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COMPARISON OF THE CORROSION RATE OF FeAl, Fe_3Al AND STEEL IN DISTILLED WATER AND 0.5 M SODIUM CHLORIDE

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Abstract

The corrosion rate of an Fe_3Al alloy (FA117) and an FeAl (FA362) alloy in distilled water and 0.5 M NaCl was determined and compared to two low carbon steels. The results demonstrate that the corrosion rate of these two intermetallic compounds were more than an order of magnitude less than that of the two steels in both of the environments. The corrosion rates of the two iron aluminides were not significantly different.

Introduction

Iron aluminide alloys are being developed for a variety of different applications. Because these alloys may prove to be more corrosion resistant than plain carbon steels and less costly than stainless steels, experiments are being conducted on the corrosion, electrochemical and stress-corrosion cracking behavior of these alloys. This work will enable the identification of potential applications and contribute to the development of more corrosion resistant alloys. Initially, it was decided that simple exposure tests with weight loss measurements would enable the evaluation of the relative corrosion behavior of iron aluminide alloys. As a result, an Fe_3Al alloy and a 1020 steel were exposed to distilled water and a sodium chloride solution for 50 days with the samples weighed approximately every 10 days. The results of these measurements were previously reported but will be included here for throughness[1]. Because the corrosion rate of the Fe_3Al alloy was dramatically less that that of the carbon steel, it was decided to run similar experiments on an FeAl alloy and compare the results of these experiments to the results of the earlier experiments.

Experimental

Fe_3Al (FA117) and 1020 Steel

Samples were cut from a 0.8 mm thick sheet of Fe_3Al alloy and from a sheet of 1020 steel. The iron aluminide alloy was provided by Oak Ridge National Laboratory and the composition of this alloy is given in Table I. The 1020 steel was standard commercial stock. The samples were ground to a 600 grit finish and ultrasonically cleaned in distilled water and acetone. Each sample was weighed before commencing and exposure tests and at the end of each exposure interval. Each sample was placed into a 15 mm diameter test tube containing ≈10 ml of either double distilled water or 0.5 M NaCl. The samples were removed for weighing and the solutions were replaced at 10 day intervals. The test tubes were partially open to the air and stirred daily so that the solutions would be thoroughly aerated.

FeAl (FA362) and 1017 Steel

Samples were cut from a 0.8 mm thick sheet of the FeAl alloy and from a sheet of 1017 steel. The FeAl alloy, FA362, was provided by Oak Ridge National Laboratory and the composition of this alloy is given in Table I. The 1017 steel was standard commercial stock. The samples were ground to a 600 grit finish and ultrasonically cleaned in distilled water and acetone. Each sample was weighed before commencing and exposure tests and at the end of each exposure interval. Each sample was placed into a 20 mm diameter test tube containing ≈35 ml of either double distilled water or 0.5 M NaCl. The samples were removed for weighing and the solutions were replaced at 10 day intervals. The test tubes were covered with a parafin film and the solutions were in contact with the air in the test tubes above the solution level. Therefore, the solutions contained dissolved oxygen and should be considered aerated. For these experiments, the solutions were not agitated daily.

Results and Discussion

Within the first hour of immersion, the solutions in the test tubes containing the steel samples began to turn orange and in time orange precipitates formed which covered the steel samples. However, the solution in the test tubes containing the iron aluminide samples remained clear and there was no visual evidence of attack. After removal and ultrasonic cleaning of the samples, the surface of the 1020 steel samples were covered with black deposits which were only partially removed by ultrasonic cleaning and rubbing with a cotton swab. On the other hand, the samples of the Fe_3Al alloy were bright and shiny with the scratches from the sample preparation process still evident. Some discoloration of the FeAl alloy was noted. The surfaces of the iron aluminide samples were examined with a light microscope and no evidence of localized attack or pitting was found.

The results of the weight loss measurements corroborate the visual observations. In figure 1, the results of the experiments on the Fe_3Al alloy and on the 1020 steel are shown. In this figure, it can be seen that significant decreases in weight with exposure time were observed for the steel samples in both solutions while only a slight decrease in weight was observed for the Fe_3Al samples in the same solutions. For the 1020 steel, the rate of weight loss was significantly greater in sodium chloride than in distilled water. However, only a slight difference was observed between the corrosion rates of the Fe_3Al alloy in these solutions. In figure 2, the results of the experiments on the FeAl alloy and on the 1017 steel are presented. While these experiments were conducted over a longer time period, the results are essentially identical to those for the Fe_3Al alloy and the 1020 steel.

The corrosion behavior of each alloy in each environment was analyzed by linear regression of the sample weight changes on the exposure times. The results of this analysis are given in table II and the regression lines are shown in figures 1 and 2[2]. If the corrosion rate of an alloy in an environment is constant with respect to time, then the slopes of the regression line through the weight loss measurements will be an estimate of the actual corrosion rate for the alloy in that environment. However, it is unlikely that the corrosion rate is constant and instead it will vary with the amount of oxygen available and the coverage of the surface with corrosion products. These variations and the statistical measurement errors will cause scatter in the weight loss measurements. This scatter will result in a level of uncertainty for the value determined for the corrosion rate. For these results, this uncertainty is quantified by determining the 90% confidence interval for each corrosion rate estimate using Student's t-distribution[2]. The value for the estimated corrosion rate calculated for each alloy and environment and the 90% confidence interval range are given in table II.

The magnitudes of the corrosion rates determined for the Fe_3Al alloy in distilled water and in sodium chloride are small compared to the range of the confidence interval and the corrosion rate of zero lies within the confidence limits. As a result, it is not possible to be certain (at this confidence level) that the observed corrosion rates are not due to statistical measurement errors and that the true corrosion rate is zero. For the FeAl alloy, the greater number of measurements and the longer time duration reduced the size of the confidence interval but, a zero corrosion rate is still within the confidence interval for distilled water. The corrosion rate determined for the 1017 steel was greater than that for the 1020 steel in sodium chloride and less in distilled water. However, these differences are not great compared to the measurement scatter as indicated by the confidence interval. Similarly, the corrosion rate determined for the FeAl alloy was greater in sodium chloride and less in distilled water then those determined for Fe_3Al but, these differences were not great as compared to the confidence intervals. On the other hand, if the corrosion rates of the iron aluminide alloys are compared to the rates determined for the steels in the same environments, all of the differences are more than an order of magnitude. As a result, it is concluded the corrosion rate of both of the iron alumnide alloys are significantly less than that of steel alloys in the solution examined.

Conclusions

The corrosion rates of Fe_3Al and FeAl in aerated distilled water and aerated 0.5 M sodium chloride are significantly less than those of 1020 and 1017 steel in the same solutions. As a result, it is concluded that iron aluminide is a promising corrosion resistant alloy but, that additional evaluation of the pitting corrosion, crevice corrosion and stress corrosion cracking behavior will be required before conclusions as to the applicability of this material in a given environment can be reached.

Acknowledgement

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References

1. R. E. Ricker, "Corrosion Rate of Iron Aluminide in Distilled Water and 0.5 M Sodium Chloride as Compared to 1020 Steel," Report to Oak Ridge National Laboratory, Oct. 20, 1988, National Intsitute of Standards and Technology, Gaithersburg, MD.

2. R. E. Walpole and R. H. Myers, Probability and Statistics for Engineers and Scientists, The Macmillan Co., NY, 1972, pp. 279-299.

Table I - Composition of the iron aluminide alloys

Element	FA-117 (D03-Fe_3Al)		FA-362 (B2-FeAl)	
	Wt %	At %	Wt %	At %
Fe	79.38	68.57	78.25	63.79
Al	15.67	28.00	21.16	35.70
Cr	2.16	2.00	-	-
Mo	0.99	0.050	0.42	0.20
Nb	1.54	0.80	-	-
Zr	0.19	0.10	0.11	0.05
B	0.011	0.05	0.06	0.25
Y	0.055	0.03	-	-

Table II - Sample information and regression results

	Sample A	Sample B	Sample C	Sample D
Material	FA 117	FA 117	1020	1020
Test Environment	NaCl	Water	NaCl	Water
Exposed Area (m^2)	1.641 E-4	1.661 E-4	2.101 E-4	2.155 E-4
Initial Weight (g)	0.2734	0.2877	0.5631	0.5763
Regression slope	-0.0491	-0.0271	-1.504	-0.7473
Correlation Coef.	-0.337	-0.116	-0.997	-0.942
Est. Corr. Rate ($g \cdot m^{-2} \cdot d^{-1}$)	0.0491	0.0271	1.504	0.7473
90% Conf. Range	±0.146	±0.200	±0.136	±0.287

	Sample E	Sample F	Sample G	Sample H
Material	FA 362	FA 362	1017	1017
Test Environment	NaCl	Water	NaCl	Water
Exposed Area (m^2)	1.6 E-4	1.4 E-4	1.5 E-4	1.6 E-4
Initial Weight (g)	0.3904	0.3334	0.2753	0.2878
Regression slope	-0.0804	-0.0018	-1.5819	-0.6380
Correlation Coef.	-0.7889	-0.1581	-0.9984	-0.9880
Est. Corr. Rate ($g \cdot m^{-2} \cdot d^{-1}$)	0.0804	0.0018	1.5819	0.6380
90% Conf. Range	±0.0284	±0.0051	±0.0409	±0.0452

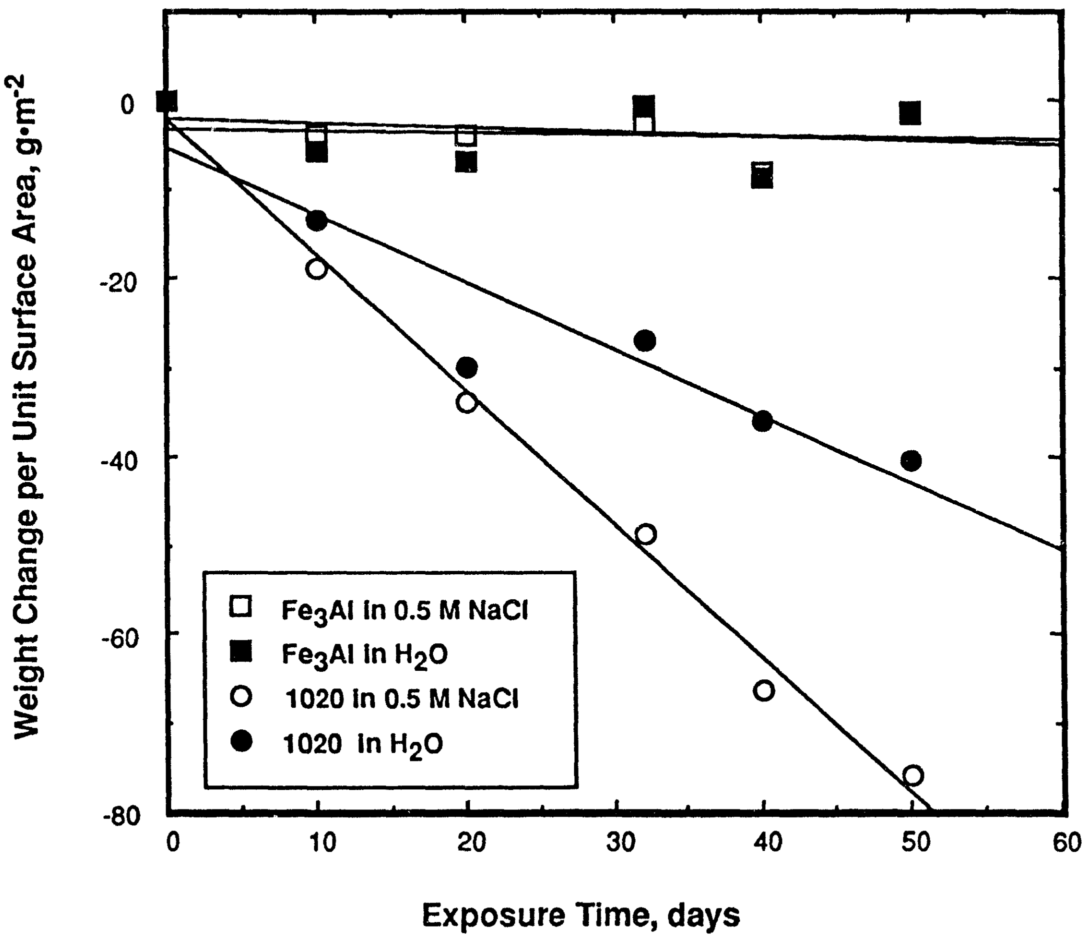
Weight Change per Unit Surface Area, g•m-2
0
-20
-40
-60
-80
0
10
20
30
40
50
60
Exposure Time, days
Fe3Al in 0.5 M NaCl
Fe3Al in H2O
1020 in 0.5 M NaCl
1020 in H2O

Fig 1

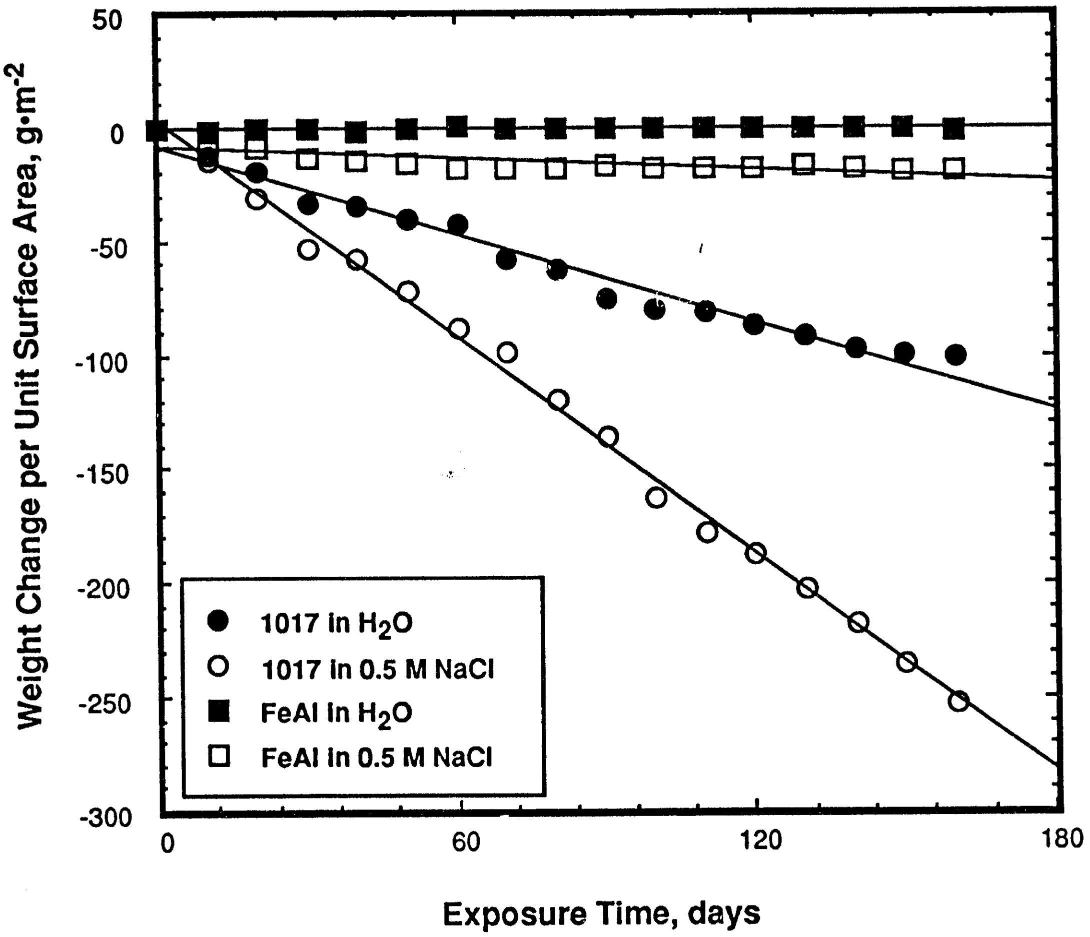
50
0
-50
-100
-150
-200
-250
-300
Weight Change per Unit Surface Area, g•m-2
0
60
120
180
Exposure Time, days
1017 in H2O
1017 in 0.5 M NaCl
FeAl in H2O
FeAl in 0.5 M NaCl

Fig 2

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