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COMPILATION OF TEST RESULTS AND STATISTICAL DATA ON PHASE 1 OF GALVANIZING RESEARCH PROJECT ZN-7
(Supplementary to Research Reports R5 and R6)

by

J. J. SEBISTY

PHYSICAL METALLURGY DIVISION

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Mines Branch Investigation Report IR 58-149

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by

J. J. Sebisty*

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SUMMARY

For record purposes, the results of work carried out on phase I of the galvanizing research project have been collected in the appendices which make up this report. This covers test work at the Mines Branch, Ottawa, accelerated corrosion tests at the Steel Company of Canada, Limited, Hamilton, Ontario, and statistical studies at the Consolidated Mining and Smelting Company of Canada, Limited, Trail, British Columbia.

With the exception of the statistical study given in appendix IV, the data tabulated have been fully discussed in reports previously issued (Research Reports R 5 and R 6) and in the corresponding papers prepared for presentation at the Fifth International Galvanizing Conference at Brussels, Belgium, June 1958.

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(62 pages, 9 tables, 18 illus.)

A P P E N D I X I

DATA ON MAIN SERIES OF TESTS IN PHASE I OF GALVANIZING PROJECT ZN-7

by

J. J. Sebisty

June 25, 1958

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INTRODUCTION

In this appendix, data pertaining to the work carried out at the Mines Branch on phase I of the galvanizing research project are given in tabular form. In order to save space, only typical melt and galvanizing logs have been included and the coating test results have been averaged. For illustrative purposes, complete coating test results are given for two typical series of specimens. The various tables included are identified as follows:

Table 1. Typical galvanizing melt log.

Table 2. Typical galvanizing log.

Table 3. Coating test results for typical series of specimens.

Table 3 (a). Surface appearance rating codes.

Table 4. Average coating test results.

Table 5. Combined coating test results. (These were derived from the findings of the preliminary statistical study given in appendix III(a). The values listed were used for graphical presentation of the coating test results in the paper and research report covering this part of the work).

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TABLE 1

Typical Galvanizing Melt Log

MINES BRANCH PHYSICAL METALLURGY DIVISION	NON-FERROUS SECTION GALVANIZING MELT LOG	Project Zn-7 Date: Nov. 21/57

Melt No. CU (Bath No. 1)

Charge 39.6 lb

Metal	Composition	Form	Amount
Zn	99.99 %	ingot	34.35 lb
Pb	99.99 %	sheet	88.5 g
Fe-Zn master	0.42 % Fe	shot	3.2 lb
Al-Zn master	4.0 % Al	"	1.86 lb

Procedure	Time	Temp	Remarks
Furnace on	8.45 a.m.	-	
Zinc charged	8.45 "	-	
	11.05 "	500°C	
Alloying			
Pb	8.45 "	-	
Fe-Zn	11.05 "	500°C	
Al-Zn	11.15 "	500°C	
extra Fe-Zn (130 g)	1.30 p.m.	480°C	) added after galvanizing of
extra Al-Zn (50 g)	1.35 "	475°C	) each lot of 12 large specimens
Poured to ingot after galvanizing run	4.30 p.m.	440°C	

Bath composition	Fe %	Al %	Pb %	
Nominal	0.03	0.2	0.5	
Actual				
1.35 p.m. Start of dipping	0.030	0.19	0.50	
2.55 " 2nd sample	0.032	0.19	0.50	(taken after 24 large specimens dipped)
4.15 " End of dipping	0.027	0.19	0.49	

TABLE 2

Typical Galvanizing Log

MINES BRANCH PHYSICAL METALLURGY DIVISION	NON-FERROUS SECTION GALVANIZING LOG SHEET	Project Zn-7 Date: Nov. 21/57

Melt No. CU (Bath No. 1)

Test No. 1, 2, 3, 4.

Material Treated
48 specimens, 4-1/2-in. x 6-1/2-in.
(24 each of No. 5 & No. 3 steel)
12 " , 3-in. x 3-in.
(6 each of No. 5 & No. 3 steel)

Pickling

Sample No.	Acid Conc	Inhibitor	Time & Temp	Rinse
All	5% H_2SO_4 sol'n.	1/2% by volume of acid (Rodine 92)	5 min at 71°C	Scrubbed and then rinsed for 1 min in cold running water. Dried in acetone.

Fluxing

Sample No.	Flux	Density	Time & Temp	Drying Time & Temp
All	Zinc chloride - Ammonium chloride (1.27:1.35 ratio flux)	10.4° Baumé	1 min at 82°C	1.5 to 2 min at 160 to 170°C

Galvanizing

Sample No.	Bath Temp °C	Immersion Speed	Immersion Time	Withdrawal Speed	Remarks
Large Specimens					
1-1 to 1-6	466, 466, 465 465, 465, 465	6 fpm	30 sec	3 fpm	No. 5 finish
1-13 to 1-18	465, 465, 465 465, 465, 465	"	"	"	No. 3 finish
2-1 to 2-6	465, 465, 465 465, 465, 465	"	2 min	"	No. 5 finish
2-13 to 2-18	465, 465, 465 465, 465, 465	"	"	"	No. 3 finish
3-1 to 3-6	444, 444, 445 445, 445, 444	"	30 sec	"	No. 5 finish
3-13 to 3-18	445, 445, 445 445, 445, 445	"	"	"	No. 3 finish
4-1 to 4-6	444, 444, 444 445, 445, 446	"	2 min	"	No. 5 finish
4-13 to 4-18	447, 447, 446 445, 445, 447	"	"	"	No. 3 finish
Small Specimens for Steel Weight Loss Measurements (each group of six dipped in pairs prior to each series of 12 large specimens)					
1-25 to 1-30	465, 465	Manual-approx. 8 fpm	30 sec	Manual-approx. 8 fpm	3 each of No. 5 & No. 3 finish
2-25 to 2-30	465, 465	"	2 min	"	"
3-25 to 3-30	445, 445	"	30 sec	"	"
4-25 to 4-30	447, 447	"	2 min	"	"

TABLE 3

Coating Test Results for Typical Series of Specimens

Test Number	Steel Finish	Coating Wt, oz/sq ft-sheet	Iron Content mg/sq ft	Iron Content g/m^2	Steel Wt Loss, g/m^2	Alloy Thickness, mm	% Alloy	Ductility **	Adherence **	Spangle Size **	Spangle Contrast **	Brightness **	Roughness **
1	5	0.44	180	2.0	4.9	*	-	1	1	4	4	2	4
1	5	0.46	210	2.3	3.7	*	-	1	1	4	4	3	4
1	5	0.52	170	1.8	4.5	*	-	1	1	4	4	3	4
1	3	0.43	210	2.3	4.4	*	-	1	1	4	4	2	4
1	3	0.44	210	2.3	5.6	*	-	1	1	4	4	2	4
1	3	0.43	240	2.6	-	*	-	1	1	4	4	2	4
5	5	1.82	2460	26.4	28.4	0.0240	59.1	4	5.5	4	4	3	3
5	5	1.88	2500	26.9	24.0	0.0257	59.4	4	5.5	4	4	4	3
5	5	1.94	2510	27.1	23.5	0.0236	59.5	4	5.5	4	4	4	3
5	3	1.66	2380	25.7	26.1	0.0236	60.0	3	5.5	2	2	2	2
5	3	1.67	2440	26.3	27.6	0.0222	58.5	3	5.5	2	2	2	2
5	3	1.67	2410	26.0	31.9	0.0217	60.3	3	5.5	2	2	2	2

*Impossible to measure or estimate.　　**See codes in Table 3(a).

TABLE 3 (a)

Surface Appearance Rating Codes

Ductility

Rating: - 1. Excellent, no cracking
2. Good, network of fine cracks
3. Fair, general cracking, with coating broken up into small blocks
4. Poor, wide separation of medium size blocks
5. Very poor, general peeling of coating in large blocks

Spangle Size

Rating: - 1. Large
2. Medium
3. Small
4. No spangle

Brightness (Photometer readings)

Rating: - 1. 0-1.25
2. 1.5-2.75
3. 3-4.25
4. 4.5 +

Adherence

Minimum bend radius causing flaking (90° bend plus 180° reverse bend).

Rating: - 1. 0.050 in.
2. 0.070 "
3. 0.100 "
4. 0.144 "
5. 0.192 in.
6. 0.252 "
7. 0.320 "
8. 0.400 "

Spangle Contrast

Rating: - 1. Good, spangles well defined
2. Moderate, spangles well defined
3. Low or no contrast. Spangles outlined only.
4. No contrast, no spangles

Roughness

Rating: - 1. Very smooth
2. Moderately smooth
3. Fine to moderately rough sandpaper-like texture
4. Rough texture or uneven surface caused by various defects (ridges, dewetting, black spots, pimples)

TABLE 4

Average Coating Test Results*

Test Number	Steel Finish	Coating Wt, oz/sq ft-sheet	Iron Content mg/sq ft	Iron Content g/m^2	Steel Wt Loss g/m^2	Alloy Thickness mm	% Alloy	Ductility **	Adherence **	Spangle Size **	Spangle Contrast **	Brightness **	Roughness **
1	5	0.47	187	2.0	4.4	-	-	1	1	4	4	2.7	4
1	3	0.43	220	2.4	5.0	-	-	1	1	4	4	2	4
2	5	0.55	393	4.2	6.5	-	-	1	1	4	4	2	4
2	3	0.55	473	5.1	8.7	-	-	1	1	4	4	3.3	4
3	5	0.43	133	1.4	2.9	-	-	1	1	4	4	2.3	4
3	3	0.43	123	1.3	2.8	-	-	1	1	4	4	2.3	4
4	5	0.44	207	2.2	4.8	-	-	1	1	4	4	2	4
4	3	0.50	250	3.0	6.5	-	-	1	1	4	4	2.3	4
5	5	1.88	2890	26.8	25.3	0.0244	59.3	4	5.5	4	4	3.7	3
5	3	1.67	2410	26.0	28.5	0.0225	59.6	3	5.5	2	2	2	2
6	5	2.52	2680	28.9	30.0	0.0300	46.5	4	6	4	4	2.7	4
6	3	2.26	2633	28.4	31.5	0.0292	45.9	4	6	4	4	2.7	2
7	5	1.81	2360	25.4	23.2	0.0223	59.4	3.3	5.5	4	4	2	3
7	3	1.66	2320	26.1	26.6	0.0223	63.0	3.0	5.5	2	2	2	2
8	5	2.25	2577	27.8	29.6	0.0241	49.5	3	6	4	4	3.7	4
8	3	2.28	2627	28.4	28.1	0.0278	51.1	3	6	4	4	4	4
9	5	0.50	197	2.2	4.0	-	-	1	1	4	4	1.7	4
9	3	0.52	197	2.2	5.3	-	-	1	1	4	4	2	4
10	5	1.80	2523	27.3	25.0	0.0232	59.1	3.3	5.5	4	4	3	3
10	3	1.76	2567	27.7	25.3	0.0220	62.4	3	5.5	2	2	2	2
11	5	1.29	1946	21.0	18.5	0.0157	60.7	3	5.5	2.7	3.3	2	3
11	3	1.30	1993	21.4	20.8	0.0174	61.2	3	5.5	1	3	2	2
12	5	3.02	4406	47.4	48.7	0.0482	79.6	4	6	3	3	2.3	4
12	3	2.82	4376	47.1	48.3	0.0483	77.7	4	6	2.7	3	2	3
13	5	0.94	1053	13.2	13.4	0.0980	46.2	2	3.2	2	3	1.3	1
13	3	1.14	1386	14.9	10.2	0.0117	46.4	2	3.3	1	3	1	1
14	5	2.07	2896	31.2	26.5	0.0318	71.1	3	5.5	2	3	1	1
14	3	2.21	3096	33.3	38.9	0.0298	60.2	3	5.5	1	3	1	1
15	5	0.40	166	1.8	2.7	-	-	1	1	2	4	1	4
15	3	0.46	206	2.2	2.3	-	-	1	1	2	4	1.3	4
16	5	1.65	2350	25.3	28.3	0.0231	63.5	3	5.5	4	4	2.3	3
16	3	1.67	2436	26.2	25.7	0.0213	60.1	3	5.5	2	2	2.3	2
17	5	1.53	2096	22.5	19.1	0.0157	61.4	2	4.5	4	4	3.3	3
17	3	1.21	2126	22.9	19.7	0.0160	62.3	2	4.5	4	4	3.7	3
18	5	1.02	1676	18.0	18.8	0.0143	59.8	2	4	4	4	2.3	2
18	3	1.10	1696	18.2	17.8	0.0142	62.1	2	4	4	4	2	2
19	5	2.63	3710	39.9	35.8	0.0383	71.8	3	6	4	4	3	3
19	3	2.31	3570	38.4	38.3	0.0355	71.3	3	6	4	4	3	2
20	5	3.05	4530	48.8	46.2	0.0496	79.5	4	7	4	4	3.3	3.3
20	3	2.71	4500	48.5	48.2	0.0448	75.6	4	7	4	4	4	2
21	5	1.89	2516	27.1	27.1	0.0237	62.3	3	5.5	4	4	2.3	3.3
21	3	1.72	2493	26.8	24.3	0.0269	61.8	3	5.5	2	2	2	2
22	5	2.57	3613	38.8	44.3	0.0350	58.1	4	6	4	4	4	3
22	3	2.80	3756	40.4	47.7	0.0343	59.1	4	6.5	4	4	4	4
23	5	2.48	3123	33.6	35.4	0.0314	49.5	4	6.2	4	4	4	4
23	3	2.70	3216	34.5	38.3	0.0283	44.8	4	6	4	4	4	4
24	5	1.93	2076	22.2	28.8	0.0240	59.7	4	6	3.3	3.7	3.3	3.7
24	3	1.86	2033	21.8	22.6	0.0189	58.5	4	6	4	3.3	3.7	3
25	5	1.77	2270	24.3	24.4	0.0231	60.5	3	6	4	4	4	3.3
25	3	1.90	2296	24.7	26.0	0.0248	60.3	3.7	6	4	4	4	3
26	5	1.18	1543	16.6	18.4	0.0136	49.7	2	4.5	2.7	2.7	2	2
26	3	1.34	1706	18.3	19.6	0.0188	49.4	2	4.5	2	2	2	2
27	5	1.72	2336	25.1	23.4	0.0212	58.2	3	5.5	4	4	2	3
27	3	1.70	2453	26.4	27.1	0.0224	57.0	3	5.8	2	2	2	2
28	5	2.10	3093	33.3	33.0	0.0315	77.6	3.7	6	4	4	4	3
28	3	1.97	3176	34.2	32.0	0.0354	78.7	3	6	3	3	3.7	2
29	5	0.94	1303	14.0	13.3	0.0111	53.3	2	4	2	2	2	2
29	3	1.07	1436	15.5	19.1	0.0094	37.8	2	4	2	2	2	1
30	5	4.81	6950	74.8	67.1	0.0837	81.5	5	8	4	4	3	4
30	3	4.54	6876	74.1	71.4	0.0799	81.5	5	8	4	4	3	4

* - each value shown is average of three determinations.
** - see codes in Table 3(a).

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TABLE 5

Combined Coating Test Results

Aluminium Content %	Immersion Time min	Tests Combined	Combined Averages: Number of Results Averaged	Coating wt, oz/sq ft-sheet	Iron Content g/m^2	Steel Loss g/m^2	Alloy Thickness mm	% Alloy	Ductility *	Adherence *
0.2	0.5	1,3	12	0.44	1.6	3.8	-	-	1	1
	1.0	9,15	12	0.48	2.1	3.5	-	-	1	1
	2.0	2,4	12	0.52	3.6	6.4	-	-	1	1
0.1	0.25	29	6	1.01	14.8	16.2	0.0103	45.6	2	4
	0.5	11,13,17,18	24	1.20	19.1	17.1	0.0168	57.5	2.25	4.3
	1.0	5,7,10,16,21, 27,26,28	48	1.71	26.9	25.6	0.0233	61.4	3.1	5.5
	2.0	12,14,19,20	24	2.61	39.4	41.8	0.0408	73.4	3.62	6.1
	4.0	30	6	4.68	74.5	69.3	0.0819	81.6	5	8
0	0.5	24,25	12	1.87	23.6	24.6	0.0228	59.8	3.6	6
	1.0	6, 8	12	2.32	28.4	29.8	0.0226	48.3	3.6	6
	2.0	22,23	12	2.64	36.8	41.4	0.0323	52.9	4.25	6.1

* - see codes in Table 3(a).

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APPENDIX II

ACCELERATED CORROSION TESTING OF GALVANIZED PANELS

by

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(The Steel Company of Canada, Limited, Hamilton, Ontario)
January 21, 1958

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INTRODUCTION

Brief descriptions are given below of the accelerated corrosion tests performed on the galvanized test panels prepared at the Physical Metallurgy Division, Mines Branch, Ottawa. The results obtained are then listed in Tables 1 to 4 (see pages 12 to 15). These results include:

Table 1 - Diffusivity measurements for typical specimens. (Average results for all specimens are listed in Table 2.)

Table 2 - Corrosion results after humidity test.

Table 3 - Weight change data.

Table 4 - Water film test results.

CORROSION TESTS

(a) Humidity Test

The requirements for this test are galvanized panels cut to 4-in. by 5-in., clean 4-in. by 5-in. glass plates (twice as many as the number of galvanized panels), freezer, humidity cabinet, and spring clothes pins (four times as many as the number of galvanized panels). This test is completed in 48 hr and consists of the following cycle repeated twice:

(i) 5 hr in freezer at 0°F (both glass plates and galvanized panels).

(ii) Moisten two glass plates and one galvanized panel simultaneously by condensation of moist air until all of the original frost disappears.

(iii) Place the galvanized panel between the two glass plates and fasten the whole assembly with four spring clothes pins.

(iv) Place the assembly in the humidity cabinet at 95°F, 96% R.H., for 16 hr.

(v) 4 hr in humidity cabinet at 95°F, 20% R.H., to dry the samples.

After the second cycle, corrosion index values are assigned and the "diffusivity" is determined by reflectometer.

(b) Water Film Test

This test requires twice the number of clean 4-in. by 5-in. glass plates as there are 4-in. by 5-in. galvanized panels to be tested. Two glass plates and one galvanized panel are submerged together in tap water, the galvanized panel being sandwiched between the glass plates under the surface of the water. The whole assembly is fastened together with four spring clothes pins, removed from the water, and stored in the flat position in warm air for 48 hr. Corrosion index values are assigned after 24 and 48 hr, for both white and black stain.

NOTE: In both of these tests, the galvanized samples must be initially flat in order to provide the most reliable results.

CORROSION EVALUATION

In general, corrosion by the humidity test is evaluated by reflectometer, whereas corrosion by the water film test is evaluated by corrosion index.

(a) Reflectometer

The reflectometer used at present at Stelco is the Photoelectric Reflection Meter, Model 610, manufactured by Photovolt Corp., New York.

The "search head" of the instrument is placed on the surface to be evaluated. The light source within the head directs a vertical beam of parallel light towards the sample surface. A circular (washer-shaped) photoelectric cell surrounding the light beam and facing downward picks up light diffused from the sample surface (hence the term diffusivity). The e.m.f. thus generated motivates the galvanometer of the reflectometer, giving a diffusivity reading.

The diffusivity of the galvanized panels in question was actually measured in percent compared to MgO as having a diffusivity of 100. (The standard used in the test was the white standard, which has a diffusivity of 73.0% compared to MgO.) The light from the head to the panel was passed through the tri-stimulus green filter.

(b) Corrosion Index

The corrosion index is a value assigned to the corroded surface after visual examination. Generally two corrosion index values appear together, e.g. $^{1}{}_{2}$, the upper being the index of the numbered side, the lower that of the unnumbered side. The corrosion index is indicative of corrosion in the following way:

Index	0	1	2	3	4
% of Surface Corroded	0	1 to 25	26 to 50	51 to 75	76 to 100

Both white and black staining were evaluated in this manner. In some cases the latter occurred as areas the size of pin-heads, and this is indicated by the index 1°.

EXPERIMENTAL PROCEDURE

The galvanized panels were sheared to 4-in. by 5-in. prior to testing. In the shearing operation, the rough bottom edge was cut off to about 1/4-in. from the bottom. The panel was cut 5-in. up from, and parallel to, the fresh bottom edge, then the sides were trimmed off to give a width of 4-in.

After being cut to size, each panel was

(i) accurately weighed,

(ii) tested for diffusivity by reflectometer, and

(iii) subjected to the two-cycle humidity test.

Upon completion of the humidity test, each sample was

(i) evaluated by corrosion index,

(ii) weighed accurately to determine weight gain due to corrosion,

(iii) tested again for diffusivity,

(iv) treated with ammonium hydroxide to remove the corrosion products,

(v) reweighed to find weight loss due to corrosion,

(vi) subjected to the water film test for 48 hr, and

(vii) evaluated by corrosion index after 24 hr and 48 hr under the water film test.

Reflectometer readings of diffusivity were taken on the numbered sides of all of the panels, but were taken in two different patterns over the panels as illustrated below:

```
                      Top of Original Panel
       1              (Numbered Side Up)       1       2
       2
   6 7 3 8 9                                       3
       4
       5                                       4       5

   Pattern A                                   Pattern B
```

As indicated in Table 2, some specimens were tested using pattern A and the remainder using pattern B.

(Tables 1 to 4 follow,)
(on pages 12 to 15.   )

TABLE 1

Diffusivity Measurements for Typical Specimens

Test Number	Steel Finish	Time of Test	Position								
			1	2	3	4	5	6	7	8	9
1	5	B*	16	21.5	21.5	28	27				
		A**	28.5	26	30	31	30				
1	3	B	22	20	22	25	22				
		A	31	29.5	27.5	25	26.5				
5	5	B	31.5	30	31	31	30	30.5	30.5	32	35
		A	29	28	28.5	29.5	31	27	27.5	27	29
5	3	B	26.5	26.5	25	25	26	26	25.5	25.5	25
		A	30	29	29	31.5	31	31	28	28	29

* Specimens tested for diffusivity before humidity test.
** Specimens tested for diffusivity after humidity test.

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TABLE 2

Corrosion Results After Humidity Test

Test Number	Steel Finish	Average Diffusivity: Before Corrosion	After Corrosion	Gain	% Gain	Corrosion Index: White		Black	
1	5	22.8	29.1	6.3	27.6	4	4	0	0
1	3	22.2	27.9	5.7	25.7	3	3	0	0
2	5	23.3	29.3	6.0	25.8	4	3	0	0
2	3	27.7	26.5	-1.2	-4.3	3	3	0	0
3	5	21.4	26.4	5.0	23.4	4	4	0	0
3	3	22.1	29.3	7.2	32.6	3	3	0	0
4	5	20.7	29.7	9.0	43.5	4	3	0	0
4	3	21.2	26.6	5.4	25.5	3	3	0	0
5*	5	31.2	28.5	-2.7	-8.6	3	3	0	0
5*	3	25.4	29.6	4.2	16.5	3	4	0	0
6*	5	20.8	33.6	12.8	61.5	4	4	0	0
6*	3	20.7	33.6	12.9	62.3	4	4	0	0
7*	5	30.2	32.8	2.6	8.6	4	4	0	0
7*	3	27.0	32.0	5.0	18.5	4	3	0	0
8*	5	29.6	37.1	7.5	25.3	3	3	0	0
8*	3	31.1	36.7	5.6	18.0	4	3	0	0
9	5	15.3	30.5	15.2	99.3	3	3	0	0
9	3	15.5	29.0	13.5	87.1	3	3	0	0
10*	5	30.8	32.1	1.3	4.2	3	3	0	0
10*	3	25.0	28.4	3.4	13.6	2	3	0	0
11	5	26.9	31.5	4.6	17.1	4	3	0	0
11	3	22.4	31.5	9.1	40.6	4	3	0	0
12	5	32.7	32.4	-0.3	-0.9	3	3	0	0
12	3	28.1	32.8	4.7	16.7	4	3	0	0
13	5	20.7	26.6	5.9	28.5	3	3	0	0
13	3	18.9	24.4	5.5	29.1	3	3	0	0
14	5	20.2	26.5	6.3	31.1	2	3	0	0
14	3	19.1	26.1	7.0	36.6	3	3	0	0
15	5	18.7	31.2	12.5	66.8	3	3	0	0
15	3	18.6	31.1	12.5	67.2	3	3	0	0
16	5	36.3	33.7	-2.6	-7.1	3	3	0	0
16	3	29.6	34.6	5.0	16.8	3	3	0	0
17	5	51.2	37.1	-14.1	-27.5	2	3	0	0
17	3	49.6	40.1	-9.5	-19.1	4	4	0	0
18	5	30.2	30.4	0.2	0.6	1	2	0	0
18	3	30.6	32.8	2.2	7.1	2	3	0	0
19	5	38.1	34.9	-3.2	-8.3	3	2	0	0
19	3	36.6	35.3	-1.3	-3.5	3	3	0	0
20	5	47.1	38.3	-8.8	-18.6	2	3	0	0
20	3	47.1	36.5	-10.6	-22.5	2	2	0	0
21	5	31.4	30.0	-1.4	-4.4	3	2	0	0
21	3	26.1	30.9	4.8	18.3	3	3	0	0
22	5	42.8	42.1	-0.7	-1.6	2	3	0	0
22	3	43.3	41.4	-1.9	-4.3	2	3	0	0
23	5	40.0	41.1	1.1	2.7	3	3	0	0
23	3	35.4	38.8	3.4	9.6	3	4	0	0
24	5	30.4	36.0	5.6	18.4	3	3	0	0
24	3	33.4	38.7	5.3	15.8	3	4	0	0
25	5	40.5	42.1	1.6	3.9	3	3	0	0
25	3	42.1	41.9	0.8	1.9	2	3	0	0
26	5	24.8	23.4	-1.4	-5.6	3	2	0	0
26	3	25.8	24.9	-0.7	-2.7	3	3	0	0
27	5	27.1	26.9	-0.2	-0.7	3	4	0	0
27	3	26.0	28.7	2.7	10.3	3	3	0	0
28	5	33.5	30.1	-3.4	-10.1	3	3	0	0
28	3	32.8	27.6	-5.2	-15.8	2	2	0	0
29	5	24.8	22.9	-1.9	-7.6	2	3	0	0
29	3	25.4	24.7	-0.7	-2.7	3	3	0	0
30	5	33.6	29.1	-4.5	-13.3	3	3	0	0
30	3	33.9	31.8	-2.1	-6.1	3	4	0	0

*Pattern A diffusivity measurements; the results shown are averages of nine measurements. All others are Pattern B, and the results shown are averages of five measurements.

TABLE 3

Weight Change Data (Humidity Test)

(All weights in grams)

Test Number	Steel Finish	Original Weight	Weight After Humidity Test	Weight Gain from Corrosion	Weight of Panel After Removal of Corrosion Products	Weight Loss from Corrosion
1	5	68.4729	68.5328	0.0599	68.3451	0.1278
1	3	69.8985	69.9625	0.0640	69.7457	0.1528
2	5	68.9820	69.0275	0.0455	68.9000	0.0820
2	3	71.1273	71.1721	0.0448	71.1287	0.0986
3	5	69.0423	69.0945	0.0522	68.9404	0.1019
3	3	70.4530	70.4910	0.0380	70.3732	0.0798
4	5	68.4492	68.4891	0.0399	68.3711	0.0781
4	3	70.3004	71.1009	0.8005	70.2108	0.0896
5	5	74.1001	74.1425	0.0424	74.0418	0.0583
5	3	74.3767	74.4113	0.0346	74.3148	0.0619
6	5	76.8583	76.8995	0.0412	76.7944	0.0639
6	3	77.1475	77.1852	0.0377	77.0937	0.0538
7	5	73.8684	73.9202	0.0518	74.7602	0.1082
7	3	74.7070	74.7442	0.0372	74.6424	0.0646
8	5	76.6261	76.6804	0.0543	76.5745	0.0516
8	3	78.1841	78.2307	0.0466	78.1128	0.0713
9	5	69.0546	69.0935	0.0389	68.9760	0.0845
9	3	69.6904	69.7288	0.0384	69.5950	0.0954
10	5	75.2466	75.2893	0.0427	75.1768	0.0698
10	3	75.1932	75.2388	0.0456	75.1383	0.0549
11	5	72.7570	72.7893	0.0323	72.6899	0.0671
11	3	73.8787	73.9102	0.0315	73.8094	0.0693
12	5	79.8679	79.8958	0.0279	79.8076	0.0603
12	3	79.4068	79.4401	0.0333	79.3290	0.0778
13	5	71.4527	71.4808	0.0281	71.3919	0.0608
13	3	73.2400	73.2726	0.0326	73.1641	0.0759
14	5	75.6910	75.7136	0.0226	75.6334	0.0576
14	3	78.7700	78.7949	0.0249	77.7052	0.0648
15	5	68.7914	68.8397	0.0473	68.6960	0.0954
15	3	70.4117	70.4587	0.0470	70.3137	0.0980
16	5	74.3518	74.3997	0.0479	74.2885	0.0633
16	3	74.4883	74.5218	0.0335	74.4216	0.0667
17	5	73.8822	73.9096	0.0274	73.8303	0.0519
17	3	73.5210	73.5523	0.0313	73.4409	0.0801
18	5	72.6503	72.6647	0.0144	72.6261	0.0242
18	3	74.5702	74.5849	0.0147	74.5279	0.0423
19	5	77.8009	77.8049	0.0040	77.7357	0.0652
19	3	80.2304	80.2391	0.0087	80.1611	0.0693
20	5	76.7393	76.7476	0.0083	76.6771	0.0622
20	3	80.9137	80.9288	0.0151	80.8529	0.0608
21	5	74.7562	74.7995	0.0433	74.7216	0.0346
21	3	74.7289	74.7569	0.0280	74.6732	0.0557
22	5	77.3614	77.3887	0.0273	77.3195	0.0419
22	3	79.5998	79.7064	0.1066	79.5535	0.0463
23	5	79.1137	79.1375	0.0238	79.0621	0.0516
23	3	80.7210	80.7442	0.0232	80.6700	0.0510
24	5	73.3326	73.3667	0.0341	73.2939	0.0387
24	3	75.8824	75.9084	0.0260	75.8382	0.0442
25	5	73.9852	74.0111	0.0259	73.9313	0.0539
25	3	75.6130	75.6423	0.0293	75.5702	0.0428
26	5	72.4090	72.4300	0.0210	72.3633	0.0457
26	3	74.5979	74.6217	0.0238	74.5431	0.0548
27	5	74.4046	74.4335	0.0289	74.3150	0.0896
27	3	74.6579	74.6880	0.0301	74.5950	0.0629
28	5	73.4988	73.5284	0.0296	73.4301	0.0687
28	3	75.8618	75.8735	0.0117	75.8077	0.0541
29	5	70.2157	70.2299	0.0142	70.1595	0.0562
29	3	71.6389	71.6686	0.0297	71.5688	0.0701
30	5	85.1818	85.1997	0.0179	85.0721	0.1097
30	3	86.9878	87.0138	0.0260	86.8539	0.1339

TABLE 4

Water Film Test Results

Test Number	Steel Finish	Corrosion Index: White 24 Hr		Black 24 Hr		White 48 Hr		Black 48 Hr	
1	5	2	3	1	1	3	3	1	1
1	3	2	4	1	1	2	4	1	1
2	5	2	3	1	1	2	3	1	1
2	3	1	3	1	1	1	4	0	0
3	5	2	3	1	1	2	3	1	1
3	3	1	4	1	1	1	4	1	1
4	5	3	3	1	1	3	3	1	1
4	3	2	3	1	1	2	4	1	1
5	5	2	3	0	0	2	3	1°	0
5	3	2	3	0	0	2	4	0	0
6	5	4	3	0	0	4	3	1°	1°
6	3	4	3	0	0	4	4	0	1°
7	5	2	3	0	0	2	4	1°	0
7	3	2	3	0	0	2	3	0	0
8	5	4	4	0	0	4	4	0	0
8	3	3	2	0	0	3	2	0	0
9	5	3	2	1	1	3	3	1	1
9	3	3	2	1	1	3	2	1	1
10	5	2	3	0	0	2	3	0	0
10	3	1	3	0	0	2	3	0	0
11	5	3	1	0	0	3	2	1°	1°
11	3	3	2	0	0	3	2	1°	1°
12	5	3	2	0	0	3	2	0	0
12	3	3	3	0	0	4	3	0	1°
13	5	3	2	0	0	3	2	1°	1°
13	3	3	3	0	0	3	3	0	1°
14	5	3	2	0	0	3	2	0	0
14	3	2	2	0	0	2	3	1°	1°
15	5	2	3	1	1	2	3	1	1
15	3	4	1	1	1	4	2	1	1
16	5	3	1	0	0	3	2	0	1°
16	3	3	2	0	0	3	3	1°	1°
17	5	3	2	0	0	3	2	1°	1°
17	3	4	3	0	0	4	3	1°	1°
18	5	2	3	0	0	2	3	1°	1°
18	3	2	3	0	0	2	3	1°	1°
19	5	3	2	0	0	3	2	0	0
19	3	3	3	0	0	3	3	1°	1°
20	5	2	2	0	0	2	2	0	1°
20	3	3	3	0	0	3	3	0	0
21	5	3	2	0	0	3	2	0	1°
21	3	3	2	0	1°	3	2	1°	1
22	5	2	3	0	0	2	3	0	0
22	3	2	2	0	0	2	4	0	0
23	5	2	4	0	0	2	4	0	0
23	3	4	4	0	0	4	4	0	0
24	5	3	3	0	0	3	3	1°	0
24	3	3	3	0	0	3	3	1°	0
25	5	2	3	0	0	2	3	1	0
25	3	1	4	0	0	1	4	0	0
26	5	2	3	0	0	2	3	1°	0
26	3	3	2	0	0	3	2	0	0
27	5	2	4	1	0	2	4	1	0
27	3	2	2	0	0	2	3	1°	1°
28	5	2	3	0	0	2	3	1°	0
28	3	1	3	0	0	2	3	1°	1°
29	5	2	2	0	0	2	2	1°	1°
29	3	1	4	0	0	1	4	1°	1°
30	5	2	3	0	0	2	3	0	0
30	3	2	3	0	0	2	3	1°	1°

RECOMMENDATIONS

The results of the corrosion tests were plotted against composition, but failed to show any strong relationship. It is hoped that when the results are used in a multiple correlation a relationship may be revealed. To this end, therefore, it is recommended that the following relationships be examined by correlation:

(1) Corrosion index after humidity test against composition of coating.

(2) Gain in diffusivity (absolute or as per cent of original; the latter seems to show a much stronger trend) against composition.

(3) Weight gain during humidity test against composition.

(4) Corrosion index after the water film test against composition.

It is felt that the weight loss data are less reliable than the weight gain figures, owing to the difficulty of complete removal of corrosion products without removing zinc simultaneously. Accordingly, it is believed that correlation of weight loss figures is unlikely to yield useful results.

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APPENDIX III(a)

PRELIMINARY STATISTICAL ANALYSIS OF COATING TEST DATA

by

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February 19, 1958

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INTRODUCTION

The data produced as part of the galvanizing project being carried out at the Mines Branch, Ottawa, under the sponsorship of the Canadian Zinc Research and Development Committee have been studied.

The data consisted of "test logs" obtained in a statistically designed experiment. The various properties of interest have been treated separately and the findings to date are set forth below.

Standard regression analyses were applied to each set of data for both steel finishes. In each case, an equation of the type shown below was fitted.

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{34}X_3X_4$$

where: X_1 = (bath temperature °C -455)/10,

X_2 = log (immersion time, min)/0.3010,

X_3 = (aluminium content % -0.1)/0.1,

X_4 = (lead content % -0.5)/0.5,

Y = the dependent variable in question, and

b's = the unknown regression coefficients.

All regression coefficients were then tested for significance, using a "t" test. Most of those which were found to be non-significant were eliminated and the calculations repeated. In the case where quadratic or interaction terms were significant, the corresponding linear terms were left in the equation even though in some cases they were not significant. Also in the case where a term was significant for one steel finish but not for the other, the non-significant term was left in for comparative purposes.

The standard deviation (S_s) of the variation between specimens within baths, the standard deviation (S_B) of the variation between similar baths, and the standard deviation (S_R) of the variation about regression have also been calculated and are shown for each of the first six dependent variables. The "yardsticks" used in measuring the last six dependent variables were too rough to obtain measures of S_B or S_s, therefore only S_R is shown for these variables. The number of degrees of freedom upon which the various standard deviations are based is also shown. The standard error of each regression coefficient has been set forth directly beneath its respective coefficient. Where the regression coefficient is not significant, it has been marked by an asterisk. All statistical tests were carried out at the 95% confidence level.

It is intended that this study be continued. A canonical analysis will be carried out on the significant variables affecting each dependent variable. Where no significant difference has been found between the relationships for the two types of steel finish, these will be combined and a canonical analysis carried out on the combined data. The results of these analyses will be forwarded as completed.

Y_1 - COATING WEIGHT (oz/sq ft)

<u>No. 3 Steel Finish</u>

$$Y_1 = 1.66 + 0.11X_1^{*} + 0.59X_2 - 0.91X_3 + 0.25X_2^2 - 0.44X_3^2$$

SE b's	0.09	0.06	0.06	0.09	0.06	0.12

$S_R = 0.31 \quad df = 24$
$S_B = 0.03 \quad df = 5$
$S_s = 0.06 \quad df = 60$

<u>No. 5 Steel Finish</u>

$$Y_1^1 = 1.75 + 0.17X_1 + 0.63X_2 - 0.90X_3 + 0.24X_2^2 - 0.55X_3^2$$

SE b's	0.12	0.08	0.08	0.12	0.08	0.15

$S_R = 0.40 \quad df = 24$
$S_B = 0.09 \quad df = 5$
$S_s = 0.09 \quad df = 60$

These equations show that immersion time (X_2) and aluminium content (X_3) are the most important of the factors studied. The effect of bath temperature (X_1) is minor and lead content (X_4) failed to show a significant effect. The relationships found for the two types of steel finish do not differ to a significant degree.

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Y_2 - IRON CONTENT OF COATING (g/m^2)

<u>No. 3 Steel Finish</u>

$$Y_2 = 26.57 + 3.28X_1 + 9.99X_2 - 13.51X_3 + 4.27X_2^2 - 13.21X_3^2$$

SE b's	- 1.50	1.06	1.06	1.50	0.98	1.95

$S_R = 5.21 \quad df = 24$
$S_B = 0.59 \quad df = 5$
$S_s = 1.28 \quad df = 60$

<u>No. 5 Steel Finish</u>

$$Y_2^1 = 25.98 + 3.45X_1 + 10.21X_2 - 13.49X_3 + 4.28X_2^2 - 13.03X_3^2$$

SE b's	= 1.69	1.19	1.19	1.69	1.10	2.19

$S_R = 5.84 \quad df = 24$
$S_B = 0.94 \quad df = 5$
$S_s = 1.30 \quad df = 60$

The factors, bath temperature, immersion time and aluminium content, were found to affect the iron content of the zinc coating to a significant degree. The latter two are the most important. Variation in lead content failed to show a significant effect. The relationships found for the two types of steel finish did not differ to a significant degree.

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Y_3 - STEEL WEIGHT LOSS (g/m²)

<u>No. 3 Steel Finish</u>

$$Y_3 = 26.83 + 3.52X_1 + 10.44X_2 - 13.30X_3 + 4.36X_2^2 - 10.66X_3^2 - 3.77X_2X_3$$

SE b's = 1.30 0.92 0.92 1.30 0.84 1.69 1.59

$S_R = 4.50$ df = 23
$S_B = 0.77$ df = 5
$S_s = 4.03$ df = 60

<u>No. 5 Steel Finish</u>

$$Y_3^1 = 24.97 + 3.33X_1 + 9.34X_2 - 13.56X_3 + 3.57X_2^2 - 9.36X_3^2 - 3.22\overset{*}{X}_2X_3$$

SE b's = 1.69 1.20 1.20 1.69 1.10 2.20 2.07

$S_R = 5.86$ df = 23
$S_B = 0.96$ df = 5
$S_s = 3.16$ df = 60

The steel weight loss during galvanizing and subsequent stripping was found to be a function of the bath temperature, immersion time and aluminium content. The latter two are the most important. Variation in lead content failed to show a significant effect. The relationships found for the two types of steel finish did not differ to a significant degree. These equations bear a close resemblance to those found for iron content of coating, Y_2.

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Y_4 - COATING THICKNESS (mm)

<u>No. 3 Steel Finish</u>

$$Y_4 = 0.0378 + 0.0129X_2 - 0.0207X_3 + 0.0047X_2^2 - 0.0114X_3^2 - 0.0063X_2X_3$$

SE b's = 0.0021 0.0015 0.0021 0.0014 0.0027 0.0026

$S_R = 0.0072$ df = 24
$S_B = 0.0032$ df = 5
$S_s = 0.0021$ df = 60

No. 5 Steel Finish

$$Y_4^{1} = 0.0362 + 0.0139X_2 - 0.0216X_3 + 0.0053X_2^{2} - 0.0089X_3^{2} - 0.0060X_2X_3$$

SE b's = 0.0023 0.0017 0.0023 0.0015 0.0030 0.0029

S_R = 0.0081 df = 24
S_B = 0.0009 df = 5
S_s = 0.0021 df = 60

Coating thickness was found to be a function of immersion time and aluminium content. Variation in lead content and in bath temperature failed to show significant effects. The relationships found for the two steel finishes were not significantly different.

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In the case of the high aluminium data, the maximum and minimum figures given were averaged and the averages used in the calculations. A more satisfactory measurement could have been obtained originally if several measurements had been made at random and these averaged for each specimen.

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Y_5 - ALLOY THICKNESS (mm)

No. 3 Steel Finish

$$Y_5 = 0.0236 + 0.0033X_1 + 0.0108X_2 - 0.0132X_3 + 0.0047X_2^{2} - 0.0134X_3^{2}$$

SE b's = 0.0021 0.0015 0.0015 0.0021 0.0014 0.0027

S_R = 0.0073 df = 24
S_B = 0.0019 df = 5
S_s = 0.0013 df = 60

No. 5 Steel Finish

$$Y_5^{1} = 0.0229 + 0.0031\overset{*}{X}_1 + 0.0116X_2 - 0.0139X_3 + 0.0056X_2^{2} - 0.0126X_3^{2}$$

SE b's = 0.0022 0.0016 0.0016 0.0022 0.0014 0.0029

S_R = 0.0076 df = 24
S_B = 0.0010 df = 5
S_s = 0.0013 df = 60

Alloy thickness was found to be a function of bath temperature, immersion time and aluminium content. The latter two were the most important. Variation in lead content failed to show a significant effect. The relationships found for the two steel finishes were not significantly different.

In the case of the missing thickness measurements for the high aluminium specimens, an estimate of 0.0001 mm was used. Since under microscopic examination the alloy layer was found to be discontinuous and thin, and since some estimate is required for the calculations, this very small figure was chosen.

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Y_6 - RATIO, ALLOY THICKNESS : COATING THICKNESS (%)

No. 3 Steel Finish

$$Y_6 = 62.71 + 4.65X_1 + 5.23X_2 - 25.16X_3 - 34.55X_3^2$$

SE b's =	1.68	1.45	1.45	2.05	2.65

S_R = 7.11 df = 25
S_B = 2.15 df = 5
S_s = 1.32 df = 60

No. 5 Steel Finish

$$Y_6^1 = 64.14 + 4.06X_1 + 4.91X_2 - 25.50X_3 - 35.63X_3^2$$

SE b's =	1.55	1.34	1.34	1.89	2.45

S_R = 6.56 df = 25
S_B = 1.78 df = 5
S_s = 1.68 df = 60

The alloy : coating ratio was found to be a function of bath temperature, immersion time and aluminium content. Variation in lead content of the bath failed to show a significant effect. The relationships found for the two steel finishes were not significantly different.

In the case of the high aluminium specimens, even though neither alloy thickness or coating thickness were known with any degree of accuracy, an estimate had to be inserted. Since a very low ratio was indicated, 3% was chosen.

-

Y_7 - DUCTILITY (Cupping Test)

CODE 1. Excellent, no cracking
2. Good, network of fine cracks
3. Fair, general cracking, with coating broken up into small blocks
4. Poor, wide separation of medium size blocks
5. Very poor, general peeling of coating in large blocks

No. 3 Steel Finish

$$Y_7 = 2.94 + 0.19\overset{*}{X}_1 + 0.47X_2 - 1.39X_3 - 0.56X_3^2$$

SE b's = 0.11 0.10 0.10 0.14 0.17

$S_R = 0.47$ df = 25

No. 5 Steel Finish

$$Y_7^1 = 3.07 + 0.22X_1 + 0.50X_2 - 1.33X_3 - 0.74X_3^2$$

SE b's = 0.12 0.11 0.11 0.15 0.19

$S_R = 0.52$ df = 25

Ductility was found to be a function of bath temperature, immersion time and aluminium content. The latter two factors are the most important of those studied. Variation in lead content failed to show a significant effect. The relationships found for the two steel finishes did not differ to a significant extent.

Y_8 - ADHERENCE (Bend Test)

CODE - Minimum bend radius causing flaking (90° bend plus a 180° reverse bend).

1. 0.050-in.	5. 0.192-in.
2. 0.070 "	6. 0.252 "
3. 0.100 "	7. 0.320 "
4. 0.144 "	8. 0.400 "

No. 3 Steel Finish

$$Y_8 = 5.43 + 0.32X_1 + 0.65X_2 - 2.54X_3 - 1.88X_3^2$$

SE b's = 0.13 0.12 0.12 0.16 0.21

$S_R = 0.57$ df = 25

No. 5 Steel Finish

$$Y_8^{1} = 5.45 + 0.30X_1 + 0.73X_2 - 2.53X_3 - 1.93X_3^2$$

SE b's = 0.17 0.14 0.14 0.20 0.26

$$S_R = 0.70 \qquad df = 25$$

Adherence was found to be a function of bath temperature, immersion time and aluminium content. Variation in lead content failed to show a significant effect. The relationships found for the two steel finishes did not differ to a significant degree.

-

Y_9 - SPANGLE SIZE

CODE - 1. Large
2. Medium
3. Small
4. No spangle

No. 3 Steel Finish

$$Y_9 = 2.37 - 0.17\overset{*}{X}_3 - 1.03X_4 + 0.42X_3^2 + 0.13\overset{*}{X}_4^2$$

SE b's = 0.16 0.16 0.16 0.21 0.21

$$S_R = 0.59 \qquad df = 25$$

No. 5 Steel Finish

$$Y_9^{1} = 3.66 - 0.11\overset{*}{X}_3 - 0.69X_4 + 0.26\overset{*}{X}_3^2 - 0.44X_4^2$$

SE b's = 0.15 0.15 0.15 0.20 0.20

$$S_R = 0.56 \qquad df = 25$$

Panels made of steel finish No. 3 had significantly larger spangles on the average than panels of steel finish No. 5.

With finish No. 3, spangle sizes was found to be a function of the aluminium and lead contents of the bath. Bath temperature and immersion time failed to show a significant effect.

With finish No. 5, the only factor of significance was lead content.

In both cases, the amount of variation obtained in spangle size was small.

-

Y_{10} - SPANGLE CONTRAST

CODE - 1. Good, spangles well defined
2. Moderate, spangles well defined
3. Low or no contrast. Spangles outlined only.
4. No contrast (no spangles).

No. 3 Steel Finish

$$Y_{10} = 2.40 + 0.06\overset{*}{X}_3 - 0.33X_4 + 1.26X_3^2 + 0.84X_4^2$$

SE b's = 0.13 0.13 0.13 0.17 0.17

$$S_R = 0.45 \qquad df = 25$$

No. 5 Steel Finish

$$Y_{10}^1 = 3.64 + 0.03\overset{*}{X}_3 - 0.31X_4 + 0.35\overset{*}{X}_3^2 - 0.06\overset{*}{X}_4^2$$

SE b's = 0.13 0.13 0.13 0.17 0.17

$$S_R = 0.47 \qquad df = 25$$

Panels made of steel finish No. 3 showed more spangle contrast on the average than panels of steel finish No. 5.

With finish No. 3, spangle contrast was found to be a function of the lead and aluminium contents of the bath. Bath temperature and immersion time failed to show a significant effect.

With finish No. 5, the only factor of significance was lead content.

In both cases, the amount of spangle contrast obtained was small.

-

Y_{11} - BRIGHTNESS (Photometer Reading)

CODE - 1. 0 - 1.25
2. 1.5 - 2.75
3. 3.0 - 4.25
4. 4.5 +

No. 3 Steel Finish

$$Y_{11} = 2.42 + 0.38X_1 - 0.75X_3 - 0.50X_4 + 0.63X_3^2 - 0.24\overset{*}{X}_4^2$$

SE b's = 0.17 0.12 0.17 0.23 0.23 0.23

$$S_R = 0.60 \qquad df = 24$$

No. 5 Steel Finish

$$Y_{11}^{1} = 2.71 + 0.35X_1 - 0.83X_3 - 0.42X_4 + 0.23\overset{*}{X}_3^{2} - 0.48X_4^{2}$$

SE b's = 0.16   0.11   0.16   0.16   0.20   0.20

$$S_R = 0.55 \qquad df = 24$$

Brightness was found to be a function of bath temperature, aluminium content and lead content. Immersion time failed to show an effect. The relationships found for the two steel finishes did not differ to a statistically significant degree.

-

Y_{12} - ROUGHNESS

CODE -
1. Very smooth
2. Moderately smooth
3. Fine to moderately rough, sandpaper texture
4. Rough texture

No. 3 Steel Finish

$$Y_{12} = 2.06 + 0.29X_1 + 0.38X_2 - 0.25\overset{*}{X}_3 + 0.03X_3^{2}$$

SE b's = 0.13   0.11   0.11   0.16   0.21

$$S_R = 0.55 \qquad df = 25$$

No. 5 Steel Finish

$$Y_{12}^{1} = 2.76 + 0.37X_1 + 0.26\overset{*}{X}_2 - 0.50X_3 + 0.41\overset{*}{X}_3^{2}$$

SE b's = 0.16   0.14   0.14   0.19   0.25

$$S_R = 0.67 \qquad df = 25$$

Panels made of steel finish No. 5 had significantly rougher coatings on the average than panels of steel finish No. 3.

With steel finish No. 3, roughness was found to be a function of bath temperature, immersion time and aluminium content. Variation in lead content failed to show a significant effect.

With steel finish No. 5, roughness was found to be a function of only bath temperature and aluminium content.

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A P P E N D I X III(b)

PRELIMINARY STATISTICAL ANALYSIS OF ACCELERATED CORROSION TEST DATA

by

H. L. Williams

(Consolidated Mining and Smelting Company of Canada, Limited, Trail, B.C.)
March 4, 1958

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INTRODUCTION

The corrosion data that were obtained by J. G. Sibakin of the Steel Company of Canada, Limited, on the galvanizing project panels have been studied.

The various properties of interest have been treated separately in a manner similar to that of Appendix III(a).

Standard regression analyses were applied to each set of data for both steel finishes. In each case, an equation of the type shown below was fitted.

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2$$
$$+ b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{34}X_3X_4$$

where X_1 = (bath temperature °C -455)/10,

X_2 = (log immersion time, min)/0.3010,

X_3 = (aluminium content % -0.1)/0.1,

X_4 = (lead content % -0.5)/0.5,

Y = the dependent variable in question, and

b's = the unknown regression coefficients.

All regression coefficients were then tested for significance, using a "t" test. Most of those which were found to be non-significant were eliminated and the calculations repeated. In the case where quadratic terms were significant, the corresponding linear terms were left in the equation, even though in some cases they were not significant. Also, in the case where a term or terms were significant for one steel finish but not for the other, the corresponding non-significant term or terms were left in for comparative purposes.

The standard deviation of the variation between similar baths (S_B), and the standard deviation of the variation about regression (S_R), have been calculated and are shown in each case. The "yardsticks" used in measuring the "corrosion index" (Y_{14}, Y_{17}, Y_{18}) were too rough to obtain a measure of S_B and, therefore, only S_R is shown for these variables. The number of degrees of freedom upon which the various standard deviations are based is also shown. The standard error of each regression coefficient has been set forth directly beneath its respective coefficient. Where the regression coefficient is not significant, it has been marked with an asterisk. All statistical tests were carried out at the 95% confidence level.

Canonical analysis will be carried out on the significant variables of each dependent variable and our findings reported in due course.

Since black staining only occurred in a few panels, no attempt was made to treat its occurrence statistically.

Y_{13} - PERCENT GAIN IN AVERAGE DIFFUSIVITY AFTER THE HUMIDITY TEST

No. 3 Steel Finish

$$Y_{13} = 7.23 - 6.01^{*}X_1 + 10.88\overset{*}{X_3} + 8.07\overset{*}{X_4} - 7.54X_1^2 + 19.96X_3^2 + 17.78X_4^2$$

SE b's	= 6.35	3.75	5.31	5.31	3.48	6.95	6.95

S_R = 18.4 df = 23
S_B = 3.2 df = 5

No. 5 Steel Finish

$$Y^1_{13} = -7.12 - 5.13\overset{*}{X_1} + 14.68X_3 + 5.08\overset{*}{X_4} - 3.69\overset{*}{X_1^2} + 35.77X_3^2 + 20.56X_4^2$$

SE b's	= 5.80	3.43	4.85	4.85	3.18	6.35	6.35

S_R = 16.8 df = 23
S_B = 6.7 df = 5

The factors, aluminium and lead content, were found to affect the percent gain in average diffusivity to a significant degree for both finishes. Bath temperature also had a significant effect with No. 3 steel finish. Immersion time was not significant in either case.

-

Y_{14} - CORROSION INDEX - WHITE, AFTER HUMIDITY TEST

There were no significant factors found for either No. 3 or No. 5 steel finishes.

S_R = 0.55
S_B = 0.56

CODE for CORROSION INDEX:

INDEX		% OF SURFACE CORRODED
0	-	0
1	-	1 to 25
2	-	26 to 50
3	-	51 to 75
4	-	75 to 100

-

Y_{15} - WEIGHT GAIN FROM CORROSION AFTER HUMIDITY TEST

No. 3 Steel Finish

$$Y_{15} = 34.8 + 5.2\overset{*}{X}_1 + 0.9\overset{*}{X}_2 + 0.2\overset{*}{X}_3 + 5.8\overset{*}{X}_4 + 3.8X_1^{2*} - 1.3\overset{*}{X}{}_2^2 + 15.9X_3^2 - 6.5\overset{*}{X}{}_4^2$$

SE b's = 6.5 3.2 3.2 4.4 4.4 3.0 3.0 6.1 6.1

S_R = 15.9 df = 21
S_B = 6.2 df = 5

No. 5 Steel Finish

$$Y^1_{15} = 42.8 + 2.2\overset{*}{X}_1 - 2.8\overset{*}{X}_2 + 6.4X_3 + 6.5X_4 - 5.0X_1^2 - 7.3X_2^2 + 9.1X_3^2 - 8.8X_4^2$$

SE b's = 3.1 1.6 1.6 2.2 2.2 1.4 1.4 2.9 2.9

S_R = 7.6 df = 21
S_B = 7.8 df = 5

The factor, aluminium content, was found to affect the weight gain from corrosion to a significant degree for both finishes. Bath temperature, immersion time and lead content also had a significant effect with No. 5 steel finish.

-

Y_{16} - WEIGHT LOSS FROM CORROSION AFTER HUMIDITY TEST (mg)

No. 3 Steel Finish

$$Y_{16} = 64.0 + 4.1\overset{*}{X}_2 + 24.5X_3 + 8.9X_2^2$$

SE b's = 4.2 3.6 5.1 3.3

S_R = 17.6 df = 26
S_B = 4.8 df = 5

No. 5 Steel Finish

$$Y^1_{16} = 65.2 + 3.3\overset{*}{X}_2 + 21.8X_3 + 2.6\overset{*}{X}{}_2^2$$

SE b's = 4.6 4.0 5.7 3.7

S_R = 19.7 df = 26
S_B = 25.6 df = 5

The factor, aluminium content, was found to affect the weight loss from corrosion to a significant degree for both finishes. Immersion time also had a significant effect with No. 3 finish. Bath temperature and lead content failed to show a significant effect.

-

Y_{17} - CORROSION INDEX - WHITE (24 hr) - AFTER WATER FILM TEST

No. 3 Steel Finish

$$Y_{17} = 2.56 - 0.21\overset{*}{X}_3 + 0.15\overset{*}{X}{}_3^2$$

$$\text{SE b's} = 0.11 \quad 0.14 \quad 0.18$$

$$S_R = 0.48 \qquad df = 27$$

No. 5 Steel Finish

$$Y^1_{17} = 2.42 - 0.25X_3 + 0.42X_3^2$$

$$\text{SE b's} = 0.08 \quad 0.10 \quad 0.13$$

$$S_R = 0.34 \qquad df = 27$$

The factor, aluminium content, was found to affect the corrosion index (24 hr) to a significant degree for No. 5 steel finish but not for No. 3. Bath temperature, immersion time and lead content failed to show a significant effect.

-

Y_{18} - CORROSION INDEX - WHITE (48 hr) - AFTER WATER FILM TEST

No. 3 Steel Finish

$$Y_{18} = 2.77 + 0.08\overset{*}{X}_2 - 0.21\overset{*}{X}_3 - 0.02\overset{*}{X}{}_2^2 + 0.20\overset{*}{X}{}_3^2$$

$$\text{SE b's} = 0.12 \quad 0.09 \quad 0.12 \quad 0.08 \quad 0.16$$

$$S_R = 0.43 \qquad df = 25$$

No. 5 Steel Finish

$$Y^1_{18} = 2.63 + 0.02\overset{*}{X}_2 - 0.12\overset{*}{X}_3 - 0.15X_2^2 + 0.43X_3^2$$

$$\text{SE b's} = 0.09 \quad 0.06 \quad 0.09 \quad 0.06 \quad 0.12$$

$$S_R = 0.31 \qquad df = 25$$

The factors, immersion time and aluminium content, were found to have a significant effect upon the corrosion index (48 hr) of No. 5 steel finish, but not of No. 3 steel finish. Bath temperature and lead content failed to show a significant effect.

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APPENDIX IV

CANONICAL ANALYSIS OF COATING TESTS AND ACCELERATED-CORROSION DATA

by

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(Consolidated Mining and Smelting Company of Canada, Limited, Trail, B.C.)
May 23, 1958

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INTRODUCTION

A canonical analysis has been carried out on each of the relationships reported in Appendices III(a) and III(b). Where the two steel finishes failed to show a significant difference, the data were combined and the canonical analysis carried out on the combined data. Graphs have been plotted showing a few of these relationships. The nomenclature and symbols used below are the same as those used by O. L. Davies in Chapter 11 of his book, "Design and Analysis of Industrial Experiments" (Hafner Publishing Company, New York, N. Y., 1956), in which a good exposition of this type of analysis is given.

As in the previous appendices,

x_1 =(bath temperature °C -455)/10,

x_2 = log (Immersion time, min)/0.3010,

x_3 =(aluminium content % - 0.1)/0.1,

x_4 =(lead content % - 0.5)/0.5, and

Y = the dependent variable in question.

Y_1 - COATING WEIGHT (oz/sq ft)

Both steel finishes combined.

The full second degree equation was fitted to the data using standard regression techniques.

$Y_1 =$	$1.76 + 0.14x_1$	$+ 0.61x_2$	$- 0.90x_3$	$- 0.06x_1^2$	$+ 0.24x_2^2$	$- 0.51x_3^2$	
SE b's =	0.08	0.05	0.05	0.07	0.04	0.04	0.09

$+ 0.05x_1x_2$	$+ 0.01x_1x_3$	$- 0.18x_2x_3$
0.06	0.08	0.08

The standard error for each term is shown directly below its respective term.

The fitted equation was then reduced to the canonical form.

a) The coordinates x_{1s}, x_{2s}, x_{3s} of the center point S of the system and the predicted value Y_{1s} at this point were found to be as follows.
$x_{1s} = 0.49$, $x_{2s} = -1.55$, $x_{3s} = -0.61$ and $Y_{1s} = 1.60$ oz/sq ft.

b) The canonical form of the second degree equation is
$Y_1 - 1.60 = -0.06\ X_1^2 + 0.25X_2^2 - 0.52X_3^2$

c) The new coordinates (X_1, X_2 and X_3) for any point are given in terms of the old coordinates (x_1, x_2, x_3) by equations which may be written as follows.

	$(x_1 - 0.49)$	$(x_2 + 1.55)$	$(x_3 + 0.61)$
X_1	0.9964	-0.0800	0.0268
X_2	-0.0828	-0.9901	0.1138
X_3	-0.0159	0.1151	0.9932

The entries in the rows are the coefficients in the equation which expresses the X's in terms of the x's. Thus the first such equation is

$$X_1 = 0.9964\ (x_1 - 0.49) - 0.0800\ (x_2 + 1.55) + 0.0268\ (x_3 + 0.61)$$

Inspection of the canonical form (b) shows that the third term is the predominant one. Any movement away from the center point in the direction of the X_3 axis will lead to a rapid drop in coating weight, but changes in both X_1 and X_2 can be made with considerably smaller effects on yield. The X_2 coefficient is positive, therefore, a gain in coating weight can be expected on moving away from the center point S in either direction along the X_2 axis. The standard errors of the coefficients in this equation are of roughly the same magnitude as those of the quadratic effects in the original equation. The coefficient of X_1 is therefore not significant. Future experiments should be made in the direction of the X_2 axis to obtain an increased coating weight.

In Figure 1, this relationship has been plotted, by assuming that the non-significant factor X_1 is zero and by setting x_1 equal to 0.49 (460°C)(860°F). Inspection of this graph will show the promising regions.

Y_2 - IRON CONTENT OF COATING (g/m^2)

Both steel finishes combined.

For this and the following dependent variables, the various equations and their canonical forms will be listed in the order used for Y_1. A few comments will be made on each.

Second degree equation -

$$Y_2 = 26.82 + 3.36x_1 + 10.10x_2 - 13.50x_3 - 0.54x_1^2 + 4.21x_2^2 - 13.26x_3^2$$

SE b's	0.71	0.42	0.42	0.60	0.39	0.39	0.78

$$+ 1.00x_1x_2 - 0.64x_1x_3 - 2.93x_2x_3$$

0.52	0.73	0.73

Canonical form -

a) Center of system - S

$x_{1s} = 1.88$
$x_{2s} = -1.56$
$x_{3s} = -0.38$
$Y_{2s} = 24.70\ g/m^2$

b) Equation -

$$Y_2 - 24.70 = -0.59X_1^2 + 4.39X_2^2 - 13.39X_3^2$$

c) Axes -

	$(x_1 - 1.88)$	$(x_2 + 1.56)$	$(x_3 + 0.38)$
X_1	-0.9941	0.1077	0.0130
X_2	-0.1063	-0.9905	0.0880
X_3	0.0218	0.0824	0.9964

Inspection of the canonical form shows that the third term is predominant and consists mainly of the effect of aluminium content. This (X_3) term is negative and any movement away from the center point in the direction of the X_3 axis will lead to a drop in iron content of the coating. The second term (X_2) is also significant but smaller and is mainly the effect of immersion time. This term is positive and a gain in iron content can be expected on moving away from the center point S along the X_2 axis. The third term, X_1, is not significant.

In Figure 2, this relationship has been plotted by assuming that the X_1 term is zero and by setting x_1 equal to 0.49 (460°C) (860°F). A reduction in bath temperature would tend to decrease the iron content of the coating. Inspection of this graph will indicate the most promising fields for future tests.

Y_3 - STEEL WEIGHT LOSS (g/m^2)

Both steel finishes combined.

Second degree equation -

$$Y_3 = 25.76 + 3.42x_1 + 9.89x_2 - 13.43x_3 + 0.14x_1^2 + 3.98x_2^2 - 9.97x_3^2$$

SE b's = 0.70 0.41 0.41 0.58 0.38 0.38 0.76

$$+ 1.83x_1x_2 - 0.71x_1x_3 - 3.50x_2x_3$$

0.51 0.72 0.72

Canonical form:

a) Center of system - S

$$x_{1s} = 8.06$$
$$x_{2s} = -3.27$$
$$x_{3s} = -0.39$$
$$Y_{3s} = 26.02 \text{ g/m}^2$$

b) Equation -

$$Y_3 - 26.02 = -0.07X_1^2 + 4.41X_2^2 - 10.19X_3^2$$

c) Axes -

	$(x_1 - 8.06)$	$(x_2 + 3.27)$	$(x_3 + 0.39)$
X_1	0.9757	-0.2189	0.0046
X_2	-0.2181	-0.9681	0.1231
X_3	0.0234	0.1209	0.9924

The pattern here is the same as that found for Y_1 and Y_2 except that the center of the system is remote from the experimental conditions.

The coefficient of X_1 is not significant and was assumed to be zero for the purpose of plotting Figure 3. In addition, the bath temperature x_1 was set at 0.49 (460°C)(860°F). The effect of immersion time and aluminium content can be readily seen from the graph. Figures 2 and 3 may be compared directly since both have been plotted for a bath temperature of 460°C (860°F). The two plots are very similar.

Y_4 - COATING THICKNESS (mm)

Both steel finishes combined.

Second degree equation -

$$Y_4 = 0.037 + 0.013x_2 - 0.021x_3 + 0.005x_2^2 - 0.010x_3^2 - 0.006x_2x_3$$

SE b's = 0.002 0.001 0.002 0.001 0.003 0.003

Canonical form -

a) Center of system - S

$x_{2s} = -1.67$
$x_{3s} = -0.53$
$Y_{4s} = 0.03$ mm

b) Equation -

$$Y_4 - 0.031 = 0.006X_2^2 - 0.011X_3^2$$

c) Axes -

	$(x_2 + 1.67)$	$(x_3 + 0.53)$
X_2	0.9815	-0.1915
X_3	0.1915	0.9815

This relationship is shown in Figure 4.

-

Y_5 - ALLOY THICKNESS (mm)

Both steel finishes combined.

Second degree equation -

$$Y_5 = 0.023 + 0.003x_1 + 0.011x_2 - 0.014x_3 - 0.0002x_1^2 + 0.005x_2^2$$

SE b's = 0.001 0.001 0.001 0.001 0.001 0.001

$$- 0.013x_3^2 + 0.001x_1x_2 - 0.001x_1x_3 - 0.002x_2x_3$$

0.001 0.001 0.001 0.001

Canonical form -

a) Center of system - S

$x_{1s} = 3.08$
$x_{2s} = -1.64$
$x_{3s} = -0.48$
$Y_{5s} = 0.022$ mm

b) Equation -

$$Y_5 - 0.022 = -0.0003X_1^2 + 0.0053X_2^2 - 0.0130X_3^2$$

c) Axes -

	$(x_1 - 3.08)$	$(x_2 + 1.64)$	$(x_3 + 0.48)$
X_1	0.9905	-0.1356	-0.0227
X_2	-0.1339	-0.9887	0.0675
X_3	0.0320	0.0646	0.9974

The pattern here is similar to that found for Y_1 to Y_4 with the center of the system remote from the experimental conditions in regard to x_1.

In plotting Figure 5, since X_1 is not significant, it was assumed to be zero. In addition x_1, the bath temperature was taken at the zero level or 455°C (851°F).

-

Y_6 - RATIO, ALLOY THICKNESS: COATING THICKNESS (%)

Both steel finishes combined.

Second degree equation -

$$Y_6 = 61.32 + 4.35x_1 + 5.07x_2 - 25.33x_3 + 1.22x_1^2 + 1.14x_2^2 - 34.56x_3^2$$

SE b's = 0.92 0.54 0.54 0.77 0.50 0.50 1.00

$$+ 0.86x_1x_2 - 1.59x_1x_3 + 1.71x_2x_3$$

0.66 0.94 0.94

Canonical form -

a) Center of system - S

$x_{1s} = -1.54$
$x_{2s} = -1.37$
$x_{3s} = -0.37$
$Y_{6s} = 59.1\%$

b) Equation -

$$Y_6 - 59.13 = 0.79X_1^2 + 1.61X_2^2 - 34.60X_3^2$$

c) Axes -

	$(x_1 + 1.54)$	$(x_2 + 1.37)$	$(x_3 + 0.37)$
X_1	0.6733	-0.7394	-0.0049
X_2	0.7392	0.6735	0.0009
X_3	0.0226	-0.0242	0.9995

In Figures 6(a), 6(b) and 6(c), this relationship has been plotted. These figures have been plotted setting the aluminium content, the major variable, at 0, 0.1 and 0.2% and showing the effect of the two minor variables at each aluminium level.

These graphs show the relative effects of the three variables and indicate the most promising fields for future tests.

It should be remembered that in the original data, the high aluminium coatings (0.2%) failed to show an alloy layer of measureable thickness. An estimate of 3% was used in each case to facilitate the calculations. Figure 6(c) is therefore, only a rough approximation of the true relationship.

In Figure 6(d), the ratio of alloy thickness: coating thickness has been plotted against aluminium content of the bath for a bath temperature of 455°C (851°F) and an immersion time of one minute.

-

Y_7 - COATING DUCTILITY (Cupping Test)

Both steel finishes combined.

CODE -
1. Excellent, no cracking
2. Good, network of fine cracks
3. Fair, general cracking, small blocks
4. Poor, wide separation of medium-sized blocks
5. Very poor, general peeling of coating in large blocks.

Second degree equation -

$$Y_7 = 3.01 + 0.21x_1 + 0.49x_2 - 1.36x_3 - 0.11x_1^2 + 0.10x_2^2 - 0.65x_3^2$$

SE b's = 0.06 0.04 0.04 0.05 0.04 0.04 0.07

$$+ 0.10x_1x_2 + 0.08x_1x_3 - 0.08x_2x_3$$

0.05 0.07 0.07

Canonical form -

a) Center of system - S

$x_{1s} = -0.59$
$x_{2s} = -2.44$
$x_{3s} = -0.93$
$Y_{7s} = 2.99$

b) Equation -

$$Y_7 - 2.99 = -0.11X_1^2 + 0.12X_2^2 - 0.65X_3^2$$

c) Axes -

	$(x_1 + 0.59)$	$(x_2 + 2.44)$	$(x_3 + 0.93)$
X_1	-0.9720	0.2168	-0.0903
X_2	0.2210	0.9745	-0.0401
X_3	-0.0796	0.0594	0.9951

This relationship has been plotted in a manner similar to that used for Y_6. Figures 7(a), 7(b), 7(c) have been plotted setting the aluminium content, the major variable, at 0, 0.1 and 0.2% and showing the effect of the two minor variables at each aluminium level.

A comparison of the three graphs will show the relative effects of the three variables.

In Figure 7(d), the coating ductility has been plotted against aluminium content of the bath for a bath temperature of 455°C (851°F) and an immersion time of one minute.

-

Y_8 - COATING ADHERENCE (Bend Test)

Both steel finishes combined.

CODE - Minimum bend radius causing flaking (90° bend plus a 180° reverse bend).

1.	0.050-in.	5.	0.192-in.
2.	0.070 "	6.	0.252 "
3.	0.100 "	7.	0.320 "
4.	0.144 "	8.	0.400 "

Second degree equation -

$$Y_8 = 5.38 + 0.31x_1 + 0.69x_2 - 2.54x_3 - 0.09x_1^2 + 0.16x_2^2 - 1.89x_3^2$$

SE b's = 0.08 0.05 0.05 0.07 0.05 0.05 0.09

$$- 0.07x_1x_2 - 0.02x_1x_3 - 0.04x_2x_3$$

0.06 0.09 0.09

Canonical form -

a) Center of system - S

$x_{1s} = 2.36$
$x_{2s} = -1.79$
$x_{3s} = -0.66$
$Y_{8s} = 5.97$

b) Equation -

$$Y_8 - 5.97 = -0.10X_1^2 + 0.16X_2^2 - 1.89X_3^2$$

c) Axes -

	$(x_1 - 2.36)$	$(x_2 + 1.79)$	$(x_3 + 0.66)$
X_1	-0.9913	-0.1315	0.0073
X_2	-0.1316	0.9913	-0.0095
X_3	0.0059	0.0103	0.9999

Examination of the canonical form shows the third term (X_3) to be predominant and this term is mainly the effect of changes in aluminium content. The first term (X_1) which is mainly the effect of bath temperature is not significant. The second term (X_2) although significant is small and consists mainly of the effect of immersion time.

By assuming that X_1 is zero and by setting bath temperature at the zero level (455°C)(851°F), Figure 8 has been plotted showing the effects of immersion time and aluminium content changes on adherence.

-

Y_9 - SPANGLE SIZE

CODE -

1. Large
2. Medium
3. Small
4. No spangle

No. 3 Steel Finish

Second degree equation -

$$Y_9 = 2.37 - 0.17x_3 - 1.03x_4 + 1.42x_3^2 + 0.13x_4^2 - 0.50x_3x_4$$

SE b's= 0.16	0.16	0.16	0.21	0.21	0.28

Canonical form -

a) Center of system - S

$$x_{3s} = 1.13$$
$$x_{4s} = 6.11$$
$$Y_{9s} = -0.86$$

b) Equation -

$$Y_9 + 0.86 = 1.47X_3^2 + 0.08X_4^2$$

c) Axes -

	$(x_3 - 1.13)$	$(x_4 - 6.11)$
X_3	0.9830	-0.1837
X_4	0.1837	0.9830

No. 5 Steel Finish

Second degree equation -

$$Y_9^1 = 3.66 - 0.11x_3 - 0.69x_4 + 0.27x_3^2 - 0.44x_4^2 - 0.50x_3x_4$$

SE b's = 0.15	0.15	0.15	0.20	0.20	0.27

Canonical form -

a) Center of system - S

$$x_{3s} = -0.35$$
$$x_{4s} = -0.59$$
$$Y_{9s}^1 = 3.88$$

b) Equation -

$$Y_9^1 - 3.88 = 0.34X_3^2 - 0.52X_4^2$$

c) Axes -

	$(x_3 + 0.35)$	$(x_4 + 0.59)$
X_3	0.9531	-0.3027
X_4	0.3027	0.9531

These two relationships have been plotted in Figure 9.

-

Y_{10} - SPANGLE CONTRAST

CODE -

1. Good, spangles well defined
2. Moderate, spangles well defined
3. Low or no contrast. Spangles outlined only
4. No contrast (no spangles).

No. 3 Steel Finish

Second degree equation -

Y_{10} =	2.40	$+ 0.06x_3$	$- 0.33x_4$	$+ 1.26x_3^2$	$+ 0.84x_4^2$	$+ 0.00x_3x_4$
SE b's =	0.13	0.13	0.13	0.17	0.17	0.20

Canonical form -

a) Center of system - S

$$x_{3s} = -0.02$$
$$x_{4s} = 0.20$$
$$Y_{10s} = 2.37$$

b) Equation -

$$Y_{10} - 2.37 = 1.26X_3^2 + 0.84X_4^2$$

c) Axes -

	$(x_3 + 0.02)$	$(x_4 - 0.20)$
X_3	1.0000	0
X_4	0	-1.0000

No. 5 Steel Finish

Second degree equation -

$$Y^1_{10} = 3.64 + 0.03x_3 - 0.31x_4 + 0.35x_3^2 - 0.06x_4^2 + 0.00x_3x_4$$

SE b's =	0.13	0.13	0.13	0.17	0.17	0.20

Canonical form -

a) Center of system - S

$x_{3s} = -0.08$
$x_{4s} = -2.42$
$Y^1_{10s} = 4.01$

b) Equation -

$$Y^1_{10} - 4.01 = 0.35X_3^2 - 0.06X_4^2$$

c) Axes -

	$(x_3 + 0.08)$	$(x_4 + 2.42)$
X_3	1.0000	0
X_4	0	-1.0000

These two relationships have been plotted in Figure 10. For the No. 5 steel finish, very little variation in spangle contrast was experienced. As a result, only one contour line falls within the experimental region. An improvement in contrast is indicated in the direction of the arrow marked 3.

-

Y_{11} - BRIGHTNESS (Photometer Reading)

Both steel finishes combined.

CODE -

1. 0 - 1.25
2. 1.5 - 2.75
3. 3.0 - 4.25
4. 4.5^+

Second degree equation -

$$Y_{11} = 2.40 + 0.36x_1 - 0.79x_3 - 0.46x_4 + 0.17x_1^2 + 0.47x_3^2 - 0.32x_4^2$$

SE b's =	0.13	0.07	0.11	0.11	0.07	0.14	0.14

$$+ 0.00x_1x_3 + 0.00x_1x_4 - 0.46x_3x_4$$

0.13	0.13	0.18

Canonical form -

a) Center of system - S

$x_{1s} = -1.05$
$x_{3s} = 0.37$
$x_{4s} = -0.98$
$Y_{11s} = 2.29$

b) Equation -

$$Y_{11} - 2.29 = 0.19X_1^2 + 0.53X_3^2 - 0.38X_4^2$$

c) Axes -

	$(x_1 + 1.05)$	$(x_3 - 0.37)$	$(x_4 + 0.98)$
X_1	1.0000	0	0
X_3	-0.0008	-0.9657	0.2596
X_4	0.0002	-0.2595	-0.9657

Examination of the canonical form shows that the effect of factor X_1 is small and is almost entirely due to x_1. In plotting Figure 11, it was therefore assumed that X_1 is zero, and x_1 was set at the zero level (455°C) (851°F). Only the effects of x_3 and x_4 upon brightness are shown.

An increase in bath temperature within the range of experimental conditions will tend to increase the photometer readings.

-

Y_{12} - ROUGHNESS

CODE -

1. Very smooth
2. Moderately smooth
3. Fine to moderately rough, sandpaper texture
4. Rough texture

No. 3 Steel Finish

Second degree equation -

$$Y_{12} = 1.95 + 0.29x_1 + 0.38x_2 - 0.25x_3 + 0.06x_1^2 + 0.06x_2^2 + 1.05x_3^2$$

SE b's = 0.14 0.09 0.09 0.12 0.08 0.08 0.16

$$+ 0.06x_1x_2 + 0.25x_1x_3 + 0.00x_2x_3$$

0.10 0.15 0.15

Canonical form -

a) Center of system - S

$x_{1s} = -2.27$
$x_{2s} = -2.01$
$x_{3s} = 0.39$
$Y_{12s} = 1.20$

b) Equation -

$$Y_{12} - 1.20 = 0.08X_1^2 + 0.02X_2^2 + 1.07X_3^2$$

c) Axes -

	$(x_1 + 2.27)$	$(x_2 + 2.01)$	$(x_3 - 0.39)$
X_1	0.6110	0.7890	-0.0653
X_2	0.7820	-0.6144	-0.1043
X_3	0.1228	0.0038	0.9924

No. 5 Steel Finish

Second degree equation -

$$Y_{12}^1 = 2.84 + 0.37x_1 + 0.26x_2 - 0.50x_3 - 0.11x_1^2 + 0.02x_2^2 + 0.39x_3^2$$

SE b's = 0.17 0.10 0.10 0.14 0.09 0.09 0.18

$$- 0.15x_1x_2 + 0.42x_1x_3 + 0.00x_2x_3$$

0.12 0.17 0.17

Canonical form -

a) Center of system - S

$x_{1s} = 1.67$
$x_{2s} = -0.64$
$x_{3s} = -0.25$
$Y^1_{12s} = 3.13$

b) Equation -

$$Y_{12}^1 - 3.13 = 0.21X_1^2 + 0.04X_2^2 + 0.46X_1^2$$

c) Axes -

	$(x_1 - 1.67)$	$(x_2 + 0.64)$	$(x_3 + 0.25)$
X_1	-0.9012	-0.2951	0.3173
X_2	0.2582	-0.9538	-0.1541
X_3	0.3479	-0.0565	0.9358

For both steel finishes X_2 is not significant and has been assumed to be zero for plotting purposes. In addition, immersion time (x_2), although it does have an effect upon roughness, has been set at the zero level (1 min) to facilitate the plotting of Figure 12.

In the canonical form X_3 is the most important variable in both cases and its effect is related mainly to the aluminium content of the bath.

-

Y_{13} - PERCENT GAIN IN AVERAGE DIFFUSIVITY AFTER THE HUMIDITY TEST

No. 3 Steel Finish

Second degree equation -

$$Y_{13} = 7.23 - 6.01x_1 + 10.88x_3 + 8.07x_4 - 7.54x_1^2 + 19.96x_3^2 + 17.78x_4^2$$

SE b's = 6.66   3.94   5.57   5.57   2.58   5.16   5.16

$$- 1.11x_1x_3 + 4.60x_1x_4 + 6.10x_3x_4$$

4.83   4.83   6.82

Canonical form -

a) Center of system - S

$$x_{1s} = -0.42$$
$$x_{3s} = -0.26$$
$$x_{4s} = -0.13$$
$$Y_{13s} = 6.53\%$$

b) Equation -

$$Y_{13} - 6.53 = -7.77X_1^2 + 22.14X_3^2 + 15.84X_4^2$$

c) Axes -

	$(x_1 + 0.42)$	$(x_3 + 0.26)$	$(x_4 + 0.13)$
X_1	-0.9952	-0.0301	0.0932
X_3	0.0300	0.8115	0.5836
X_4	-0.0933	0.5836	-0.8067

No. 5 Steel Finish

Second degree equation -

$$Y_{13}^{1} = -7.12 - 5.13x_1 + 14.68x_3 + 5.08x_4 - 3.69x_1^2 + 35.77x_3^2$$

SE b's = 6.21 3.68 5.20 5.20 3.40 6.81

$$+ 20.56x_4^2 + 0.66x_1x_3 - 0.62x_1x_4 + 0.92x_3x_4$$

6.81 6.37 6.37 9.01

Canonical form -

a) Center of system - S

$x_{1s} = -0.70$
$x_{3s} = -0.20$
$x_{4s} = -0.13$
$Y_{13s} = -7.09\%$

b) Equation -

$$Y_{13}^{1} + 7.09 = -3.69X_1^2 + 35.79X_3^2 + 20.55X_4^2$$

c) Axes -

	$(x_1 + 0.70)$	$(x_3 + 0.20)$	$(x_4 + 0.13)$
X_1	-0.9999	0.0085	-0.0128
X_3	0.0082	0.9995	0.0302
X_4	0.0133	0.0301	-0.9995

Examination of the canonical forms for both steel finishes shows that X_1 is small and not significant and its effect is related mainly to x_1 the bath temperature. To facilitate plotting of the two graphs in Figure 13 the variable X_1 was assumed to be zero and the bath temperature x_1 taken as -0.7 (448°C)(838°F).

Y_{14} - CORROSION INDEX - WHITE, AFTER HUMIDITY TEST

There were no significant factors found for either of the two steel finishes. There is, therefore, no Figure 14.

-

Y_{15} - WEIGHT GAIN FROM CORROSION AFTER HUMIDITY TEST (mg)

Both steel finishes combined.

Second degree equation -

Y_{15} =	38.8	+ $3.7x_1$	- $1.0x_2$	+ $3.3x_3$	+ $6.2x_4$	- $4.4x_1^2$	- $4.3x_2^2$	+ $12.5x_3^2$
SE b's =	3.5	1.7	1.7	2.5	2.5	1.6	1.6	3.3

- $7.7x_4^2$	+ $1.9x_1x_2$	- $2.3x_1x_3$	- $1.5x_1x_4$	- $6.9x_2x_3$	+ $2.2x_2x_4$	- $0.6x_3x_4$
3.3	2.1	3.0	3.0	3.0	3.0	4.3

Canonical form -

a) Center of system - S

x_{1s} = 0.39
x_{2s} = 0.12
x_{3s} = -0.05
x_{4s} = 0.38
Y_{15s} = 40.6 mgs

b) Equation -

$$Y_{15} - 40.6 = -3.99X_1^2 - 4.88X_2^2 + 13.28X_3^2 - 8.29X_4^2$$

c) Axes -

	$(x_1 - 0.39)$	$(x_2 - 0.12)$	$(x_3 + 0.05)$	$(x_4 - 0.38)$
X_1	0.8156	0.5521	0.1730	-0.0192
X_2	0.5233	-0.7338	-0.1175	-0.4171
X_3	0.0742	0.1966	-0.9774	0.0225
X_4	0.2449	-0.3373	-0.0284	0.9085

With a four-factor system, as with a three-factor system, some assumptions have to be made and some conditions set, in order to plot the important factors in two dimensions.

Canonical factors X_1 and X_2 are small and of doubtful significance compared to X_3 and X_4; therefore, by assuming that X_1 and X_2 are not different from zero and by setting x_1 and x_2 both at the zero level (i.e., a bath temperature of 455°C (851°F) and a one-minute immersion time), a two-dimensional system in x_3 and x_4 may be plotted.

This plot only roughly represents the true relationship but is sufficient for our purpose. Examination of the canonical form will give a better idea of the whole system.

-

Y_{16} - WEIGHT LOSS FROM CORROSION AFTER HUMIDITY TEST (mg)

Both steel finishes combined.

Second degree equation -

$$Y_{16} = 60.4 + 3.7x_2 + 23.2x_3 + 6.2x_2^2 + 9.6x_3^2 - 7.8x_2x_3$$

SE b's = 3.6 2.5 3.6 2.3 4.7 4.4

Canonical form -

a) Center of system - S

$$x_{2s} = -1.42$$
$$x_{3s} = -1.80$$
$$Y_{16s} = 36.9 \text{ mgs}$$

b) Equation -

$$Y_{16} - 36.9 = 3.65X_2^2 + 12.14X_3^2$$

c) Axes -

	$(x_2 + 1.42)$	$(x_3 + 1.80)$
X_2	0.8334	0.5527
X_3	0.5527	-0.8334

This relationship is shown in Figure 16.

-

Y_{17} - CORROSION INDEX - WHITE (24 hr) - AFTER WATER FILM TEST

$$Y_{17} = 2.49 - 0.23x_3 + 0.28x_3^2$$

Here only one factor was significant and it has been plotted directly in Figure 17.

-

Y_{18} - CORROSION INDEX - WHITE (48 hr) - AFTER WATER FILM TEST

Both steel finishes combined.

Second degree equation -

$$Y_{18} = 2.70 + 0.05x_2 + 0.17x_3 - 0.08x_2^2 + 0.31x_3^2 - 0.09x_2x_3$$

SE b's = 0.08 0.06 0.08 0.05 0.11 0.10

Canonical form -

a) Center of system - S

$x_{2s} = 0.42$
$x_{3s} = -0.20$
$Y_{18s} = 2.69$

b) Equation -

$$Y_{18} - 2.69 = -0.09X_2^2 + 0.32X_3^2$$

c) Axes -

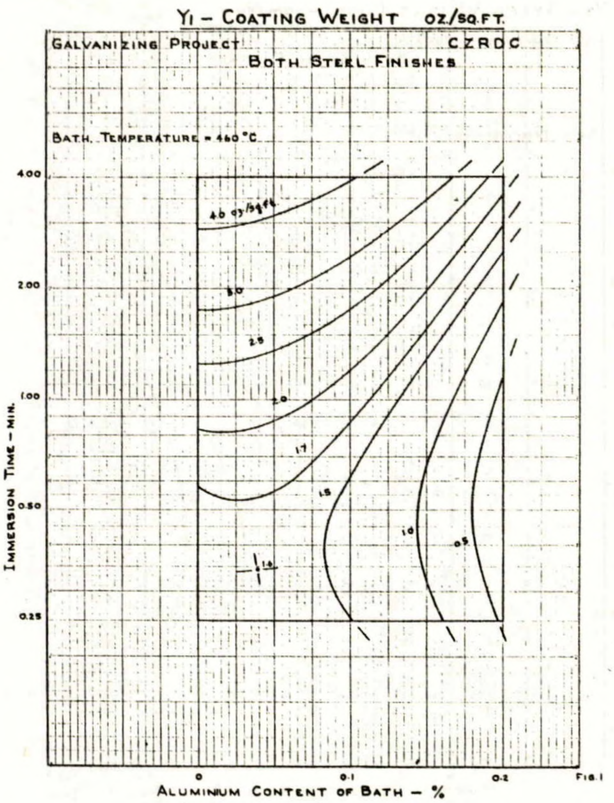
	$(x_2 - 0.42)$	$(x_3 + 0.20)$
X_2	0.9934	0.1150
X_3	0.1150	-0.9934

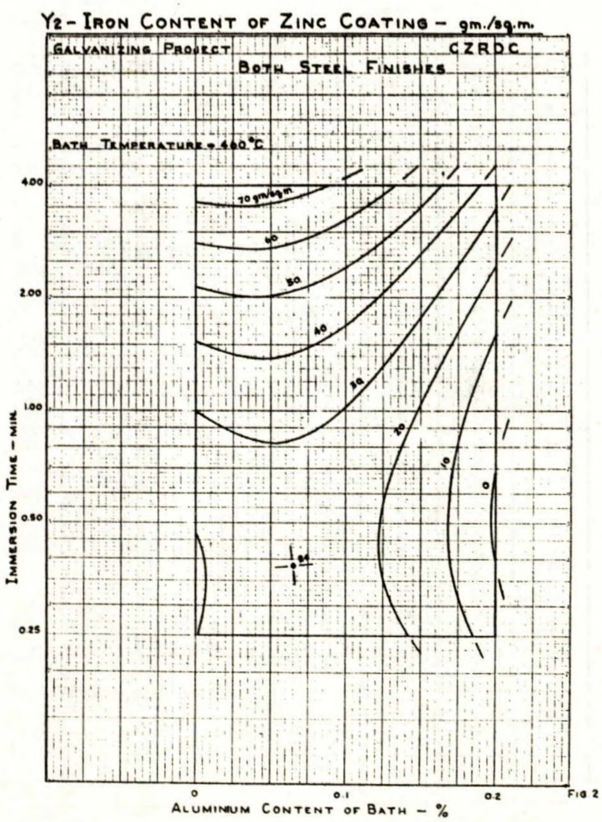
This relationship is shown in Figure 18.

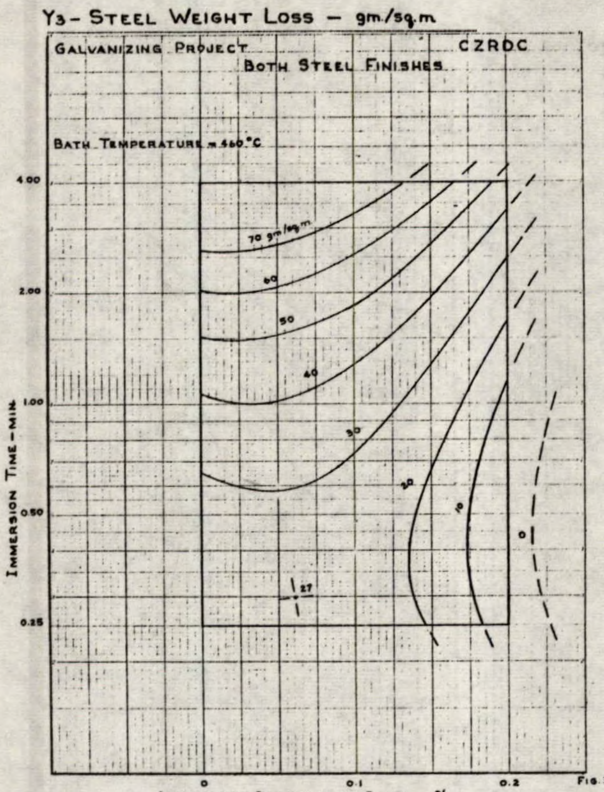
* * *
*

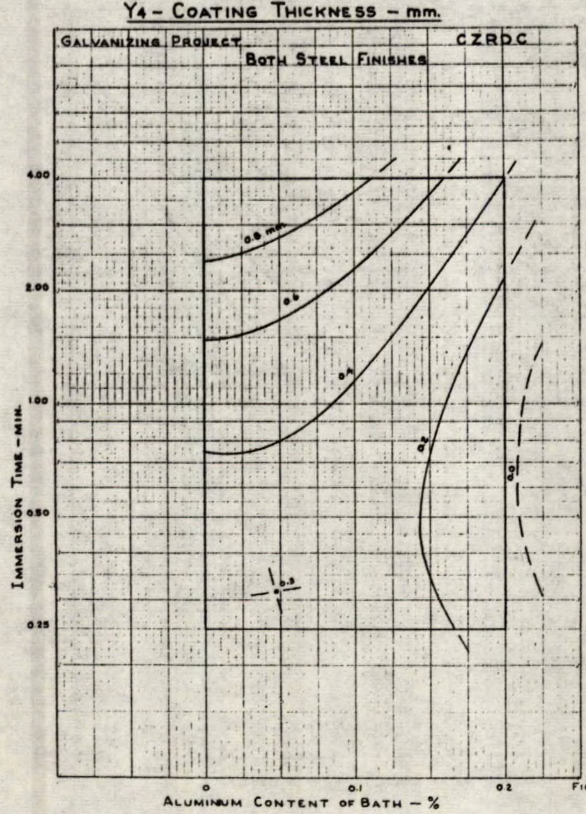
JJS:(PES)vb

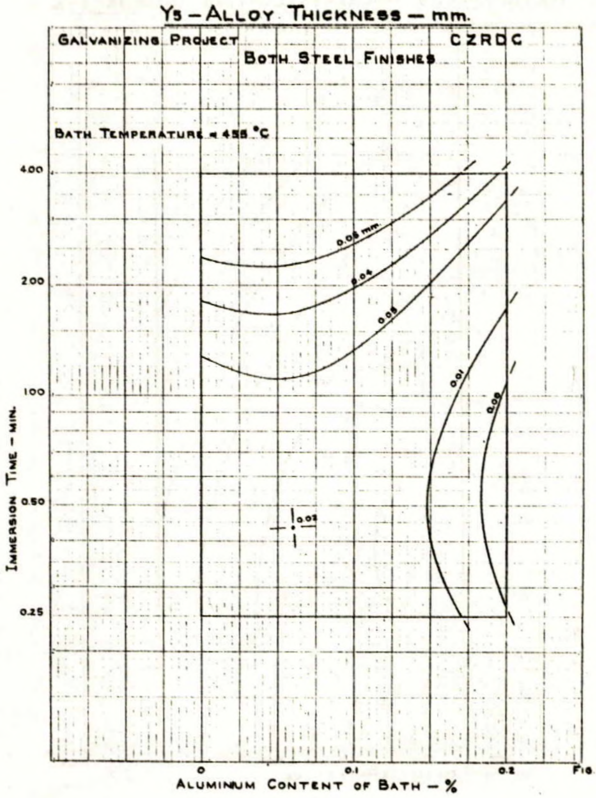
(Figures 1-18 follow,)
(on pages 51 to 62.)

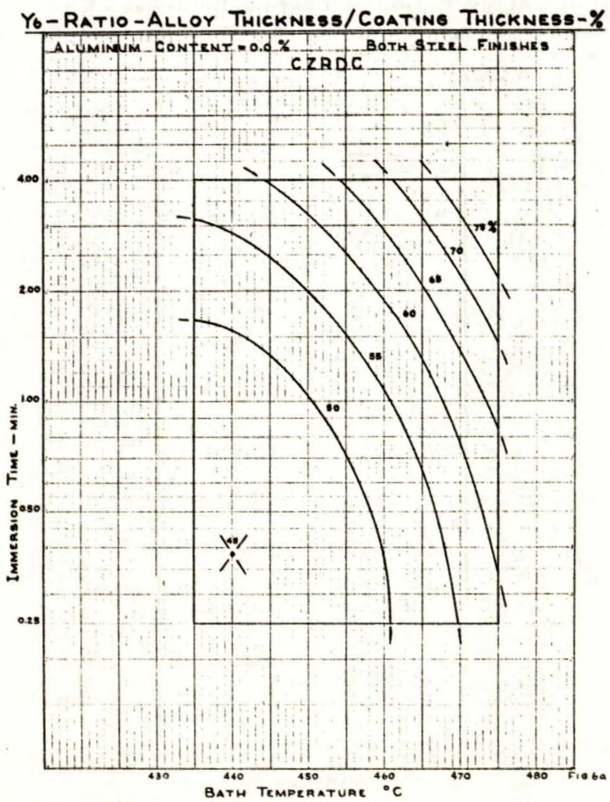

Y1 – Coating Weight oz/sq.ft.
Galvanizing Project
CZRDC
Both Steel Finishes
Bath. Temperature = 460 °C
Immersion Time – min.
Aluminium Content of Bath – %
Fig. 1


Y2 – Iron Content of Zinc Coating – gm./sq.m.
Galvanizing Project
CZRDC
Both Steel Finishes
Bath Temperature = 460 °C
Immersion Time – min.
Aluminium Content of Bath – %
Fig 2


Y3 - Steel Weight Loss - gm./sq.m
Galvanizing Project
CZRDC
Both Steel Finishes
Bath Temperature = 460°C
70 gm/sq.m
60
50
40
30
20
10
0
27
4.00
2.00
1.00
0.50
0.25
Immersion Time - min.
0
0.1
0.2
Aluminum Content of Bath - %
Fig. 3


Y4 - Coating Thickness - mm.
Galvanizing Project
CZRDC
Both Steel Finishes
0.8 mm.
0.6
0.4
0.2
0.0
0.3
4.00
2.00
1.00
0.50
0.25
Immersion Time - min.
0
0.1
0.2
Aluminum Content of Bath - %
Fig. 4


Y5 – ALLOY THICKNESS – mm.
GALVANIZING PROJECT
CZRDC
BOTH STEEL FINISHES
BATH TEMPERATURE = 455 °C
IMMERSION TIME – MIN.
ALUMINUM CONTENT OF BATH – %
0.05 mm
0.04
0.03
0.01
0.02
4.00
2.00
1.00
0.50
0.25
0
0.1
0.2
FIG. 5


Y6 – RATIO – ALLOY THICKNESS/COATING THICKNESS – %
ALUMINUM CONTENT = 0.0 %
BOTH STEEL FINISHES
CZRDC
IMMERSION TIME – MIN.
BATH TEMPERATURE °C
75 %
70
65
60
55
50
4.00
2.00
1.00
0.50
0.25
430
440
450
460
470
480
FIG. 6a

Y6 - Ratio - Alloy Thickness/Coating Thickness - %

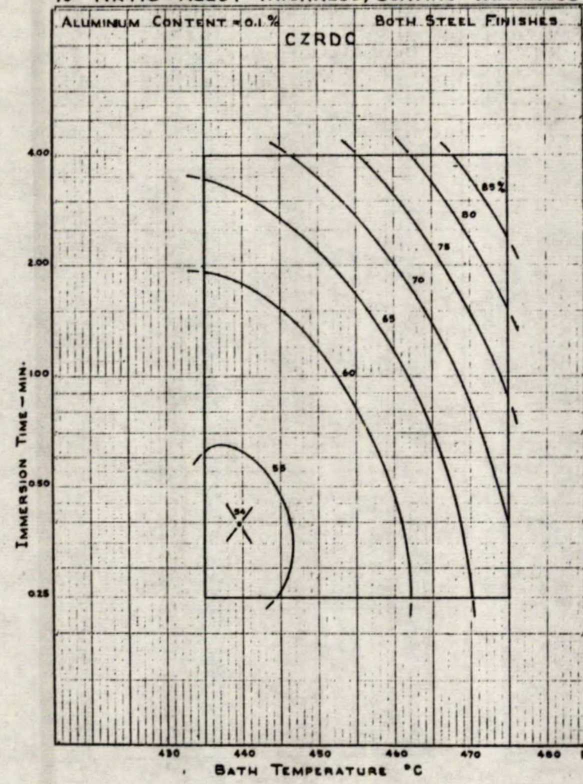


Fig. 6b

Y6 - Ratio - Alloy Thickness/Coating Thickness - %

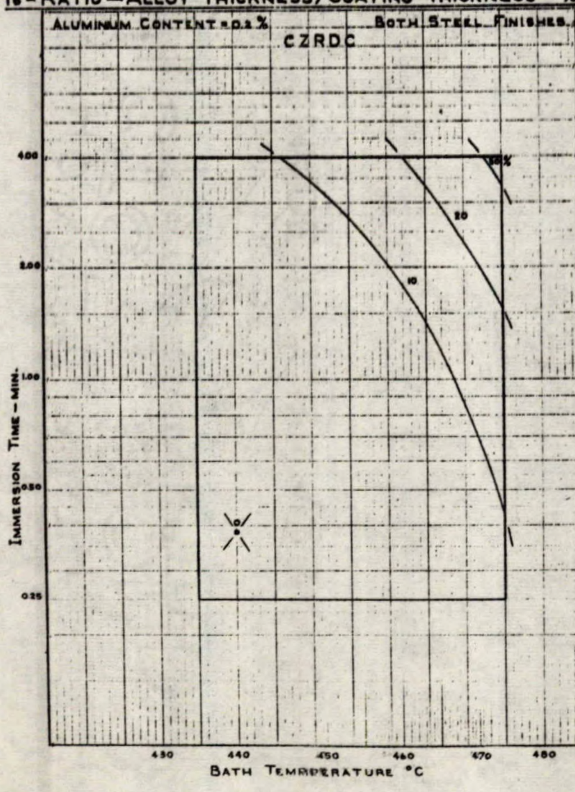


Fig. 6c

Y6 – Ratio – Alloy Thickness/Coating Thickness – %

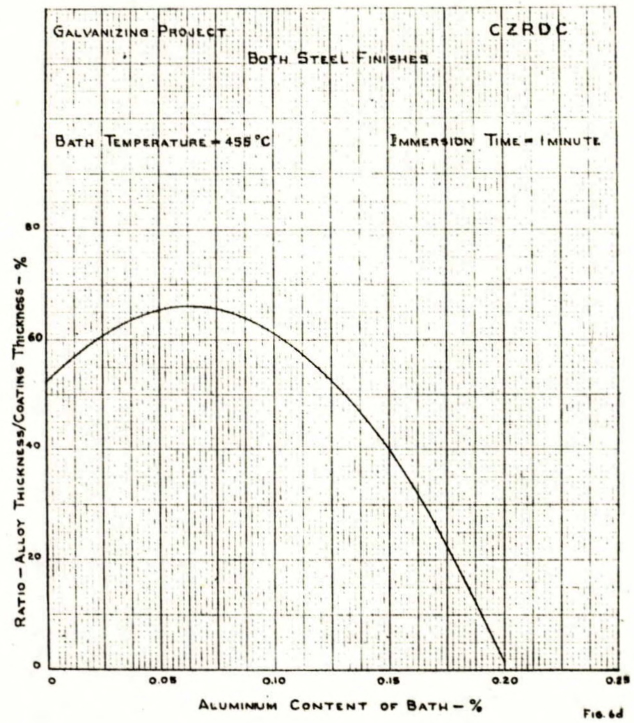


Fig. 6d

Y7 — Coating Ductility — Cupping Test

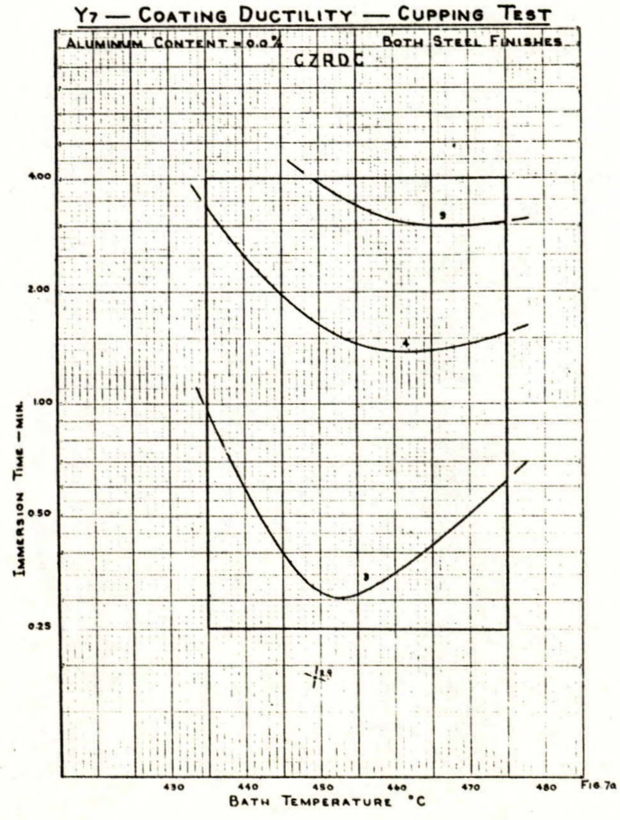


Fig. 7a

Y7 – COATING DUCTILITY — CUPPING TEST

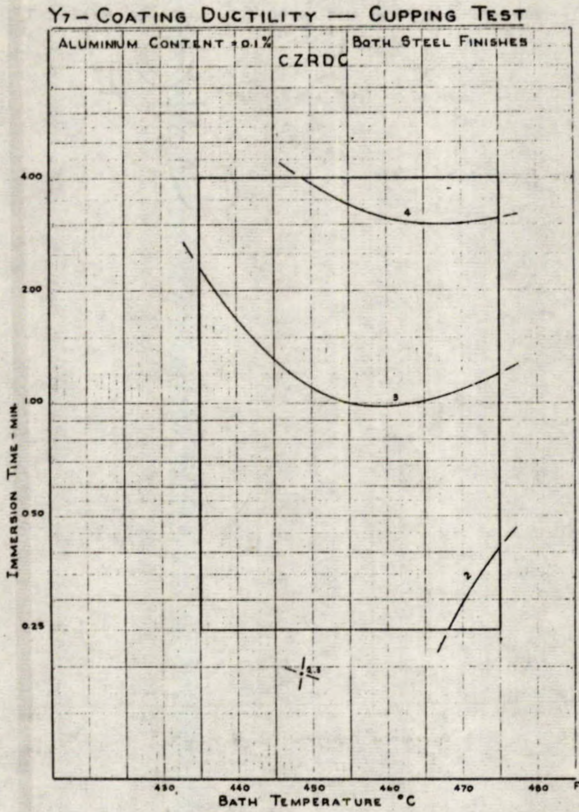


FIG. 7b

Y7 — COATING DUCTILITY — CUPPING TEST

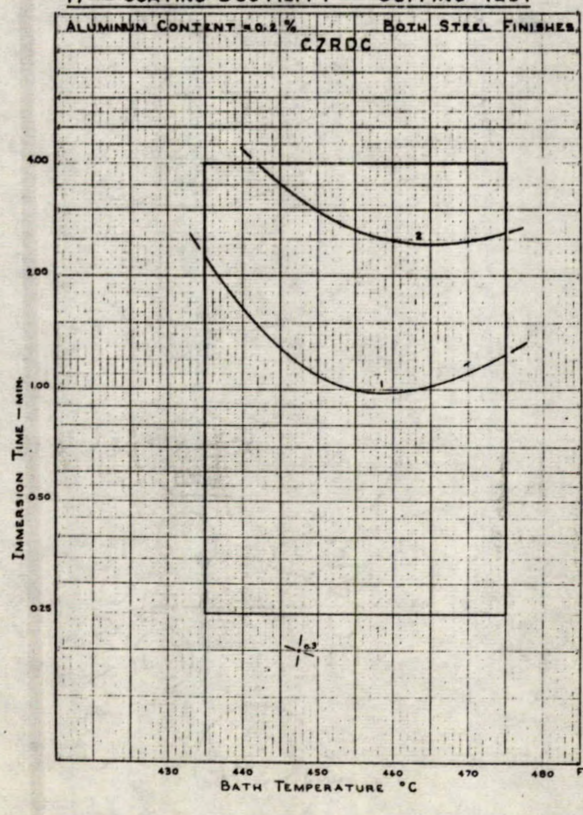


FIG. 7c

Y7 – Coating Ductility – Cupping Test

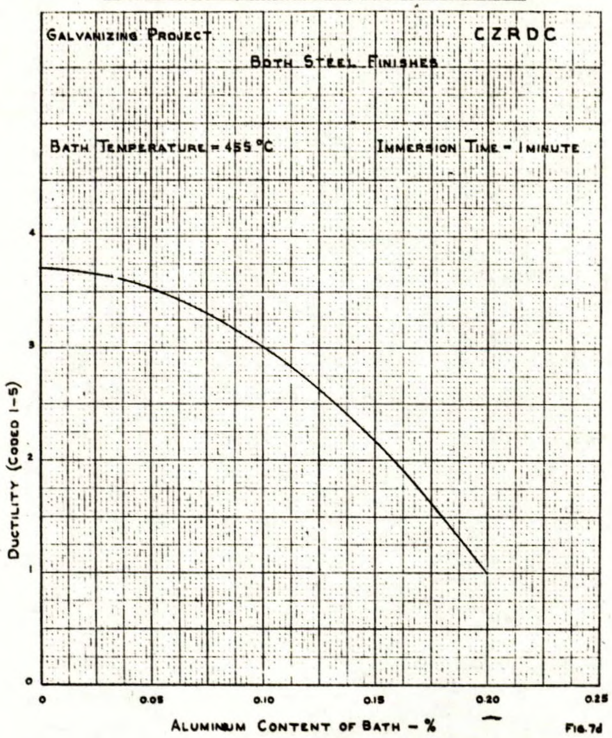


Fig. 7d

Y8 – Coating Adherence (Bend Test)

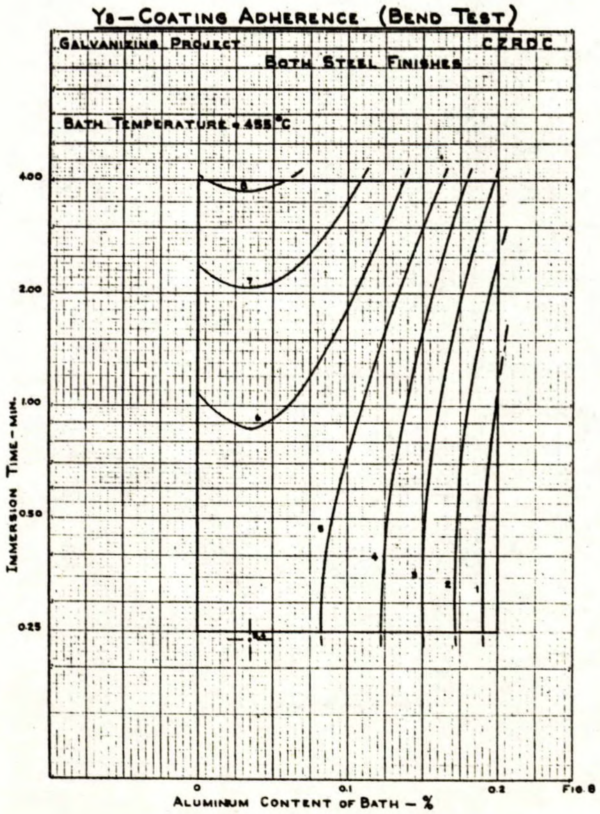


Fig. 8

Y9 – Spangle Size

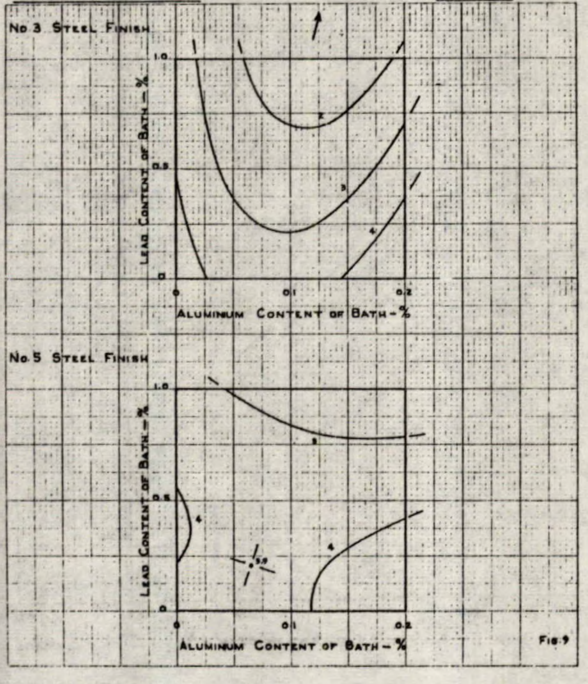


Fig 9

Y10 – Spangle Contrast

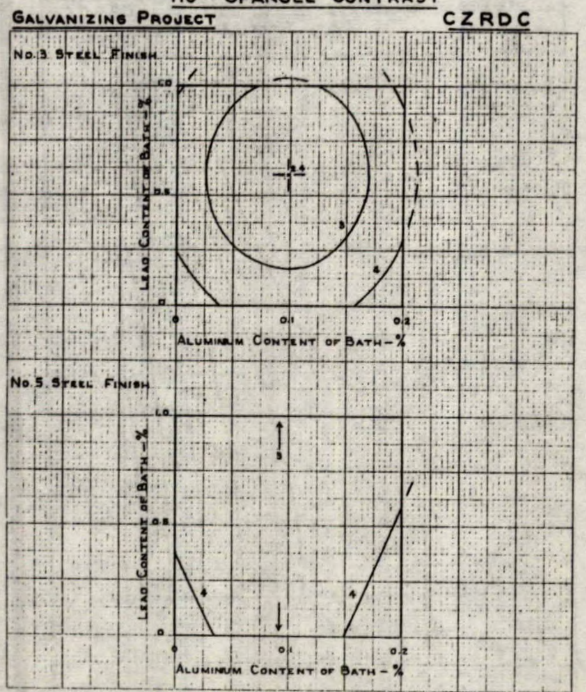


Fig 10

Y11 — Brightness — Photometer Reading

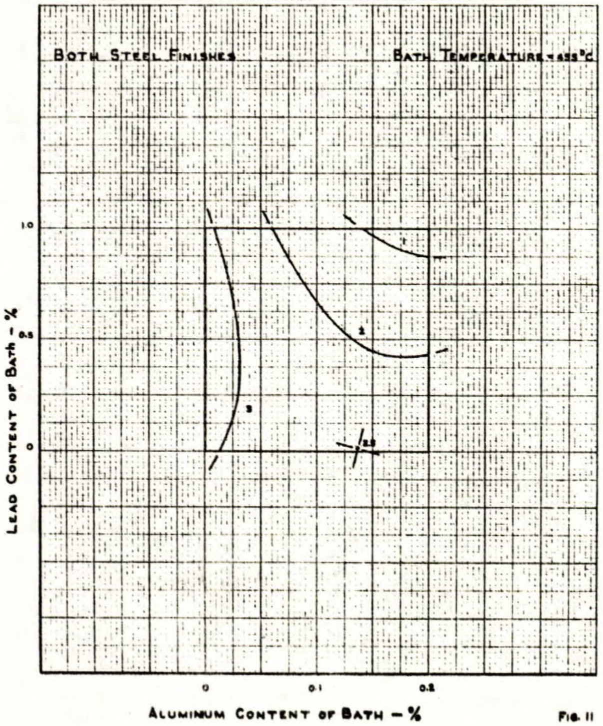


Fig. 11

Y12 - Roughness

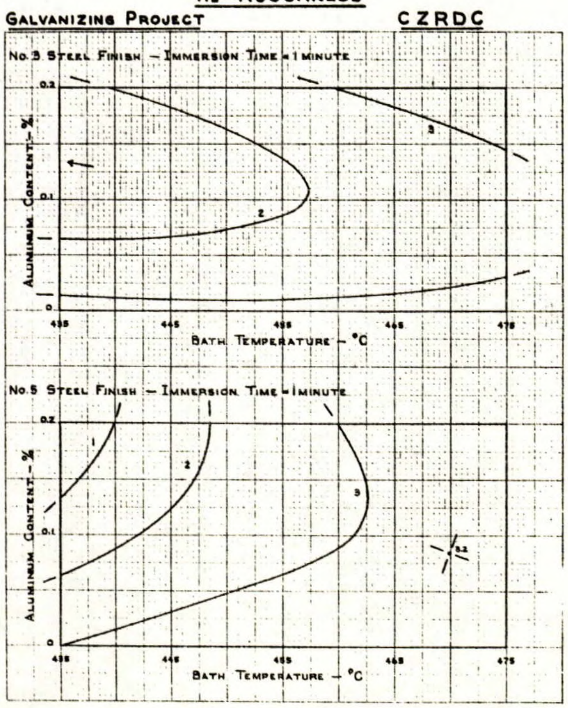


Fig. 12

Y13 – PERCENTAGE GAIN IN AVERAGE DIFFUSIVITY AFTER THE HUMIDITY TEST

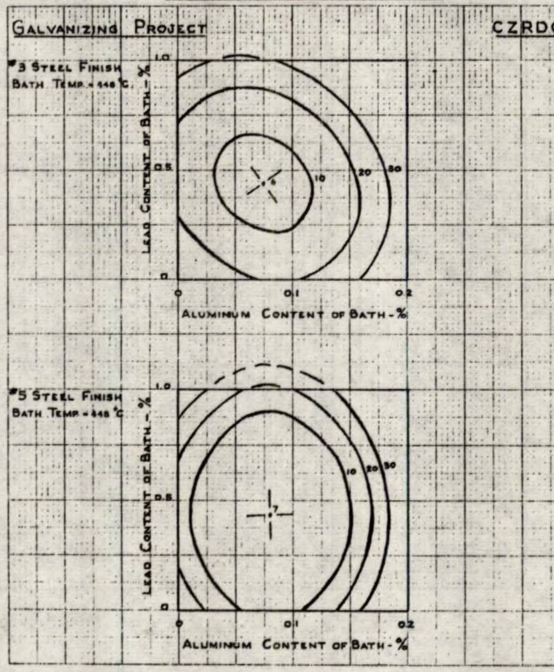


FIG 13

Y15 – WEIGHT GAIN FROM CORROSION AFTER HUMIDITY TEST – mg.

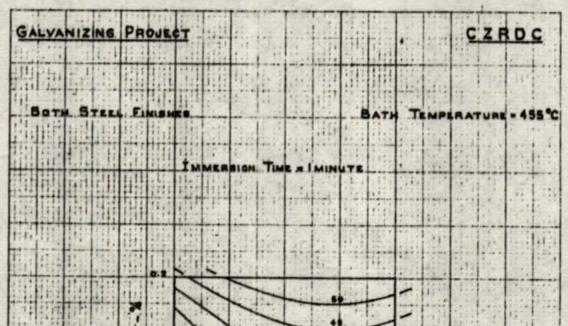


FIG 15

Y16 – Weight Loss from Corrosion after Humidity Test - mg.

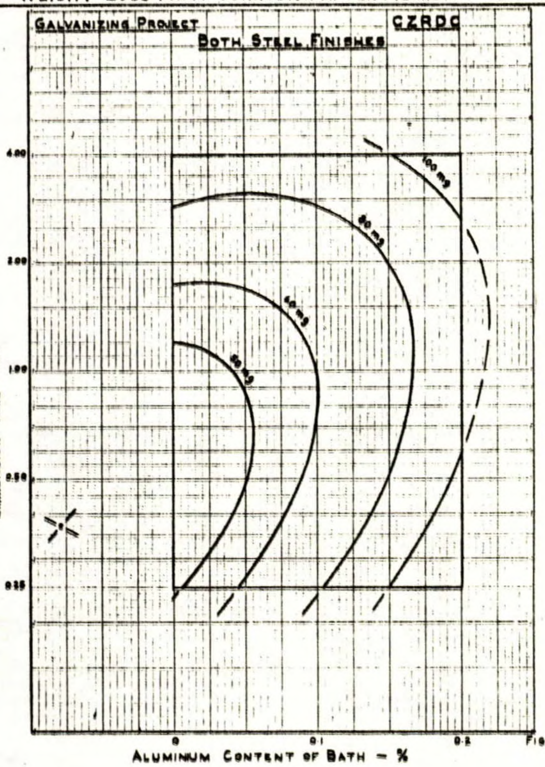


Fig 16

Y17 – Corrosion Index – white (24hr.) – Water Film Test

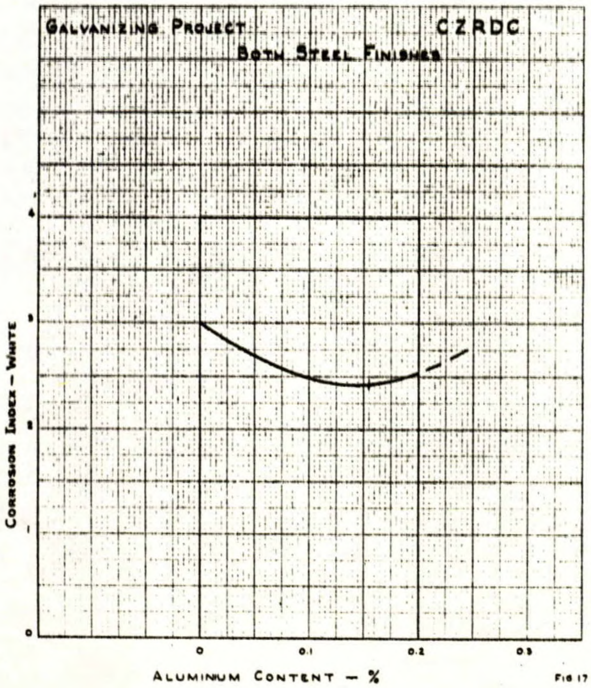


Fig 17

Y18 — Corrosion Index - White (48 HR) - Water Film Test

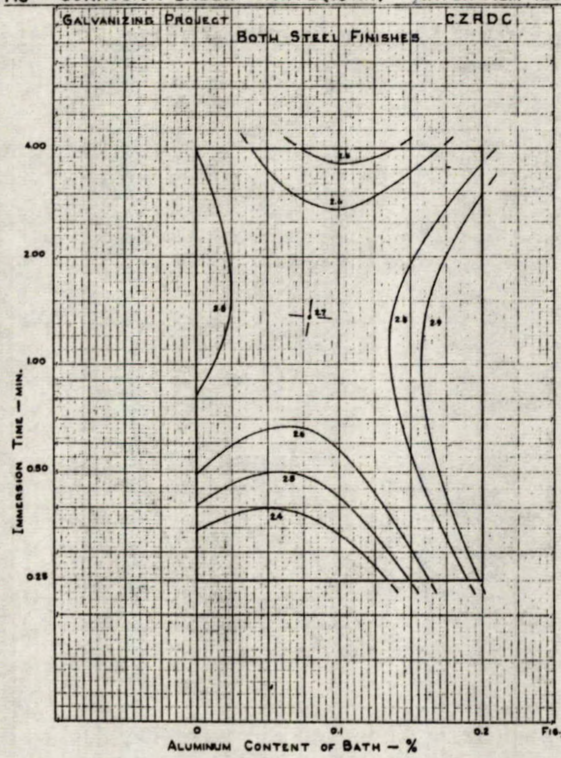


Fig. 18