantage of the coming growth? There are now 47 GALFAN Licensees; 32 sheet, 8 wire and 7 tube, but only 27 are in commercial production.

We think we must have **more producers** in order to bring the **sales promotion** to a level commensurate with the **sales potential**. At the same time, we encourage those who are producing to use all means available to **increase production**. Profits improve as costs are reduced and costs are reduced as production rates are increased. But more important in the long haul, longer campaigns give greater opportunity to improve quality. We urge you, if you haven't already, to install a program for constantly **reviewing and improving** quality.

With the overcapacity for hot dip galvanizing, the galvanizer who can deliver the quality to the market they serve will be the one who benefits the most from the growth. You cannot wait until the growth has become a statistic for even at that moment, someone else already has the business.

The single largest change for the steel industry in the automotive market since World War II was the shift from CR steel to galvanized steel. Many of us recall the distress amongst the hot dip galvanizers as the experts predicted there was no place for any but electrogalvanizers. The hot dip community made great strides in technology and know-how and not only persevered but actually grew. This process is simply too good to be dismissed; so long as we constantly improve it, we can stay up with the market demands.

Automotive's use of GALFAN now includes a broad range of sheet products which are stamped or deep drawn, wire products from springs to windshield wiper arms, tubing products and hot band body frame parts.

The prize that has eluded us are the large sheet panels. I am confident we have solved the denting problem. the attributes of GALFAN will become appealing enough to overcome the automakers' resistance to the minor changes in welding and we can be positioned for that market. When that day arrives the 10-year anti-corrosion guarantee can be extended even more.

The architectural market also offers a growth opportunity. We have already demonstrated that GALFAN is the consistent winner in the contest for coil coating. Elimination of early gray patina will make it aesthetically acceptable for many hundreds of thousands of tons/year of unpainted architectural panels. For architectural framing and corrugated roofing, it is a product that can be produced on all but the most primitive hot dip lines in the emerging countries. All of these are growing markets and again, will go to the system that offers the greatest value.

This architectural market now accounts for three fourths of the GALFAN products about half being painted. This statistic is certainly influenced by the fact that the large GALFAN producers are strong in the architectural market . . . not that being a GALFAN producer brings the architectural market to the Licensee.

The appliance and office equipment markets are also moving to pre-painted coil for many quality, cost and environmental considerations.

There's no question but what pre-painted coil will be a big part of GALFAN's future because its major benefits are maximized in the applications of pre-paint coil.

THE FUTURE

We have reached such technological maturity that we can **safely assume** the needed technical improvements or innovations will be there when they are needed, giving some credibility to the old saying that "Our hands can achieve what our minds can conceive".

Even with appreciation for and emphasis on quality, a free market will always impose the pressure of competitive pricing. Here again hot dip coatings have the competitive edge and will continue to hold that advantage. Additionally, GALFAN will allow actual reductions in coating thickness but still provide greater corrosion resistance. This will attract new business as well as to preserve existing business against aluminum, plastic and other hopeful replacements.

The question then becomes, "Can GALFAN meet the quality standards of the future which require constant improvement and new technologies and still offer economic advantage?"

The evidence says YES!

GALFAN has lived through 3 major problems:

1) Alloy Optimization
2) Gray Patina
3) Dents

You have heard Frank Goodwin report that the GALFAN Steering Committee unanimously accepted the premise that GALFAN should be alloyed close to the eutectic and then use **process control and coating line technology** to control the product characteristics. The alloy has been optimized.

You have heard Dr. Hirose's Paper describing an on-line process to delay the **gray patina** long enough to satisfy most objections. Weirton has never experienced the gray patina problem and when we get into next year's investigation and evaluation of all the different GALFAN sheet samples, we may find out why. At any rate, gray patina should no longer keep anyone from using GALFAN to improve their product.

Surface dents were a serious problem because they kept us from contending for the more critical pre-painted coil market but you saw samples of appliance white at Weirton which are very acceptable. The results from research involving IF steels will make still further improvements.

I feel confident that with Lehigh University's study of GALFAN of IF steel, rapid cooling, thinner coatings and skin passing, we can already compete for the more critical applications. Constant process improvement could easily win automotive body panels to GALFAN.

There are other issues impacting GALFAN's potential in the 1990's. These include:

- Ecological
- Unified Markets
- Information Technology
- Human Comfort

We are already sensitized to the impact of ecological considerations. Some are sort of silly . . . like Susan Molloy in Marin County, California who wants to make it unlawful for anyone to wear perfume, cologne or body deodorant. But many changes are necessary to prevent damaging our environment and ecological systems, and many more regulations and restrictions are yet to come.

The pollution of air, water and soil has a market price that encourages industry to use materials and processes which are friendly to the environment. Landfills are rapidly running out so the responsibility for the cost of non-recyclable products will be assigned to those who specify materials. In other words, materials will be specified because they are recyclable, or <u>not</u> specified because they cannot be recycled with prevailing methods.

Concentrating the pollutant collection will increase industries such as coil coaters . . . one large paint booth at the coil coater instead of hundreds at scattered fabrication sites.

GALFAN coated steel can meet these challenges but nobody will know about it if we keep it a secret. We need the GALFAN Regional Development Associations to get that kind of information out to Users, Specifiers, Regulators and Government agencies.

UNIFIED MARKETS

The advent of a single internal market in Europe next year seeks to create a true free market by ensuring free enterprise across national boundaries. This could produce demand for products which are now available only in the countries which produce them. Existing GALFAN Licensees should move quickly to establish themselves as **experienced** GALFAN producers.

The European Licensees have a tremendous opportunity in **eastern Europe** . . . an opportunity to sell into that market or to form partnerships with local galvanizers. We know there is interest in GALFAN already and we have made arrangements to provide special GALFAN promotional and educational efforts in that region.

Japan has already developed the largest market for GALFAN and since the very idea of constant improvement came from Japan, we encourage the Japanese Licensees to continue.

India, Malaysia and China represent golden opportunities for Japanese GALFAN Licensees to establish technical partnerships with galvanizers in these regions as they become licensed.

North America has also become more of a common market with the new Trade Agreements between the USA, Mexico and Canada. With only two tube Licensees in Canada and a potential wire Licensee in Mexico, the Licensees in the US have an opportunity to either sell GALFAN into those markets or to establish technical partnerships.

South and Central American countries are also clustering into common markets. We expect to license several galvanizers to position themselves as a supplier of GALFAN in some of these markets. Certainly the users of corrugated roofing and siding applications have a lot to gain from GALFAN.

A number of Licensees have been established in India, a market which should explode very soon. ILZIC is sponsoring a large seminar in November which will gather present and potential licensees for an up-date. At least one sheet Licensee plans to start producing GALFAN in the near future.

This kind of movement encourages universalization of standards and specifications within each regional market. That effort must come from the various Regional GALFAN Development Associations even as NAGDA is already positioned to do.

INFORMATION TECHNOLOGY

Information Technology is already influencing trade but we are just seeing the tip of the iceberg. The influence IT will have is generally not well understood much less allowed for. IT will premeate every aspect of doing business.

- IT will identify preferred suppliers.
- IT will identify preferred customers.
- IT will match specifications to requirements.
- IT will negotiate the terms and conditions of a transaction.
- IT will control production schedules from many kinds of remote inputs, some **very** remote.

These developments will change the manner in which every department is operated, from the sales department to the shipping department, from R & D to fabrication methods. The "just-in-time" principle will pervade throughout the entire flow chart of steel-making to delivered part, not just to the final User.

The benefits to the producer will be in the ability to respond faster while at the same time, making better use of resources such as plant facilities, inventories and cash. The customer will benefit in improved quality, delivery schedule reliability and value.

IT will move participants toward a **perfect market** . . . that is a market in which all participants are fully informed about all aspects of the market. Electronics will allow IT to bring about three major changes in the next few years.

Electronic Marketing allows the **use** of information to make market data and sales efforts more accurate and effective.

Electronic Purchasing will provide better information on availability, selection and cost for a greater choice of products and sources.

Electronic Markets will link multiple buyers and multiply suppliers together in a variety of partnerships, joint ventures and other relationships.

HUMAN COMFORT

Noise reduction products will be in demand in the 1990's. Government regulations of maximum noise levels are already in place in Europe, Japan and North America.

As an example, anti-noise in automobile design will include reinforcement of engine blocks and the use of vibration damping material. Chrysler is already using MPM (metal-plastic-metal) laminated steel on three of their new V-6 engines for oil pans, valve covers and front covers, an annual requirement of about 2,500 tons.

Vibration damping steel sheets are composites made by sandwiching a resin layer or organic film between two pieces of galvanized steel. GALFAN coated steel is ideal for this application. Not only does it have the damping qualities but its advantages of superior corrosion resistance and greater formability are matched to the requirement.

CONCLUSION

The key to future profitable competitiveness is through the process of **constant improvement**. We must never be satisfied that we have reached the final improvement. The relentless efforts that found solutions to GALFAN problems thought to be unsolved is good evidence to support that philosophy.

We find ourselves at this point having achieved the knowledge of what can be done to conquer the three historic GALFAN problems:

- The alloy has been optimized without compromising corrosion resistance, formability or paintability.
- Elimination of early gray patina need no longer restrict use of unpainted GALFAN.
- Elimination of dents need no longer restrict use of painted GALFAN.

There are many other problems which we will have to address on a given application, production set-up or customer specification, but we can say with confidence that together, we will solve these. It will require cooperation from every partner in the GALFAN program but the **time** is right . . . the **technology** is right . . . the **organization** is right . . . the **product** is right. None are perfect but with constant improvement we can get close enough to grow the business.

PHONE: (313) 588-6500

MID-WESTERN PROCESSES, INC.

P.O. BOX 567 • MADISON HEIGHTS, MICH. 48071

Continuous Dipolar Electrofluxing

16th GALFAN Licensee Meeting

October 4, 1991

Michael R. Morin

Mid-Western Processes Inc.

Hot dip coatings such as galvanize, Galvalume and, in particular, Galfan, have shown to have excellent corrosion resistance on steel. However, the excellent properties of Galfan require that the coating is continuous and without surface defects. Since the raw product will be formed, and in some way be worked into a final product, this coating must have superior adhesion to the base steel. To achieve these properties, the steel must be pretreated to remove any interfering soils, surface oxides and improve wettability.

In the past, various techniques have been used to prepare the raw product. Methods such as heat treatment in a reducing atmosphere, mechanical abrasion and conventional acid fluxes have all shown to be less than optimum, particularly in view of the complication encountered when the coating alloy contains aluminum.

To overcome the shortcomings of previous methods, acids have been used to remove the oxides and even the metallic surface to assure cleanliness.

It has been found that conventional fluxing followed by a molten zinc dip that is very thin will result in a coating with excellent adhesion. This is nothing more than a hot dip galvanize primer. Unfortunately, this method has one serious drawback. When bare steel is exposed to molten zinc, there is an intermetallic alloy layer formed of iron and zinc. This crystaline layer is extremely brittle, and this effect is still felt even after a subsequent Galfan dip. This extreme brittleness gives rise to problems if the raw stock is formed.

To overcome the alloy problem it has been found that electroplated zinc does not form any intermetallic layers, and as a result, coatings applied over electroplated zinc do not exhibit any more brittleness than the coating itself. This electroplated zinc layer would require a flux to coat properly, but that technology does exist.

A variation of this theme is contained in the Electroflux patent held by ILZRO. Zinc is electroplated from a bath that also serves as a flux. This eliminates the standard rinse and flux steps after conventional zinc plate.

The technology of electroplating is well known and requires a source of direct current, anodes and a suitable electrolyte to provide the metal for deposit. In still electroplating, the electrical contact to the work piece is made through a physical contact in the holding fixture.

In the case of continuous electroplating, this contact is much more difficult to establish. Conventionally, this electrical contact has been made by a sliding, shoe-type contact or a wheel. This is illustrated in drawing #1. Both of these methods are less than perfect. To assure good electrical contact with the tube or wire, the contact pressure must be high enough to carry this current through a very small cross section area. This contact pressure will leave scratches or rubs marks of some type. If the contact momentarily jumps, or the pressure fails, the contact will arc and create a surface defect that will fail in corrosion testing, due to the oxides created and attendant lack of adhesion of the Galfan. As the line speed of the product is increased the current for electroplating needs to be increased. This only serves to make the contact problem even more severe.

Contacts are noted for maintence problems of tension adjustment and extreme wear on sliding shoe contacts or rotary contacts in wheel type units.

There does exist a method that overcomes these deficiencies. This method is known as Continuous Dipolar Electroplating (or Bipolar). This is illustrated in drawing #2. In this method no physical contact is made to the moving stock. Two electrolytic cells are connected in series. One cell is anodic, usually an acid dip, while the second is the cathodic electroplating cell. The electrical potential is imposed upon the electrodes in the two electrolytic cells while the connection between the cells becomes the moving work itself. With no moving contact, this equipment will result in no physical damage to the work and also will result in significantly simpler and more efficient equipment. All electrical connections are permanently bolted to the electrode systems.

Because the current is put into the work over a larger area, there are no hot spots as can occur with conventional contact systems.

The use of anodic electropickle has the added advantage of generating an extremely clean and active surface, although any electrolyte will complete the circuit.

There are some accommodations that must be made with this system. The distance between cells must be kept to a minimum, since the work is typically carrying several thousand amps per square inch of cross section area. This current density can be maintained only if the time and therefore distance, is short. Since a rinse is required between the electropickle and the electroplate, the design of this area of the equipment is critical.

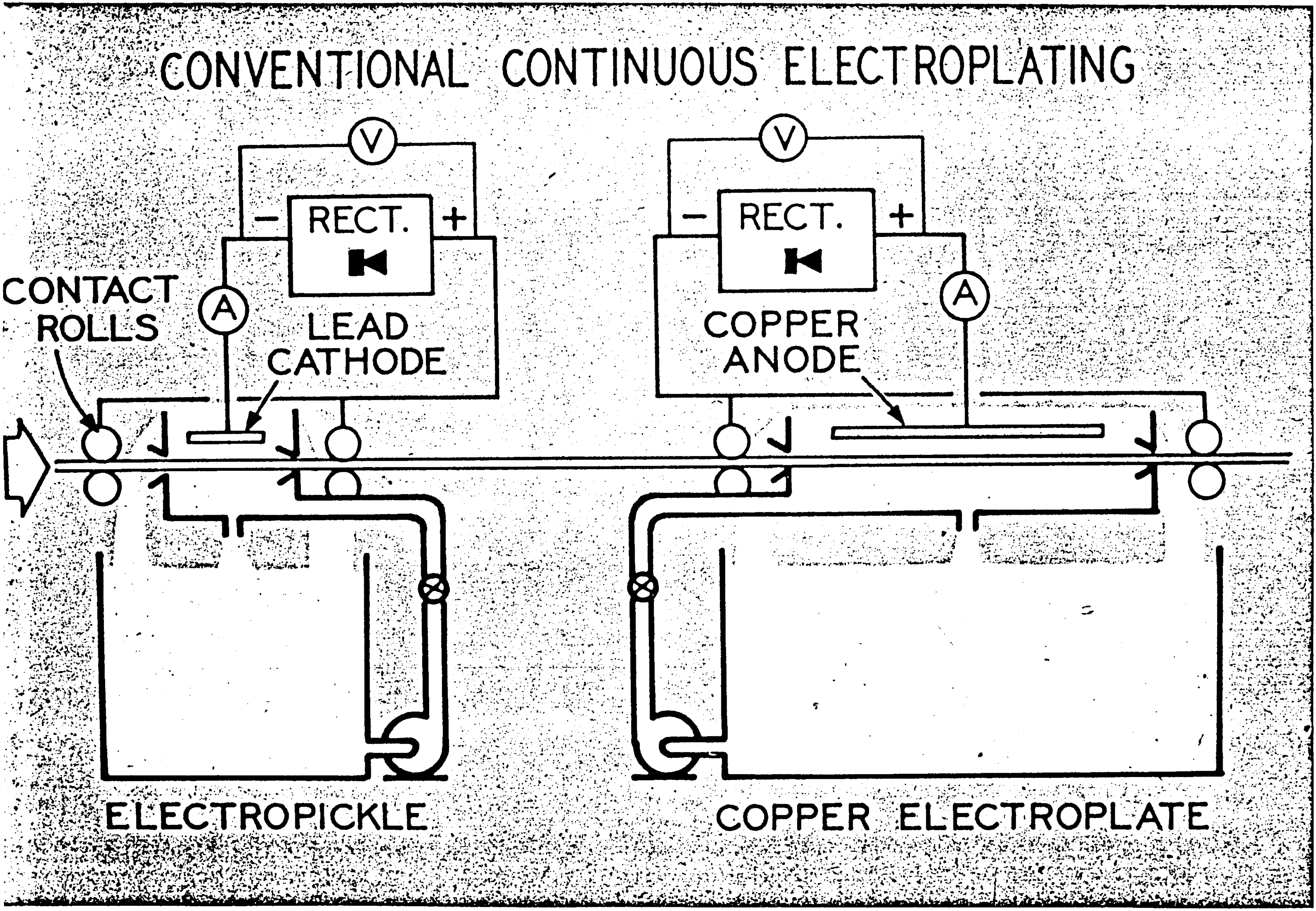
The machines we have constructed have used a unitized tank system with common walls. This can keep the cell-to-cell distance to approximately 24"-36". This requires vigorous rinsing in the space available. We have accomplished this using air blow-offs and high velocity nozzles throughout the machine. This is illustrated in drawing #3.

The solutions are recirculated from the reservoir tanks through the nozzles, flooding the trough, and are allowed to flow by gravity back to the reservoir tanks. This vigorous agitation of the surface allows higher current densities.

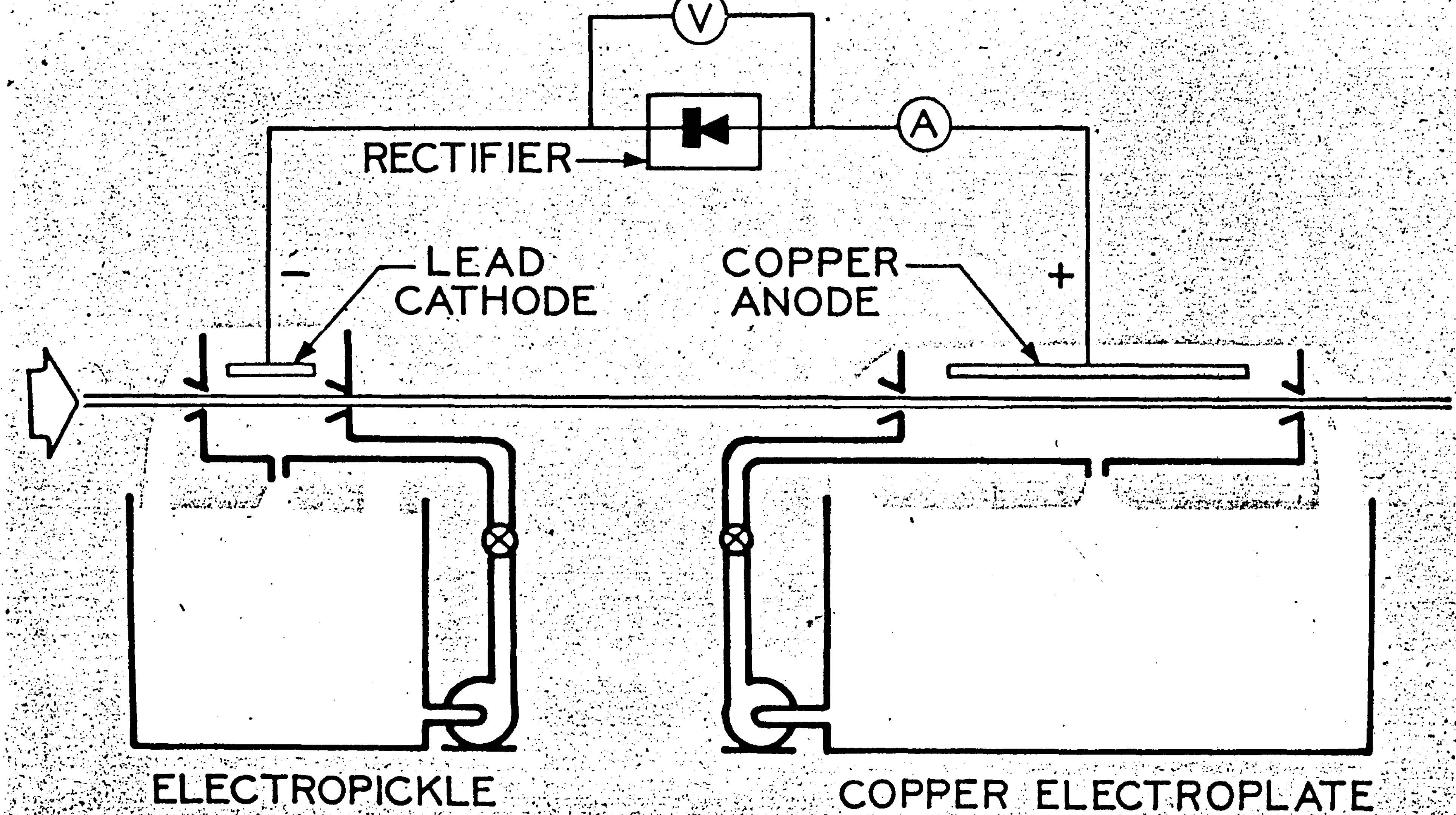
This plating system can use consumable anodes such as zinc and/or copper slugs, or non-consumable electrodes such as lead or carbon.

There are presently five of these machines performing copper or zinc plating on tubing. When the plated stock is coated with hot dip metal, the plating is followed by a separate flux station. Machines containing a final rinse section are 20-25 feet long by 4 feet wide by 4-4 1/2 feet tall, while those without these sections are only 12-15 feet long. These units are operating at speeds up to 500 ft./minute. The maintenance of these machines has proven to be minimal. Several of these machines are over ten years old, the oldest being fourteen years old. A new machine for electrofluxing is presently on our floor and will be delivered soon.

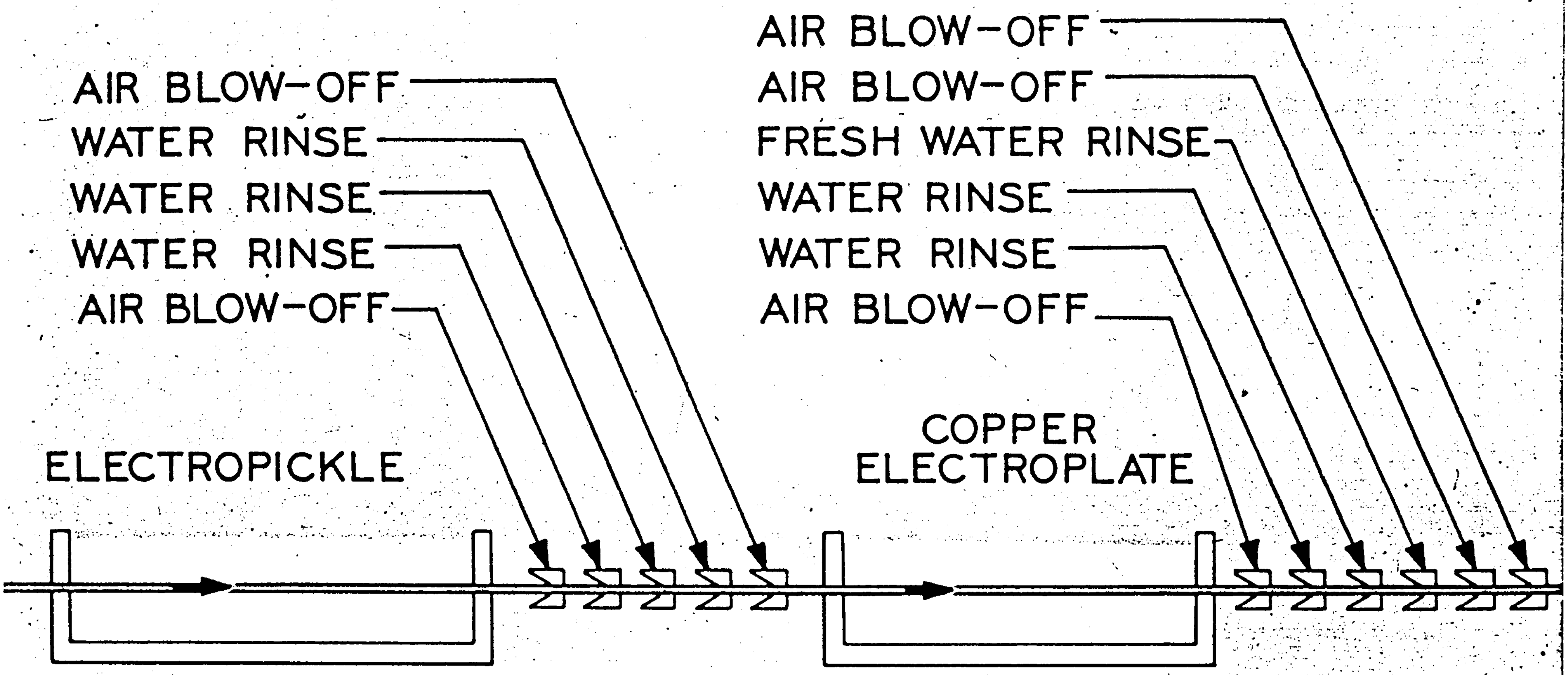
This concept is obviously applicable to copper plating, zinc plating and electrofluxing. We have also constructed an electropolish machine for stainless steel and a 60" wide zinc plate strip line, all using the dipolar concept. The concept can also be used for a dual-electrolytic anodic/cathodic electrocleaner system, or anodic / cathodic acid pickel for heavy scale removal or stock reduction.


CONVENTIONAL CONTINUOUS ELECTROPLATING
V
RECT.
−
+
CONTACT ROLLS
A
LEAD CATHODE
V
RECT.
−
+
A
COPPER ANODE
ELECTROPICKLE
COPPER ELECTROPLATE

CONTINUOUS DIPOLAR ELECTROPLATING



TUBING COPPER PLATER



BUSCH INTERNATIONAL 904 MT. ROYAL BOULEVARD • PITTSBURGH, PA 15223-1061 • 412/487-4131 • FAX 412/487-7106
DIVISION OF BUSCH CO.

JET*STAR STRIP COOLER

JET*STAR Strip Coolers are the most efficient means to air cool strip in the metals industry. JET*STAR has been designed to cool heavier gage strip with thicker coatings at higher strip speeds with less energy than other methods used for air cooling. In retrofit applications, JET*STAR will reduce the length of the cooling zone and lower strip outlet temperatures.

JET*STAR's performance superiority over other types of coolers is shown by the enclosed graph of strip speed as a function of strip thickness. In addition, JET*STAR provides an extremely high cooling rate which is critical for optimum GALFAN quality. This is demonstrated by the graph of average cooling rate as a function of strip speed.

During development of JET*STAR, experimental models were built to study aerodynamically induced instability of vertical strip. Tests were also run to determine the heat transfer film coefficient generated by JET*STAR over a wide range of conditions.

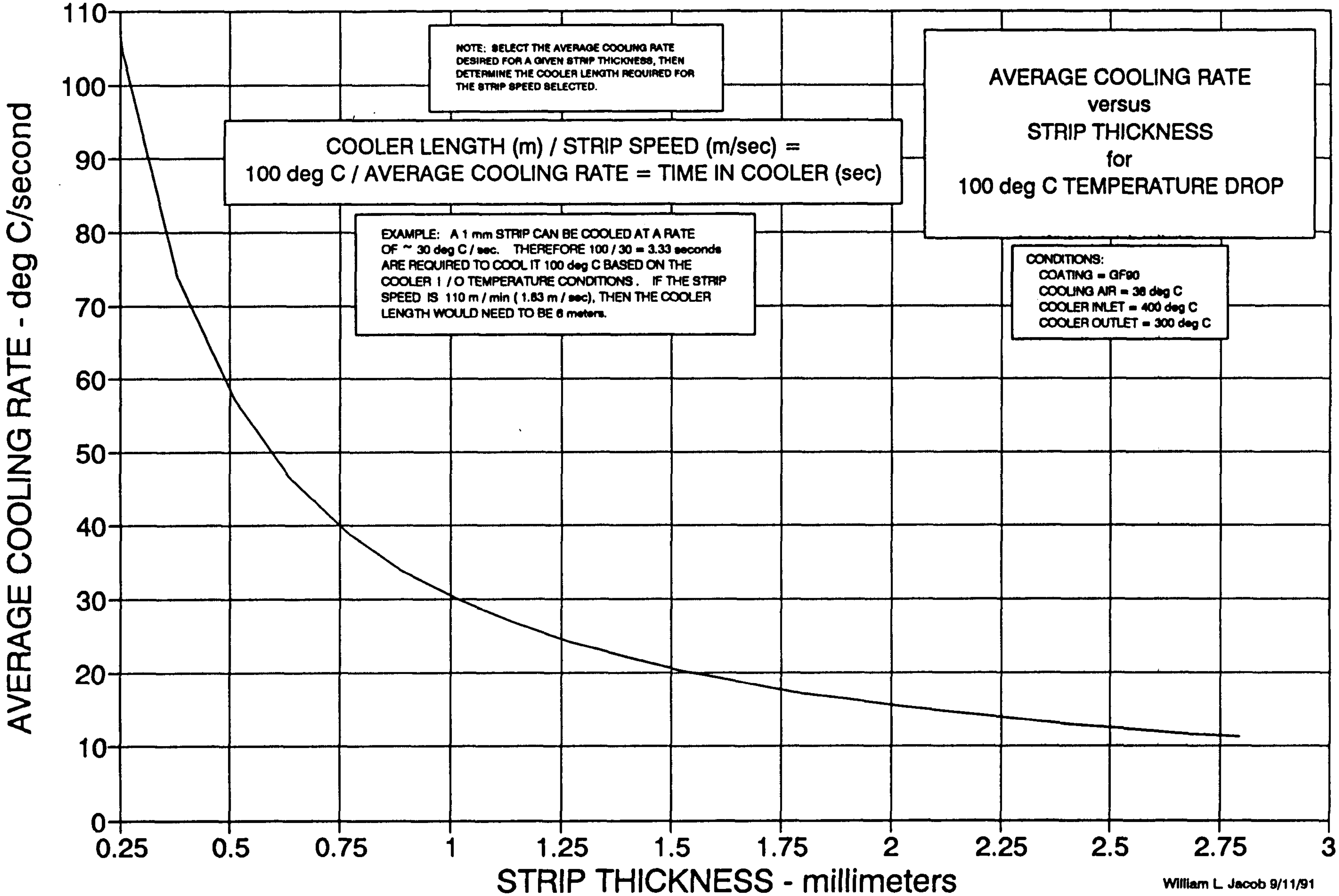
In testing strip instability, we simulated problems frequently encountered in the industry and considered strip thickness, width, length, tension, and uniformity of tension. These tests also included the effects of crossbow. The JET*STAR design allows the use of a strip stabilization technique which puts a strip into an aerodynamically produced force field. This minimizes flutter of strip having uniform or near-uniform tension. In the case of non-uniform tension, JET*STAR tends to correct strip-to-cooler attachment and strip flapping problems.

By design, JET*STAR eliminates the loss in thermal efficiency associated with crossflow and reentrainment of spent air. This system will also reduce thermal contamination from the holding and alloying furnaces located under the cooler. JET*STAR Coolers are usually placed 10" from the strip. This facilitates maintenance as well as strip observation during operation.

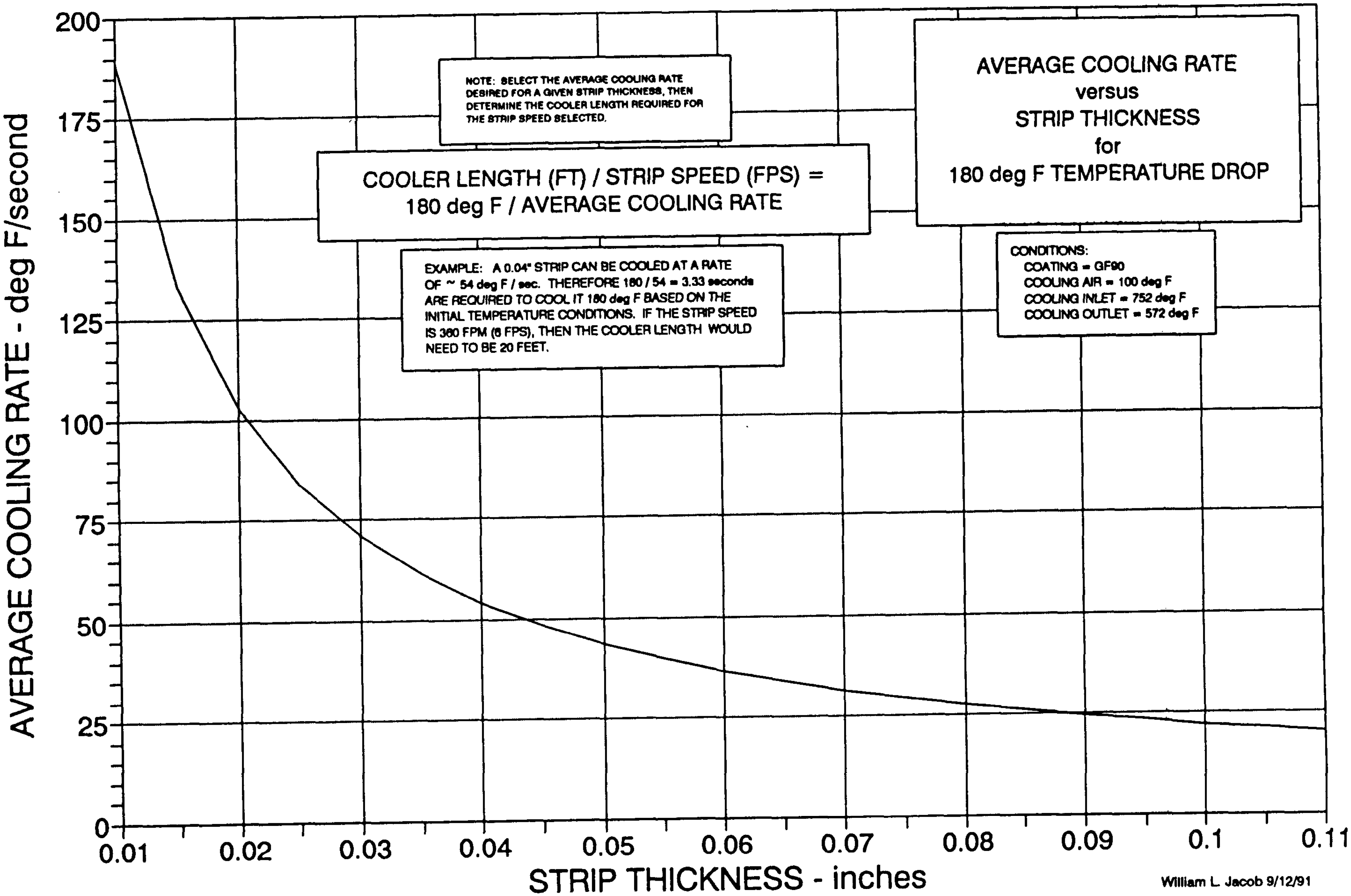
JET*STAR can be provided with either filtered and ducted supply systems or without duct as separate modules consisting of cooler and attached air-mover. Acoustic properties of these units are within commonly accepted industry guidelines.

Busch International's test set-up is available for use in determining JET*STAR performance based on customer selected preconditions such as cooler-to-strip spacing, cooling air velocity, cooling air temperature and one-sided strip cooling.

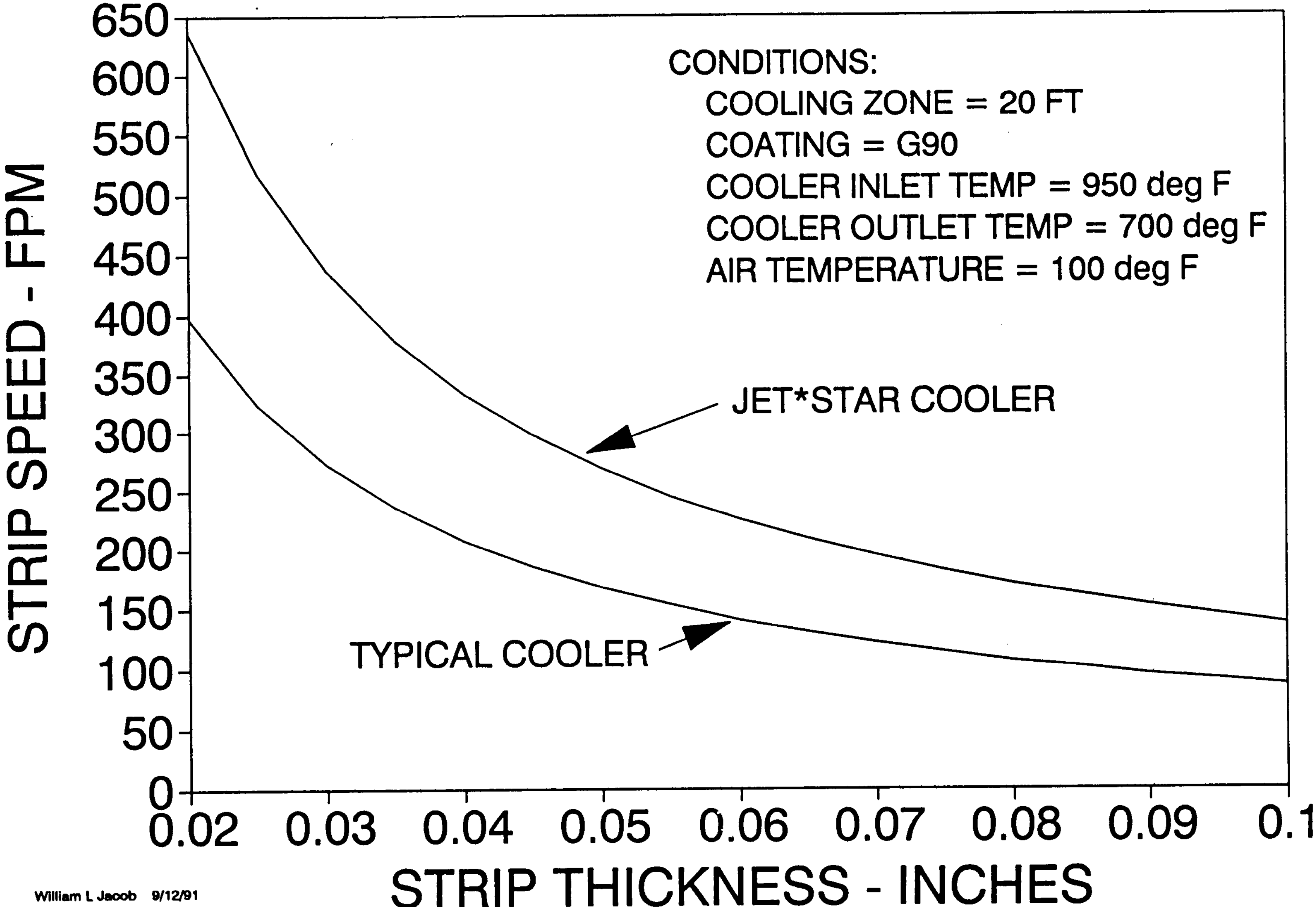
BUSCH INTERNATIONAL
JET*STAR COOLER PERFORMANCE



BUSCH INTERNATIONAL
JET*STAR COOLER PERFORMANCE



COOLER PERFORMANCE



William L Jacob 9/12/91
BUSCH INTERNATIONAL