INTERNATIONAL LEAD ZINC RESEARCH ORGANIZATION, INC.

GALFAN TECHNICAL RESOURCE CENTER

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MEMORANDUM

TO: All Galfan® Sheet Licensees

FROM: John L. Hostetler, P.E., Director
Galfan Technology Centre

DATE: 27 February 1996

SUBJ: Addendum to 20th Sheet Licensee Meeting Proceedings

Enclosed you will find a two-page presentation made by Vernon John during the Sheet Licensee Meeting in Chicago, Illinois on September 22, 1995.

At the time the proceedings were published, this material was not available and therefore not included in the proceedings. Please add Mr. John's presentation to your copy of the proceedings.

Thank you.

JLH:ja

Encl.

British Steel | Strip Products

Welsh Technology Centre

AN ASSESSMENT OF NON-CHROMATE CONTAINING PRIMERS FOR PREPAINTED STEEL

The growing international concern over the carcinogenic effects of hexavalent chromium has meant that research into finding alternative pigments that are environmentally acceptable must be intensified. As the environmental pressures continue to increase, it is conceivable that the future use of chromium in pretreatments and primers will be restricted or even prohibited.

Since the coil coating industry consumes a considerable portion of the total output of steel strip, it is in the interest of the steel industry world-wide to ensure that the coating industry is in a position to respond to any future legislation.

An exterior weathering programme on non-chromate systems started in 1990 and the weathering of the non-chromate pretreatments and primers on Galfan and Galvalume are showing trends in performance after 2 years of exposure. On Galfan, the non-chromate systems were found to be slightly better than the chromate control with a borate-based pigment performing consistently well. This, however, was not the case on Galvalume where a high chromate containing primer and pretreatment were needed to provide adequate edge corrosion resistance.

The accelerated corrosion performance for the pretreatment/primer combinations on Galfan differed greatly from the exterior weathering results. In the accelerated tests, an organic zirconium-based pretreatment was found to be a better pretreatment than a silicate-based pretreatment and the standard chromate. The borate-based pigmented system which was the best primer at Rye , England did not perform very well in the laboratory corrosion tests. An explanation for this difference was found in the electrochemical studies where the performance of borate-based pigment was seen to be dependent on the environment.

The accelerated performance of the Galvalume sample, however, emphatically showed that a high chromate pretreatment and primer is required for good cut-edge resistance. This was in accordance with the exterior weathering results.

Electrochemical studies into the interaction between the substrate and the pigment have shown most of the non-chromate pigments to be anodic inhibitors. Each of these pigments dissolve partially in an aqueous electrolyte to provide a passive film on the substrate. The only non film-forming pigment was an aluminium silicate-based pigment. This was found to be a mildly acidic pigment which neutralises the hydroxyl ions produced from the cathodic reactions. It, therefore, acts as a cathodic depolariser.

V. JOHN

GTC 95-031

GALFAN®
IMPROVED GALVANIZING

20th
SHEET LICENSEE MEETING PROCEEDINGS

Chicago, Illinois USA

September 22, 1995

Sponsored by

International Lead Zinc Research Organization, Inc.
Galfan Technology Centre
Research Triangle Park, NC USA

SHEET LICENSEES MEETING PROCEEDINGS

TABLE OF CONTENTS

AGENDA

20th Galfan Licensees Meeting
Sheet/Alloy Licensees

Dinner

Thursday, September 21, 1995
LaSalle 5 - Palmer House
7:30 - 9:30 p.m.

Technical Session

Friday, September 22, 1995
Dearborn 1 Room - Palmer House
8:30 a.m. - 12:30 p.m.

AGENDA

8:30 a.m.	Welcome	*J.L. Hostetler, GTC*
8:40 a.m.	Galfan Status Report	*J.L. Hostetler, GTC*
9:00 a.m.	Chrome-Free Passivation	*V. John, British Steel*
9:30 a.m.	Mischmetal Solubility & Reactions in Galfan	*N-Y Tang, Cominco*
10:00 a.m.	**Coffee Break**	
10:15 a.m.	Proposal to Catalog ASTM Standards	*F.E. Goodwin, ILZRO*
10:30 a.m.	Summation of Work to Develop Dent-Free Galfan	*F.E. Goodwin, ILZRO*
10:45 a.m.	Proposal for Continuing Development of Dent-Free Galfan	*F.E. Goodwin, ILZRO*
11:30 a.m.	Galfan Start-Up on BSC #6	*F.G. Williams, British Steel*
12:00 noon	Other Agenda Items • Electronic Files for Galfan Data • Life Cycle Analysis - Is it Good for Galfan? • Publications	*J.L. Hostetler, GTC*
12:15 p.m.	**Adjournment**	
	GTC Unitholders Meeting • Elect Members of Research Committee	
12:30 p.m.	**Lunch**	
1:30 p.m.	**GTC Research Committee**	*F.E. Goodwin*

Minutes of the

GALFAN® SHEET LICENSEE MEETING

September 22, 1995

ATTENDEES:

Name	*Company*
Bechem, W.	BREGAL
DuBois, M.	Cockerill Sambre
Feron, S.	R&D Cockerill Sambre
Goodwin, F.	ILZRO
Hammerton, R.	Weirton Steel
Hostetler, J.	Galfan Technology Centre
John, V.	British Steel Welsh Technology Center
Kawanishi, Y.	Sumitomo Metal Industry
Kelly, B.	Weirton Steel
Kolisnyk, P.	Cominco
Malmgreen, J.	Eastern Alloys
Pankert, R.	Union Miniere
Peltolc, A.	Rautaruukki Oy
Pesonen, J.	Outokumpu
Quantin, D.	Sollac
Rourke, D.	Noranda
Sivula, J.	BREGAL
Skubick, S.	Eastern Alloys
Tang, N-Y	Cominco, Ltd
Warnecke, W.	Thyssen Stahl AG
Williams, G.	British Steel Shotton Works

The 20th Galfan Sheet Licensees meeting was held following Galvatech '95 for the convenience of the licensees. The schedule offered limited time but still allowed several important papers and discussions of them.

GALFAN AND GTC STATUS REPORT

Mr. Hostetler reported the present status of Galfan and of GTC. The full report is included herein.

The importance of complete and accurate production reporting was stressed by Mr. Hostetler. It becomes increasingly more important to have reliable production information to benefit the Galfan program and its licensees as well as for promotion and media release. He stressed again the confidentiality of individual licensee data; that only category, regional and world-wide information will be released.

Some licensees have resisted supplying the requested production data. Although ILZRO has not enforced compliance as called for in the license agreement, it will become a more serious matter with ILZRO.

Galfan's growth will be influenced by the various ASTM, Euronorm and JIS specifications. It will become increasingly important that channels for impacting and influencing the standards and specifications be established and managed.

The role of GTC as shown on Figures 3 and 4 in the written report was explained in some detail. Perhaps the most difficult change to establish is that research must be funded from income derived from the sale of new licenses.

CHROME-FREE PASSIVATION

Vernon John, Senior Research Officer, Coated Products, British Steel Corporation, presented a progress report on the work British Steel is doing as part of a research project sponsored by the European Coal and Steel Community. A previous progress report was made at the 17th Galfan Licensee meeting in Tokyo, October 1992.

Mr. John commented that inspections of the panels exposed outdoors show the chrome-free to be more effective on the Galfan substrates than on the regular galvanized substrates. Mr. John's paper was not available at the time these proceedings were published but several graphs from his presentation are included herein.

MISCHMETAL SOLUBILITY & REACTIONS IN GALFAN

N.Y. Tang, Senior Research Metallurgist, Cominco presented a paper previously distributed to the members of the Galfan Bath Management Task Force (GBMTF). Dr. Tang's work was done in conjunction with the GBMTF using samples supplied by them.

The paper is the property of the GBMTF and is not included in these proceedings. There was considerable discussion that led to the conclusion that more investigation of the functions and benefits of the mischmetals was needed - particularly in terms of bath management.

STANDARDS AND SPECIFICATIONS

A large segment of Galfan's market is covered by standards and specifications. It is increasingly difficult to sell into markets that have standards and specs for other metallic coatings but have none specifically for Galfan or at least for Zn - 5% Al alloys. Selling Galfan against a specification calling for a minimum mass/unit area of zinc often creates a non-competitive situation.

GTC had asked for proposals to develop a program that would aggressively pursue monitoring the major specifications such as ASTM, Euronorm and JIS and further, to nominate new specifications or revisions to existing ones that would better serve the interests of Galfan and its producers.

No such comprehensive proposal was received. Lynch and Associates did however respond with a broad general proposal including a proposal for a contract to investigate the costs and to then prepare a plan. GTC declined to consider such an arrangement but decided in favor of a multi-phase plan.

The first phase of the GTC plan is to identify all existing ASTM, Euronorm and JIS specifications relating to Galfan and to index them along with a short abstract. The index would be published and distributed to the licensees as the second phase with a questionnaire asking for pertinent comments, nominations for new specifications, etc.

GTC would then plan the third phase that would include preparation of a Request for Proposals for the fourth phase which would be to identify contact persons and committees that control the changes in existing specifications or acceptance of the nominations for new ones.

Lynch and Associates was invited to submit a proposal for Phase I. That proposal was presented to the meeting by F.E. Goodwin, Chairman of the GTC Research Committee.

GTC PROPOSED GALFAN SPECIFICATIONS PROGRAM

Phase	Description	By Whom
I	Identify and index all existing ASTM, Euronorm and JIS specifications relating to Galfan.	*Selected Contractors*
II	Publish the index of specifications complete with abstracts and notes. Prepare questionnaire to go with index soliciting nominations, comments, suggestions and application by Galfan licensees.	*GTC and Licensees*
III	Prepare comprehensive program to monitor specifications and nominate changes and additions.	*GTC and Licensees*
IV	Prepare Requests for Proposals from contractor to carry out the program developed in Phase III.	*GTC and Research Comm.*
V	Manage the program and report progress to GTC.	*ILZRO*

DENT-FREE GALFAN FOR SHEET

Prepainted Galfan is the largest single product category (tonnage) in all of the three market regions. It's constant improvement therefore must be given high priority and attention.

The most significant improvement to be considered now is the elimination or reduction in the depth of dents that appear at triple-points on the heavier Galfan coatings. Experience has shown that "mini-spangle" and "skin-passing" are satisfactory for the lighter coating weights and thus high-quality Galfan sheet for pre-painting is available from many of the licensees.

Resolution of the dent defect by other process controls is desirable because mini-spangle control is difficult and skin-passing is costly at best and not available at worst.

NOMINATED RESEARCH PROJECTS

Discussions relating to various areas of Galfan characterization and production produced a list of nominated research projects.

The 6 October memorandum from Dr. F.E. Goodwin lists those projects. Mr. Hostetler reported his expectations for new license income by year's end would allow the Research Committee to proceed with one or more of the projects.

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A Report on

THE STATUS OF GALFAN AND GTC

to the

GALFAN SHEET LICENSEES
The Palmer House Hotel, Chicago, IL
Sept. 22, 1995
by
John L. Hostetler

A one-word Galfan status report would be 'maturing.'

The three million tons of steel protected better by Galfan since it was introduced in 1983 moves it out of the 'new coating' category. It is interesting to compare the first eleven years of Galfan production (1983-1994) with Galvalume's first 11 years (1972-1983) as shown in Figures 1 and 2.

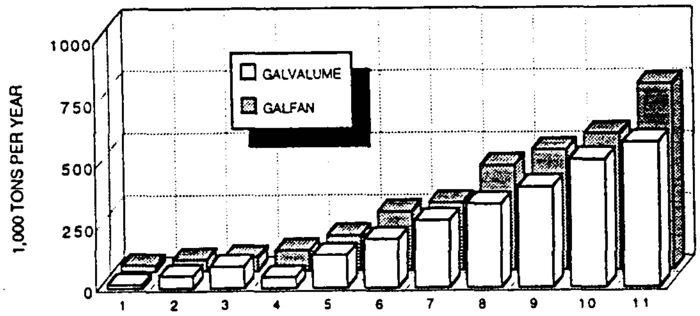


FIG 1 COMPARING PRODUCTION OF GALFAN AND GALVALUME IN EACH OF FIRST 11 YEARS

Our experience in continuously coating sheet, wire and tube with Galfan forms a body of technology and technical information that can assure good results both for first-time users and first-time producers .

Galfan appears in more and more specifications written by architects and engineers for their clients as well as by manufacturers and converters.

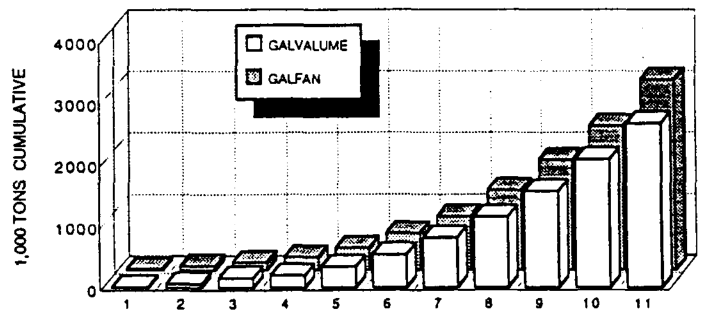


FIG. 2 COMPARING PRODUCTION OF GALFAN AND GALVALUME CUMULATIVE DURING FIRST 11 YEARS

Galfan is well-positioned to move from the development stage to the more mature phase of gaining market penetration for applications where it outperforms other metallic coatings. A product or technology moving from one phase into another calls for changes in the *modus operandi* just as moving from one stage of life into another calls for an adjustment in attitudes and lifestyles.

The original search for Galfan was motivated by the threat of losing zinc sales to Galvalume®. Increased zinc sales is still the objective but today's and tomorrow's strategies and tactics have to be different than those of the early years to be effective. The threat from Galvalume was real then and, in most areas, it is even more so today.

ILZRO is an important part of the zinc industry. Its function is to target and manage research that leads to increased use and sales of zinc. The list of current ILZRO-managed projects and its worldwide recognition are signs of its success. One of ILZRO's major contributions to that end has been the critical research in the early 1980s that led to the invention of Galfan and the development of its growth.

Figure 3 shows the relationship of GTC to the zinc industry through ILZRO as well as GTC's tactical program that is to create and transfer Galfan technology, generate income to fund needed Galfan research and development and teach and promote constant improvement of Galfan products.

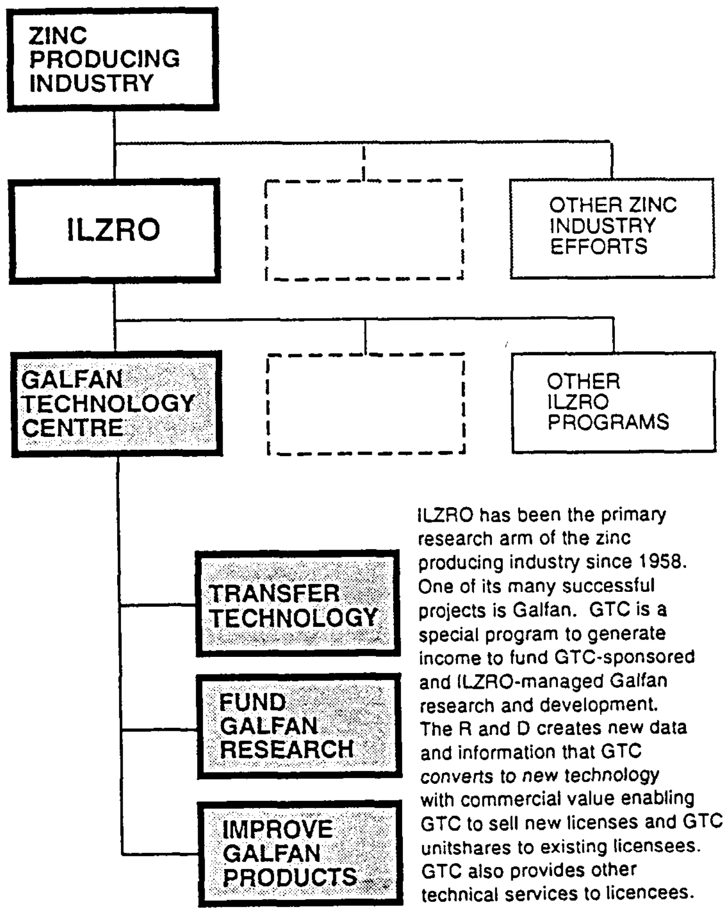


Figure 3

Galfan is now commercialized and able to create sales and profits for its licensees. Objectives for the investment by ILZRO owners in that early research have been accomplished. We find however, that this new phase requires still more research to prevent serious loss of zinc sales to Galvalume. One reason is that Galvalume's aggressive promotional activities create the perception that regular galvanizing is totally inadequate.

The focus must now be on continual process and product improvement rather than the search for basic knowledge because end users are raising the quality and performance standards. The alloy has been optimized. We need now to exploit every possible application where it enhances the image or use of zinc coatings.

Funds to pay for the research must come from new sources. ILZRO has changed the management of the Galfan program from the *reactive* Galfan Technical Resource Center (GTRC) to the more *proactive* Galfan Technology Centre (GTC) so that it can create the needed funding.

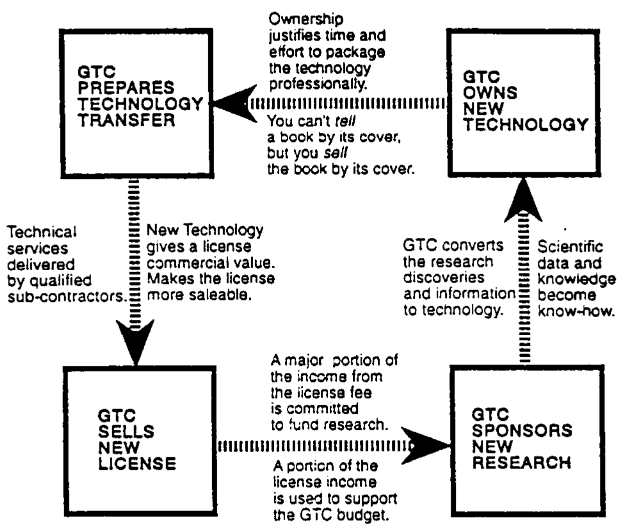


FIGURE 4 GTC IS THE SOURCE OF FUNDING FOR NEW GALFAN RESEARCH

Another way of looking at GTC's plan can be seen in Figure 4. It shows a simple closed-loop plan starting with the sale of a new Galfan license to

⇓

collect new license fees that fund new research to

⇓

create new technology to

⇓

make it easier to sell another new license, etc.

Licensees can stay updated with all new technology each year by buying a GTC unitshare, thus becoming a GTC unit-holder and co-owners of the technology.

The Galfan Sales Representatives and Galfan Technology Transfer Contractors are an important part of the plan because they give GTC the advantage of a field support presence without the cost of a large staff.

1994 Galfan Production

Three regions are actively producing significant tonnage of Galfan; Europe, Japan and North America. Japan has been the dominant region but as Table One and Figure 5 show, Europe became the largest in 1994. The forecasts show Europe will continue a rapid rate of growth while Japan remains more or less flat. This may be more the result of differing forecast policies because we know of no reason why the Japan region will not continue to grow as before. Forecasts and production data are based on information available from licensees . More complete reporting is needed for accuracy's sake.

FIG. 5
1992-1999 GALFAN PRODUCTION BY REGION

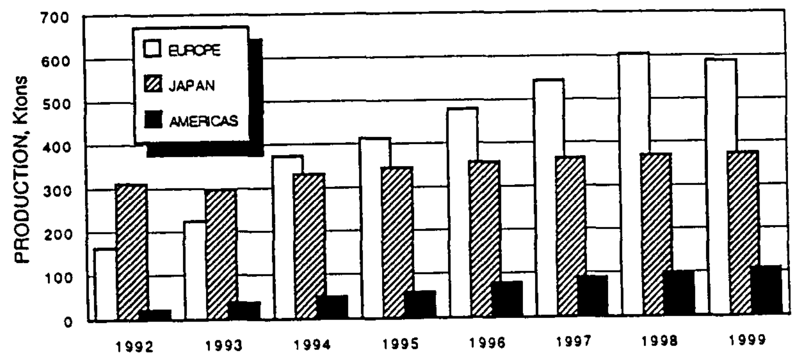


TABLE ONE

1994 GALFAN PRODUCTION ANALYSIS

BY PRODUCT TYPE		BY MARKET REGION	
TYPE	TONS	REGION	TONS
Sheet	694,500	Europe	372,400
Wire	36,400	Japan	330,800
Tube	21,400	Americas	49,100
Total	752,300	Total	752,300

Galfan licensees reported 752,300 metric tons of steel galvanized with Galfan in 1994 as shown in Table One.

The distribution of Galfan products by market type has changed slightly from the previous reports.

Figure 6 shows a higher percentage of Galfan sheet was sold to the appliance market. Pre-painted Galfan sheet for architectural panels continues to be the largest single segment but with unpainted architectural (and construction) not far behind.

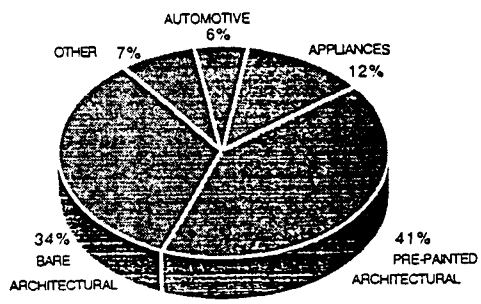


FIG. 6
1994 GALFAN SHEET PRODUCTION

Production of Galfan-coated wire is about equally divided between fence and wire rope at 35% each with utility, automotive and 'other' accounting for the balance. All of the Galfan tubing is small diameter ERW and is produced for the North American automotive market.

Changes in the Galfan License

The main assets of the Galfan license from 1982 through 1994 was the right to use the ILZRO patented alloy and the registered trademark. The main assets now offered in the license are Galfan technology and the right to use the trademark. Before the license was in effect until the ILZRO patents expired in the licensee's country; now the license is in effect for ten years with an automatic renewal for five years unless either party chooses to terminate it.

The Galfan license has been granted to a specific production line since 1983. Although there were several companies operating more than one licensed line by 1992, GTRC was reporting and accounting for licenses by *companies* rather than by production lines until 1993.

Table Two shows the licensed lines as of July 1995 by market region and license category. It represents an increase of 20 licensed lines since May 15, 1993, as follows:

Alloy:	1
Sheet:	6
Wire:	4
Tube:	8
Parts:	1

TABLE TWO

GALFAN LICENSE STATISTICS AS OF JULY 1995

NUMBER OF LICENSED PRODUCTION LINES

MARKET REGION	LICENSE CATEGORY					TOTAL
	ALLOY	SHEET	WIRE	TUBE	PARTS	
Asia*	0	2	0	0	0	2
Australia	1	2	2	1	1	7
China	1	0	1	0	0	2
Europe	7	17	6	0	0	30
India	0	3	0	0	0	3
Japan	6	7	1	1	0	15
N. America	6	6	4	15	0	31
S. America	0	0	2	0	0	2
Other	1	1	0	0	0	2
TOTAL	22	38	16	17	1	94
Active	8	19	10	15	1	53
GTC	5	9	7	7	1	29

* Not including China and Japan

Table Three shows the projected licensed lines by the end of 1996 and Table Four shows the difference between July 1995 and the end of 1996. It shows that more than half of the new licenses will be granted in North America where present sheet and wire production is limited to one producer each.

TABLE THREE

GALFAN LICENSE STATISTICS PRO-FORMA AS OF YEAR END, 1996

NUMBER OF LICENSED PRODUCTION LINES

MARKET REGION	LICENSE CATEGORY					TOTAL
	ALLOY	SHEET	WIRE	TUBE	PARTS	
Asia*	0	4	0	0	0	4
Australia	1	2	2	1	1	7
China	1	1	2	0	0	4
Europe	7	17	7	1	2	34
India	0	3	0	0	0	3
Japan	6	7	1	1	0	15
N. America	7	8	7	17	1	40
S. America	0	0	2	0	0	2
Other	1	1	0	0	0	2
TOTAL	23	43	21	20	4	111
Active	9	23	14	19	4	69
GTC	6	16	13	8	4	47

*Not including China and Japan

TABLE FOUR

GALFAN LICENSE STATISTICS CHANGE: JULY 1995 to END of 1996

NUMBER OF LICENSED PRODUCTION LINES

MARKET REGION	LICENSE CATEGORY					TOTAL
	ALLOY	SHEET	WIRE	TUBE	PARTS	
Asia*		2				2
Australia						0
China		1	1			2
Europe			1	1	2	4
India						0
Japan						0
N. America	1	2	3	2	1	9
S. America						0
Other						0
TOTAL	1	5	5	3	3	17
Active	1	4	3	4	3	15
GTC	1	7	6	1	3	18

*Not including China or Japan

Existing Galfan automotive tubing lines are running at near-capacity. Increased demand in North America during the next period will be satisfied by existing line upgrades and two new lines. GTC is working closely with one of the major world-wide automakers to write specifications for all tubing fabrications for all their models in all of the world. This requirement alone will need the output of six to nine new high-speed production coating lines to satisfy the demand.

The Delot process, originally designed to galvanize re-bar in a horizontal passline, may be an important new technology for Galfan tubing. It may be the process that allows us to introduce Galfan automotive tubing into Japan and Europe where more reliable process control is required. The process will be introduced to the tubing licensees at their meeting in Detroit on Nov. 28, 1995.

GTC also expects to introduce automatic batch-dipped Galfan auto parts into Europe. A research effort involving two different kinds of spin-part Galfan galvanizing is also scheduled for completion in 1996.

Five sheet galvanizers are in the 'serious negofiating' phase in China and Southeast Asia. GTC expects to license three of them in this period as well as two in North America.

Income from these seventeen new licenses by the end of 1996 is projected to be about $1.5 million out of which GTC expects to provide funding for about

$600,000 in Galfan research. Disbursement of projected income from the new licenses is shown in Figure 7.

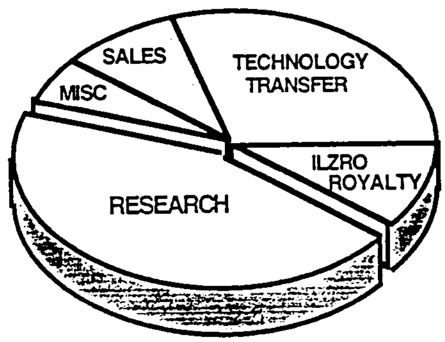


FIG. 7 DISTRIBUTION OF NEW GALFAN LICENSE INCOME

Sales are commissions paid on sales to the Galfan License and Sales representatives. *Technology Transfer* includes:

(a) initiation fees paid to GTC,

(b) payment for one year's GTC unitshare and

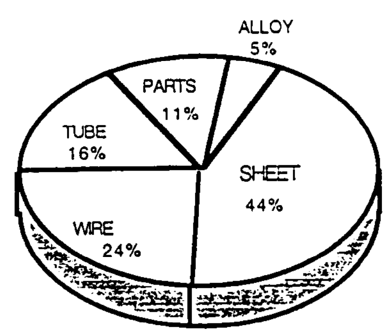
(c) fees paid to the Galfan Technology Transfer Contractors.

Misc. includes advertising and legal fees to defend patents and trademarks.

GTC's operating budget is funded by the income from GTC unitshares and from the initiation fees taken from new license fees.

Prioritizing the proposed research and development projects will not be easy for the Research Committee. Data such as shown in Figure 8 however, will serve as a guide for them in recognizing the category sources generating the funds. There will be an attempt made to allocate the funds by category on the same ratio as the income by category.

FIG. 8



INCOME % BY LICENSE CATEGORY
1995-1997 GALFAN LICENSES

New Publications

GTC is preparing several new publications that are badly needed to support licensees' sales and marketing efforts. These include:

Comparing Regular Galvanizing, Galfan and Galvalume for Pre-painted Sheet. This publication will summarize the published work from Progress Reports, Licensee reports and other sources that have made controlled comparisons of the coatings is accelerated and long-term corrosion tests. Availability: Dec. 1995.

Galfan-coated Tubing for Automotive Applications. This work is justified by the likelihood of 25 to 30 new production lines in Europe, Japan and North America from 1996 to 1999. GTC will use this publication in their role to provide technical assistance to the automakers who want to write tests and specifications for better corrosion-resistant tubing. The publication will include new coating technologies and control variables for the commonly used processes on the different types of Galfan production lines. Availability: Early 1996.

More work on *Life Cycle Cost for Galfan Products,* especially unpainted Galfan sheet and Galfan wire products will be developed emphasizing the benefit that a small premium first cost for a Galfan product will pay back large savings in the long-term. Availability: Spring 1996.

MEMORANDUM

TO: ZCO-5 File

FROM: Frank E. Goodwin
Vice President, Materials Sciences

DATE: 6 October 1995

SUBJ: Research topics to be developed into summary plans relating to Galfan

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1. Standards - Thickness-based rather than weight-based. Prove this on a technical basis.

2. Use of Galfan in housing framing.

3. Mischmetal solubility - minimum required and maximum where dross becomes a problem.

4. Bath Management Task Force - survey and review of techniques for operation.

5. Denting - development of a depth measurement technique. Survey of producers.

6. Long term corrosion behavior on painted, unpainted and formed material.

7. Study of lead limits, effects of intergranular corrosion at 100 ppm, benefits of lowering lead levels. Review current knowledge.

8. Slitting powder problem. Identify plans of Cockerill Sambre; determine problems with Zn/Al coatings.

cc: JLH

LABORATORY EXPERIMENTS WITH INDUSTRIAL GALFAN COATED STEEL SHEETS

Summary of a visiting scientist programme at
Lehigh University

Werner Maschek

Department of Materials Science and Engineering
Lehigh University
Bethlehem, Pennsylvania

Feb. 1995

INTRODUCTION

In continuation of the Galfan project "Development of Smooth Surface Galfan for Coil Coating Applications" the aim of this work was to figure out some practical features based on the PhD thesis of Scott Bluni. In a brief proposal it was established to perform a study of industrial galfanized material, by remelting the Galfan coating on the Gleeble HAZ 1000. The study was splitted in three sections:

(1) Study of the reaction behavior at the steel/coating interface

(2) Studying the effect of the cooling rate on the solidification behavior of the Galfan coating without any extensive interface reaction

(3) Studying the effect of introducing nucleation agents on the molten Galfan surface

EXPERIMENTAL

MATERIAL

Four different galfanized materials were received from the industry (Cockerill Sambre - CS and Voest Alpine - VA). The specification and the production data of these materials are given in Table I, as far as they were known. Included in Table I is the roughness of the steel substrate and the coating weight determined by Cockerill Sambre. Two of the samples, CS and VA2 were mainly used in this work.

GLEEBLE SIMULATION PROCESS

For Gleeble simulation the as received materials were cut into samples, 230 x 50 mm, using a table shear. Two thermocouple weld spots were etched onto the surface using hydrochloric acid, so that the thermocouple wires could be fixed directly to the steel surface by percussion welding. The thermocouple wires were welded at the top (labeled) side of each sample as shown in Figure 1. Only the shaded region between the thermocouples was used for analyzation. Different temperature profiles programmed on the Gleeble were performed, whereby the measured temperature in general did follow the given profiles, although always an overshot of 10-15^{o}C at the peak temperature was estimated. The difference between both measured temperatures was usually less then 10^{o}C. The opposite side of the sample was used for analyzation, because it was found that the etching process also influences the surrounded area of the Galfan coating surface. The programmed and measured Gleeble data for all specimens are given in Table II.

SAMPLE ANALYSIS

Most of the performed samples were analyzed in cross section and at a surface view. For cross section analysis up to five specimens (20 x 10 mm) were stuck together to an assembly and mounted in epoxy. The metallographic procedure used for sample preparation is described elsewhere [1]. All cross section specimens were etched in a 1% nitric acid in amyl alcohol solution, which was found to work statisfying for both the resolution of the Galfan microstructure and also for the intermetallic phases at the interface. The etching time was 10s. For surface analysis specimens (20 x15 mm) were mounted planar in epoxy, and the same metallographic preparation technique as for cross section specimens, starting at a 600grit SiC paper was used. The planar view samples were etched in a mixture of hydrchloric acid and water (1:3) to reveal the Galfan microstructure.

The analysis of the prepared samples was performed with some modifications in the same way as described by Bluni [2]. Again both, manual image analysis (Donsanto digitaliztion path in combination with Nikon Photomat light optical microscope) and automated image analysis (Leco 2001 system) were used.

SEM, EDX and EPMA analysis of intermetallic phases locally detected at the interface were performed on a selected sample. The micropropbe (Jeol 733 Superprobe) was operated at 15kV with a beam current of 20mA.

RESULTS AND DISCUSSION

ANALYSIS OF AS-GALFANIZED MATERIAL

The results of the analysis of the as-galfanized materials are shown in Table III. The results in general support the trends found by Bluni [2]:

-) As coating thickness $\Uparrow$ percentage denting $\Uparrow$ and also percentage dented grain boundary $\Uparrow$.

-) As percentage proeutectic phase $\Uparrow$ the eutectic cell size $\Downarrow$

-) As tertiary arm spacing $\Downarrow$ the eutectic cell size $\Downarrow$

-) As the eutectic cell size $\Downarrow$ percentage dented grain boundary $\Downarrow$

INTERMETALLIC GROWTH AT THE INTERFACE

Samples given in Table II were analyzed for intermetallic growth at the unprepared surface and also in cross section. The results are summarized in Figure 2 and 3 where the occurence of extensive interface reaction (y- interface reaction: n- no interface reaction) is plotted in a peak temperature versus holding time diagram. As expected the peak temperature for the onset of alloying decreases with increasing holding times. A different behavior of the investigated materials (CS and VA2) can be seen by comparing Figure 2 and 3. Different substrate compositions and galfanizing procedures might affect the reactivity at the interface. The growth of the intermetallic phase was found to occur very localized and to propagate in both directions, towards the surface and also into the steel substrate (Figure 4). It has been established in the literature [3] that intermetallic growth at the interface will affect the Galfan microstructure in the coating, as the amount of proeutectic zinc will increase when intermetallic growth occurs. This has been confirmed in the present study (Figure 5). Therefore it should be obvious that the growing intermetallic phase is an Fe-Al intermetallic as also proposed from the phase diagram and as documented in the literature [3,4].

EDX and EPMA analysis were made in order to confirm the existence of an intermetallic iron aluminum phase at the interface. The EDX analysis was performed in the region shown in Figure 6. Proeutectic zinc phase, eutectic region, and Fe-Al intermetallic phase were identified qualitatively by different analysis spots (Figures 7 a-c). Another phase has been found at the interface near the Fe-Al intermetallic (Figure 6). It is suggested that this phase is an Fe-Zn intermetallic, since it was observed at regions, where the proeutectic zinc phase was in contact with the steel substrate (Figure 4 and 6), however the EDX data of this phase (Figure 7d) is difficult to interprete. The compostion range of the intermetallic Fe-Al phase was determined by micropobe analysis (17 spots at different regions) as follows:

46-55 wt% Al Average: 52 wt%Al

32-38 wt% Fe Average: 36 wt%Fe

6-14 wt% Zn Average: 9 wt%Zn

It was found by Ghuman [4], that with galvanizing in 1-3wt% aluminum containing zinc baths a zinc bearing Fe_2Al_5 phase (42-44wt%Al, 34-39 wt%Fe and 20-22wt%Zn) forms at the interface, while with galvanizing in 5-10wt% aluminum containing zinc baths at 450^{o}C a zinc bearing FeAl3 phase (44-45wt%Al, 31-35wt%Fe and 20-25wt%Zn) forms. Further the zinc content of the latter phase was found to decrease by increasing the galvanizing temperature (e.g. at 525^{o}C: 45-48wt%Al, 36-38wt%Fe and 17-20wt%Zn). However, all phases observed by [4] formed as continuous layers due to the very long dipping times. In the present study only localized "outbursts" of the Fe-Al intermetallic phase was seen and the composition is very consistent with results for Fe-Al intermetallic outbursts found by Sharp [5], who also showed that the Zn content of the Fe-Al intermetallic increases with higher annealing temperatures and longer holding times. The propagation of the Fe-Al reaction further consumes the aluminum of the Galfan-coating, whereas the zinc of the coating is suggested to diffuse in the intermetallic layer. For a clear identification of the Fe-Al phase present at the interface X-ray diffraction analysis as performed by [4] is necessary. The existence of a Fe-Zn phase near the Fe-Al intermetallic at the interface, as suggested from the EDX analysis and as also mentioned by Sharp [5], could not be determined by the microprobe. Sharp [5] gives the composition of this phase with $FeZn_{10}$-Al_y.

The prepared cross sectional and surface view samples were observed for the characteristics in the Galfan coating microstructure, like % proeutectic zinc phase, % denting and eutectic cell size.

Proeutectic zinc phase

The morphology of the proeutectic zinc phase was found to change when the coating was molten and resolidified during a Gleeble cycle. Figures 8a and 8b show two different regions of sample C25. Due to the low peak temperature the Galfan coating of this sample was just locally molten during Gleeble simulation. Fig. 8a shows the original dendritic structure of the proeutectic zinc, while in the molten and resolidified region (Fig. 8b) a mostly non dendritic structure is visible. In general the original dendritic structure could only be reproduced locally on some samples cooled with higher cooling rates during Gleeble simulation (e.g. sample V81, Fig. 9a). However no marked dendritic structure of the proeutectic zinc phase could be found in the Galfan coating of the comparable Cockerill base sample (C81, Fig. 9b). Cross sectional observations (Fig. 10a and b) also show differences between the original and the Gleeble modified structure. From Fig. 10b it can be suggested, that nucleation of the proeutectic zinc phase takes place on the surface of the coating during the Gleeble cycle. Since the melting point of pure zinc is higher then that of the eutectic composition, and therefore the proeutectic zinc is the first solidifying phase, it is believed that the solidification process of the Galfan coating starts at the surface and propagates to the steel coating interface during Gleeble simulation. Exactly the opposite is the case for the original industrial galfanized sample (Fig. 10a).
The determination of the % proeutectic zinc phase for the Gleeble modified samples is not useful, since the result is dependant of the amount coating ground away during preparation of the sample by grinding and polishing. These was also found by measurements on selected and carefully prepared samples, where an extraordinary high standard deviation was established for the % proeutectic zinc. The results are therefore not included in this summary.

Denting

The denting on the surface of the Galfan coating can usually be determined very easy by automative quantitative image analysis of the unprepared surface, since there is a big contrast between dented region and original surface. However, the Gleeble simulation produced additional defects in the coating, like holes and especially at higher cooling rates very rough surfaces. This makes image analysis more difficult, but more important holes in the coating also influence the value for % denting, since denting was found to be a volume contraction problem [2]. Furthermore the chromate layer on the surface of the VA2 material obstructed the analysis of the modified Galfan structure on these samples. Therefore no measurement of %denting was performed.

Eutectic cell size

The cell size was deteremined by both, automative and manual image analysis, on prepared surface view samples. The results given in table II were plotted in three different diagrams (Fig. 11-13), where the data of CS and VA2 samples are included. From these diagrams no influence of holding time and peak temperature of the Gleeble heating cycle on the eutectic cell size in the Galfan coating can be seen (Fig. 11,12). Fig. 13 shows the influence of the cooling rate. A tendency to smaller eutectic cell size with higher cooling rates can be established and this is consistent with the general solidification theory.

SUMMARY

The Gleeble simulation of the galfanizing process is very useful for the study of interface reactions between steel substrate and coating. However there are problems in simulating the microstructure in the coating itself. No results were found in this study when the surface of the coating was the place of interest, because it was impossible to produce a high quality surface especially at higher cooling rates. Furthermore the solidification process of the Galfan coating in commercial production and Gleeble simulation are believed to be different, since some features for a start of the solidification on the surface of the coating were found.

The influence of the cooling rate on the eutectic cell size was shown as well as the occurence of an interface reaction and the formation of Fe-Al intermetallics at the substrate/coating interface.

Since the original microstructure in the Galfan coating could not be reproduced by Gleeble simulation the third step of the programme, to study the influence of introducing nucleation agents on the molten Galfan surface, was canceled.

REFERENCES

1. C.E. Jordan et al., "Metallographic Preparation Technique for Hot-Dip Galvanized and Galvannealed Coatings on Steel", Materials Characterization, No. 31, 1993, pp. 107-114

2. S.T. Bluni and A.R. Marder, "The Development of Smooth Surface Galfan for Coil Coating Applications", Final report prepared for ILZRO, Lehigh University, July 1994

3. P.G. Caceres et al., " Mechanisms of Formation and Growth of Intermetallic Layer during Hot Dipping of Iron in Zn-3Al and Zn-6Al Baths", Materials Science and Technology, Vol. 2, August 1986, pp. 871-877

4. A.R.P Ghuman and J.L. Goldstein, " Reaction Mechanisms for the Coatings Formed During the Hot Dipping of Iron in 0 to 10 pct. Al-Zn Baths at 450°C to 700°C", Metallurgical Transactions, Vol. 2, October 1971, pp. 2903-2914

5. R.M. Sharp, J.T. Gregory and Z.W. Chen, "Intermetallic Phases formed during Hot Dipping of Low Carbon Steel in a Zn-5%Al Melt at Temperatures up to 575°C", Materials Forum, 16, 1992, pp. 205-214

Table I: Specification and production data of the received industrial galfanized steel sheets

Sample	CS	VA1	VA2	VA3
Steel substrate type	CQ type	low carbon	low carbon	construction
wt% C in substrate		approx. 0.05	approx. 0.05	0.18
Substrate thickness [mm]	0.75	0.70	0.60	0.64
Substrate roughness[1] Ra [μm] f/b	L 1.4/1.3 P 1.6/1.6	L 1.2/0.9 P 1.0/0.7	L 1.7/1.0 P 0.9/0.9	L 0.8/0.7 P 0.5/0.5
Line speed [m/min]	98	84	80	95
Snout temperature [°C]	435	487	484	464
Bath temperature [°C]	438	437	442	464
Bath Al [wt%]		4.5	5.0	4.4
Coating weight [1] [g/m²] f/b	93 / 98	44 / 38	89 / 83	72 / 72

[1] estimated by Cockerill Sambre; both, the coating thickness and the roughness were determined on the front (f) and on the back (b) side of the sheet, furthermore the roughness was measured parallel (L) and perpendicular (P) to the rolling direction of the steel substrate

Table II: Gleeble data; programmed temperature cycle and measured maximum peak temperature, temperature difference between both thermocouples and measured cooling rate

Sample[1]	Cycle[2]	max. Peak T [°C]	ΔT [°C]	Cooling rate [°C/s]	Cell size [mm] average/Std.dev.
C1	1 - 400	409	6	5.6	0.59 / 0.11
C2	1 - 420	426	3	5.2	0.95 / 0.16
C3	1 - 450	465	11	5.5	0.88 / 0.20
C4	1 - 460	463	0	6.0	0.95 / 0.21
C5	1 - 470	478	5	5.9	0.78 / 0.16
V5	1 - 470	476	6	8.0	0.67 / 0.13
C6	1 - 480	494	11	5.9	0.91 / 0.17
C7	5 - 470	480	6	5.9	1.00 / 0.17
V7	5 - 470	479	6	8.2	0.74 / 0.19
C8	5 - 480	487	4	5.7	1.08 / 0.30
V8	5 - 480	486	2	8.4	
C9	5 - 460	467	3	5.6	0.96 / 0.19
V9	5 - 460	480	17	8.0	
C10	5 - 450	453	2	5.8	0.87 / 0.22
C11	5 - 420	438	10	5.8	1.00 / 0.26
C12	10 - 460	469	6	5.9	1.05 / 0.15
V12	10 - 460	466	3	7.5	1.06 / 0.32
C13	10 - 400	409	7	5.0	0.90 / 0.23
C14	10 - 450	455	3	5.5	0.89 / 0.16
V14	10 - 450	459	6	7.3	0.80 / 0.20
C15	10 - 420	427	6	5.3	0.97 / 0.20
C16	30 - 450	462	10	5.5	1.17 / 0.30
V16	30 - 450	468	14	7.0	1.70 / 0.48
C17	30 - 420	426	4	5.1	0.95 / 0.20
V17	30 - 420	434	12	7.3	

Table II: Continued

Sample[1]	Cycle[2]	max. Peak T [°C]	ΔT [°C]	Cooling rate [°C/s]	Cell size [mm] average/Std.dev.
C18	60 - 420	[3]	[3]	[3]	0.90 / 0.14
V18	60 - 420	434	11	7.2	
C19	10 - 470	[3]	[3]	[3]	0.98 / 0.19
V19	10 - 470	482	8	8.0	1.25 / 0.89
C20	30 - 400	[3]	[3]	[3]	1.02 / 0.36
C21	60 - 400	[3]	[3]	[3]	1.31 / 0.32
C22	90 - 420	433	10	6.7	1.21 / 0.29
V22	90 - 420	440	17	8.0	1.44 / 0.61
C23	60 -450	477	24	6.0	1.23 / 0.32
V23	60 - 450	464	12	4.2	2.54 / 0.38
C24	20 - 450	[3]	[3]	[3]	1.12 / 0.21
V24	45 - 450	462	10	4.2	
C25	5 - 350	358	7	4.2	1.21 / 0.21
V25	5 - 350	352	2	4.9	5.10 / 1.19
CV4	1 - 500	512	6	8.1	1.24 / 0.27
VV4	1 - 500	510	5	8.4	
V26	5 - 500	504	0	8.5	2.34 / 0.56
V27	10 - 480	498	14	8.4	
V28	30 - 470	490	17	8.7	
C81	30 - 450	462	9	20	0.95 / 0.29
V81	10 - 450	460	7	19	0.55 / 0.15
C82	10 - 450	454	10	36	0.71 / 0.15
V82	10 - 450	454	8	36	0.63 / 0.16
C83	10 - 450	455	5	32	0.69 / 0.15
V83	10 - 450	454	8	42	0.64 / 0.19

Table II: Continued

Sample[1]	Cycle[2]	max. Peak T [°C]	ΔT [°C]	Cooling rate [°C/s]	Cell size [mm] average/Std.dev.
VW1 [4]	10 - 450	453	4	22	0.25 / 0.04
CW2 [4]	10 - 450	453	0	44	0.30 / 0.09
CW3 [4]	10 - 450	454	7	37	0.34 / 0.09
VW4 [4]	10 - 450	453	4	51	0.45 / 0.08

[1] Labels starting with "C" refer to CS-base material, those starting with "V" refer to VA2-base material

[2] The heating rate was constant as follows: 100°C/s to 350°C and 20°C/s to peak temperature Holding time [s] and peak temperature [°C] are given in the table.

[3] For some reason the Gleeble data of these samples were not collected.

[4] The samples were cooled by using a mist of air and water

Table III: Characterization of the as-galfanized materials; average values are given followed by standard deviation in parenthis

	coating thickness [μm]	eutectic cell size [μm]	% proeutectic phase	tertiary arm spacing [μm]	% denting / % dented gb.[1]
CS	22.8 (2.7)	1320 (390)	28.5 (3.9)	7.7 (1.1)	4.3 / 0.28
VA1	5.7 (4.2)	4860 (1320)	29.8 (2.6)	10.7 (1.4)	0.2 / 0.05
VA2	22.2 (2.0)	4720 (2060)	15.9 (3.5)	9.5 (1.5)	2.1 / 0.48
VA3	19.2 (1.3)	1390 (380)	26.2 (2.9)	5.5 (1.1)	2.5 / 0.17

[1] Percentage dented grain boudary was calculated using the formula given by Bluni [2]

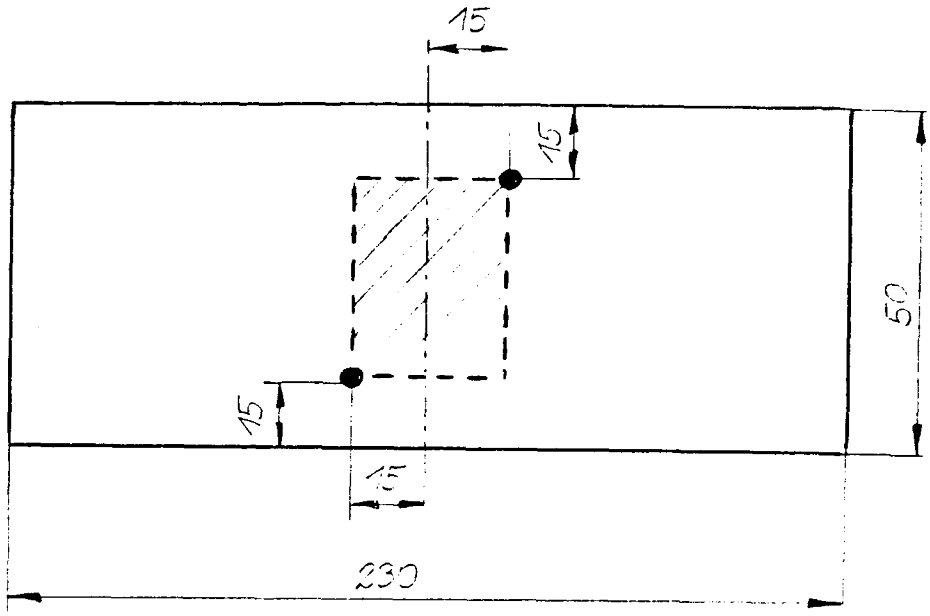


Figure 1: Arrangement of thermocouples on the Gleeble samples

Intermetallic growth at the steel/coating interface of Galfan

Base: Cockerill Sambre industrial galvanized material (CS)

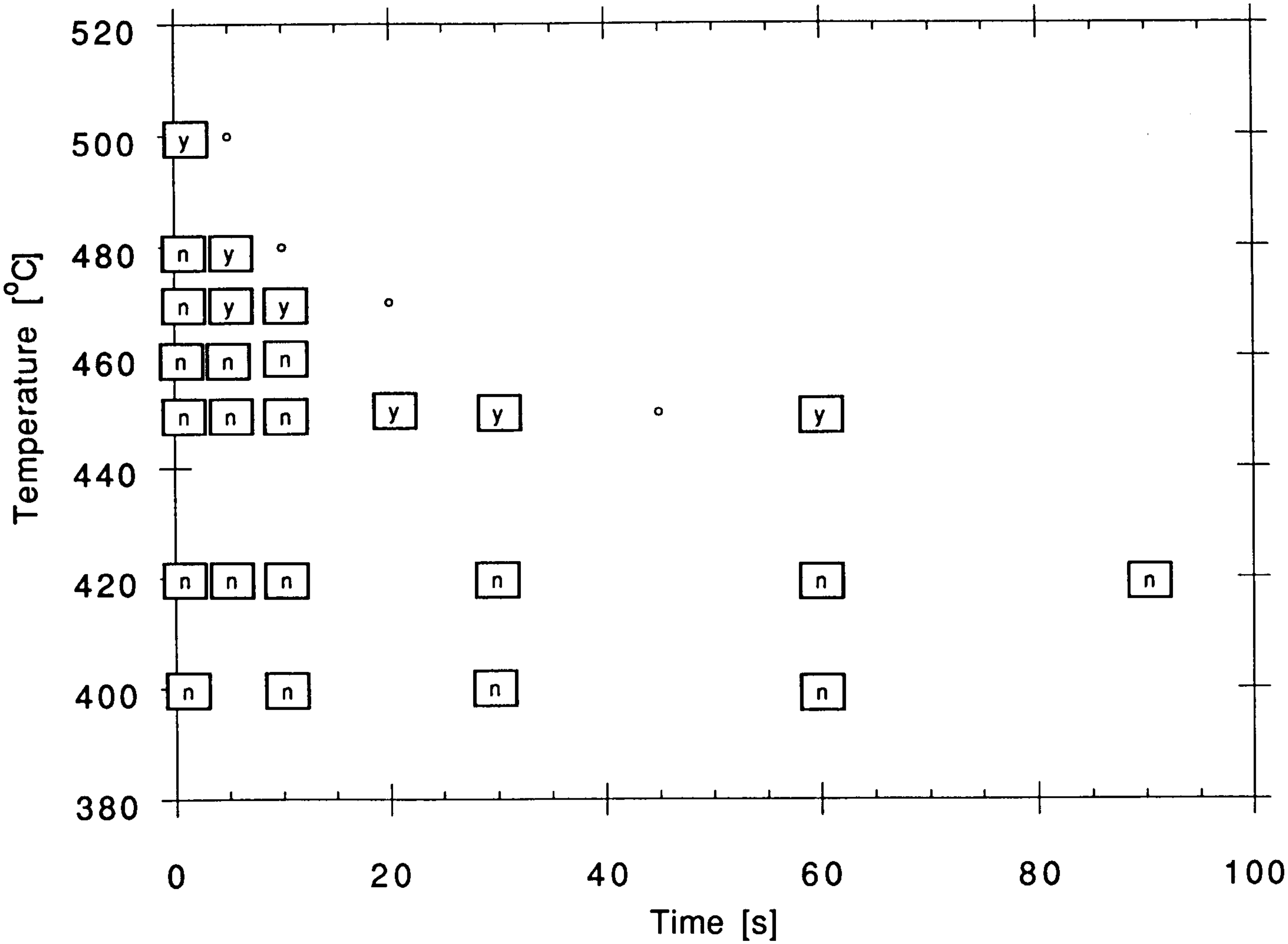


Figure 2: Observation of intermetallic reaction at the interface (y-yes; n-no)

Intermetallic growth at the steel/coating interface of Galfan

Base: Voest Alpine industrial galvanized material (VA2)

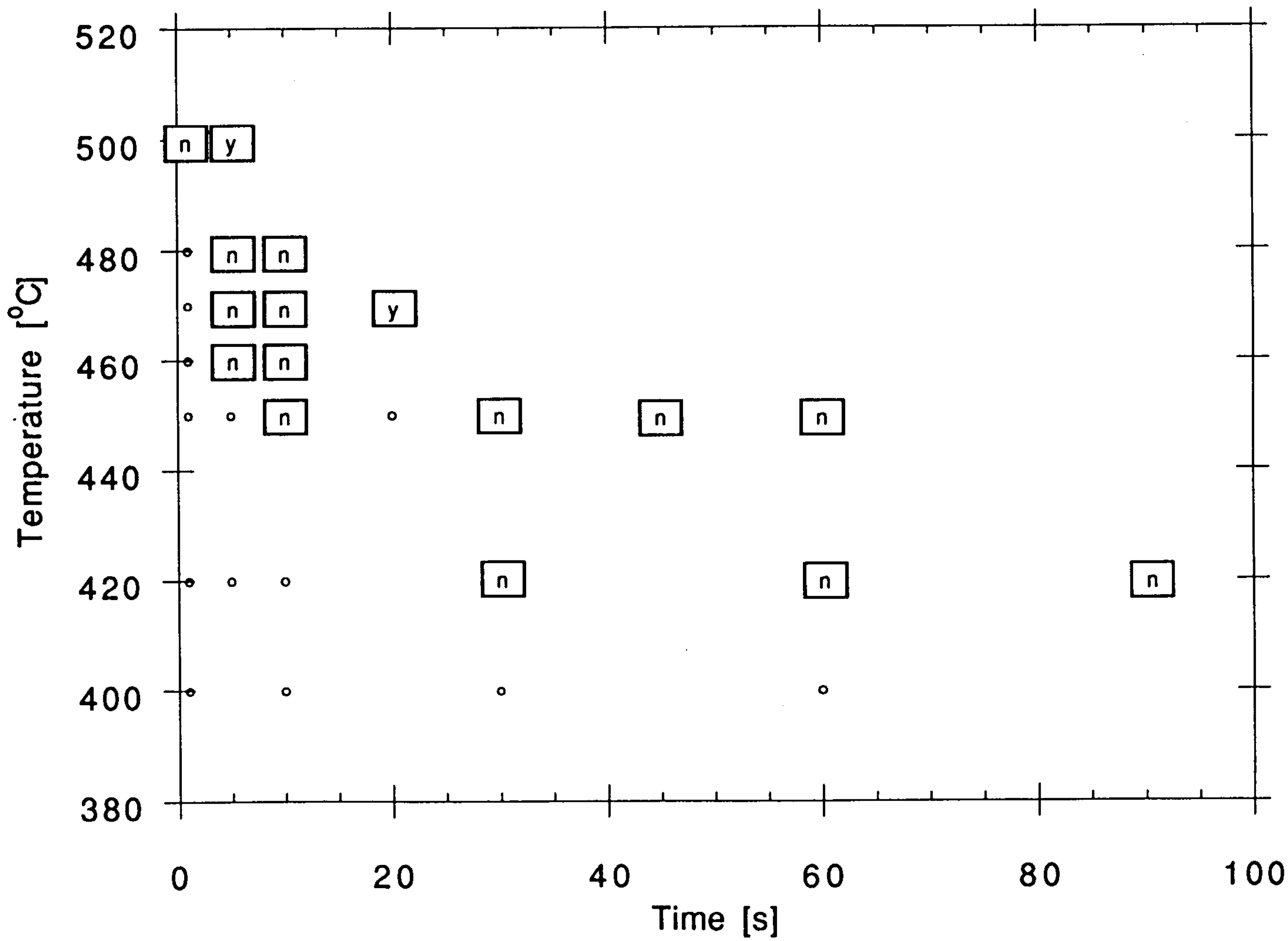


Figure 3: Observation of intermetallic reaction at the interface (y-yes; n-no)

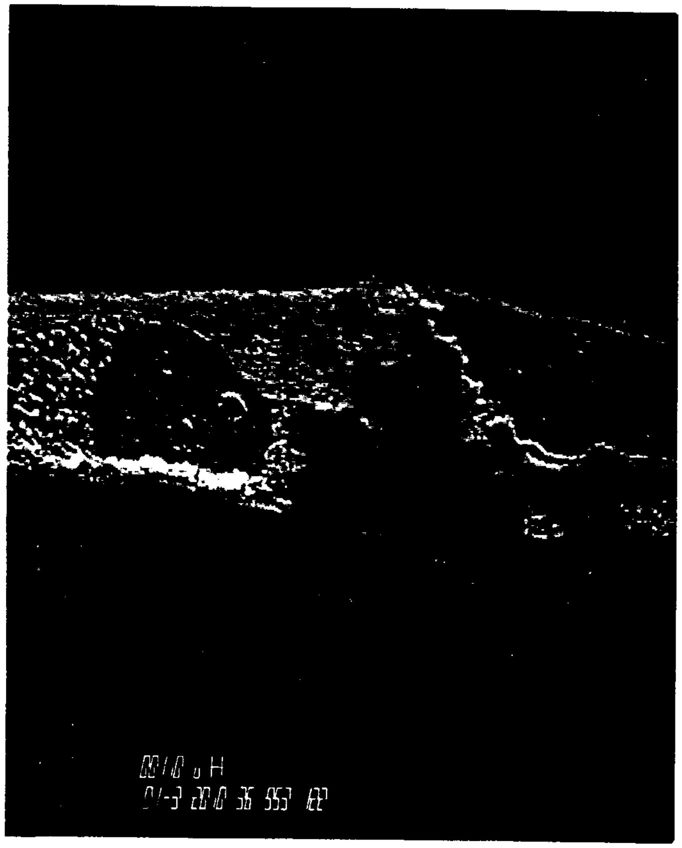


Figure 4: Growth of an intermetallic Fe-Al outburst at the steel/coating interface (Magnification 1000x)

Figure 5: Microstructure in the Galfan coating with intermetallic growth at the interface (Magnification 500x)

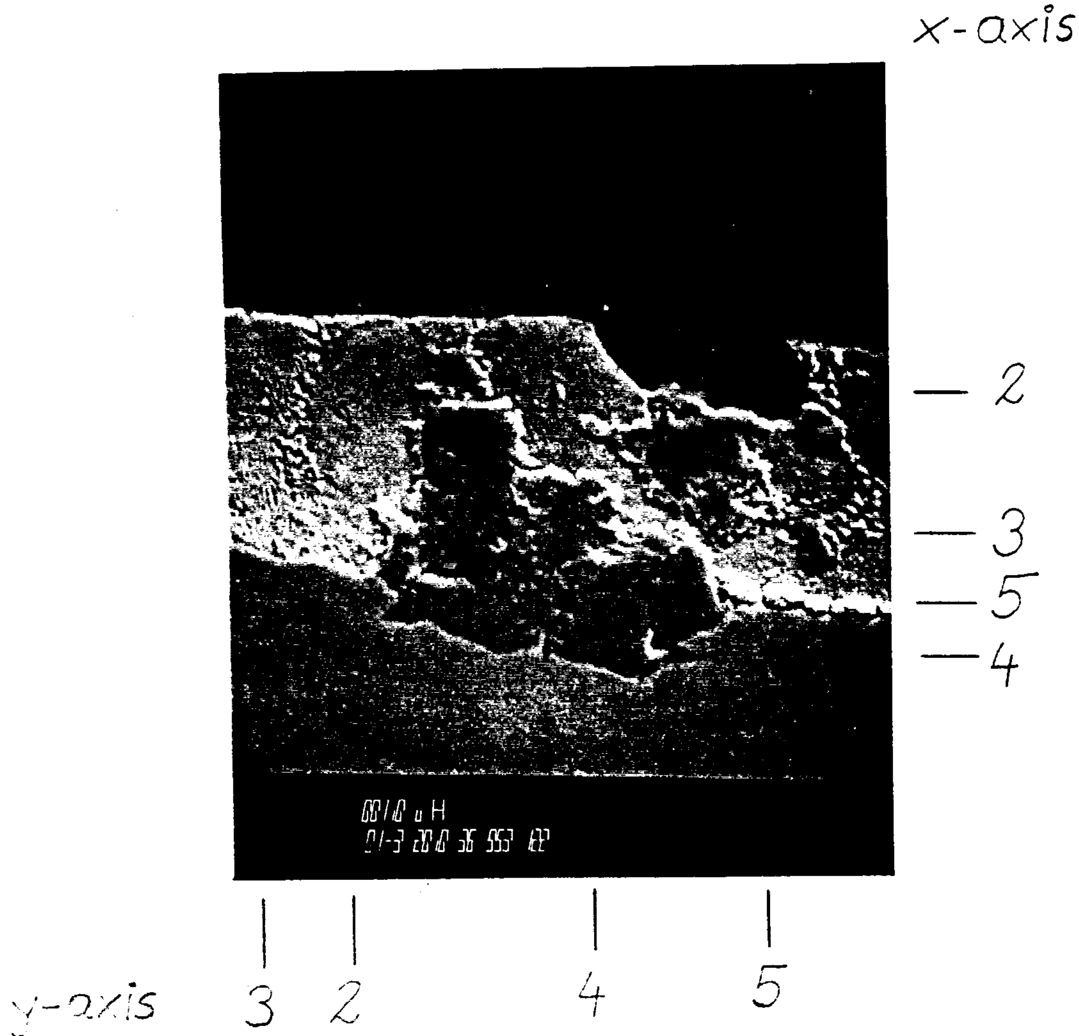


Figure 6: EDX spot analysis was performed at the intersections of the x- and y- axis line (Magnification 1000x)

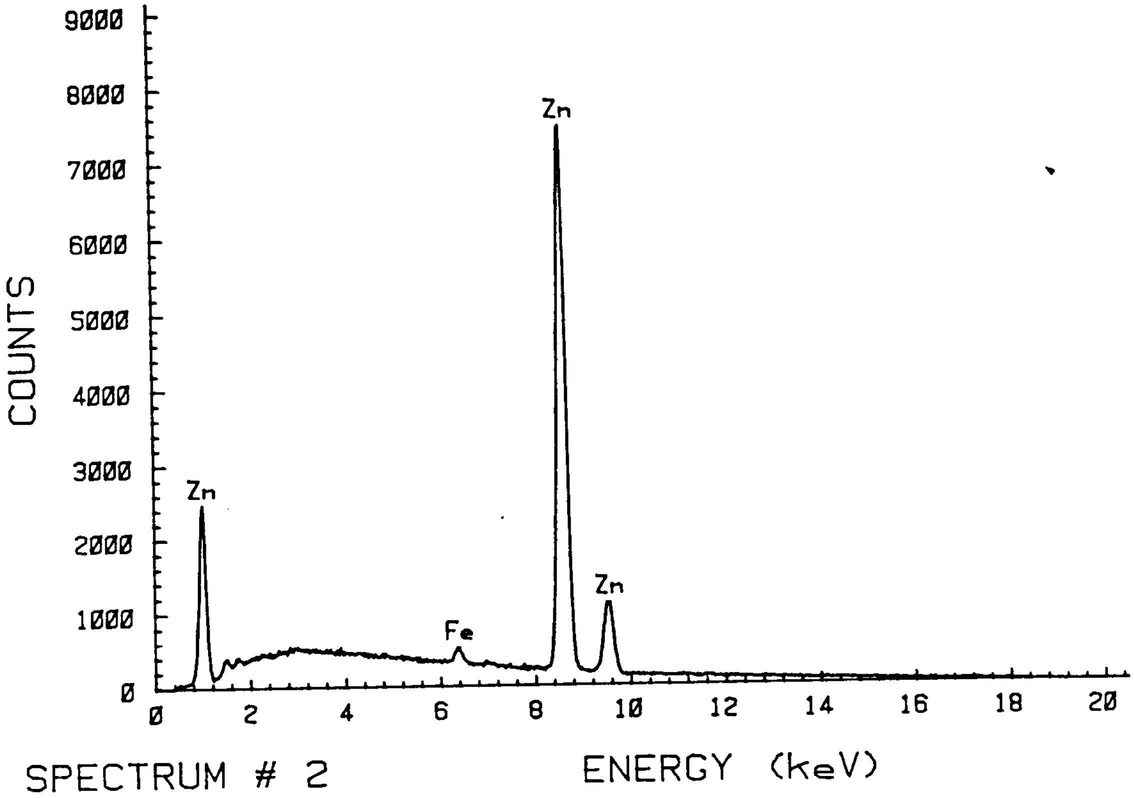


Figure 7a: EDX analysis of the proeutectic zinc region (2)

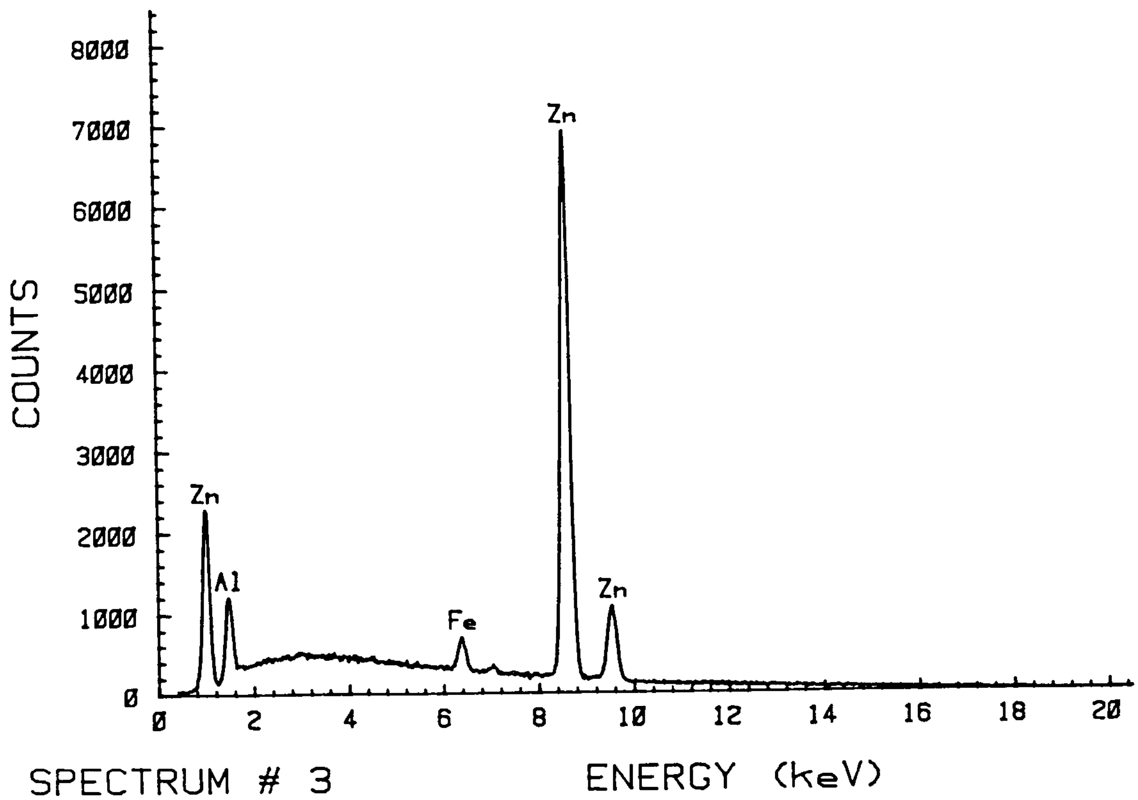


Figure 7b: EDX analysis of the eutectic region (3)

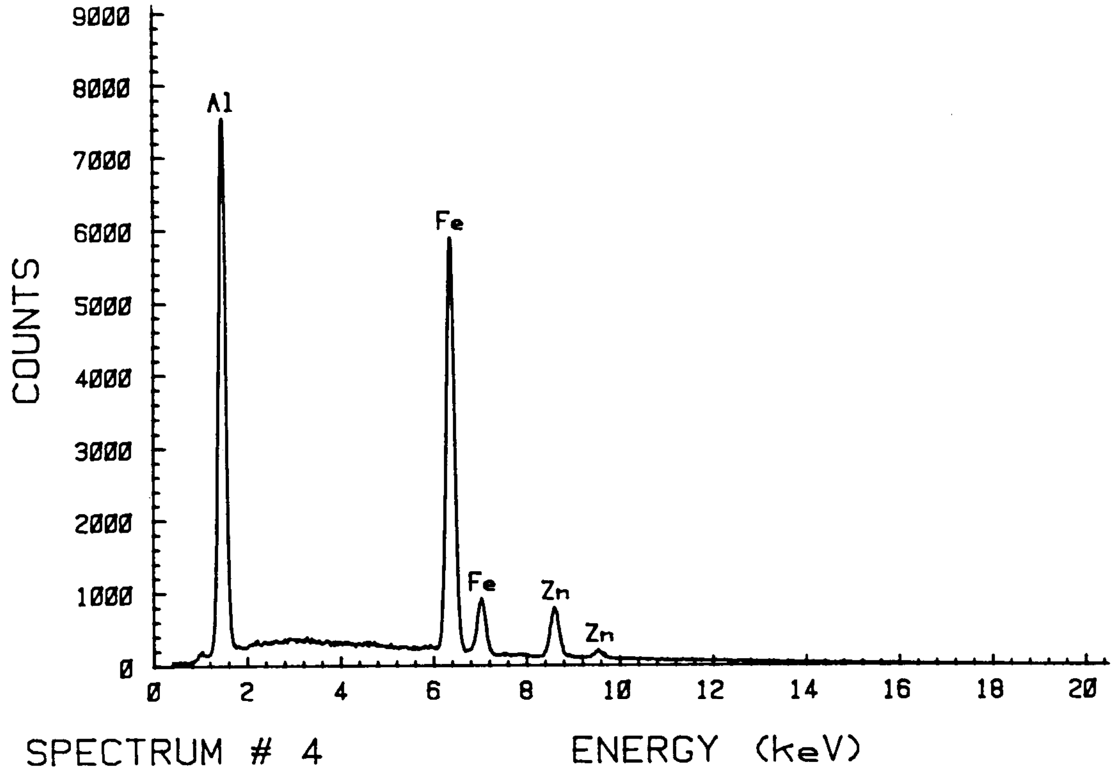


Figure 7c: EDX analysis of the intermetallic Fe-Al phase region (4)

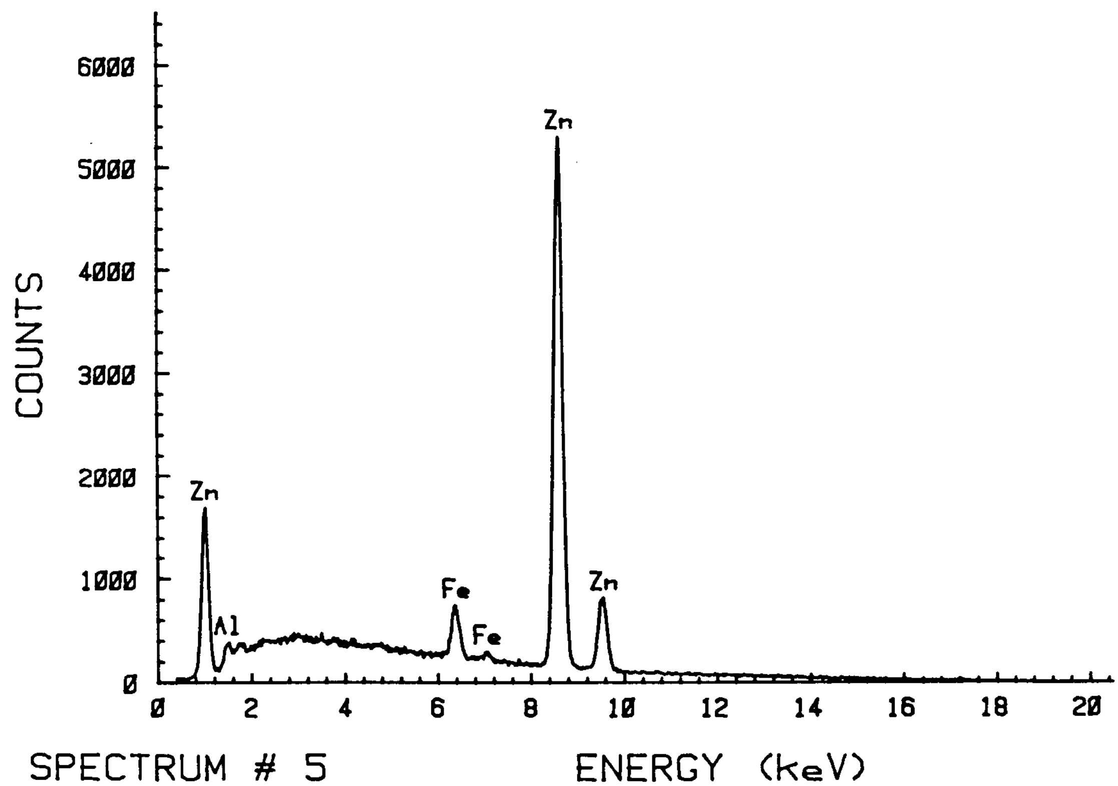


Figure 7d: EDX analysis of the intermetallic Fe-Zn phase region (5)

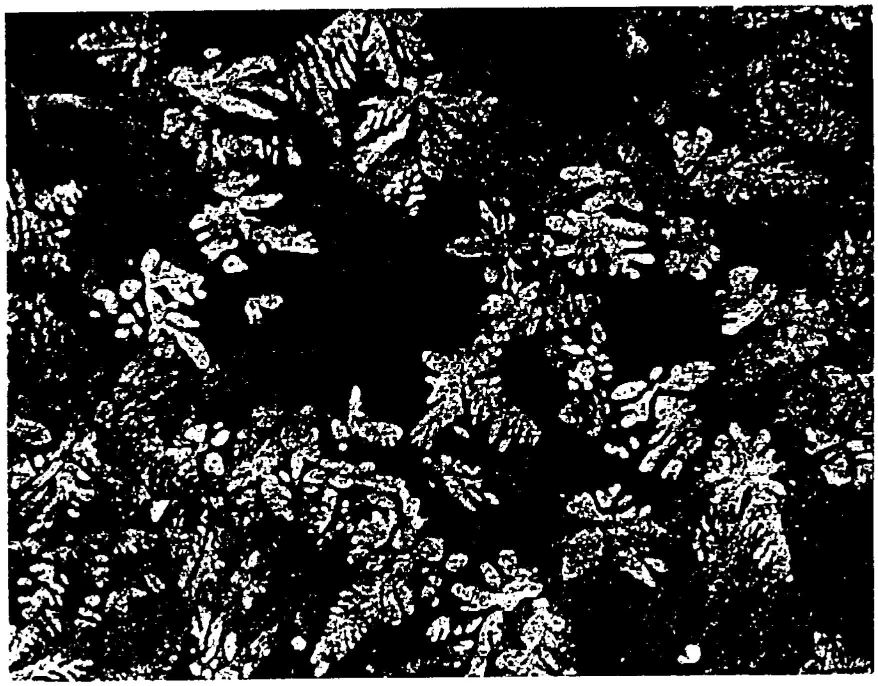


Figure 8a: Dendrite structure of the proeutectic zinc phase in the original Galfan coating (surface view; Magnification 200x)

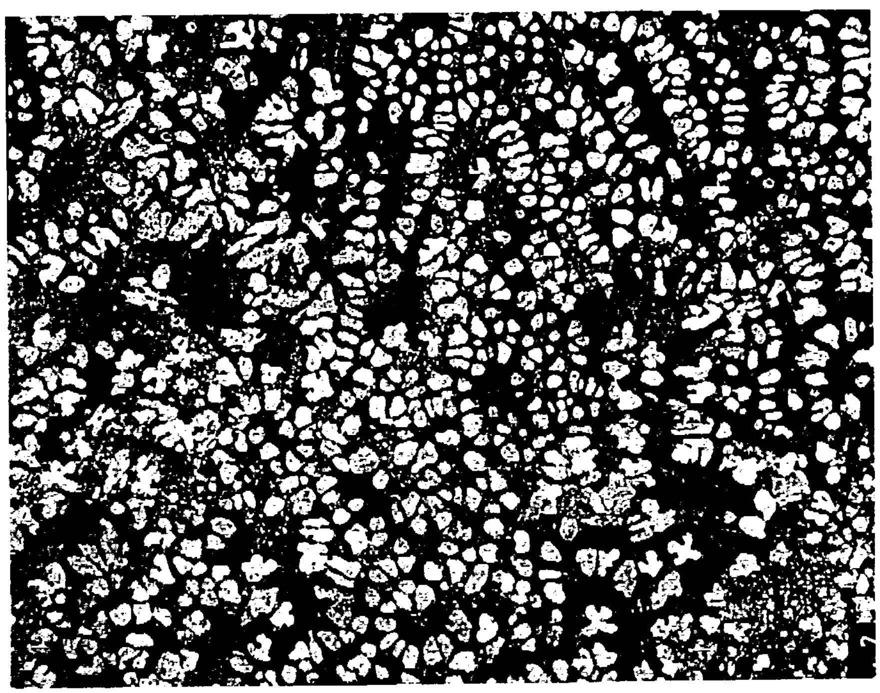


Figure 8b: Mostly non dendrite structure of the proeutectic zinc phase in the molten and resolidified coating (surface view; Magnification 200x)

Figure 9a: Dendrite structure of the proeutectic zinc phase performed at the Gleeble using higher cooling rates (Sample V81 - surface view; Magnification 200x)

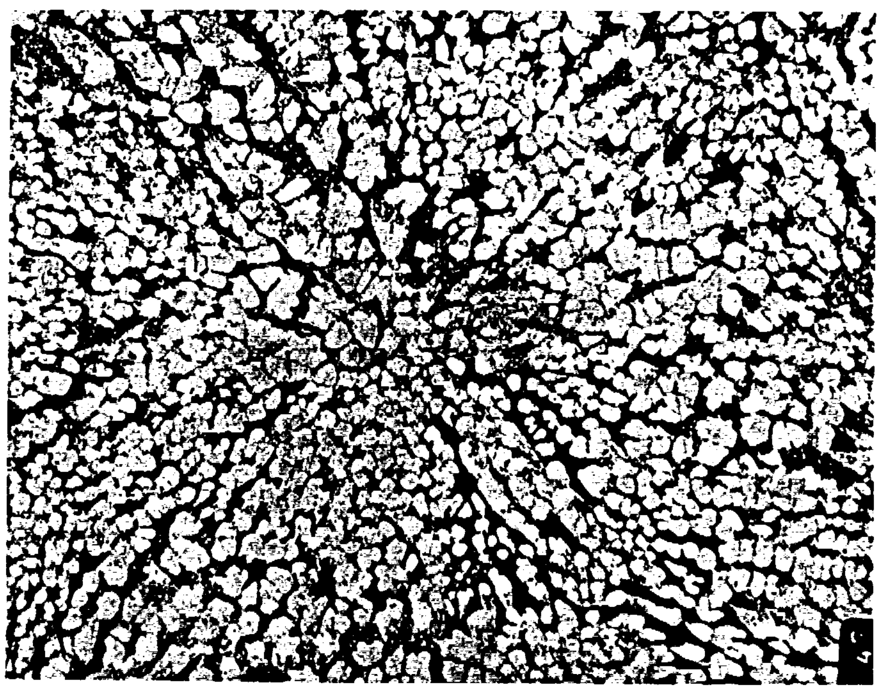


Figure 9b: Sample C81(surface view; Magnification 200x)

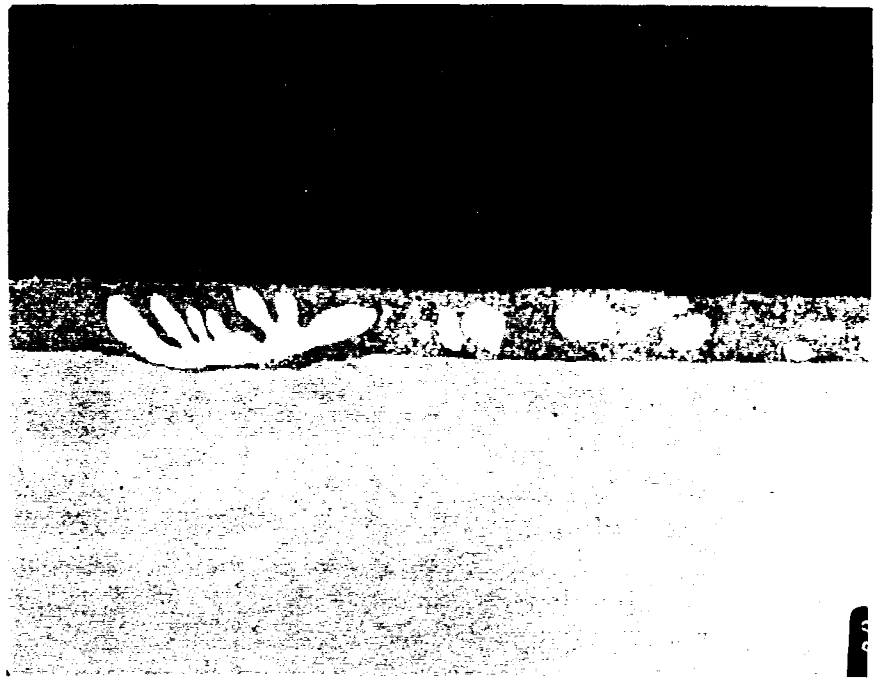


Figure 10a: Cross section of the original coating (Magnification 500x)

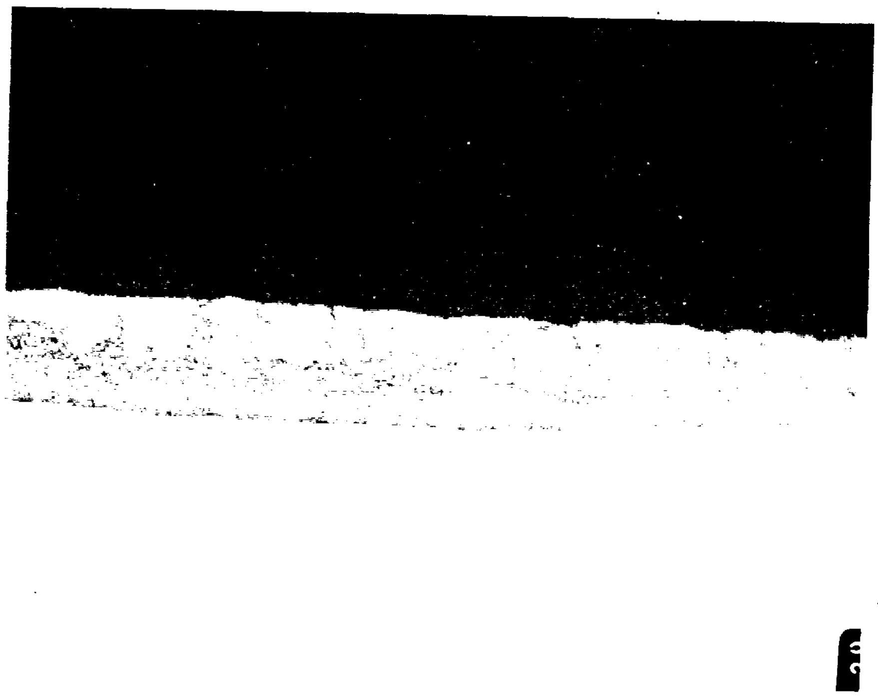


Figure 10b: Typical cross section of a Gleeble modified coating (Magnification 500x)

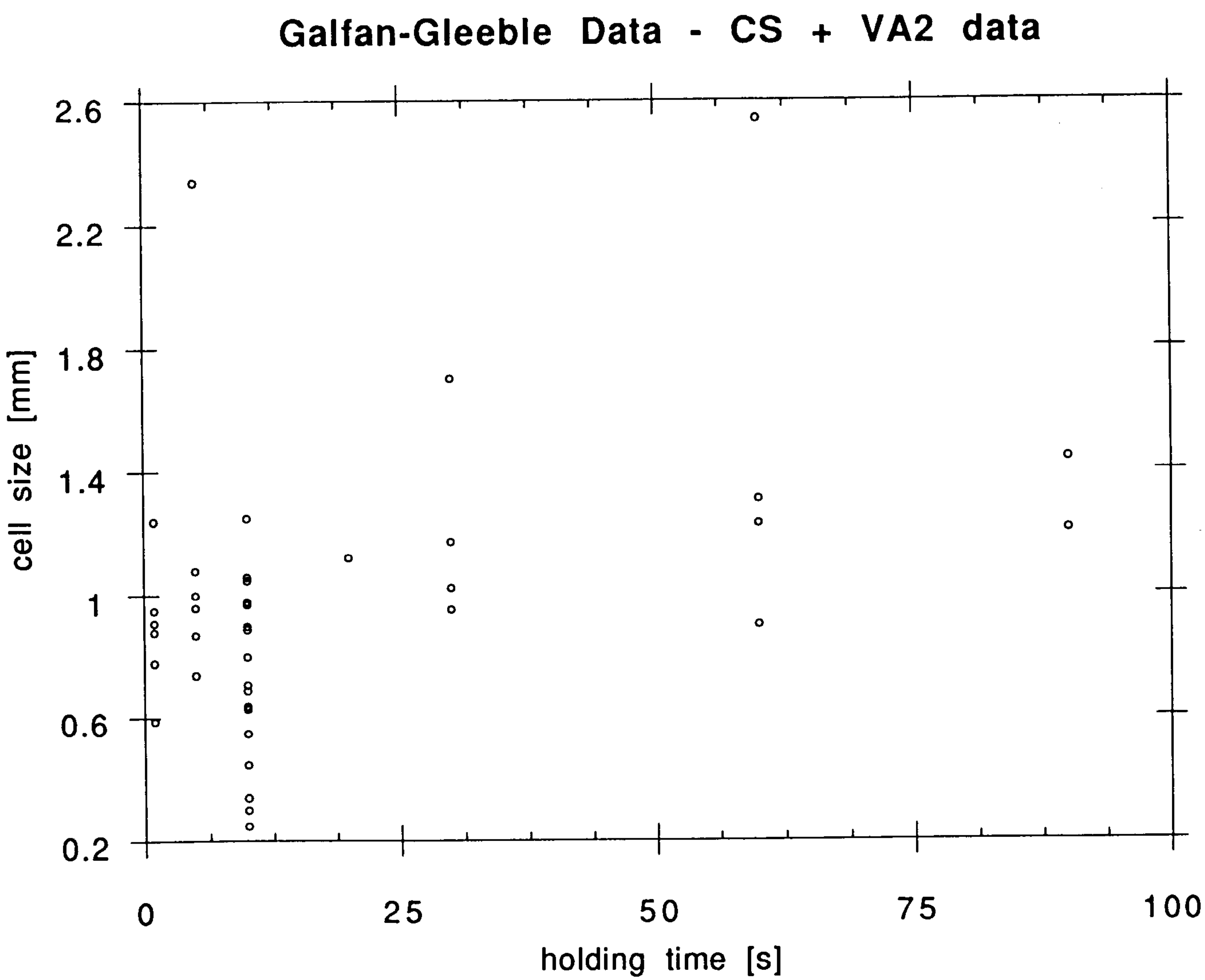


Figure 11 : Holding time versus cell size; combined plot for CS and VA2 material

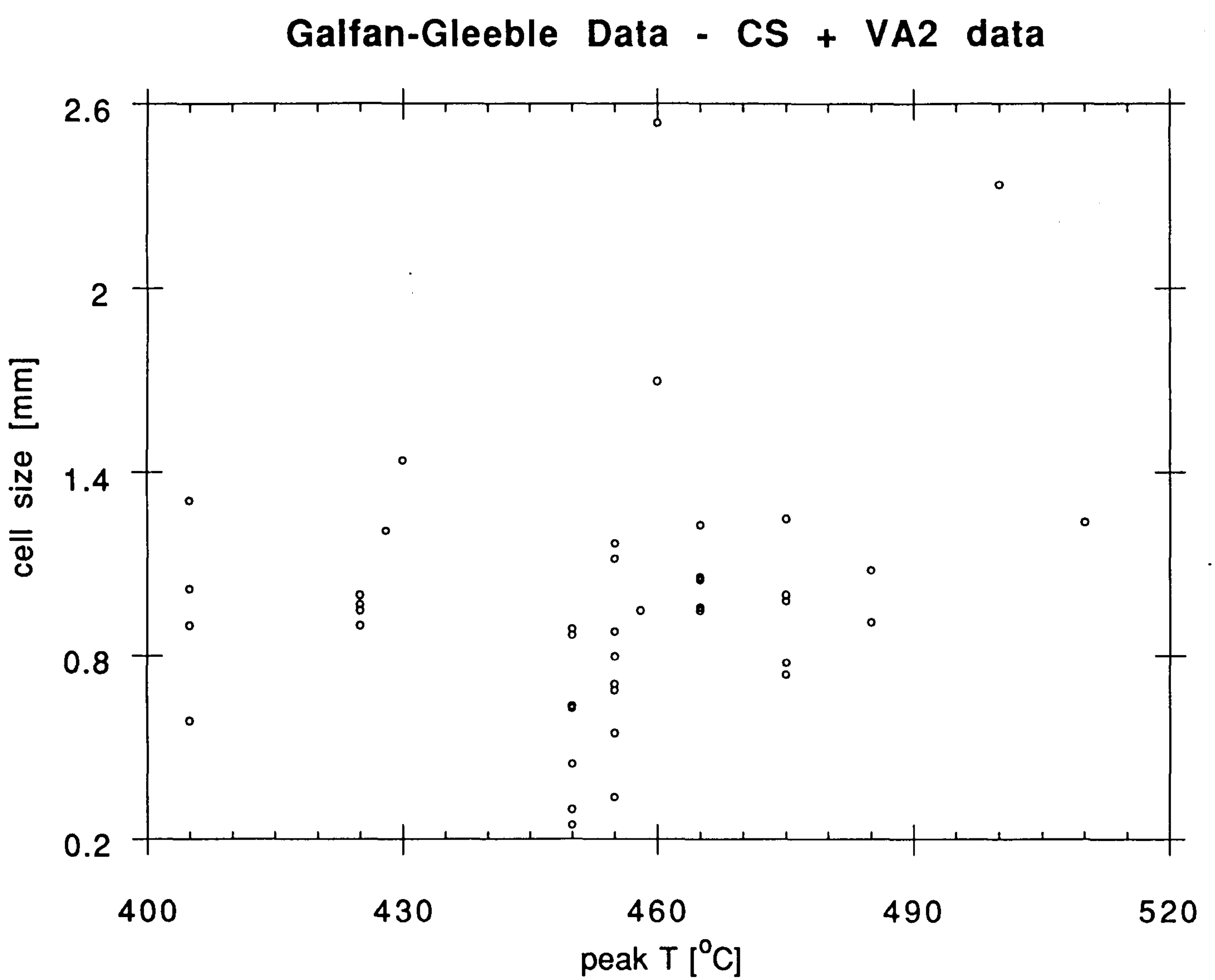


Figure 12: Peak temperature versus cell size; combined plot for CS and VA2 material

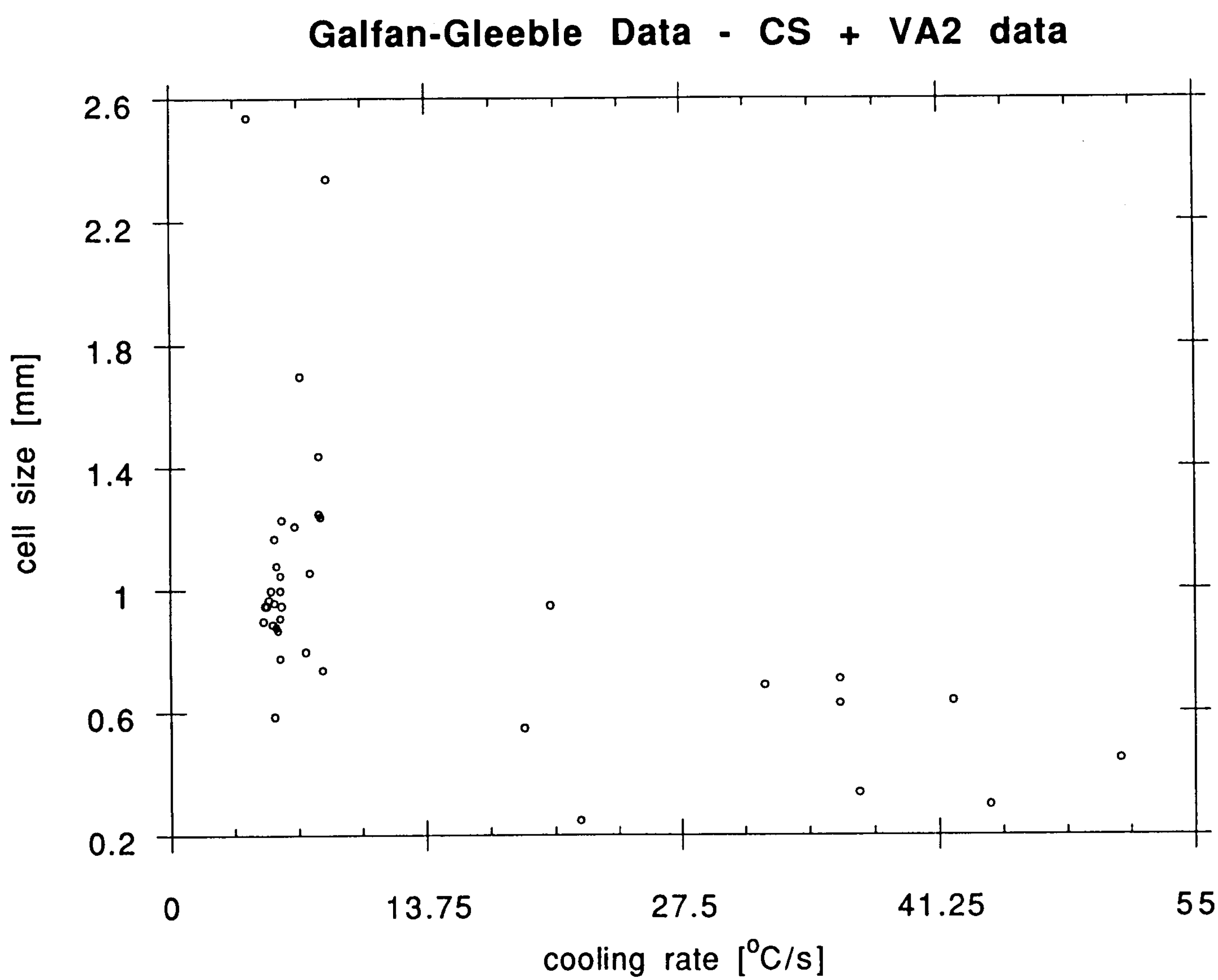
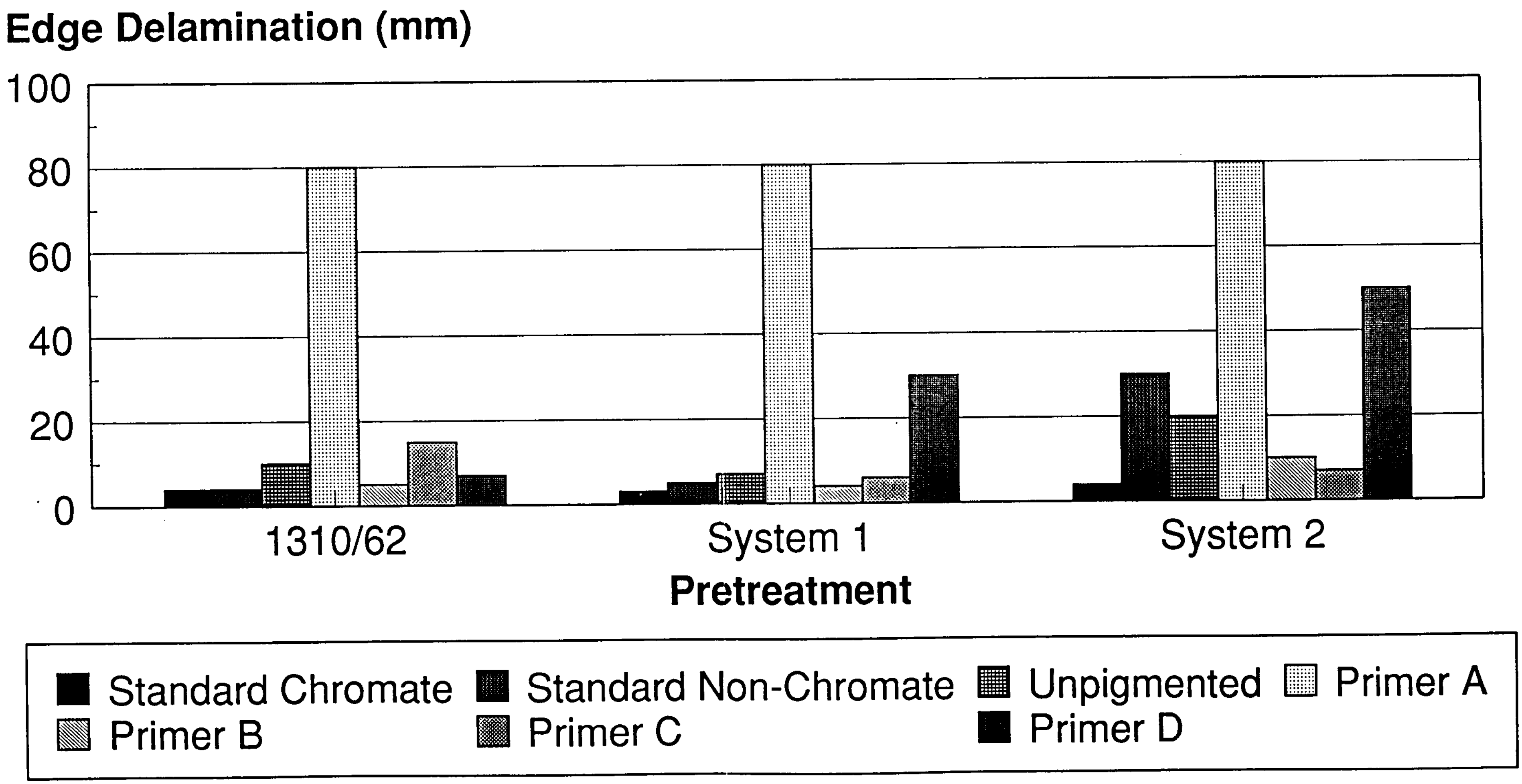
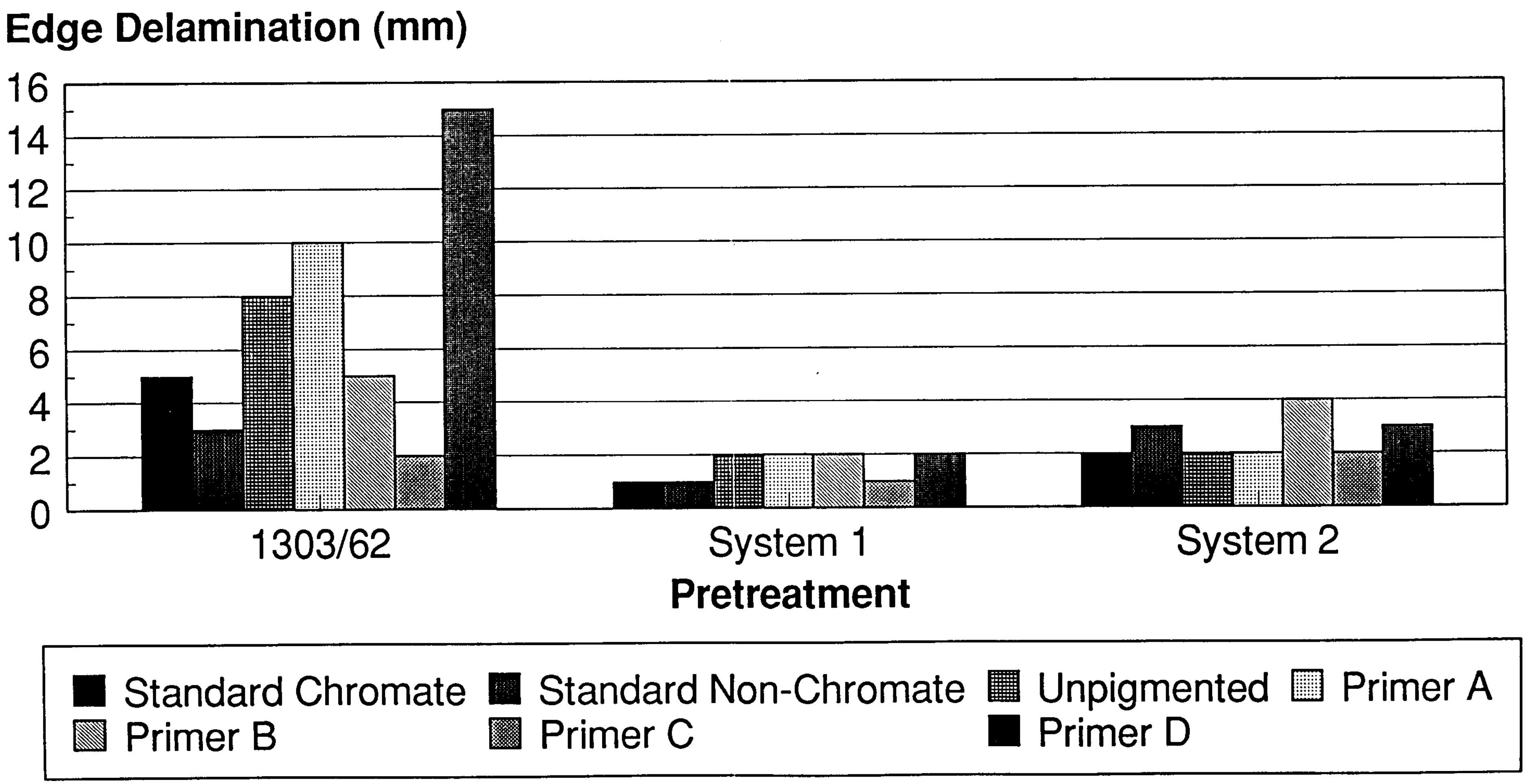


Figure 13: Cooling rate versus cell size; combined plot for CS and VA2 material

Exterior Weathering Performance Of The Epoxy Primer On Galvalume After 2 Years Exposure



Exterior Weathering Performance Of The Epoxy Primer On Galfan After 2.5 Years Exposure



PRELIMINARY

PROPOSAL

DEVELOPMENT OF DENT-FREE GALFAN SURFACES

by

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Lehigh University

August 31, 1995

INTRODUCTION

Galfan coating, a hot-dip zinc based alloy containing approximately 5wt.% aluminum and up to 0.10 wt.% mischmetal, offers many advantages over other galvanized products. Of these, formability is considered to be far superior to other Zn-based coatings due to the limited formation of an intermetallic compound layer at the coating/substrate interface enhanced by mischmetal additions(1). The use of Galfan has significantly increased over the past decade, leading to a growth in production from 10,000 tons in 1983 to almost 752,000 tons in 1994. Although there are numerous uses for Galfan and the demand for this coating continues to increase, it is sometimes not suitable for applications that have stringent surface requirements because the coating often contains small surface defects termed "dents". The problematic surface conditions of Galfan coatings has led to numerous investigations into the denting phenomenon by a number of research laboratories(2-5). In recent work at Lehigh University(5-8), sponsored by ILZRO, the Galfan surface defects were characterized, factors contributing to the formation of these defects were identified, and limited relationships between line processing parameters, coating microstructure and surface appearance were determined. Additional research investigated the nucleation characteristics of off-eutectic Al-Zn alloys(9).

BACKGROUND

Defects on Galfan coatings were found to include shrinkage cavities, impurity segregation and solidification cracks(5-7), Figure 1. All of these occur at eutectic grain boundaries and/or triple points. Solidification experiments on Galfan compositions without a steel substrate showed that these surface defects occur due to the solidification process and not the influence of steel substrate composition. As a result of these studies, a mechanism for cavity and crack formation was suggested(5-6), Figure 2.

Based on studies of 72 commercially produced coating samples from several producers, coatings were microscopically examined and quantitatively characterized(8). The results of this study suggests, besides utilizing skin passing to improve surface quality, figure 3, that eutectic grain size is an important factor for the control of Galfan denting. The occurrence and severity of surface defects was found to decrease with a decreasing coating grain size, figure 4. Furthermore, since grain size is controlled by the number of nucleation sites, grain size (and therefore denting) was found to decrease with an increasing cooling rate (wipe pressure), figure 5, and the area % proeutectic zinc, figure 6, which serves to nucleate the eutectic.

A relationship was also found between denting and coating thickness. explained by jet wiping pressure, which when increased, limits the coating thickness and increases the cooling rate, figure 7. The result is a coating with finer grain size and diminished surface defects. Thus with an increased number of nucleation sites, the solidification growth front will travel a decreased distance before impinging on adjacent growing grains. Consequently, the curved surface boundary formed upon impingement will be less pronounced since there will only be a limited amount of liquid which undergoes a volumetric contraction upon solidification between the eutectic grains. Dents will therefore be more shallow and less wide for a smaller grain size.

Suggestions for improving the Galfan surface conditions were made as a result of the most recent study[8]:

1. Minimize the lead content of the Galfan bath

    Decreasing the bath lead content should prevent solidification cracking in the coating[6,7].

2. Utilize skin passing

    A secondary method for improved surface appearance, skin passing will cosmetically improve the surface quality.

3. Decrease the coating eutectic grain size[8]

    Eutectic grain size can be decreased by increasing the number of nucleation sites in the liquid coating layer prior to nucleation. This could be achieved as follows:

    (a) increasing the cooling rate or gas wiping

    As was shown in the above referenced study[8], increased cooling rate or gas wiping decreased the denting defect but the elimination of the denting problem is limited by coating thickness requirements[10] and the cooling rates attainable in production.

    (b) increase the amount of proeutectic phase

    It has been shown[9] that off-eutectic compositions produce large proeutectic aluminum or zinc particles across the coating thickness, however the resultant change in eutectic morphology was limited. The depth of denting was only slightly decreased for hypereutectic alloys containing the pro-eutectic zinc phase[2] and these alloys were expected to possess inadequate corrosion resistance in humid environments. However, other investigators(11) have shown that small additions of Mg increase the amount of proeutectic aluminum and improve corrosion resistance.

(c) introducing nucleating agents to the liquid coating

Introducing innoculents or nucleating agents to the liquid coating may significantly decrease the eutectic grain size by providing nucleation sites and further reducing the denting defect. The well known Heurty Process, in which Zn powder is blown on the surface of the liquid Zn coating after exiting the zinc bath, has been used as a method of producing a fine spangle (i.e. grain size) coating. Si intermetallic particles have also been shown to refine the grain size of 55% Al - Zn (Galvalume) coatings(12).

REFERENCES

1. Y. Yang and Z. Yu, "Effect of Mischmetal on Reaction Between Solid Iron and Liquid Zinc - 5wt % Al", Acta Met Sinica, 29, 1993, 540.

2. M. Lamberights, V. Leroy and F.E. Goodwin, "Galfan Solidification Control and Associated Effects on Coating Quality and Microstructure", The Third International Zinc Coated Sheet Conference, Barcelona, 1991, S1D/1.

3. M. Lamberights and V. Leroy, "Galfan Reactivity with Steel Substrate, Mg Containing Galfan and Classical Galfan Ductility", Progress Report CRM no. 25, 1992.

4. A. Marder, "A Fundamental Investigation of the Occurrence of Grain Boundary Dents in Galfan", Proceedings of the 17th Galfan Licensees Meeting, Tokyo, 1992, I-1.

5. S. T. Bluni and A. R. Marder, "Galfan Microstructure and Surface Characteristics", The Physical Metallurgy of Zinc Coated Steel, A.R. Marder, ed., TMS, Warrendale, PA, 1993, 99.

6. S.T. Bluni and A. R. Marder, "Impurity and Processing Effects on Galfan Surface Appearance", The Fourth International Zinc Coated Sheet Conference, Paris, 1994, SC6/1.

7. S. T. Bluni, A. R. Marder and J. I. Goldstein, "Surface Characterization of Hot-Dip Galfan Coatings", Materials Characterization, 33, 1994, 93.

8. S. T. Bluni and A. R. Marder, "The Development of Smooth Surface Galfan for Coil Coating Applications", Final Report, Lehigh University, 94-500-15-29, 1994.

9. S. T. Bluni, M. Notis and A. R. Marder, "Nucleation Characteristics and Microstructure of Eutectic and Off-Eutectic Al-Zn Alloys", Acta Met. Mat., 43, 1995, 1775.

10. Y. Hirose, "Gas-Wiping Characteristics of Zinc and Galfan Alloy, Note for the 5th Galfan Meeting, Nov. 8, 1984.

11. Y. Tajiri, S. Shimada, T. Yarmaji and T Adaniya, "Effect of Coating Structure on Corrosion Resistance of Hot Dipped Zn-5%Al+Mg Alloy Coated Steel Sheet", Galvatech'95, ISIJ, Tokyo, 1989, 553.

12. J.H. Selverian, M.R. Notis and A. R. Marder, Microstructure of 55 w/o Al-Zn-Si: (Galvalume) Hot-Dip Coatings, J. Mat. Engr., 9, 1987, 133.

OBJECTIVE

The objective of this research is to develop galfanizing processing parameters that will enable the production of dent free Galfan surfaces.

WORKSCOPE

Task 1: Nucleation Process Simulation

This task is designed to confirm the effect of nucleating agents on the solidification and refinement of the Galfan structure. As noted above, it has been shown that a refinement in microstructure, notably eutectic cell size and dendrite arm spacing, reduces the denting problem. In addition, it has also been shown that increased proeutectic phase reduces denting. Several nucleating agents will be selected for their potential to induce solidification and refine the microstructure. Nucleating agents such as zinc dust and Galfan powder will be studied, but other agents will be considered. The objective of this task will be to quantitatively determine the effect of nucleant particle size and amount on eutectic cell size.

There will be four milestones in this task which will include: (a) a review and implementation of the Heurty process in the hot-dip simulator, (b) Acquisition of Zinc and Galfan powders in extremely fine sizes which will be an important precursor to the major milestone of (c) Nucleation Processing Parameters. In the last milestone, powder chemistry and powder quantity will be evaluated keeping powder size and velocity constant. In addition, bath temperature and strip temperature will be held constant. Finally, in (d) Microstructural Characterization, the microstructure of the coatings will be evaluated.

Task 2: Pilot Line Simulation

An industrial partner with a pilot line facility will be utilized to evaluate the galfanizing processing parameters necessary to produce an improvement in the denting problem. Based on the results found in Task 1, the induced nucleation and refinement of the Galfan coating will be confirmed and the effect on denting will be quantitatively measured. Since increased cooling rate has been found to decrease denting, the fastest feasible production cooling rate will be used throughout this study. The objective of this task is to develop a workable pilot line galfanizing process to significantly reduce denting that can be applied in a follow-on mill trial.

There will be three milestones in this task: (a) pilot line modification, (b) process variable evaluation and (c) microstructural characterization. The pilot line modification will depend upon the industrial partner facilities. The process variables to be initially studied will be powder velocity and line speed. Task 1 will fix powder chemistry, size and amount. The bath temperature and strip temperature will be held constant.

PERSONNEL

The project will be managed by A. R. Marder, Professor of Materials Science and Engineering and Associate Director of the Energy Research Center of Lehigh University. Dr. Marder was employed by the Homer Research Laboratories of Bethlehem Steel for 21 years before joining the faculty and staff of Lehigh University in 1986. He has authored over 100 technical papers edited 3 books and received 20 U.S. and international patents. He has written 36 papers in the field of zinc coatings and recently edited a book, The Physical Metallurgy of Zinc Coated Steel. He leads a coatings research group of two research engineers and 10 graduate students with facilities for hot-dipping, electrodeposition, weld overlay coatings and thermal cycle simulation. He was elected Fellow in the ASM International in 1990 for his research on coatings and received the ASTM Joseph Vilella for his paper on quantitative microscopy techniques for coatings in 1994. Prof. Marder will be assisted by a graduate student in the materials science and Engineering Department.

SCHEDULE

It is anticipated that this project will take 30 months to complete. Task 1, Nucleation Processing Simulation, will be completed in 18 months. Task 2, Pilot Line Simulation, will be started 12 months after the project begins in order to make the proper changes to the pilot line in anticipation of the testing of the process variables which will be initiated at the end of Task 1. It will take 18 months to complete Task 2, however since part of each task will be studied concurrently, the project will only require 30 months to complete.

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EDUCATION

PhD Metallurgy and Materials Science, Lehigh University, 1968
MS Metallurgical Engineering, Polytechnic Institute of Brooklyn, 1965
BS Metallurgical Engineering, Polytechnic Institute of Brooklyn, 1962
PE Commonwealth of Pennsylvania, 1988

PROFESSIONAL EXPERIENCE

1991-Present Professor, Materials Science and Engineering, Lehigh University
1987-Present Associate Director, Energy Research Center, Lehigh University
1965-1986 Homer Research Laboratories, Bethlehem Steel Corp.
1962-1965 Engineer, Wright Aero. Div., Curtiss-Wright Corp.

RESEARCH ACTIVITY

Current research interests include processing-structure-property relationships of coatings, including zinc coatings, thermal spray coatings, electrodeposited coatings, diffusion coatings and weld overlay coatings.

SELECTED PUBLICATIONS (Zinc Coatings)

1. J.H. Selverian, M.R. Notis and A.R. Marder, The Microstructure of 55 w/o Al-Zn-Si (Galvalume) Hot-Dip Coatings, Surface Modifications and Coatings, ed. R.D. Sisson, Jr., ASM, Metals Park, OH, 1986, 447.
2. J.H. Selverian, A.R. Marder and M.R. Notis, Preparation of Cross Sections of Thin-Coated Sheet Steel for Analytical Electron Microscopy Observation, J. Electron Microscopy Techniques, 5, 1987, 223.
3. J.H. Selverian, M.R. Notis and A. R. Marder, Microstructure of 55 w/o Al-Zn-Si: (Galvalume) Hot-Dip Coatings, J. Mat. Engr., 9, 1987, 133.
4. J.H. Selverian, A.R. Marder and M.R. Notis, The Reaction Between Solid Iron and Liquid Al-Zn Baths, Met. Trans. A, 19A, 1988, 1193.
5. M. Gu and A.R. Marder, Alpha Phase in a Zn-Fe Electrodeposited Coating, Scripta Met., 22, 1988, 1173.
6. J.H. Selverian, A.R. Marder and M.R. Notis, The Effects of Si on the Composition and Growth Kinetics in the Fe-Al-Zn System, Phase Transformations '87, G.W. Lorimer, ed., Inst. of Metals, 1988, 182.
7. J. H. Selverian, A. R. Marder, and M. R. Notis, "The Effect of Silicon on the Reaction Between Solid Iron and Liquid 55 Wt Pct Al-Zn Baths", Met. Trans., 20A,
8. M. Gu and A. R. Marder, "Mossbauer Spectroscopy of Zn-Fe Intermetallic Phases", Met Trans., 21A, 1989, 273.
9. M. Gu and A. R. Marder, "Structure of As-Plated Electrodeposited Zinc-Iron Coatings", Galvatech '89, ISIJ, 1989, 462.
10. M. Gu and A. R. Marder, "Phase Transformations of Zn-Fe Electrodeposited Coatings During Heating", ibid., 470.
11. A. R. Marder, "Microstructural Characterization of Zinc Coatings", Zinc Based Steel Coating Systems, G. Krauss and D. Matlock, eds., TMS, 1990, 55.
12. M. Gu and A. R. Marder, "Isothermal Heating of Zn and Zn-Fe Electrodeposited Coatings, ibid., 43.
13. Rapid Heat Treatment of EZA Coatings, ibid., 31.
14. M. Gu and A. R. Marder, "A New Method to Fabricate Single δ-Phase Zn-Fe Coating", Plating and Surface Finishing, 1991, 77.

15. M. Gu and A. R. Marder, "Morphological Changes of Electrodeposited Zn and Zn-Fe Coatings During Heating", J.Materials Science, 1991, 4588.
16. C. A. Drewien, A. O. Benscoter, and A. R. Marder, "A Metallographic Preparation Technique for Electrodeposited Iron-Zinc Alloy Coatings on Steel, Materials Characterization, 1991, 45.
17. M. Gu, M. R. Notis and A. R. Marder, "The Effect of Continous Heating on the Phase Transformations in Zn-Fe Electrodeposited Coatings, Met. Trans., 1991, 1737.
18. M. Gu and A. R. Marder, "Quantitative Analysis of a Textured Coating by a New X-Ray Diffraction Method", Powder Diffraction, 6, 1991, 89.
19. M. Gu and A. R. Marder, "Activation Energy of δ–Γ_1 Transformation in a Zn-Fe Electrodeposited Coating", Met. Trans., 1991, 1887.
20. K. M. Goggins and A. R. Marder, "Crack Initiation and Propogation in Hot Dip Galvanneal Steel Sheet During Bending, Intergalva '91, 1991, S4I/1.
21. A. R. Marder, "Zinc Coatings of Interstitial-Free Steel Sheet", International Symposium on I-F Steel Sheet Processing, 30th Annual Conf. of Metallurgists, Ottawa, Canada, 1991, 157.
22. C. E. Jordan, K. M. Goggins, and A. R. Marder, "Kinetics and Formability of Hot-Dip Galvanneal Coatings", Galvatech '92, CRM, eds., 1992, 137.
23. C. E. Jordan, K. M. Goggins, A. O. Benscoter and A. R. Marder, "Metallographic Preparation Technique for Hot-dip Galvanized and Galvannealed Coatings on Steel", Materials Characterization, 31, 1993, 107.
24. C. A. Drewien and A. R. Marder, "Effect of Annealing Upon Decomposition of Electrodeposited Iron-Zinc Alloy (EZA) Coatings", Journal of Materials Science, 29, 1994, 965.
25. C. A. Drewien, J. I. Goldstein, and A. R. Marder, "Structure of as-Deposited Iron-Zinc Coatings from Chloride Bath", Met. Mat. Trans., 25A, 1994, 249.
26. C. E. Jordan and A. R. Marder, "Morphology Development in Hot-dip Galvanneal Coatings", Met. Mat. Trans., 25A, 1994, 937.
27. C. E. Jordan, K. M. Goggins, and A. R. Marder, "Kinetics and Formability of Hot-Dip Galvanneal Coatings", 35th Mechanical Working and Steel Processing Coference, ISS-AIME, 31, 1994, 91.
28. S. T. Bluni and A. R. Marder, " Galfan Microstructure and Surface Characteristics, The Physical Metallurgy of Zinc Coated Steel, A. R. Marder, ed., TMS, Warrendale, PA., 1994, 99.
29. C. E. Jordan and A. R. Marder, "A Model for Galvanneal Morphology Development, ibid., 197.
30. S. T. Bluni, A. R. Marder and J. I. Goldstein, "Surface Characteristics of Hot-Dip Galfan Coatings", Materials Charaterization, 33, 1994, 93.
31. C. A. Drewien, J. I. Goldstein, and A. R. Marder, "η to G Phase Transformation in Electrodeposited Iron-Zinc Alloy Coatings", Met. Mat. Trans., 25A, 1994, 1119.
32. C. E. Jordan, K. M. Goggins, and A. R. Marder, "Interfacial Layer Development in Hot-Dip Galvanneal Coatings on Interstitial Free (IF) Steel", Met. Mat. Trans., 25A, 1994, 2101.
34. S. T. Bluni, M. Notis and A. R. Marder, "Nucleation Characteristics and Microstructure of Eutectic and Off-Eutectic Al-Zn Alloys", Acta Met. Mat., 43, 1995, 1775.
35. W. Maschek, S. P. Hayes and A. R. Marder, "Cross Section Studies of Zinc Iron Phase Growth in an Environmental Scanning Electron Microscope", Galvatech '95, Chicago, to be published.
36. C. E. Jordan and A. R. Marder, "Alloy Layer Growth During Hot-Dip Galvanizing at 450^{0}C", Galvatech '95, Chicago, to be published.

FACILITIES

Coating Processing Labs

The materials laboratories of Lehigh University has extensive equipment in both process simulation and characterization of zinc coatings. A hot dip simulation facility enables substrates to be cleaned in preparation for dipping by electrocleaning, fluxing, etc. prior to controlled preheating, hot dipping in a furnace with interchangeable baths, and controlled cooled. Speeds on the simulator are computer controlled and simulate commercial line speeds. The GLEEBLE, a high temperature thermal cycle apparatus, is used to simulate the various thermal cycles found in commercial Galvannealing lines. Heating rates of up to 1000^{o}C/sec can be obtained in this resistance heated equipment and similar cooling rates can be obtained by use of a unique quench system that combines air and water to produce a range of cooling conditions. The entire process is computer controlled.

Microscopy Labs

Microstructural characterization is accomplished in both the light optical microscopy laboratories as well as the electron optics laboratories. Besides the standard preparation equipment and microscopes, the LOM labs have several units capable of quantitative image analysis (QIA) including a digitizing pad, a QIA unit interfaced with a MAC computer, and a LEECO 20001 QIA with special programs written for coating analysis, especially Zn coating alloy thickness measurements. The electron optics laboratories contain several scanning electron microscopes (SEM), transmission electron microscopes (TEM), a new VG scanning transmission electron microscope (STEM), electron microprobe (EPMA) and a recently acquired Environmental Scanning Electron Microscope (ESEM) for in-situ measurements under temperature, such as the solidification of Zn and Zn Alloy coatings and the observation of the Galvannealing processes.

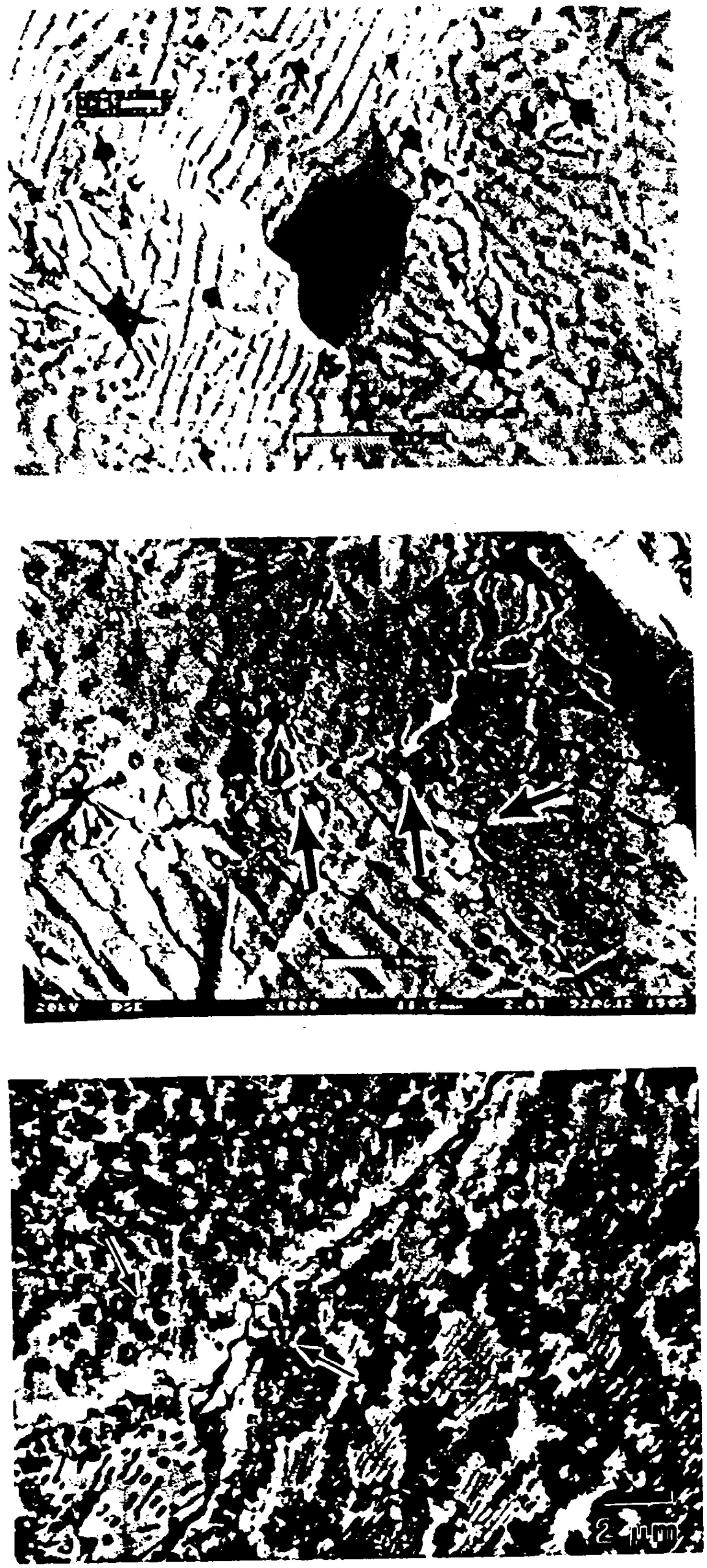


Figure 1. Defects in Galfan coatings: (a) shrinkage cavity, (b) Pb impurity segregation and (c) solidification cracks

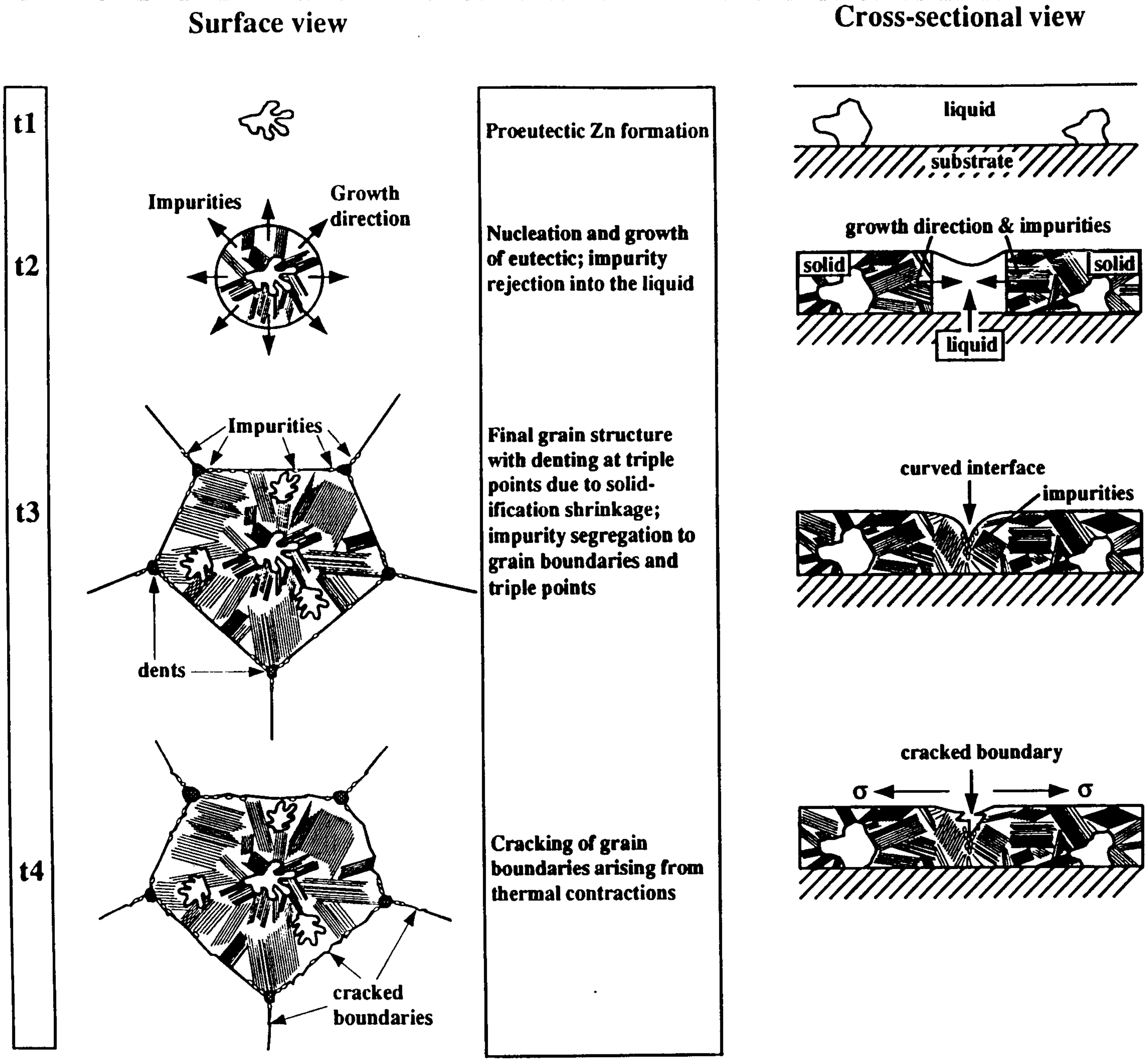


Figure 2. Galfan solidification process including surface and cross-sectional views.

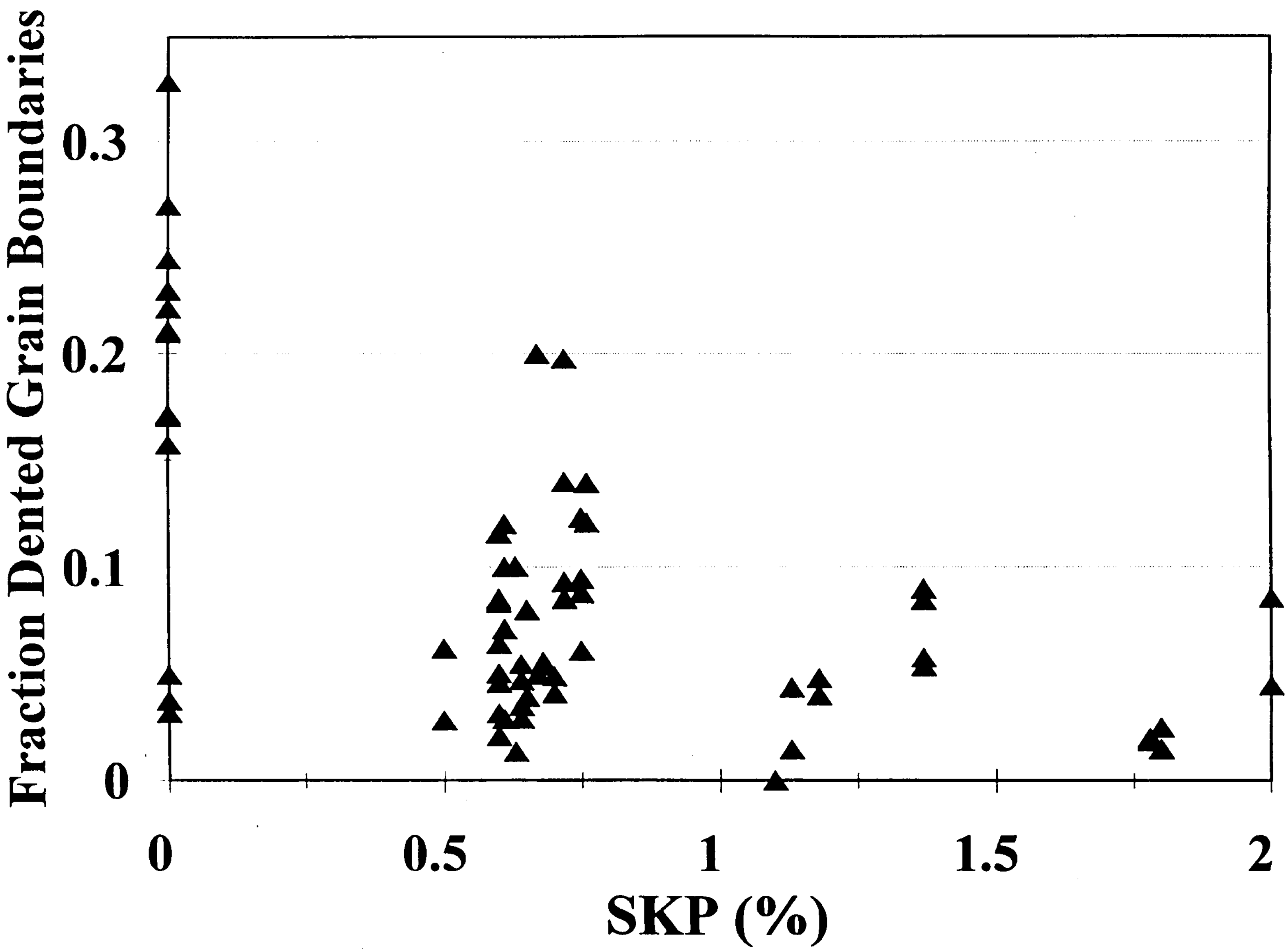


Figure 3. Denting as a function of percent skin pass reduction.

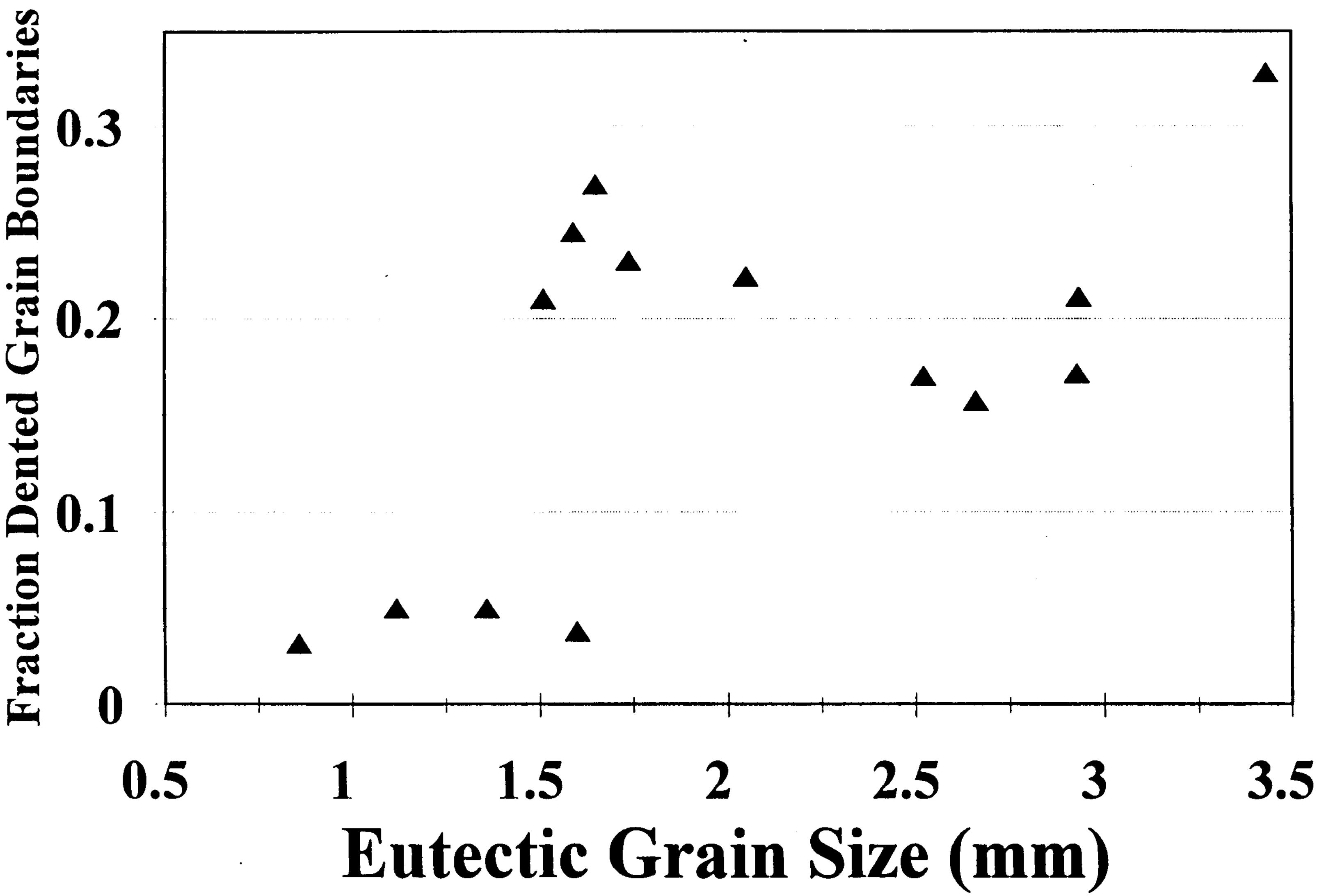


Figure 4. Denting as a function of eutectic grain size for non-skin passed commercial Galfan.

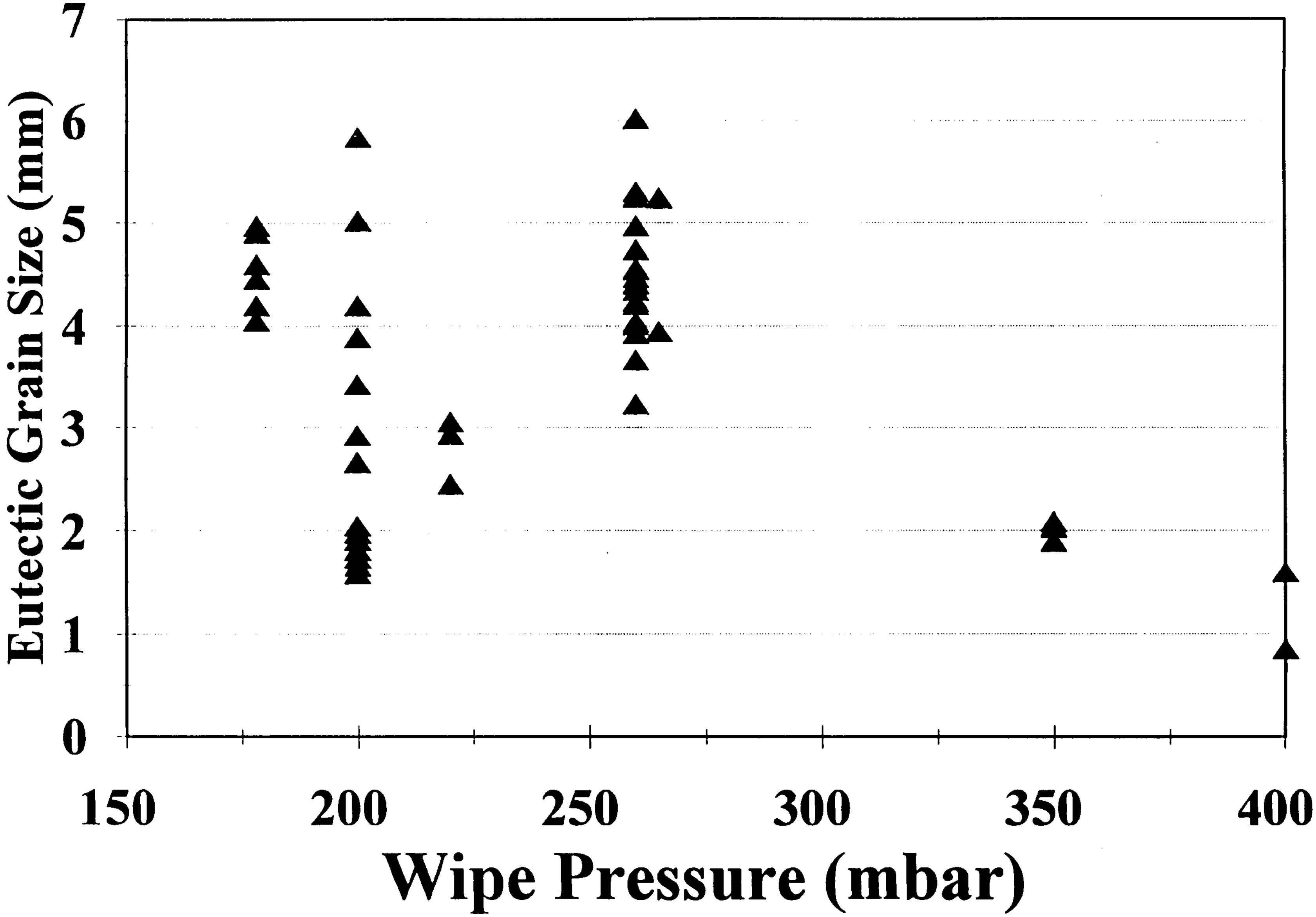


Figure 5. Galfan eutectic grain size as a function of wipe pressure.

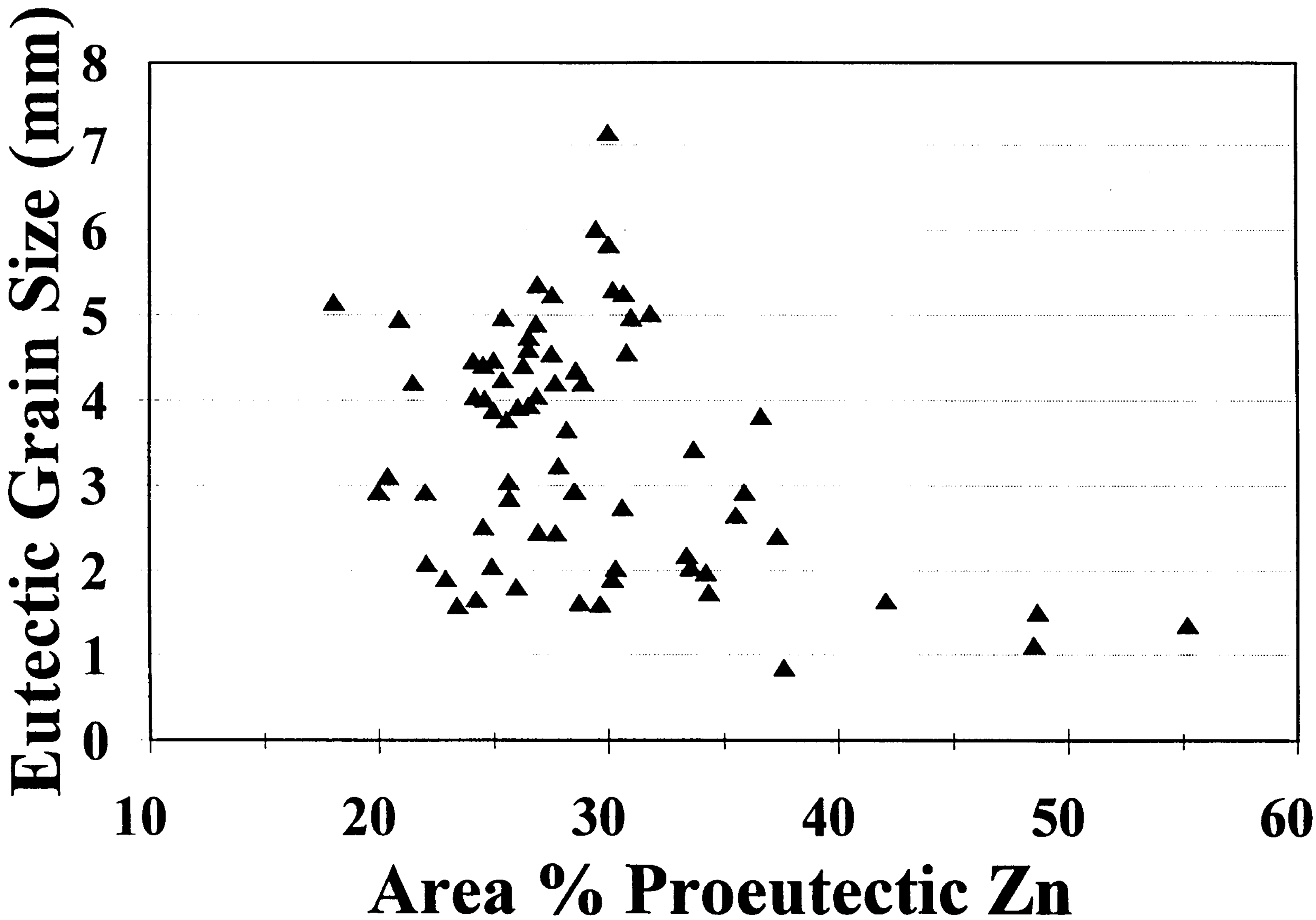


Figure 6. Galfan eutectic grain size as a function of area % proeutectic zinc.

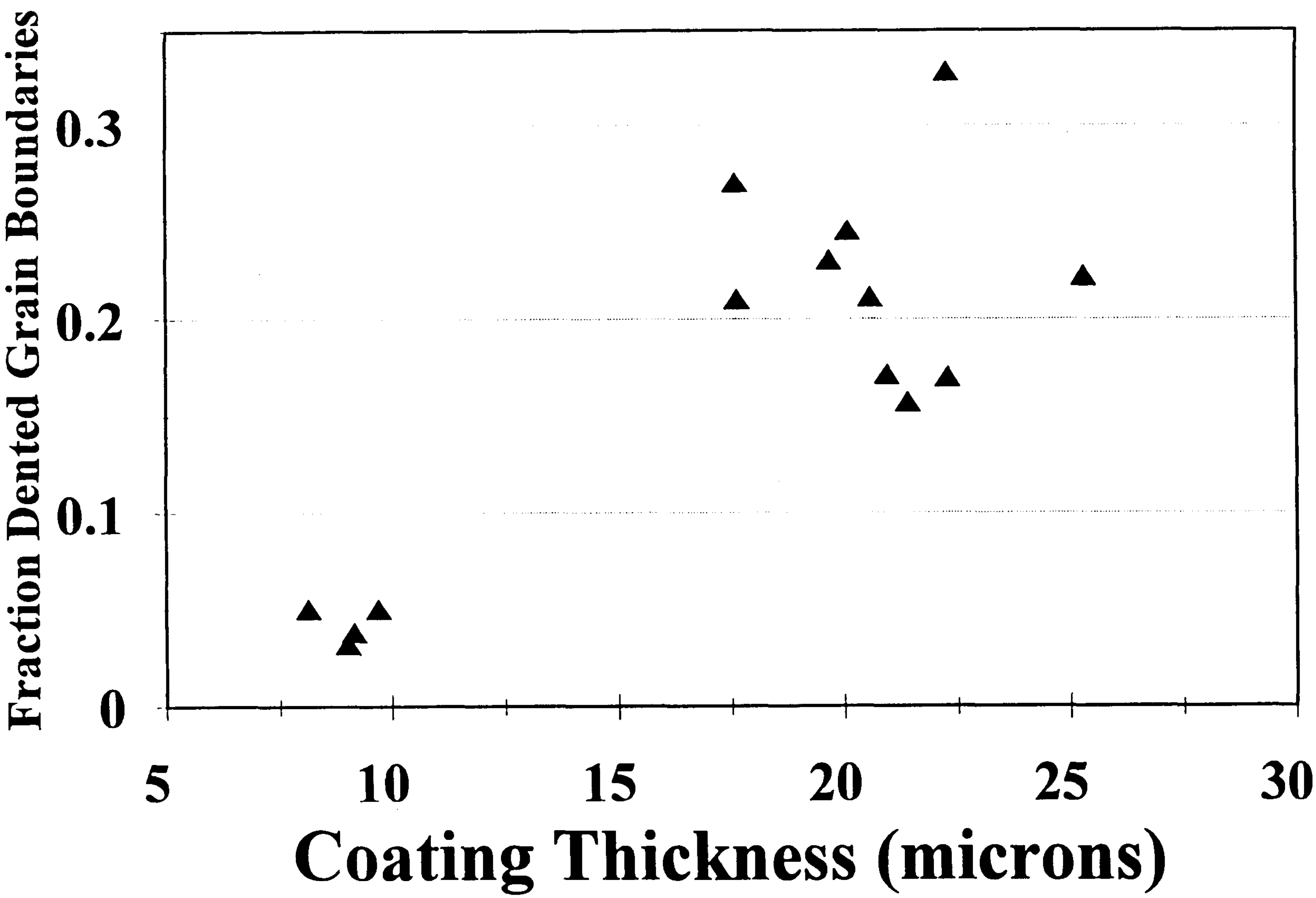
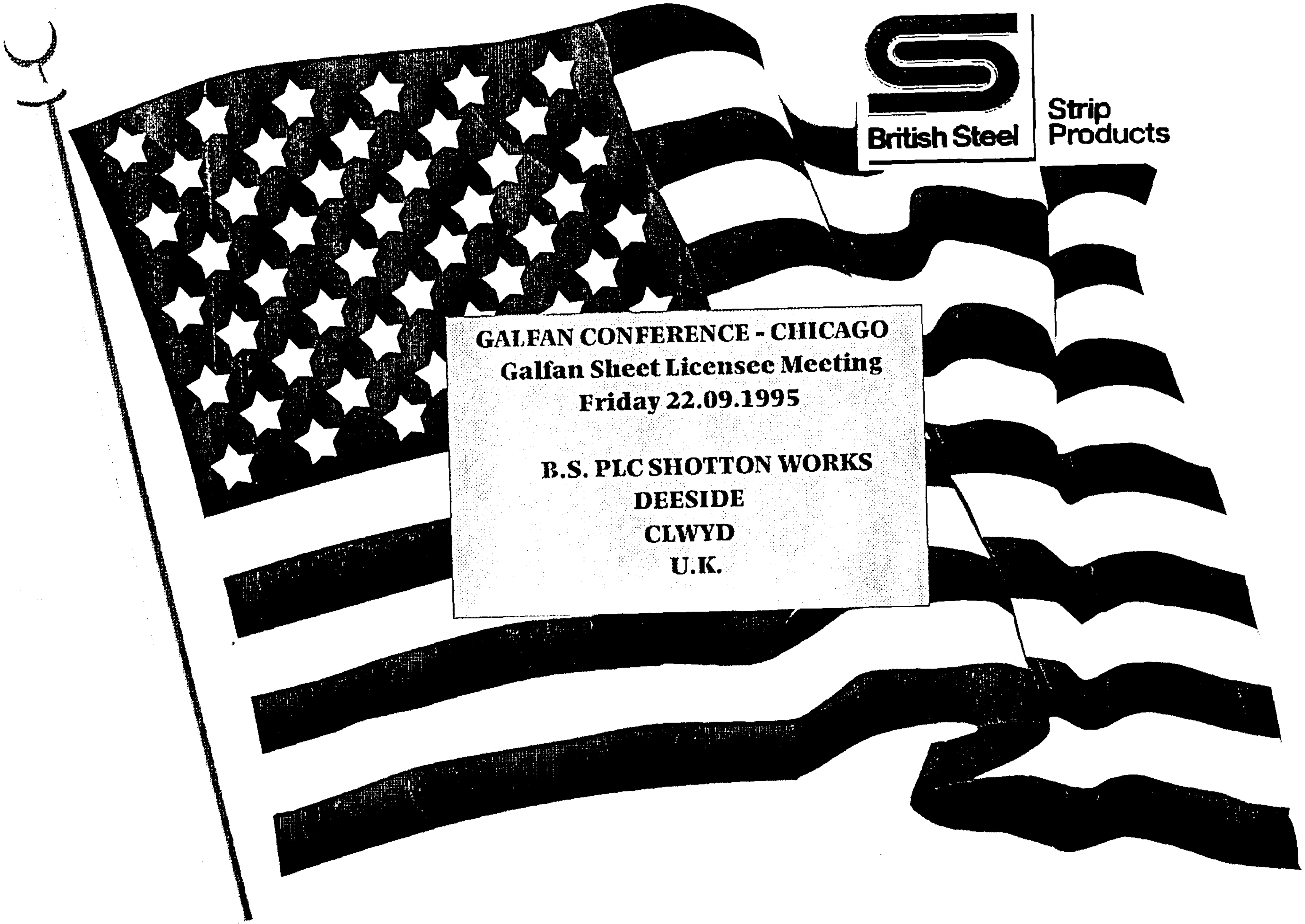


Figure 7. Denting as a function of coating thickness for non-skin passed commercial Galfan.


British Steel
Strip Products
GALFAN CONFERENCE - CHICAGO
Galfan Sheet Licensee Meeting
Friday 22.09.1995
B.S. PLC SHOTTON WORKS
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CLWYD
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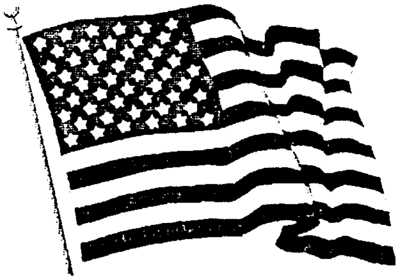

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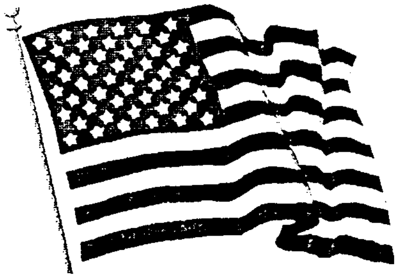
GALFAN CONFERENCE - CHICAGO

1. **PREPARATION FOR GALFAN TRIALS ON NO. 6 HOT DIP COATING LINE**

2. **LINE TRIALS WEEK 27 AND 33**



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BATH STRATEGY 'v' GALFAN TRIAL

ZINC BATH	**Pb 0.003%**
	Sb 0.08%-0.12%
ZALUTITE BATH	**Si 1.5%**

SILICON AND ANTIMONY ARE NOT CONDUSIVE TO GOOD GALFAN PRACTICE

PROBLEM RESOLVED DUE TO THE MECHANICAL DAMAGE IDENTIFIED IN THE REFRACTORY OF THE MAIN ZALUTITE BATH

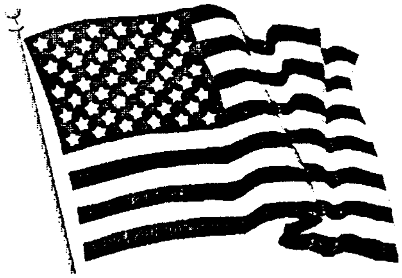
i.e. REFRACTORY LINING REQUIRED REPLACING SUMMER 1995

DECISION TAKEN TO UTILISE THE REFURBISHED BATH FOR GALFAN TRIAL

GALFAN PROGRAMME

	W/C 30.4.95 Week 18	W/C 7.5.95 Week 19	W/C 14.5.95 Week 20	W/C 21.5.95 Week 21	W/C 28.5.95 Week 22	W/C 4.6.95 Week 23	W/C 11.6.95 Week 24	W/C 18.6.95 Week 25	W/C 25.6.95 Week 26	W/C 2.7.95 Week 27	W/C 9.7.95 Week 28	W/C 13.8.95 Week 33	W/C 20.8.95 Week 34	W/C 27.8.95 Week 35	W/C 3.9.95 Week 36	W/C 10.9.95 Week 37
	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F S	S M T W T F
ZAL 7700T CAMPAIGN																
PREP FOR PUMP OUT																
1ST PUMP OUT MID INDUCTORS																
2ND PUMP OUT																
REMOVAL OF INDUCTORS																
WRECKING & REBUILD 24 HOUR PROGRAMME																
REPLACE INDUCTORS																
AIR DRYING REFRACTORY																
CHARGE INGOT TO BOTTOM OF BATH																
PREHEATING REFRACTORY																
INDUCTORS ON LOW HEAT																
CHARGE INDUCTORS																
PUMP OUT FOR ANALYSIS ADJ. & RECHARGE (IF NECESSARY)																
1ST GALFAN TRIAL																
PRODUCT EVALUATION											5 WEEKS (27 - 32)		5 WEEKS (33 - 38)			
2ND GALFAN TRIAL																
PUMP OUT & RE-ADJUST TO 55% Al & 1.5% Si FOR ZALUTITE																

FGW/jh/galfpro3.wk4/13.09.95



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GALFAN CONFERENCE - CHICAGO

NO. 6 HOT DIP COATING LINE IS A

DUAL PURPOSE FACILITY

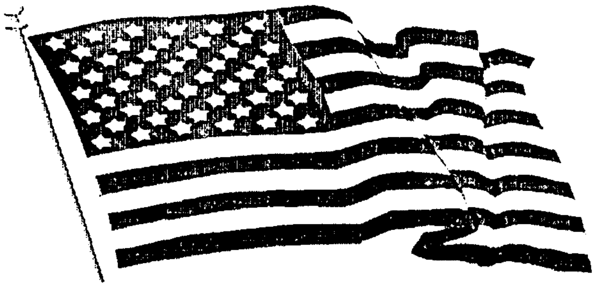
i.e. GALVANISED PRODUCTS

INCLUDING GALVANNEAL AND

ZALUTITE (GALVALUME)

WEEK 27 GALFAN TRIAL 1
WEEK 33 GALFAN TRIAL 2

SUNDAY 2ND JULY SUNDAY 13TH AUGUST		ZINC PRODUCTION 900 TONNES
MONDAY 3RD JULY MONDAY 14TH AUGUST	7 am - 7 pm	MAINTENANCE & PRODUCT CHANGE OVER
	7 pm - 7 am	FURNACE ATMOSPHERE CONDITIONING AND MONITORING BATH ANALYSIS TO MEET GALFAN SPECIFICATION
TUESDAY 4TH JULY TUESDAY 15TH AUGUST	7 am - 10 am	FINAL ASSESSMENT OF BOTH FURNACE ATMOSPHERE & BATH ANALYSIS
TUESDAY 4TH JULY TUESDAY 15TH AUGUST	10 am Plan 1300 Tonnes Trial 1 Plan 1700 Tonnes Trial 2	COMMENCE HOT DIP PRODUCTION OF GALFAN - ASSESSMENT OF PRODUCT QUALITY (ADHESION, COATING MASS, HARDNESS, TENSILE STRENGTH, DUCTILITY, SURFACE QUALITY-DENTS ETC) WITH CONTINUED MONITORING OF FURNACE ATMOSPHERE AND ZINC BATH ANALYSIS
THURSDAY 6TH JULY THURSDAY 17TH AUGUST		PRODUCT CHANGE OVER FROM GALFAN TO ZINC DURING THE NIGHT SHIFT OF THE 6TH JULY - TRIAL 1 17TH AUGUST - TRIAL 2



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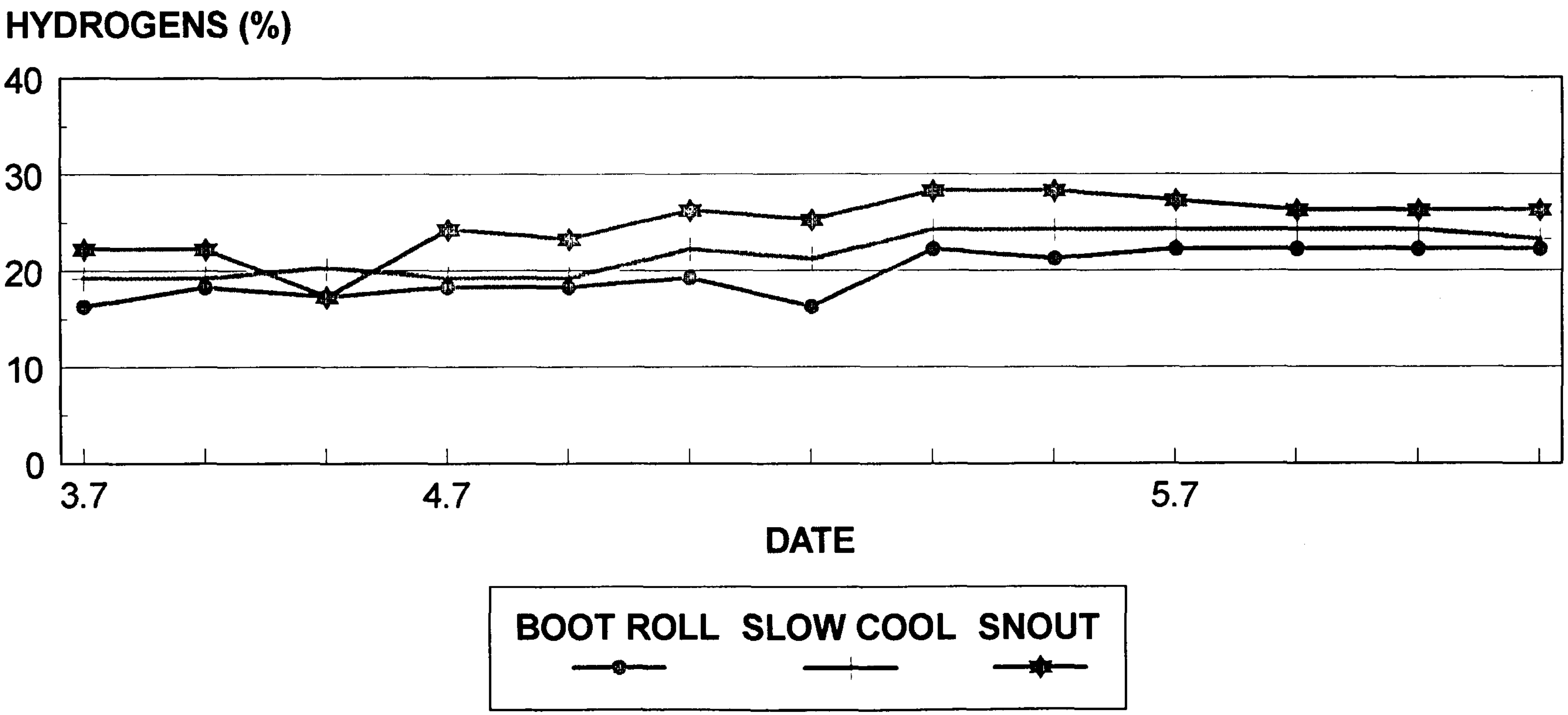
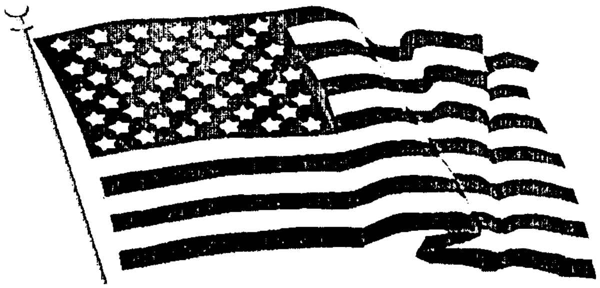
GALFAN CONFERENCE - CHICAGO

NO. 6 DP LINE

HYDROGENS - GALFAN TRIAL





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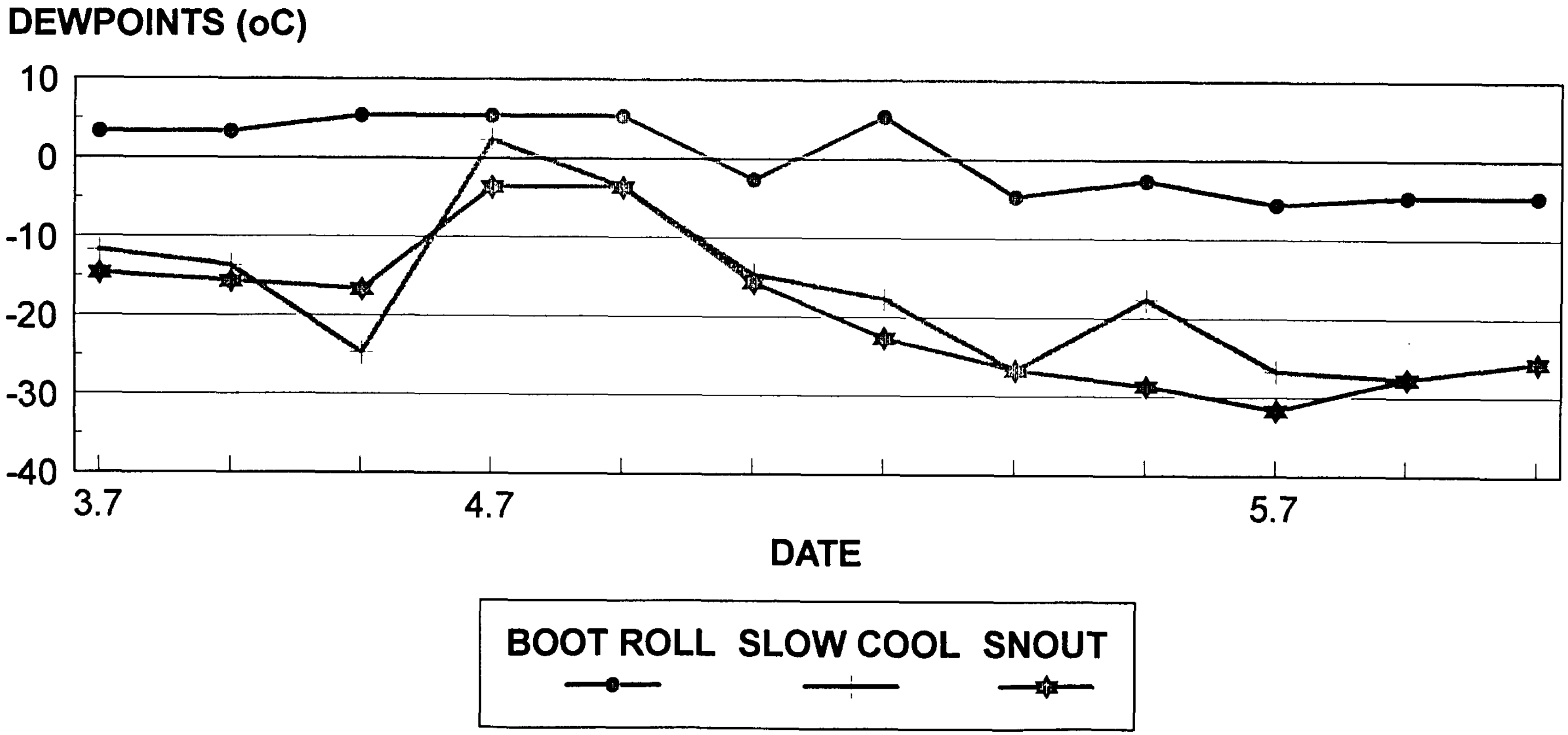
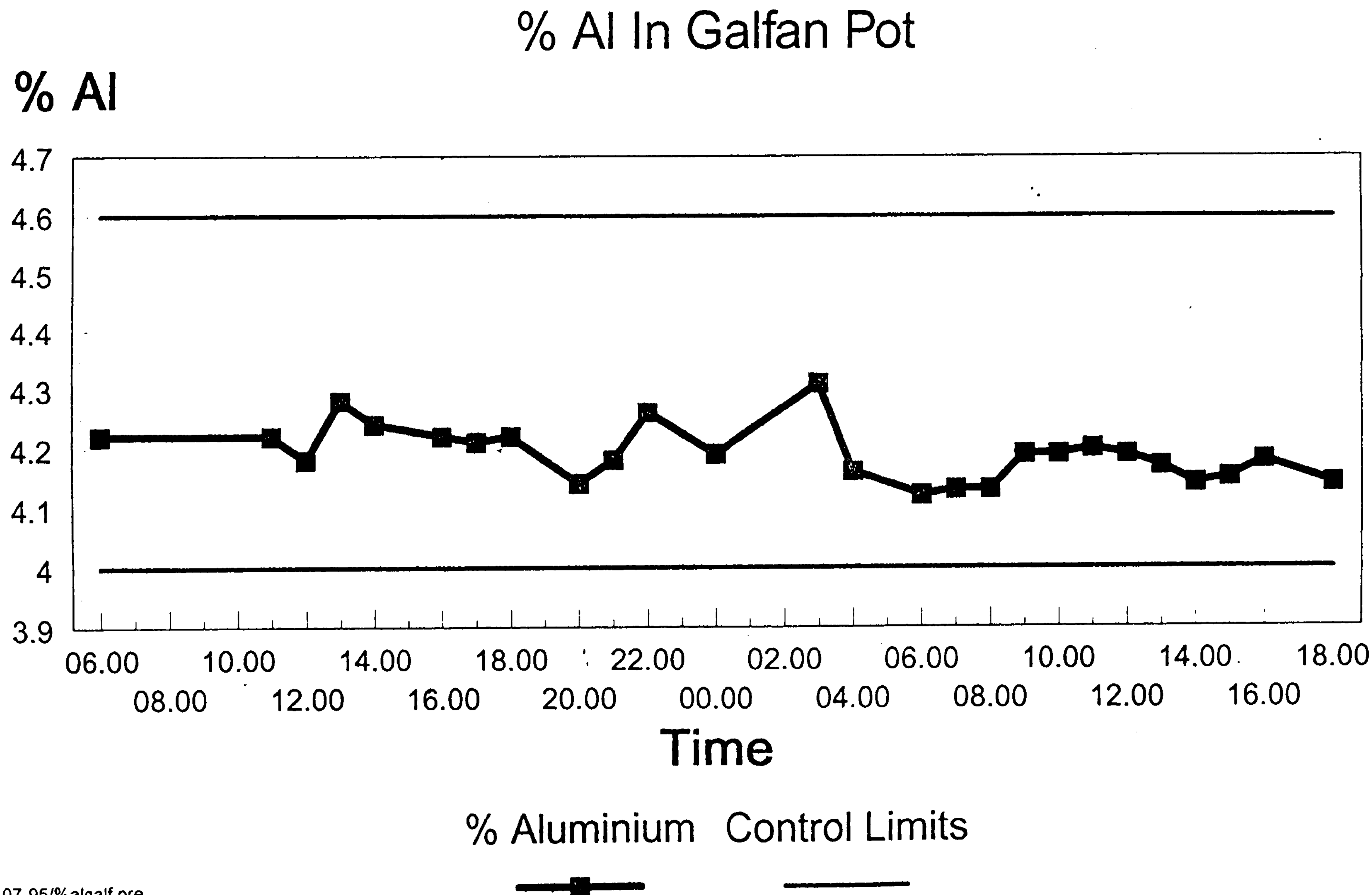
GALFAN CONFERENCE - CHICAGO

NO. 6 DP LINE

DEWPOINTS - GALFAN TRIAL



GALFAN TRIAL - 04/05 JULY '95



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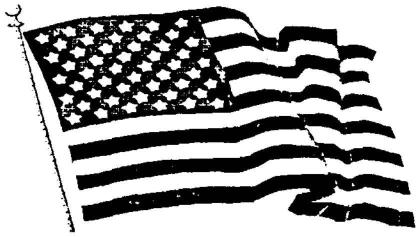
CRITICAL PROCESS CHANGES

GALFAN TRIAL NO. 1

TIME/DATE	RI	DIMENSIONS	LINE SPEED (m/min)	STRIP ENTRY TEMP (oC)	BATH TEMP (oC)
11.00 Hours 4th July	364074	0.55 x 1276	105	460	460
2105 Hours 4th July	453910	0.5 x 1226	140	440	440
1300 Hours 5th July	764122	0.65 x 1231	98	440	440

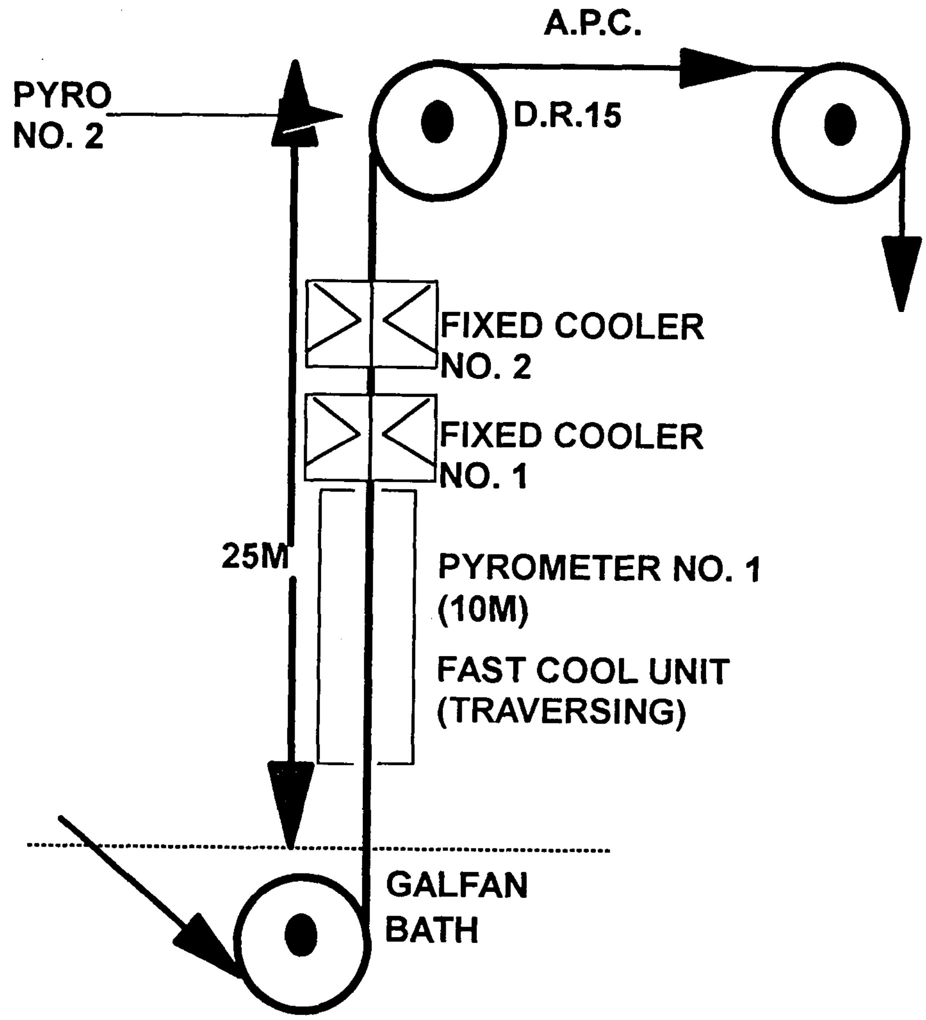
GALFAN TRIAL NO. 2

TIME/DATE	RI	DIMENSIONS	LINE SPEED (m/min)	STRIP ENTRY TEMP (oC)	BATH TEMP (oC)
1750 Hours 15th August	657986	1231 x .49	123	434	451
1230 Hours 16th August	953930	1071 x .36	154	460	447
2315 Hours 16th August	470142	1236 x .70	99	470	466
0517 Hours 17th August	963471	1256 x .65	104	471	468



British Steel Strip Products

B.S. NO. 6 LINE GALFAN CAMPAIGN
TYPICAL COOLING RANGE AFTER COATING



AIM FOR A MAX. STRIP TEMPERATURE OF 320oC D.R.15

GAUGE MM	L/S M/M	STRIP ENTRY TEMP oC	BATH TEMP oC	PYRO 1 TEMP oC	COOLING RATE OC/SEC	PYRO 2 oC	COOLING RATE oC/SEC
0.55	118	439	438	312	24.8	227	16.6
0.65	98	440	442	302	22.8	226	14.0