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Experimental Investigations on Corrosion Behaviour of Cast Al-Mg Alloys

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Abstract

5XXX series alloys provide excellent resistance to all forms of corrosion. This accounts for their common use in a variety of applications requiring good corrosion resistance, including building products, chemical processing, and food handling. For a fixed amount of cold work, the mass loss due to corrosion in cast Al-Mg alloys is determined as a function of concentration of magnesium. The mass loss is decreased with increase in magnesium concentration of the alloy. The high-magnesium alloys have greater strength than the low-magnesium alloys, and hence they possess outstanding corrosion resistance. Keeping the magnesium concentration constant, the deformation is varied and the mass loss due to corrosion is determined. With increase in deformation, the mass loss due to corrosion is decreased. In Al-Mg alloys strength is developed mainly through work hardening and to a lesser extent by grain size effects. With increase in plastic deformation, the grain size becomes finer and hence the strength and hardness. The corrosion resistance of the alloy subjected to different heat treatments are also studied.

Keywords: *Corrosion, deformation, composition, ageing*

1. Introduction

Wide research in the field of precipitation hardening performed in the 20th century has defined the level of development of structural aluminum alloys. Aluminum and its alloys were assessed as a possible replacement for steel, due to a high corrosion resistance and a potential of considerable weight saving, as its density is almost three times lower than the density of steel (2.73 g/cm3 for aluminum vs. 7.85 g/cm3 for steel). The ageing behaviour and changes in mechanical properties of Al-Mg alloys have been extensively studied by several investigators and it has been confirmed that the changes were caused mainly by the formation of Guiner-Preston (GP) zones [2]. The hardening accompanying GP zones formation was relatively small compared to the one resulting from β^1 formation which precipitates at temperatures above the reversion temperature of the GP zones [1]. Several investigators have studied the IGC and SCC susceptibility of Al-Mg alloys and the general consensus is that it is caused by preferential precipitation of Mg rich particle, the β phase (Al3Mg2) along the grain boundaries [3]. The susceptibility of Al-Mg alloys to different forms of corrosion (intergranular, stress corrosion and exfoliation) depends not only on the presence of β –phase particles, but mostly on its form and distribution in the structure. Microstructures with continuous layer of β- phase are highly susceptible to corrosion, while randomly distributed β-phase provides high corrosion resistance [4]. Attempts have been made to determine the ageing response of Al-8wt%Mg alloys. The susceptibility to inter granular corrosion of the age hardened samples is also determined using Nitric Acid Mass Loss test.

Several investigators have been reported that magnesium segregation is crucial to cause stress corrosion susceptibility in aluminum alloys. The recent work of Joshi et al [7, 8] made no attempt to discriminate between segregated and precipitated solute at grain boundaries. However, the work of Pow et al. [6], who examined actual intergranular stress corrosion fracture surfaces using a scanning Auger microscope, tended to support the observation of Chen [5] since a significantly increased level of magnesium, particularly near the stress corrosion crack tip, was discerned. Diminishing segregation with increased solution heat treatment temperature has been reported both by Taylor et al. [9] for Al-Zn-Mg alloys and by Scamans et al. [10] for Al-Mg alloys using indirect techniques of anodic replication and reaction with water vapour saturated air respectively.

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2. Experimental

2.1 Specimen preparation

Table 1 The mass loss due to corrosion in 40% deformed Al-Mg alloys as a function of concentration of magnesium

Alloy	Dia (cm)	Height (Cm)	Surface area(cm^2)	Mass loss (Mg)		Mass loss (Mg)	Mass Loss (Mg/Cm2)
				Before acid test	After acid test		
Al-2Mg	1.291	0.6012	5.0575	2184.2	1786.5	397.7	78.65
Al-4Mg	1.3	0.6254	5.2121	2160.1	1824.6	335.5	64.37
Al-6Mg	1.31	0.5998	5.1687	2136.6	1862.5	274.1	53.03
Al-8Mg	1.297	0.6122	5.1404	2114.2	1916.4	197.8	38.48

Cylindrical samples of 10mm x 10mm are prepared from the cast and homogenised ingots of Al-2Mg, Al-4Mg, Al-6Mg and Al-8Mg alloys. All the alloys are given 40% deformation by upsetting. Al-8Mg alloys are given 20%, 30% and 40% deformation by upsetting. Al-8Mg alloys are solutionised at 450^0C for two hours and aged at 200^0C.

2.2 Corrosion testing apparatus

An inert non-metallic container is used to contain the nitric acid and specimens during the test. The specimens are situated in the container in an inclined position so that the edges rest on the bottom and side wall of the container.

2.3 Corrosion testing reagents

The reagent grade HNO_3 with a specific gravity 72 weight % is used for the test solution. The NaOH solution used for etching and HNO_3 used for dismutting are also of reagent grade. Pure water is used for preparing the NaOH solution and for rinsing purposes. The test solution temperature is maintained at $30\pm1\ ^0$C.

2.4 Corrosion testing procedure

The susceptibility to IGC of the Al-Mg samples is determined using Nitric Acid Mass Loss Test. The edges of the samples are cleaned and smoothened with a fine emery paper. The total surface areas of the samples are calculated using $2\pi\ (r^2+rh)$. Where r-radius of the cylindrical sample, h-height of the cylindrical sample. The samples are immersed in 5% NaOH solution at 80^0C for 1min and water rinsed. Then the samples are immersed in reagent grade HNO_3 having specific gravity 72 Wt% for 30 seconds followed by water rinse. The samples are dried and weights are measured. The weighed samples are immersed in a container containing HNO_3 test solution kept at $30\pm1\ ^0$C. The specimens are positioned in an inclined manner so that the edges rest on the bottom and side wall of the container. After 24 hours of immersion the samples are removed from the container and cleaned with water. The loose particles are removed with a soft brush and air dried. The specimens are weighed again and mass losses are calculated. The mass loss per unit area is calculated in Mg/Cm^2 for all the samples.

3. Results and discussion

For a fixed amount of cold work, the mass loss due to corrosion is determined as a function of concentration of magnesium. The mass loss due to corrosion in 40% deformed Al-Mg alloys for a variation in concentration of magnesium is shown in table 1. The corresponding curve showing the mass loss is shown in figure 1. The mass loss is decreased with increase in magnesium concentration of the alloy. In Al-Mg alloys with high magnesium content (>3%Mg) solid solution is supersaturated with magnesium solute atoms, because the magnesium content is higher than 1.9% Mg, which is the equilibrium solubility of magnesium in Al-matrix at room temperature [11]. In that case magnesium solute atoms tend to precipitate out as an equilibrium β-phase (Mg_5Al_8) along the grain boundaries or randomly distributed in the structure. The susceptibility of Al-Mg alloys to different forms of corrosion (intergranular, stress corrosion cracking and exfoliation) depends not only on the presence of β-phase particles, but mostly on its form and distribution in the structure. The high-magnesium alloys have greater strength than the low-magnesium alloys, and they have outstanding corrosion resistance [12]. The results obtained are consistent with this reference.

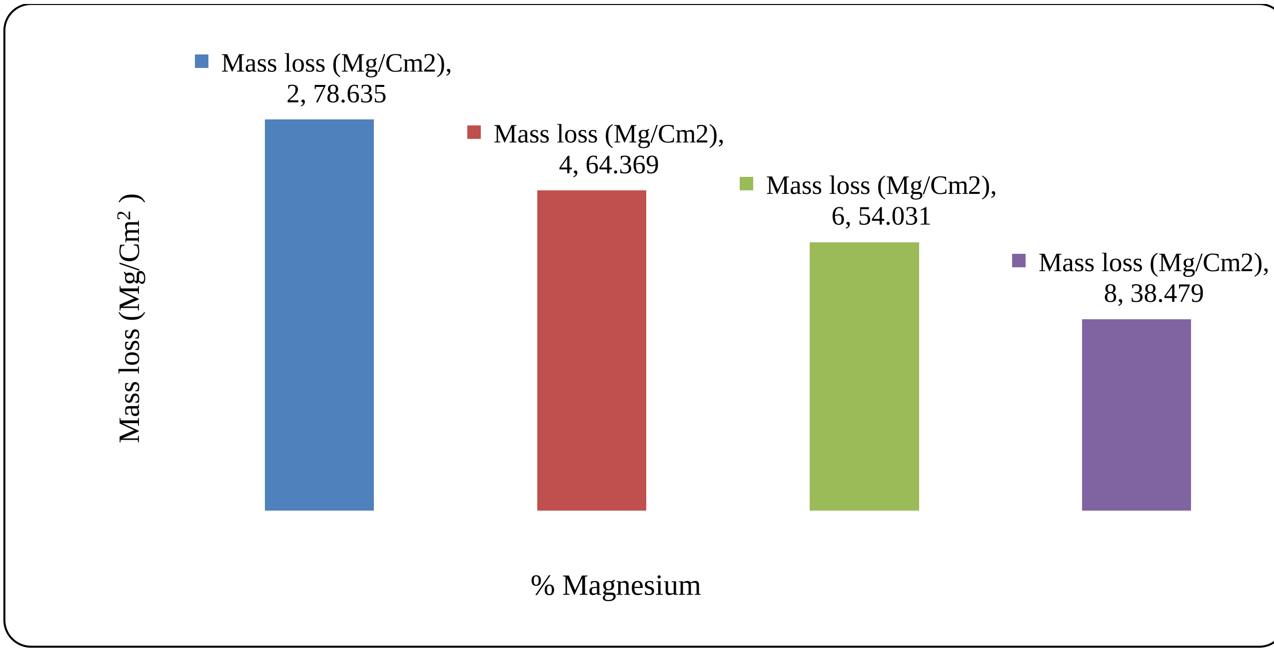

Fig 1 Mass loss due to corrosion in 40% deformed Al-Mg alloys as a function of concentration of Mg in the alloy

Table 2 Mass loss due to corrosion in Al-8Mg alloys as a function of deformation

Deformation	Diameter (Cm)	Height (Cm)	Surface area(cm^2)	Mass loss (Mg)		Mass loss (Mg)	Mass Lossloss (Mg/Cm2)
				Before acid test	After acid test		
20%	1.1178	0.7914	4.7438	2117	1863.2	253.8	53.5
30%	1.195	0.7055	4.8934	2109.4	1892.4	216.6	44.26
40%	1.2972	0.6122	5.1404	2114.2	1916.4	197.8	38.48

Keeping the magnesium concentration constant, the deformation is varied and the mass loss due to corrosion is determined. The mass loss due to corrosion in Al-8Mg alloys as a function of deformation is shown in table 2. The corresponding curve showing the mass loss due to corrosion as a function of deformation is shown in figure 2. With increase in deformation, the mass loss due to corrosion is decreased. In Al-Mg alloys strength is developed mainly through work hardening and to a lesser extent by grain size effects. With increase in plastic deformation, the grain size becomes finer and hence the strength and hardness. The deformation causes not only a decrease in the grain size but also the decomposition of the supersaturated solid solution, with the result all the excess impurity or its part escapes the solid solution and hence the corrosion resistance increases.

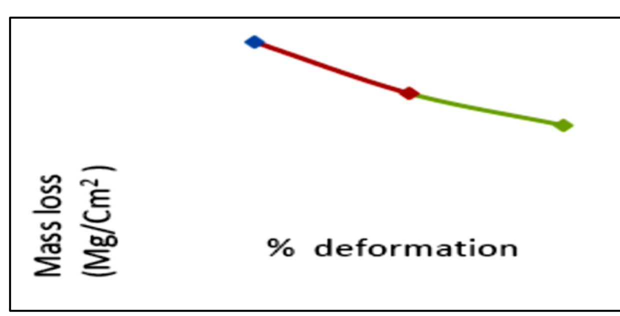

Fig 2 Mass loss due to corrosion in Al-8Mg alloys as a function of deformation

Table 3 Mass loss due to corrosion in Al-8Mg alloys as a function of heat treatment

Deformation	Diameter (Cm)	Height (Cm)	Surface area(cm2)	Mass loss (Mg)		Mass loss (Mg)	Mass loss(Mg/Cm^2)
				Before acid test	After acid test		
Homogenised	1.008	1.035	4.87	2067.1 1	1746.2	320.9	65.898
solutionised	1.012	1.047	4.937	2117	1743.5	373.5	75.647
T6 Condition	1	1.068	4.925	2104.2	1892.1	212.1	43.06
Over aged	1.006	1.09	5.037	2167.7	1970.6	197.1	39.13

Table 3 shows the variation of mass loss due to corrosion in cast Al-8Mg alloys for various heat treatments. The mass loss in the peak aged sample is lesser as compared to the solutionised sample and the mass loss is further lowered in the over aged sample. The artificial aging process that is used to strengthen the Al-Mg alloys can have a significant impact on corrosion resistance. The peak aged condition that provides maximum strength also provides reduced corrosion resistance. By over ageing, there is a small decrease in strength but a significant improvement in exfoliation and stress-corrosion-cracking resistance. High resistance to corrosion develops on over ageing or stabilization as free magnesium is reduced and coarse grain boundary precipitates are developed [13] and hence the mass loss obtained in the over aged sample is the minimum compared to the mass loss obtained in the samples given other heat treatments.

The ageing of the automotive body sheet alloys is frequently accomplished by the paint bake cycle that is applied during the coating process. In addition to impacting grain-boundary chemistry, ageing may serve to relieve stresses created in the material during rolling or extrusion. Stress corrosion cracking susceptibility in Al-Mg alloys is strongly influenced by grain boundary precipitation. To oversimplify, high temperature precipitation and extended precipitation times at moderately elevated temperatures are beneficial whereas short low temperature precipitation treatments are detrimental. It should be realised that Al-Mg alloys are immense to stress corrosion cracking in the as-quenched non-precipitated condition. Hence during precipitation on grain boundaries at room temperature and moderately elevated temperatures susceptibility rapidly increases as grain boundary precipitation occurs. It is conceivable therefore that all grain boundaries go through an immense to susceptible to highly resistant sequence as grain boundary precipitation occurs at all temperatures.

4. Conclusions

The following conclusions can be drawn from the present investigations on the study of corrosion behaviour of Al-Mg alloys.

1. With increasing the concentration of Mg in the deformed Al-Mg alloys, the corrosion resistance increases.
2. The corrosion resistance of Al-Mg alloys increases with deformation
3. Age hardening treatment increases the strength of the alloys and hence the corrosion resistance.
4. Significant increase in corrosion resistance is observed in the peak aged sample as compared to the solutionised sample
5. High resistance to corrosion develops on over ageing or stabilization as free magnesium is reduced.

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