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THE EFFECT OF SINGLE ELEMENT ADDITIONS TO AISI TYPE 430 STAINLESS STEEL IN DIP-AND-DRY CORROSION TESTS

HUGH M. WELD

PHYSICAL METALLURGY DIVISION

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by

Hugh M. Weld*

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ABSTRACT

The corrosion properties of a series of eight stainless steel alloys were determined in a "Dip-and-Dry Corrosion Test". This cyclic type of test has been frequently used to test stainless steel alloys for automobile trim and it has shown some correlation with actual field test results.

Each alloy series tested was made from a basic AISI Type 430 ferritic stainless steel but modified by a number of small additions of one of the following elements: Mo, V, W, Ta, Si, Re, Pd, or Ge. The final composition never exceeded 3.11% of addition element.

The corrosion resistance of AISI Type 430 stainless steel containing 1.5% and 3.1% Mo showed a marked superiority, both in appearance and in weight loss, compared to the base alloy. An alloy containing 1.8% Re also has superior corrosion resistance in this test.

Small additions of tantalum, silicon or germanium, to AISI Type 430, all improved corrosion resistance with increased alloy content. Tungsten produced a slight improvement in corrosion resistance and appearance. Vanadium or palladium additions did not improve these corrosion properties of their alloys, and showed no consistent trend with increasing alloy addition.

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EFFETS DE L'ADDITION D'ÉLÉMENTS SEULS À L'ACIER INOXYDABLE AISI 430 DANS LES ESSAIS DE CORROSION PAR IMMERSION-SÉCHAGE

par

Hugh M. Weld*

RÉSUMÉ

La résistance à la corrosion d'une série de huit alliages d'acier inoxydable a été déterminée au moyen d'un "essai de corrosion par immersion-séchage". Ce type d'essai cyclique a été utilisé fréquemment pour l'étude des alliages d'acier inoxydable servant à la fabrication de garnitures d'automobile et il a montré une certaine corrélation avec les résultats des essais en service.

Chaque série d'alliages étudiée était constituée d'acier inoxydable ferritique de type AISI 430 auquel on avait ajouté de petites quantités d'un des éléments suivants: Mo, V, W, Ta, Si, Re, Pd, ou Ge. L'élément d'apport n'a jamais dépassé 3.11 p. 100 dans la composition finale.

La résistance à la corrosion de l'acier inoxydable de type AISI 430 contenant 1.5 et 3.1 p. 100 de molybdène a montré une nette supériorité, tant pour l'apparence que pour la perte de poids, sur l'alliage de base. Un alliage contenant 1.8 p. 100 de rhénium a aussi montré une résistance à la corrosion supérieure au cours de cet essai.

De faibles additions de tantale, de silice et de germanium à l'acier AISI 430 ont toutes amélioré la résistance à la corrosion en fonction de la quantité d'élément d'apport. Le tungstène a entraîné une légère amélioration de la résistance à la corrosion et de l'apparence. Les additions de vanadium et de palladium n'ont pas amélioré la résistance à la corrosion de leurs alliages et n'ont pas montré de tendance soutenue à mesure qu'on augmentait leur proportion.

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INTRODUCTION

Ferritic stainless steels generally do not have as good corrosion-resistance properties as does the nickel-containing austenitic type. The possibility of improving the corrosion resistance of the ferritic stainless steels through small alloy additions has long been sought. To this end, a series of eight ferritic alloys of the AISI Type 430, modified by the addition of individual metallic elements in various small amounts, was produced. Some of the corrosion properties of these alloys have already been examined by G. J. Biefer[1], who has shown that small amounts of Mo, V and W improved the corrosion resistance in non-oxidizing normal sulphuric and normal hydrochloric acid solutions, while Pd additions, in the range 0.46 to 1.91%, brought about passivation in normal sulphuric acids and thus out-performed AISI Type 304 austenitic stainless steel in that medium. He also reported that, of this group of alloys, Mo and Re were the only additions which conferred improved corrosion resistance in normal ferric chloride solution.

This present work represents an extension of the testing of these alloys by a cyclic dip-and-dry test which is frequently used to test automobile stainless steel trim in the laboratory[2]. This test has been reported to show a reasonable correlation with field exposure tests[3], although, as with all accelerated tests, the results should be confirmed by field tests[4, 5]. The effect of molybdenum in improving the corrosion properties of AISI Type 430 steels has been shown in field service and in cyclic dip tests[6, 7, 8].

EXPERIMENTAL

Material

The steels used in these tests were produced in the Physical Metallurgy Division, and their compositions are given in Table 1.

AISI Type 430 stainless steel formed the base material from which several series of alloys were produced. Each series contained alloys with a specific addition element, in various small amounts, as well as a control alloy.

Steels identified from A to X (omitting E, F, G, H) comprise the block containing the Mo, V, W, Ta and Si series. Each of these series was made from one 50-lb aluminum-killed induction melt of Type 430 steel which was split into four parts; one part was used as a control and the other three were alloyed to various levels. The resulting castings were forged, rolled to 1/4-in. plate, annealed one hour at 840°C (1550°F), and furnace cooled. Rectangular coupons, 1 x 1/2 x 3/16 in., were machined from the plate and, in each, a 3/16-in. hole was drilled for mounting.

Steels identified from 7A to 6D comprise a second block of alloys, containing the Re, Pd and Ge series. These steels were made in 4-lb melts, split in half for alloying, then cast into 3/4-in.-diameter core sand moulds. After being cropped and then surface-ground, the ingots were swaged to 3/8-in.-diameter rods at about 1090°C (2000°F) and annealed for one hour at 840°C (1550°F). The rods were then ground until a good metallic surface was obtained, which in some instances reduced the diameter to about 1/4 in. Cylindrical pieces were cut from the rod about 1/4 in. in length and a 1/16-in.-diameter hole was drilled axially through each.

The coupons and cylinders of the various series were prepared for cyclic testing as outlined in Appendix 1 under Sample Preparation.

Testing

Each of the series of alloys was dip-and-dry corrosion-tested as outlined in Appendix 1. Quadruplicate tests, numbered 1, 2, 3 and 4, were run on the first block of alloys, while only triplicate tests, numbered 5, 6 and 7, were run on the second block of alloys. The cycle of the dip-and-dry machine did not quite conform to the specifications, being 85 seconds drying

TABLE 1

Chemical Analyses of AISI 430 Test Steels

Steel	Basic Composition (%)						% Alloy Addition
	C	Cr	Mn	P	S	Si	
A	0.06	17.38	0.80	0.013	0.018	0.42	-
B							0.70 Mo
C							1.48 Mo
D							3.11 Mo
I	0.07	17.39	0.84	0.011	0.028	0.62	-
J							0.67 V
K							1.13 V
L							2.18 V
M	0.06	17.31	0.76	0.012	0.023	0.47	-
N							0.47 W
O							0.94 W
P							2.30 W
Q	0.06	17.40	0.82	0.015	0.022	0.48	-
R							0.41 Ta
S							0.72 Ta
T							1.37 Ta
U	0.06	17.52	0.64	0.018	0.024	0.39	- *
V						0.84	Si
W						1.33	Si
X						1.78	Si

Steel	Basic Composition (%)						% Alloy Addition
	C	Cr	Mn	P	S	Si	
7A	0.09	17.02	0.53	0.003	0.024	0.37	-
7B							0.59 Re
8C							1.15 Re
8D							1.84 Re
9A	0.09	17.02	0.53	0.003	0.024	0.37	-
9B							0.06 Pd
10C							0.10 Pd
10D							0.26 Pd
3B	0.06	16.94	0.76	0.014	0.019	0.44	0.46 Pd
4C							0.99 Pd
4D							1.91 Pd
5A	0.06	16.94	0.76	0.014	0.019	0.44	-
5B							0.41 Ge
6C							1.03 Ge
6D							2.01 Ge
6266**	0.06	19.47	1.77	0.017	0.022	0.57	10.19 Ni

* Nominal Si content for AISI Type 430 ferritic stainless steel.

**AISI Type 304 austenitic stainless steel.

and 10 seconds dipping. The pH of the test solution was 9.30, and the period of testing was 8 hours as specified.

Results of Tests

Photographs typical of the appearance of the samples after exposure to the 8-hour test are presented in Figures 1, 2, 3A, 3B, 4A and 4B. In all cases, the sample on the left is the control sample with no alloy addition; moving to the right, the composition is increasingly enriched in the designated element. Figure 5 is a photograph of two austenitic specimens of AISI Type 304 stainless steel as they appear after dip-and-dry testing for 8 hours. They are shown for comparison with the ferritic steels.

Other results, classified by alloy blocks, are shown in Tables 2 to 7. Tables 2 and 5 record the weight loss, in mg/cm^2, of individual samples as well as the averaged weight loss per test. This is interpreted as an indication of the corrosion rate that might be found under actual road conditions.

Tables 3 and 6 record the observed pH of the test solutions taken immediately after the completion of the 8-hour test, except in the case of Test 4, Table 3, when 10 hours elapsed before the pH readings were taken. This variation produced a marked decrease in pH readings and, consequently, these readings were not included in the averaged pH results. Tables 3 and 6 also record the sample appearance after testing. The appearance rating is based on visual judgment of the appearance immediately after testing, combined with an assessment of the pit-density after removal of the corrosion products. The appearance values assigned range from 0, for no corrosion or tarnish, to 9, for severe corrosion and pitting over the entire surface. The value is arbitrary, because sample areas were not always sufficient to generate good statistical data. The pitting corrosion was frequently localized in the area of inclusions or stringers and was seldom uniform.

Tables 4 and 7 are collations of the averaged results of the two series presented in the previous tables.

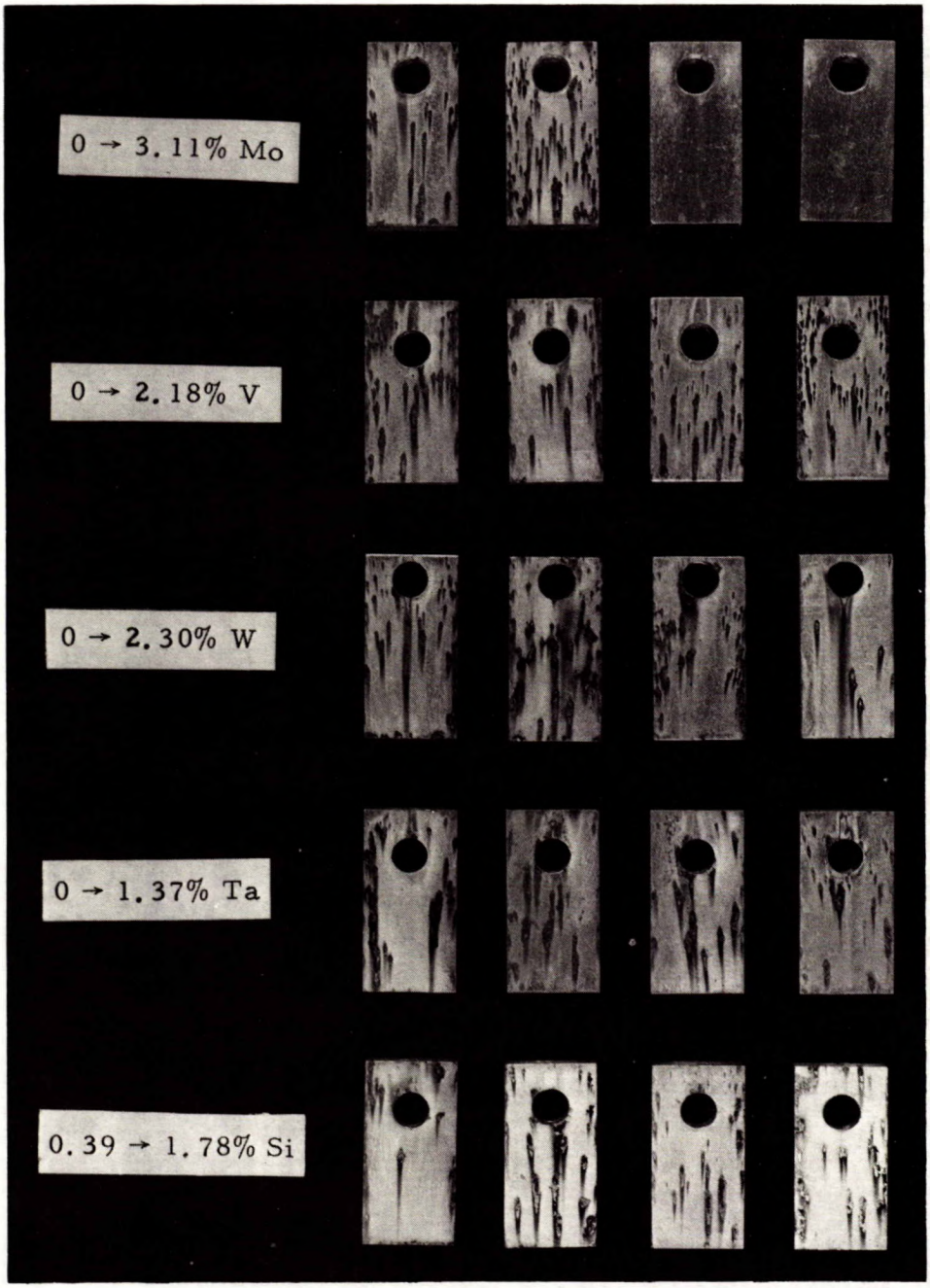


Figure 1. Appearance of samples from Test 1 after 8 hours' exposure, showing pits and rust-streaks. The control specimens are on the left and increase in alloy content on moving to the right.

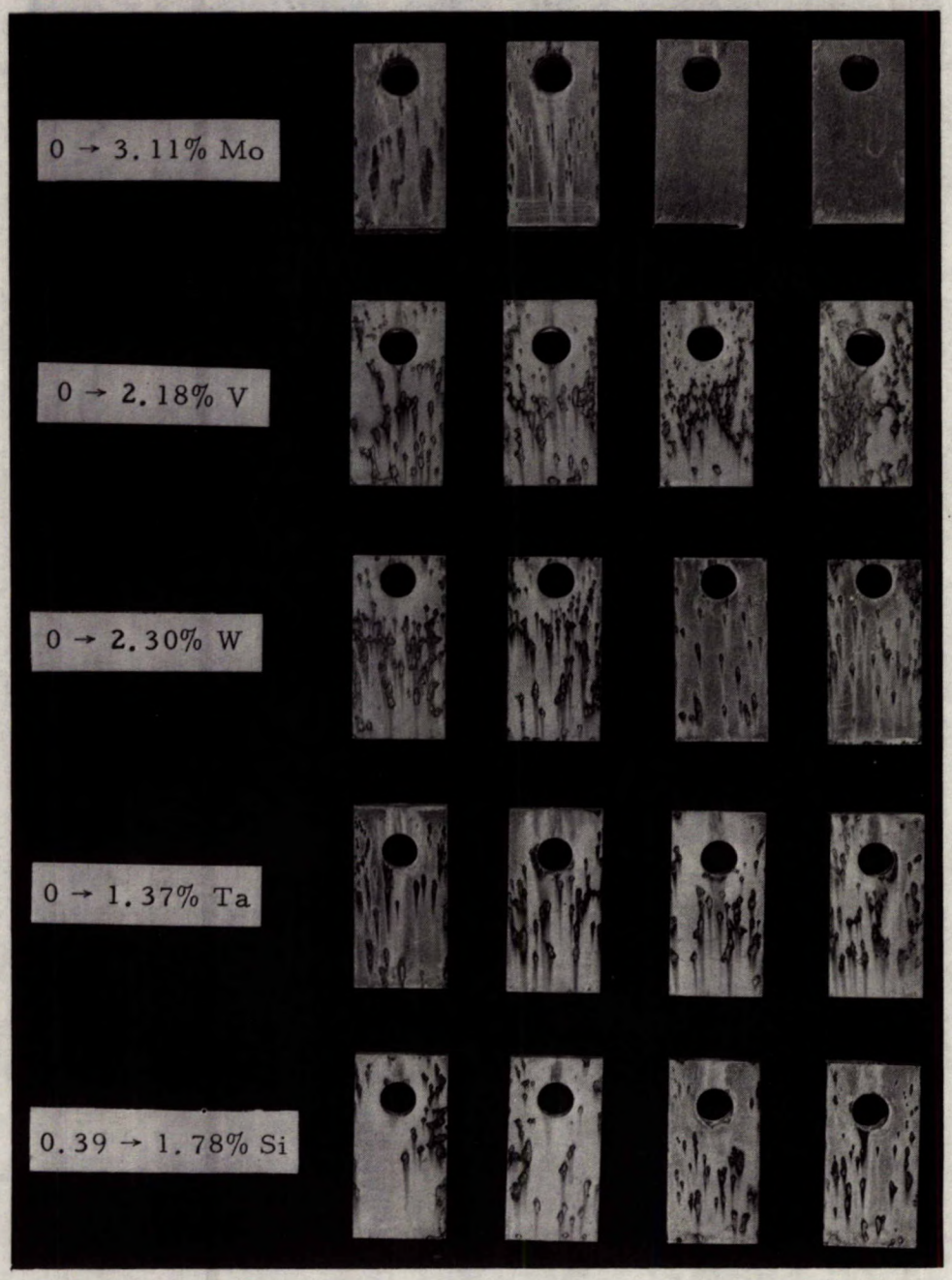
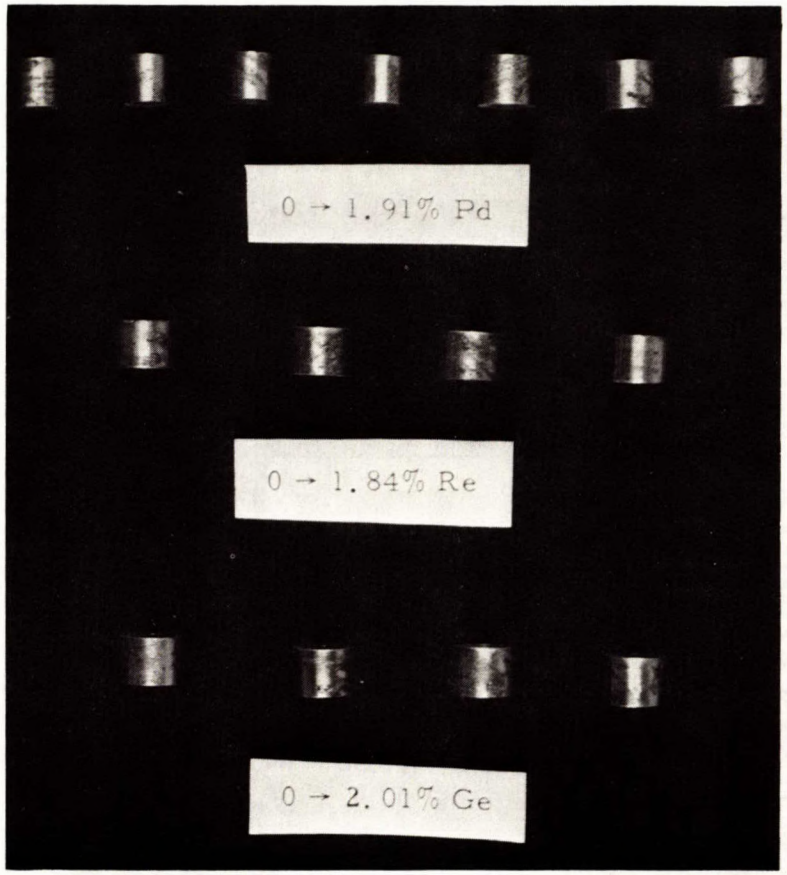
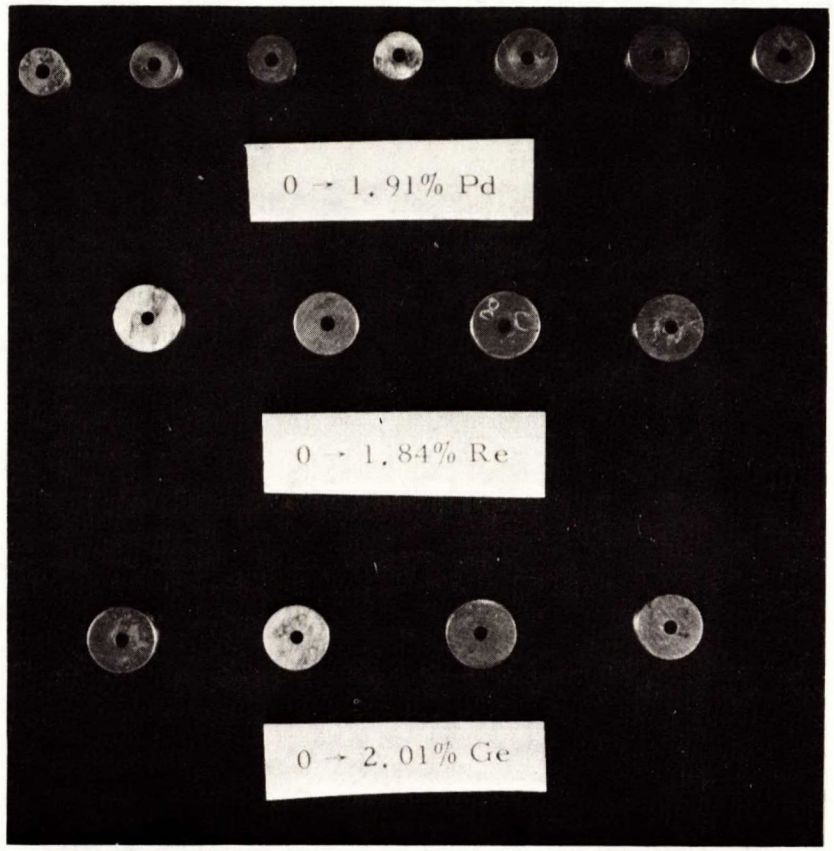
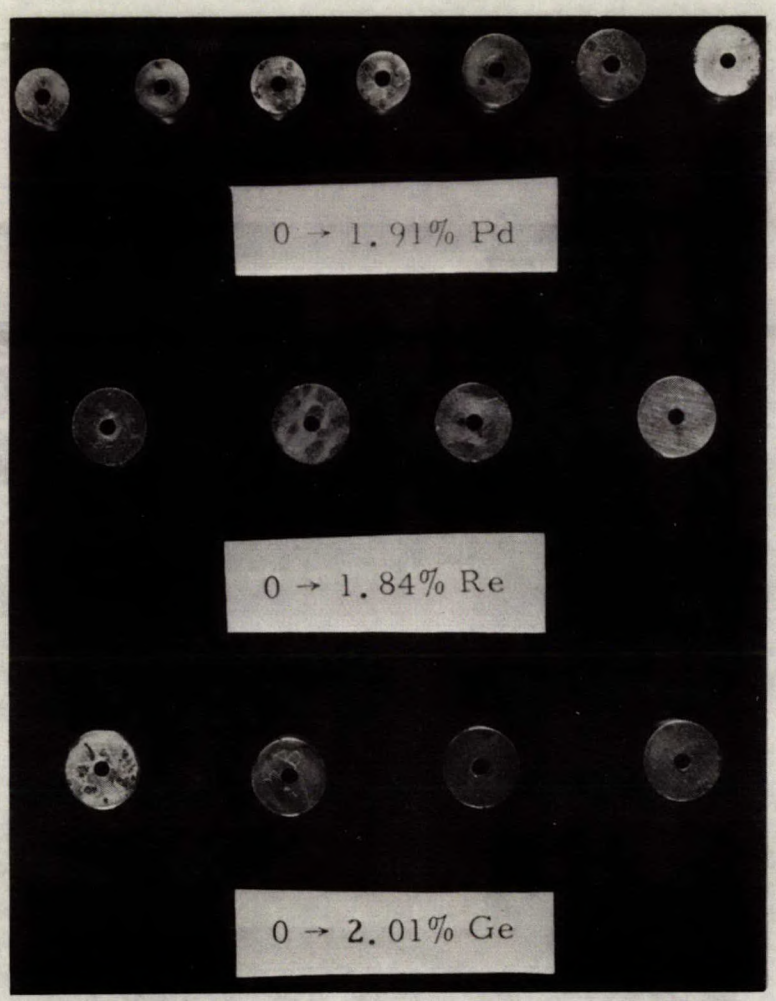


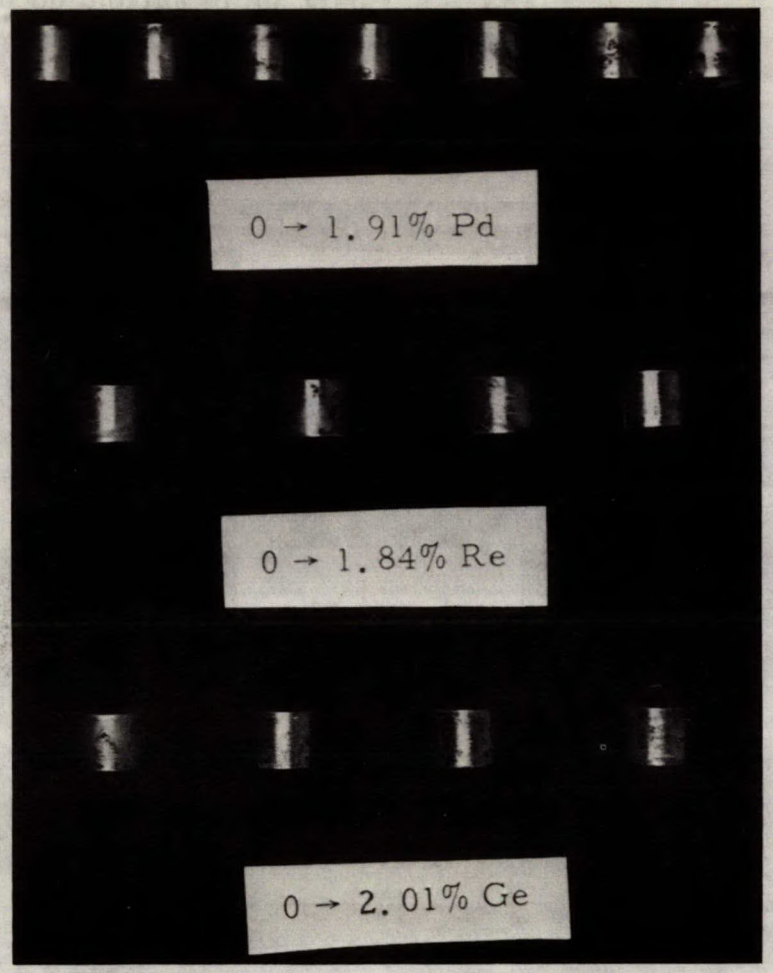
Figure 2. Appearance of samples from Test 2 after 8 hours' exposure, showing pits and rust streaks. The control specimens are on the left and increase in alloy content on moving to the right.





Figures 3A and 3B. Appearance of samples from Test 5 after 8 hours exposure to the dip-and-dry test. The side and end of the same cylindrical specimens are shown, with the control specimens on the left and increase in alloy content on moving to the right.





Figures 4A and 4B. Appearance of samples from Test 6 after 8 hours' exposure to the dip-and-dry test. The side and end of the same cylindrical specimens are shown, with the control specimens on the left and increasing in alloy content on moving to the right.

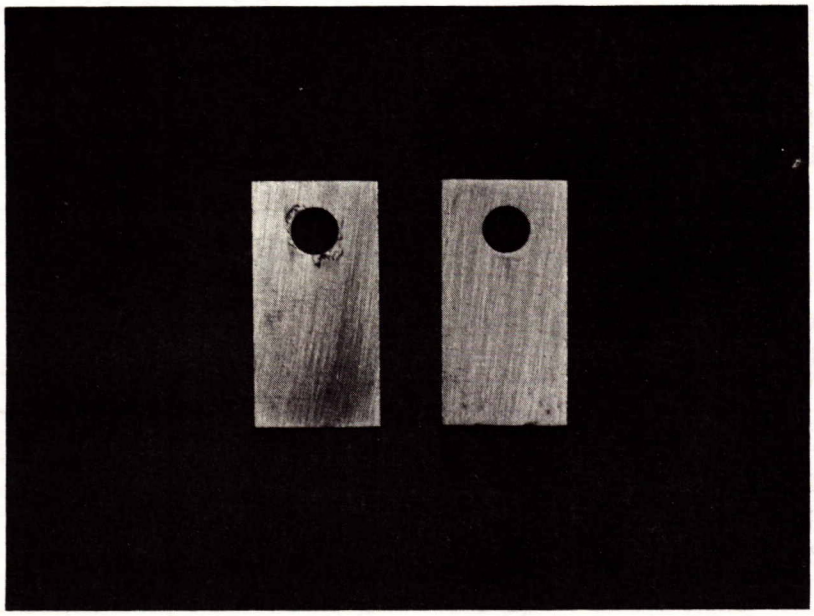


Figure 5. Two specimens of AISI 304 stainless steel exposed for 8 hours to the dip-and-dry test for comparison with Type 430 stainless steel samples.

TABLE 2

Weight Loss after the 8-Hour Test (Tests 1-4)

Steel	% Alloy Addition	Weight Loss (mg/cm^2)				
		Test 1	Test 2	Test 3	Test 4	Average
A	-	0.31	0.39	0.35	0.36	0.35
B	0.70 Mo	.37	.19	.40	.26	.31
C	1.48	.02	.05	.02	.02	.03
D	3.11	+ .01	.00	.01	.03	.01
I	-	0.46	0.42	0.27	0.41	0.39
J	0.67 V	.46	.41	.38	.43	.42
K	1.13	.44	.42	.36	.47	.42
L	2.18	.40	.37	.24	.38	.36
M	-	0.43	0.34	0.35	0.41	0.38
N	0.47 W	.44	.36	.31	.38	.37
O	0.94	.27	.29	.24	.38	.30
P	2.30	.29	.31	.31	.32	.31
Q	-	0.44	0.43	0.40	0.55	0.46
R	0.41 Ta	.39	.37	.30	.36	.36
S	0.72	.45	.37	.40	.39	.40
T	1.37	.38	.35	.28	.40	.35
U	0.39 Si	0.38	0.35	0.45	0.47	0.41
V	0.84	.26	.36	.43	.44	.37
W	1.33	.30	.37	.36	.37	.35
X	1.78	.26	.30	.28	.31	.29

TABLE 3

Sample Appearance and pH of Solution after Test (Tests 1-4)

(Appearance rated from 0, perfect (no corrosion), to 9, severe pitting corrosion. Starting pH, 9.30.)

Steel	% Alloy Addition	pH					Appearance of Test Samples				
		Test No.				Aver.	Test No.				Aver.
		1	2	3	4*		1	2	3	4*	
A	-	8.20	8.70	8.60	7.45	8.1	3	3	3	4	3
B	0.70 Mo	8.00	8.70	8.72	7.35	8.2	5	2	4	2	3
C	1.48	8.30	9.00	9.05	7.75	8.5	1	1	1	1	1
D	3.11	8.20	9.00	9.25	7.70	8.8	1	1	1	1	1
I	-	8.00	7.75	8.60	7.45	8.0	4	3	5	4	4
J	0.67 V	7.90	7.80	8.65	7.40	8.0	3	3	6	5	4
K	1.13	8.0	7.70	8.55	7.45	7.9	5	4	6	5	5
L	2.18	8.1	7.85	8.55	7.45	8.0	5	4	5	4	5
M	-	8.00	8.10	8.65	7.45	8.1	4	3	4	3	4
N	0.47 W	7.90	8.15	8.65	7.40	8.0	5	3	5	4	4
O	0.94	7.90	8.15	8.60	7.40	8.0	4	2	4	3	3
P	2.30	8.00	8.20	8.70	7.45	8.0	2	2	3	2	2
Q	-	8.90	8.20	8.60	7.40	8.3	4	2	2	4	3
R	0.41 Ta	8.80	8.20	8.60	7.40	8.3	3	3	2	3	3
S	0.72	8.80	8.10	8.55	7.40	8.2	4	3	2	3	3
T	1.37	8.70	8.10	8.50	7.40	8.2	3	4	2	3	3
U	0.39 Si	8.70	8.17	8.00	7.80	8.2	4	2	4	4	4
V	0.84	8.60	8.10	7.90	7.80	8.1	4	2	4	3	3
W	1.33	8.60	8.10	8.00	7.85	8.2	4	3	3	2	3
X	1.78	8.80	8.20	7.90	7.85	8.2	4	4	3	1	3

*Taken at room temperature 10 hours after run. Not included in average.

TABLE 4

Collation of Averaged Test Results (Tests 1-4)

Steel	% Alloy Addition	Wt Loss, mg/cm^2	Final pH	Appearance*
A	-	0.35	8.1	3
B	0.70 Mo	.31	8.2	3
C	1.48	.03	8.5	1
D	3.11	.01	8.8	1
I	-	0.39	8.0	4
J	0.67 V	.42	8.0	4
K	1.13	.42	7.9	5
L	2.18	.36	8.0	5
M	-	0.38	8.1	4
N	0.47 W	.37	8.0	4
O	0.94	.30	8.0	3
P	2.30	.31	8.1	2
Q	-	0.46	8.3	3
R	0.41 Ta	.36	8.3	3
S	0.72	.40	8.2	3
T	1.37	.35	8.2	3
U	0.39 Si	0.41	8.2	4
V	0.84	.37	8.1	3
W	1.33	.35	8.2	3
X	1.78	.29	8.2	3

*Appearance - visually rated from 0, perfect, no corrosion, to 9, severe pitting corrosion.

TABLE 5

Weight Loss after the 8-Hour Test (Tests 5-7)

Steel	% Alloy Addition	Weight Loss (mg/cm^2)			
		Test No.			Average
		5	6	7	
7A	-	0.48	0.27	0.39	0.38
7B	0.59 Re	.36	.24	.24	.28
8C	1.15	.42	.18	.33	.31
8D	1.84	.09	.03	.00	.04
9A	-	0.41	0.41	0.18	0.33
9B	0.06 Pd	.36	.24	.14	.25
10C	.10	.41	.41	.27	.36
10D	.26	.94	.23	.27	.48
3B	.46	.42	.28	.31	.34
4C	.99	.42	.24	.31	.32
4D	1.91	.39	.41	.38	.39
5A	-	0.54	0.36	0.42	0.44
5B	0.41 Ge	.39	.30	.39	.36
6C	1.03	.45	.42	.54	.47
6D	2.01	.33	.18	.33	.26
6266	AISI Type 304 Stainless Steel	0.12	0.02	0.04	0.06

TABLE 6

Sample Appearance and pH of Solution After Test (Tests 5-7)

(Appearance rated from 0, perfect (no corrosion), to 9, severe pitting corrosion. Starting pH, 9.30)

Steel	% Alloy Addition	Appearance				pH			
		Test No.			Aver.	Test No.			Aver.
		5	6	7		5	6	7	
7A	-	8.25	8.90	8.30	8.5	4	3	3	3
7B	0.59 Re	8.30	8.85	8.35	8.5	5	3	3	4
8C	1.15	8.25	8.75	8.25	8.4	4	2	3	3
8D	1.84	8.35	8.90	8.35	8.5	1	1	1	1
9A	-	8.25	8.90	8.35	8.5	4	4	3	4
9B	0.06 Pd	8.35	8.85	8.20	8.5	4	3	3	3
10C	0.10	8.45	8.85	8.35	8.5	4	4	3	4
10D	0.26	8.45	8.95	8.20	8.5	3	3	3	3
3B	0.46	8.35	8.85	8.25	8.5	5	3	4	4
4C	0.99	8.30	8.75	8.20	8.4	5	4	4	4
4D	1.91	8.25	8.80	8.20	8.4	3	4	4	4
5A	-	8.20	8.80	8.30	8.4	6	3	2	4
5B	0.41 Ge	8.20	8.70	8.20	8.4	4	3	3	3
6C	1.03	8.20	8.60	8.20	8.3	3	3	3	3
6D	2.01	8.20	8.60	8.20	8.4	3	2	2	2
6266	AISI Type 304 Stainless Steel	8.80	8.70	8.70	8.7	1	1	1	1

TABLE 7

Collation of Averaged Test Results (Tests 5-7)

Steel	% Alloy Addition	Wt Loss, mg/cm^2	Final pH	Appearance*
7A	-	0.38	8.5	3
7B	0.59 Re	.28	8.5	4
8C	1.15	.31	8.4	3
8D	1.84	.04	8.5	1
9A	-	0.33	8.5	4
9B	0.06 Pd	.25	8.5	3
10C	0.10	.36	8.5	4
10D	0.26	.48	8.5	3
3B	0.46	.34	8.5	4
4C	0.99	.32	8.4	4
4D	1.91	.39	8.4	4
5A	-	0.44	8.4	4
5B	0.41 Ge	.36	8.4	3
6C	1.03	.47	8.3	3
6D	2.01	.26	8.4	2
6266	AISI Type 304 stainless steel	0.06	8.7	1

*Appearance visually rated from 0 for perfect, no corrosion, to 9 for severe pitting corrosion.

OBSERVATIONS AND REMARKS

The scatter in the observations, as frequently occurs in corrosion data, prompts the averaging of the results in order to establish more meaningful data and observe the trends in corrosion resistance with increasing alloy addition.

Figure 6 is a plot of the averaged weighted loss in mg/cm^2 against the amount of alloying element added to the basic AISI Type 430 steel. The elements, palladium, vanadium and tungsten are not plotted. The two former did not produce readily interpretable curves; the latter, although indicating lower corrosion rates with increasing tungsten content, did not fit well and tended to confuse the other data.

Two elements, molybdenum and rhenium, are shown to produce a major improvement in the corrosion properties of this steel.

Effects of Molybdenum

Molybdenum is well known[3,6,7] for its improvement of AISI Type 430 stainless, and is the basis for AISI Type 434, a 1% Mo steel of superior corrosion resistance[4]. The present results indicate that, in the amount of 1.48 to 3.11% Mo, an alloy is produced that has a very low corrosion rate and a nearly perfect appearance.

Effect of Rhenium

The addition of 1.84% rhenium also produces a steel of similarly improved properties, and which, in these tests, more than equal the corrosion resistance of austenitic 304 stainless.

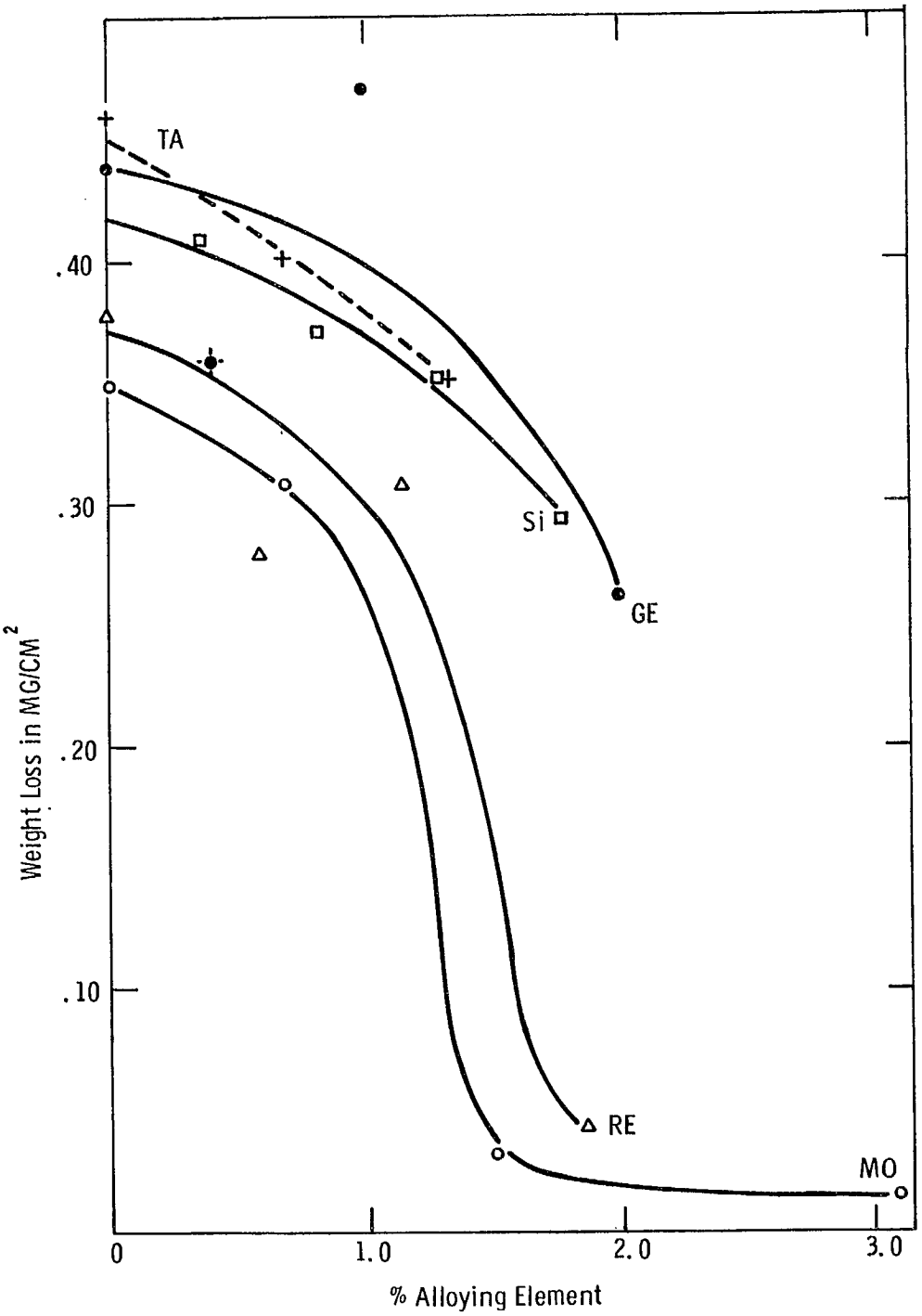


Figure 6. The effect of alloying elements on the corrosion of AISI 430 stainless steel after 8 hours' exposure in the dip-and-dry test. The points represent the averaged values found after quadruplicate or triplicate testing.

Effect of Vanadium

Vanadium additions to the Type 430 steel produced no improvement in appearance, nor consistent change in weight loss, with increasing alloy content.

Effect of Tungsten

Tungsten additions produced a small consistent improvement in the corrosion resistance of this steel, as well as a consistent improvement in appearance.

Effect of Tantalum

Additions of tantalum, although only alloyed up to 1.37%, showed a definite trend towards lower weight loss with increased alloy content; however, no improvement in appearance was observed.

Effect of Silicon

Silicon, of which the 430 alloy normally contains about 0.40%, increases the corrosion resistance of the alloy, as shown by the decrease in weight loss with increasing alloy content. In some instances, the appearance is also benefited.

Effect of Palladium

The effect of palladium was tested over a series of seven compositions, but the results are inconclusive and show no consistent trend. It is concluded that palladium does not benefit this steel in this type of corrosive environment.

Effect of Germanium

Germanium additions produce alloys that are not completely consistent in their effect; however, they indicate a trend to improved corrosion resistance as well as to improved appearance with increasing Ge content.

SUMMARY AND CONCLUSIONS

Additions of molybdenum and rhenium to AISI Type 430 stainless steel are shown to produce major beneficiation to the corrosion properties of their alloys in dip-and-dry accelerated-corrosion tests that simulate the severe service condition encountered by automobiles on salted highways. This observation is further substantiated by the results of Biefer[1] who has shown that these two alloys alone amongst the eight tested showed improved corrosion resistance in a severe oxidation test in normal ferric chloride.

Molybdenum produces a dramatic improvement in reducing corrosion and improving appearance when alloyed between 0.70 and 1.48%; moreover, the improvement is maintained up to 3.1%. The results indicate that a very corrosion-resistant alloy would contain about 1.5% Mo. The commercially available AISI Type 434 steel containing 1% Mo is used for car trim[4] and has been shown to have improved corrosion resistance. Further investigation might be warranted to determine whether this alloy might not be considerably improved by increasing the molybdenum content to 1.5%.

The addition of rhenium also produces an alloy of superior corrosion resistance; however, because 1.8% of this very expensive metal is required in the improved alloy, it would not appear to be practical.

The possibility that a synergistic effect might exist between molybdenum and rhenium in an AISI 430 steel should be considered. The combined effect of smaller quantities of each of these metals might produce

alloys with superior corrosion properties and within economic reason.

Silicon, tantalum and germanium each improve the dip-and-dry corrosion resistance of their alloys progressively up to 2% alloy addition, the upper limit of the range tested for these additions. The slopes of their corrosion curves indicate that the limit of this improvement had not been reached for any of these elements, and that increased amounts of addition might substantially improve their corrosion properties.

Tungsten produced some improvement in dip-and-dry corrosion resistance, but the improvement was mainly visual. Increasing the tungsten above the tested level would not be expected to significantly improve the corrosion resistance.

Additions of vanadium or palladium to the steel did not produce alloys that yielded a consistent trend. Neither of these elements appears to improve the corrosion resistance. Nor was the passivation of the palladium alloy, reported by Biefer[1] when using a normal sulphuric acid medium, observed in this test work.

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APPENDIX I - Procedure for Dip-and-Dry Accelerated Corrosion-Resistance Test

Object

To evaluate, by an accelerated test, the corrosion resistance of stainless steels, particularly to highway conditions where salt, slag, and calcium chloride are used for de-icing.

Method

- (This method is based on a test procedure reported by General Motors Corporation[2].)

- Samples are lowered into individual beakers of test solution and then raised into the air to drip and partially dry off before re-dipping. The results are observed as the weight loss of the sample, sample appearance as tested and after rust removal, and the final pH of the test solution.

Test Solution

This solution should be made up from C. P. chemicals weighed out to ±1 milligram and not stored more than 48 hours. The pH must be checked before using.

Chemical Composition:

1.	Sodium sulphate	-	Na_2SO_4 anhydrous	2.5 g
2.	Sodium sulphite	-	Na_2SO_3 anhydrous	1.25 g
3.	Sodium thiosulphate	-	$Na_2S_2O_3 \cdot 5H_2O$	1.20 g
4.	Sodium chloride	-	NaCl	262.5 g
5.	Calcium chloride	-	$CaCl_2$ anhydrous	149.0 g

6. Distilled water to make 5250 ml.

Adjust the pH of the solution to 9.3 ±0.05 with very dilute solutions of NaOH or HCl.

Prepackaging

It has been found that prepackaging of some of the chemicals speeds up and facilitates the preparation of this test solution.

The first four chemicals listed above are weighed out and stored dry in tightly capped polyethylene bottles. The chemicals should be mixed as little as possible and the NaCl added last over the others.

When the test solution is required, the stored chemicals are dissolved in 3500 cc of distilled water. The $CaCl_2$ is weighed out and dissolved in 1500 cc of water. When all the salts are completely dissolved, the two solutions are mixed.

A slight whitish precipitate sometimes occurs on mixing; this can be ignored and need not be filtered off. Correct the pH, bring the volume to 5250 cc, and use within 48 hours.

Testing Machine

The dip-and-dry testing machine (See Figure 7) consists of two horizontal decks held about 18 inches apart by corner posts. A mobile open frame moves vertically between the decks. The top deck supports motor and equipment for moving the frame, and also two heat lamps used to dry the specimens while in air. The bottom plate supports as many as 16 beakers of 400 cc each containing 325 cc of test solution.

Samples are suspended by teflon ribbon from the mobile frame above the beakers. The samples must be mounted at the same height; otherwise, dipping times will not be uniform.

The cycle of the frame's vertical movement is controlled by an adjustable timer which controls the hold time in the raised position, the dip and lift times being invariable. It should be noted, however, that sample size, volume of test solution, and position of beakers relative to the sample, can all vary the dip period.

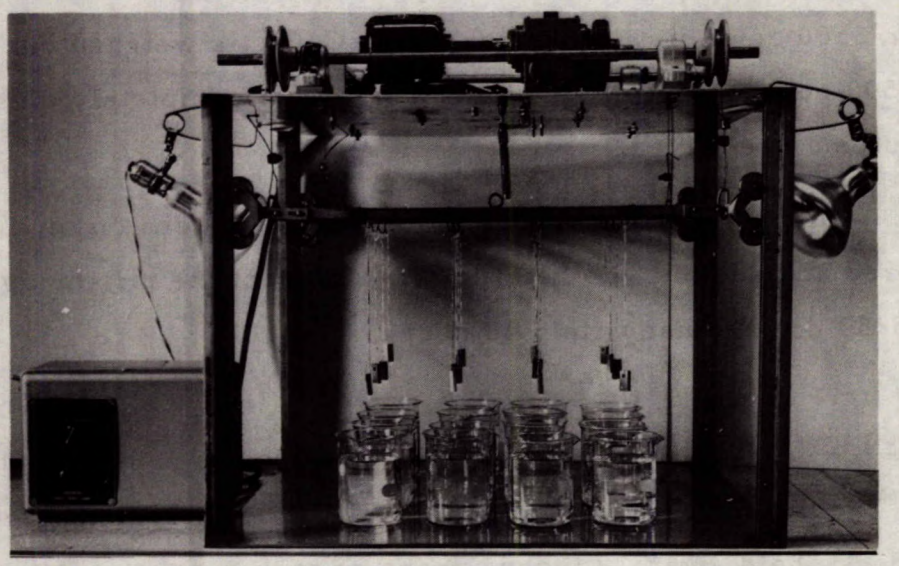

Figure 7. The dip-and-dry corrosion testing machine, with small samples suspended from the movable rack with teflon string. The temperature of the test solution in the beakers is equalized with aluminized cardboard insulation about the beakers, which is not shown.

The cycle time for the test is determined by the sum of dip time and the air-dry time. The cycle is nominally 100 seconds, of which 12 is dip and 88 air-dry time. It should be noted that the sample surface may not be completely dry at the end of the cycle and the re-immersion of the sample.

The temperature of the solution in the beakers rises during a test. The final temperature is held at 33°C ±3 by using an aluminum-coated cardboard insulation wrapped around the sides of the beakers, in the following position pattern:

	Y	X	O	O	
	X	O	O	O	Heat lamp
Heat lamp	O	O	O	X	
	O	O	X	Y	

O - fully wrapped with insulation
X - bottom half only with insulation
Y - no insulation used

Sample Preparation

Samples are nominally 2 x 2 in. steel sheets, or plates, with a 3/16-in. hole near top centre for suspension. However, the sample size may vary considerably, due to amount or shape of material available. Such variation can affect the results, particularly the significance of the final pH, and should be avoided.

Samples are ground on 120 silicon-carbide grit paper on all surfaces, degreased ultrasonically in fresh carbon tetrachloride, weighed, inspected for any flaws or scratches, and the observations recorded.

Samples are individually strung by teflon ribbon at a uniform height from the movable rack of the dip-and-dry tester.

Observations and Results

On completion of the test period, the rack is stopped in the raised position. The samples are rinsed thoroughly with clean water, sprayed with alcohol, and allowed to dry off under the heat lamps.

The individual pH of each test solution is immediately measured and recorded on completion of the test. (Note: Tube-type pH meters require at least 1/2 hour warm-up, to stabilize prior to use.)

Typical values observed for 2 x 2 in. specimens:

Badly corroded Type 430 - pH 7.50 - solution reddish

Slight corrosion Type 304 - pH 8.65 - solution clear

The corroded specimens are photographed and examined for rust, pits and tarnish.

To measure the weight loss, the samples are de-rusted in inhibited acid solution (see Appendix 2), water-washed, alcohol sprayed, and dried in warm air. When cooled the samples are weighed and the weight loss is calculated in grams/cm^2.

The pit concentration per square centimetre can be most readily found by using a clear plastic grid marked off in millimetres as an overlay on the de-rusted specimen, and counting the pits in each square millimetre. Systems have been designed to compensate for the variations in the pit area to develop a more significant corrosion number[9].

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(9) J. Nasea Jr., B. E. Tiffany and G. F. Bush - "Research Method of Rating Corrosion of Automobile Exterior Trim", Plating 49, 989 (Sept. 1962).

APPENDIX 2 - Solution for De-rusting Stainless Steel

Thiourea	0.1 g
H_2SO_4 (96%)	30 cc
H_2O	170 ml

Use at 75°C ±5.

This solution has been found to have caused little to no weight loss in most stainless steels when used with care. In the event of breakdown of the inhibiting film, the specimen must be rapidly withdrawn and thoroughly rinsed in fresh water.

After cleaning, samples should be thoroughly washed in both still and running water, sprayed with alcohol, and dried with a hair dryer or low-temperature oven.

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