EFFECT OF SELECTED FACTORS ON STRESS CORROSION CRACKING OF THE AlZn5Mg1 ALLOY

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The susceptibility to stress corrosion cracking of the AlZn5Mg1 alloy of different tempers has been investigated. Constant load and slow strain rate tests were applied. Tests were conducted in NaCl solution with addition of HCl and As_2O_3. The influence of various testing conditions on plasticity loss of specimens was evaluated. The hydrogen effects on stress corrosion cracking were confirmed. The plasticity loss of specimens tested in acid solutions was related with the strong layer corrosion. Tests showed that underaged alloy exposure in acidic solution with As_2O_3 addition was the most susceptible to stress corrosion cracking. Better resistance to stress corrosion cracking of overaged alloy is likely related with anodic protection of grain boundaries by intermetallic precipitates.

INTRODUCTION

Stress corrosion cracking (SCC) of the AlZnMg alloys has a very complex behaviour. The incubation of cracks is associated with local damage of an oxide layer by chloride ions. The crack propagation can be explained by a number of models. The first one, accepted in the past, has assumed that the cracking is due to a preferential corrosion along the grain boundaries that causes dissolution of Al matrix or intermetallic phases (anodic dissolution model), Jones (1), Chene at al (2). The second one, at present generally accepted, postulates that atomic hydrogen is adsorbed onto crack walls or absorbed within a crack tip and then it diffuses into regions of high stresses; either Hydrogen Enhanced Localised Plasticity or Hydrogen Enhanced Decohesion have been proposed to explain the crack propagation, Lynch (3), Gerberich et al (4).

Factors affecting crack propagation may be metallurgical, mechanical or environmental. Metallurgical factors influence on microstructure of an alloy and then on susceptibility to SCC. Ageing condition is believed to be the most important

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parameter. Solution heat treated alloys are immune to SCC as long as grain boundary precipitation do not occur. The volume and distribution of grain boundary precipitates control to some extent susceptibility AlZnMg alloys to SCC, Burleigh (5), Poulouse et al (6).

The importance of environmental factors is a little controversial. The presence of chlorides is thought to be essential for crack initiation but not for its propagation. As regards the solution pH, its effect may be expected at low values, although in some reports such relation was denied for the pH values between 0 and 11, Holroyd (7).

The strain rate remarkably influences mechanical properties of tested alloys in aggressive environments. The number of research works showed that at the strain rate between 10^{-5} to 10^{-7} s^{-1} the maximum susceptibility to SCC was reached, Holroyd (8).

In this work the influence of selected factors on stress corrosion cracking of the AlZn5Mg1 alloy was examined. Some suggestions concerning the possible mechanisms of failure were proposed.

EXPERIMENTAL PROCEDURE

The plate of 12 mm in thickness of AlZn5Mg1 alloy was tested. The chemical composition of the alloy is shown in the table 1.

TABLE 1 - Chemical composition of the tested alloy.

Element content, wt. %							
Zn	Mg	Cu	Mn	Si	Fe	Ti	Zr
4,30	1,26	0,10	0,22	0,17	0,30	0,02	0,12

Two different heat treatment conditions (tempers) were studied:

ta - (equivalent to T4) - solution heat treated at 430°C for 45 min., then cooled in the air and next aged at ambient temperature for at least 100 days,

tb - (equivalent to T6) - solution heat treated at 430°C for 45 min., then quenched in water, next aged at 20°C for 6 days, 90°C for 8 h, and at 145°C for 16 h.

Susceptibility to stress corrosion cracking was examined by the constant load technique and slow strain rate tests (SSRT). In constant load tests load equal to 0.9 proof stress was applied and exposure time of 2500 h. For no-failed specimens tensile tests in air were made. Then the values of reduction in area were measured.

The slow strain rate tests were performed with use 10^{-5}, 10^{-6}, 10^{-7} s^{-1} strain rates. Values of absolute fracture energy and time to failure were measured.

The following test solutions were applied:

- 3,5% NaCl solution,
- 3,5% NaCl solution with an addition of HCl (pH=1),
- 3,5% NaCl solution with an addition of HCl (pH=1) and 250 g/l of As_2O_3.

RESULTS

The tests results are shown in table 2 and table 3. In order to estimate the loss of plasticity with reference to an inert environment, relative reduction in area RA_{rel} and relative energy of fracture E_{rel} were calculated.

TABLE 2 - Time to failure and loss of plasticity for the AlZn5Mg1 alloy tested in various corrosive solutions in constant load tests (mean values).

Test solution	Temper	Time to failure, h	RA_{rel}, %
NaCl	ta	>2500	62.9
NaCl	tb	>2500	86.5
NaCl + HCl	ta	180	39.0
NaCl + HCl	tb	>2500	52.5
NaCl + HCl + As_2O_3	ta	176	29.4
NaCl + HCl + As_2O_3	tb	>2500	61.0

TABLE 3 - Time to failure and relative fracture energy for the AlZn5Mg1 alloy tested in various corrosive solutions in SSR tests (mean values).

Strain rate⇒	10^{-5} s^{-1}		10^{-6} s^{-1}		10^{-7} s^{-1}	
Solution	E_{rel} %	Time to failure, h	E_{rel} %	Time to failure, h	E_{rel} %	Time to failure, h
			ta temper			
NaCl	86.1	3.43	102.0	38.76	43.6	199.02
NaCl + HCl	76.1	3.03	36.3	18.36	16.8	101.68
NaCl + HCl + As_2O_3	48.9	2.17	60.2	26.62	8.5	86.66
			tb temper			
NaCl	95.5	2.36	94.0	24.08	50.7	28.98
NaCl + HCl	99.7	2.28	91.5	22.48	64.7	35.28
NaCl + HCl + As_2O_3	89.5	2.19	83.7	20.76	54.6	30.38

DISCUSSION

The solution composition strongly affects SCC susceptibility of tested alloy. As it is shown in the Fig.1, the addition of acid to neutral NaCl solution generally results in decreasing relative plasticity P_{rel}. The overaged alloy is far more resistant to acidic solution than the underaged alloy. The optical and electron scanning microscopy examinations of surface and cross-section revealed the strong layer corrosion without evidence of pits. Tendency to layer corrosion may affect SCC in two ways: primarily it makes the grain boundary area weaker and more susceptible to stress;

secondly, the rapid localised corrosion is associated with remarkable evolution of hydrogen in the grain boundary area which can penetrate the metal and cause hydrogen-related failure. Such mechanism may be responsible for the observed negative effect of HCl presence on plasticity of the alloy. The effect of HCl addition on plasticity of examined alloy is weaker in slow strain rate tests than in constant load tests. This effect may be attributed to the much longer exposure during constant load testing and then greater contribution of corrosion process.

The addition of As_2O_3 to NaCl + HCl solution usually resulted in decreasing of plasticity of the alloy for both tempers in both applied experimental techniques. The appearance of generally negative effect of arsenic addition on the plasticity may be explained by retarding the hydrogen recombination onto the surface of the alloy, including crack walls. This process promotes hydrogen entry into a metal where it may diffuse to the crack area and cause crack advancement. These effects give a reliable experimental evidence to support the hypothesis about contribution of hydrogen to plasticity loss and hydrogen-related stress corrosion cracking, Bond et al (9).

The obtain results show that applied heat treatment has a very strong effect on susceptibility to stress corrosion cracking of tested alloy. Almost always in applied tests the loss of plasticity was lower for the tb temper than for the ta temper. The different ageing conditions gave different microstructures, which were detected in TEM examinations. For natural aged alloy neither GP zones nor coherent grain boundaries precipitates were observed. For overaged alloy the very fine intermetallic precipitates of below 1 μm were found. In comparison, the grain boundary precipitates in some AlZnMgCu alloys were of size 40 to 250 μm, depending on ageing parameters.

According to some stress corrosion cracking mechanisms the positive effect of appearance of large precipitates which trap hydrogen entering the metal may be expected. Such trapping should lead to the decreasing concentration of interstitial hydrogen which is responsible for the crack propagation. It is however doubtful, whether small precipitates observed in tb alloy can cause such significant redistribution. According to other SCC hypothesis, appearance of intermetallic precipitates electrochemically protects the grain boundary area. The change of electrochemical behaviour is, in view of these results, a very important factor. Appearance of precipitates in tb alloy caused that grain boundaries were no longer preferred corrosion paths. The tendency to layer (intercrystalline) corrosion decreased, and simultaneously the amount of interstitial hydrogen decreased.

Slow strain rate tests showed that with decreasing strain rate the plasticity of tested alloy also decreased. The highest susceptibility to SCC was observed at strain rate 10^{-7} s^{-1}. This is evidence of contribution of corrosion to the cracking process.

CONCLUSIONS

- Addition of HCl to NaCl neutral solution decreases mechanical properties of tested alloy due to layer corrosion appearance.
- Addition of small amounts of As_2O_3 to the NaCl + HCl acidic solution increases SCC susceptibility of tested alloy through the promotion hydrogen entry into a metal.
- The effects of solution composition depend on alloy microstructure: the overaged alloy was more resistant to stress corrosion cracking than underaged alloy. The different susceptibility to SCC is likely related to anodic protection of grain boundaries by precipitates appearing in overaged alloy.
- Plasticity loss measured in slow strain rate tests was deepest at the lowest strain rate 10^{-7} s^{-1} . This effect may be attributed to the longer corrosion exposure.

SYMBOLS USED

E_{rel} = relative energy of fracture calculated as a ratio of the fracture energy tensed in any test solution to fracture energy in dry air (%)

P_{rel} = relative plasticity expressed as a ratio of value of either RA or E measured in stress corrosion test to the corresponding values measured for no-exposed alloy in air (%)

RA_{rel} = relative reduction in area calculated as a ratio of reduction in area for stress corrosion specimen to that tested in dry air (%)

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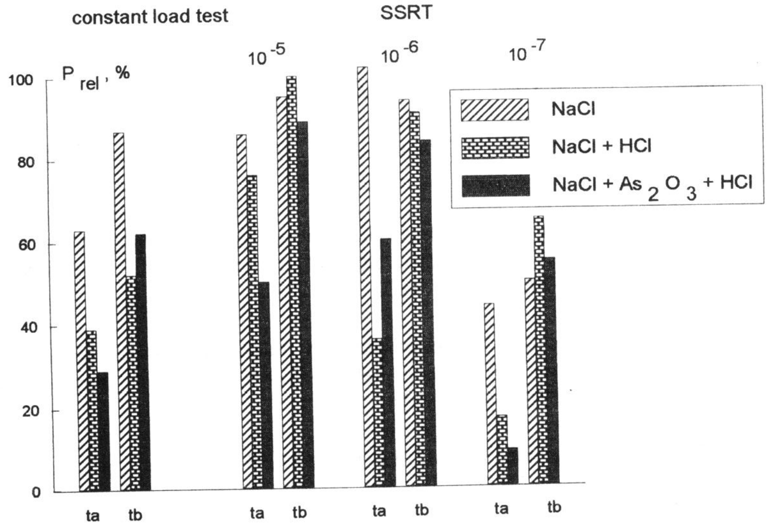

Figure 1. Effect of HCl and As_2O_3 addition to neutral NaCl solution on the relative plasticity of the AlZn5Mg1 alloy