Effect of Sensitization on Corrosion Properties of TIG Welded AL-MG Alloy

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The effect of sensitization on the intergranular corrosion (IGC) of TIG welded AlMg6Mn was investigated by means of scanning electron microscopy (SEM) and corrosion NAMLT tests. The as-received hot rolled AlMg6Mn alloy plates with a thickness of 8 mm were welded by TIG welding with S-AlMg5 as a filler material. Specimens were sensitized at 100 °C for 7 days. It was found that welded specimens are sensitive to IGC. The. mass loss in NAML test was 106.7 mg/cm^2. The welding increases the susceptibility to IGC, since the mass loss of the base metal at the same test was 70.7 mg/cm^2. The increase of susceptibility to IGC is attributed to significant continually precipitated Mg-rich phase along the grain boundaries during the sensitization treatment

Key words: **Al-Mg-Mn alloys, TIG welding, intergranular corrosion (IGC), sensitization.**

Introduction

Al-Mg alloys are suitable material for many applications since they have moderate strength, high strength-to-weight ratio, good formability, weldability and corrosion resistance. It is well known that low-magnesium alloys have very good corrosion resistance, while the high-magnesium alloys have greater strength than the low-magnesium alloys, and they have outstanding corrosion resistance in saltwater environments, but they can be susceptible to intergranular forms of corrosion, including exfoliation and stress-corrosion cracking [1-3]. Alloys with more than about 3% Mg under certain manufacturing conditions subjected to elevated temperatures above 65 to about 175 °C (50-200°C), may be prone to intensive intergranular corrosion (IGC) and stress corrosion cracking (SCC) [4-7]. This behavior is attributed to continually grain boundary precipitation of the highly anodic Mg_2Al_3 (β) phase due to limited solubility of Mg [8]. The β phase precipitates heterogeneously both at grain boundaries and on preexisting manganese enriched particles [9-11]. Temperature and mechanical deformation play a major role in precipitation and its distribution and morphology controls the degree of sensitization [12-15]. It was reported that the misorientation angle is the most important factor influencing precipitation in grain boundaries of the Al-Mg alloy, but the results are in disagreement [16-17].

Since β-phase is the highly anodic, it will be dissolved preferentially in a corrosive environment, thus increasing the susceptibility to IGC and SCC [5, 18].

This corrosion susceptibility can be avoided or decreased by controlling microstructure using particular tempers and by limiting the maximum service temperatures to 65°C [14, 19]. Applying the stabilization treatment by which magnesium is randomly precipitated within the grains or discontinuously on grain boundaries, reduces the sensitization to IGC and SCC [20-21].

It is considered that Al-Mg alloys resistant to IGC have a NAMLT value ≤15 mg cm^{-2}, and those susceptible, greater than 25 mg cm^{-2} [22]. NAMLT test is the most common method for evaluating the susceptibility of Al-Mg alloys to IGC, and it is used to evaluate the susceptibility to IGC welded material and compare to base material [23-25]. The welding process involves the local heating which affects to microstructure, physical and mechanical properties and stress around the weld. These changes lead to significant local differences in electrochemical properties, i.e. variations in corrosion potential across the welds, and onset of IGC [6, 26-27]. Therefore, the weld filler metal should be as close in electrochemical properties [6].

Many authors investigated the effects of welding on the corrosion of Al-Mg alloys containing up to 5 % Mg, mostly about alloy containing Mn (EN AW-5083) [14, 17, 28-30], but lack of results regarding alloy with higher content of Mg [19, 24, 28-30].

In this study the IGC susceptibility of sensitized TIG welded joints of Al-Mg alloys with high %Mg was investigated by NAMLT test.

The distribution of β-phase was investigated in sensitized TIG welds of AlMg6Mn alloy with S-AlMg5 as a filler material.

Experimental

Material

The material used in this study were welded specimens of AlMg6Mn alloy. Hot rolled plates of AlMg6Mn alloy, 8 mm thickness, were welded using the TIG process under Ar (99.5 %) atmosphere and S-AlMg5 as a filler wire, using following welding parameters: current of 115 A, voltage of 15 V, and speed of 100 mm/min. The chemical composition of the used base metal, as well as, filler wire are given in Table 1.

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Sensitization

Sensitization treatment of the welded specimens was conducted at 100°C for 7 days.

Corrosion test

The susceptibility to IGC was determined by the nitric acid mass loss test (NAMLT) according to the ASTM G67 standard. Three specimens of welded joint and parrent metal were used. In order to calculate the mass losses per unit area more precisely, face and root reinforcement was considered.

Microstructure

The microstructures were characterized by scanning electron microscope (SEM-JEOL JSM-6610LV). Metallographic samples were prepared using grinding and polishing using up to 1 μm diamond paste. To reveal the particles along the grain boundaries, the samples were etched in 10 % orthophosphoric acid at 50ºC for 2,5 min. 2.5 Surface morphology

Surface morphology of the specimens after NAMLT test were characterized by scanning electron microscope (SEM-JEOL JSM-6610LV)

Results

Corrosion properties

The results of NAMLT test of both specimens, sensitized TIG welded and base metal are given in Table 3. It was found that the mass loss of sensitized specimens is aver. 106.8 mg cm^{-2}, while the mass loss of base metal specimens is 70.74 mg cm^{-2}.

Table 1. Chemical composition of the base and filler metal, (wt. %)

|	Mg	Si	Cu	Mn	Fe	Zn	Ni	Ti	Cr	Al
Base metal	5.95	0.12	0.015	0.54	0.36	0.07	0.01	0.01	-	Bal.
Filler wire	4.5-5.5	max 0.25	0.1	0.05-0.2	max 0.4	max 0.1	/	0.06-0.2	0.05-0.2	Bal.

Table 2. Metal loss in NAMLT test, mg/cm^2

| Specimen	Area (cm^2)	Mass before NAMLT (g)	Mass after NAMLT (g)	Mass loss (g)	Mass loss (mg/cm^2)	
BM	14.59	6.1256	5.0947	1.0309	70.62	70.74
	14.62	6.1461	5.1049	1.0412	71.23	
	14.55	6.152	5.128	1.0240	70.37	
TIG	14.75	6.209	4.6736	1.5354	104.12	106.76
	14.68	6.4092	4.8263	1.5829	107.84	
	14.72	6.3933	4.7985	1.5948	108.32	
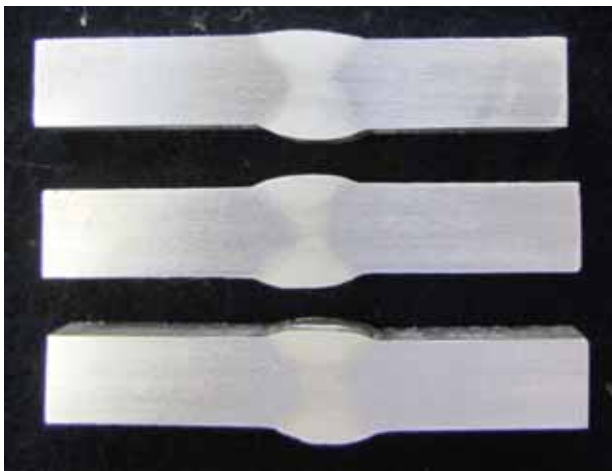
**Figure 1.** Macrostructure of the welded specimens

Microstructure

Microstructure of TIG welded specimens of AlMg6Mn alloy with AlMg5 as a filler, after sensitization treatment is shown in Fig.2. The etching in ortophosphoric acid revealed the presence of β-phase precipitates along the grain boundaries and uniformly distributed precipitates within grains in all parts of the weld joint. It seems that precipitates formed almost continuous film at grain boundaries during the sensitization treatment.
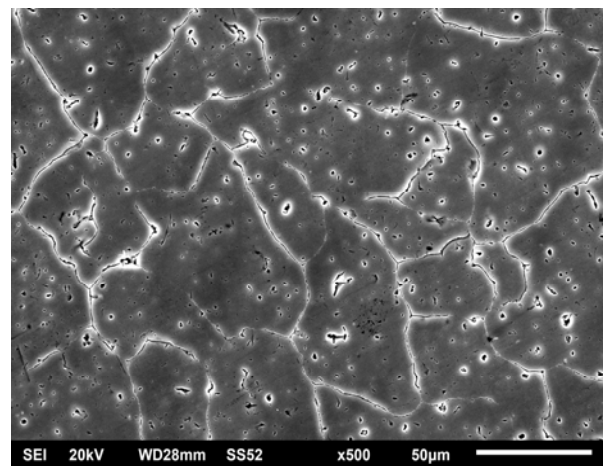
a)
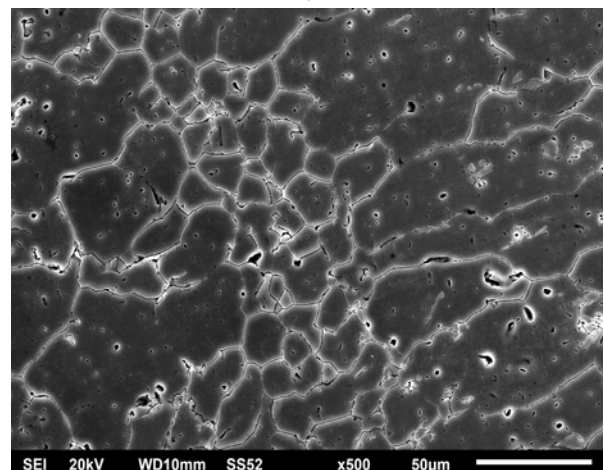
b)
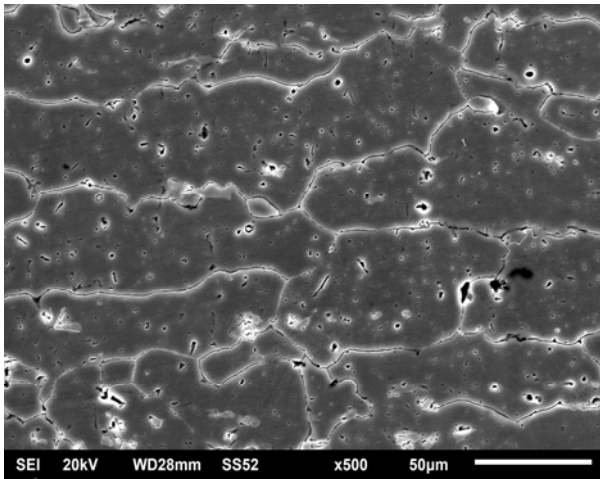
c)

Figure 2. SEM images of the microstructures of sensitized samples after etching a) weld metal; b) fusion zone; c) heat affected zone
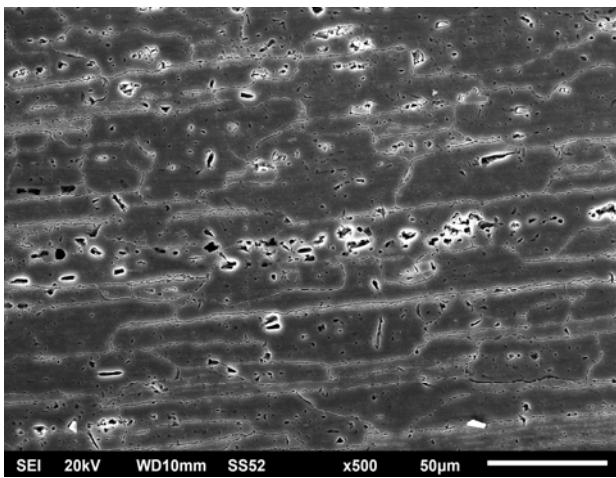

Figure 3. SEM images of the microstructures of sensitized AlM6Mn alloy (base metal) after etching.

Surface morphology after NAMLT test

Fig.4 shows the appearance of the test sample after the corrosion test. The surface is rough after 24 hours exposure to nitric acid and large pits were visible in the weld zone.
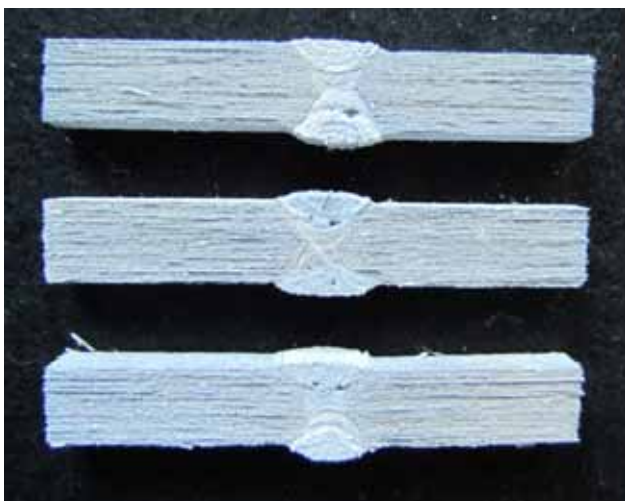

Figure 4. Specimens of sensitized TIG welded AlMg6Mn alloy after NAMLT test.

The effect of sensitization on the IGC susceptibility of the TIG welded specimens after corrosion test, observed by SEM

at low magnification, is shown in Fig.5. The intensive corrosion attack can be seen in weld metal, HAZ and base metal.
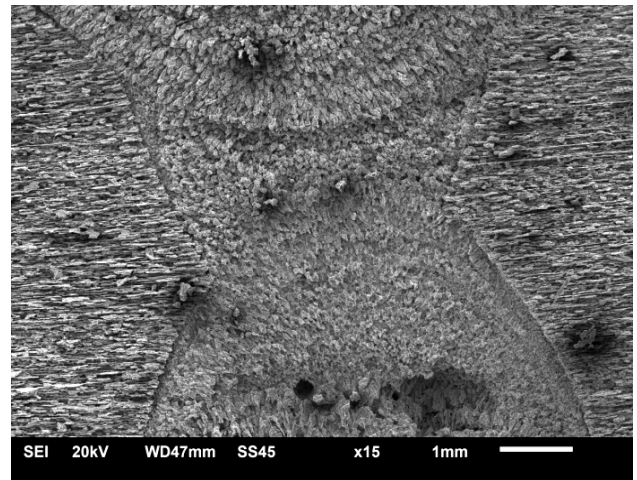

Figure 5. Macroscopic surface morphology of the welded specimen after NAMLT test.

SEM observation of these welds after sensitization at higher magnification, revealed severe localized intergranular attack on all parts of the welds, as shown in Fig.6. The grain boundary attack of the base metal is also observed, as shown in Fig.7 (the rolling direction is along the horizontal direction).
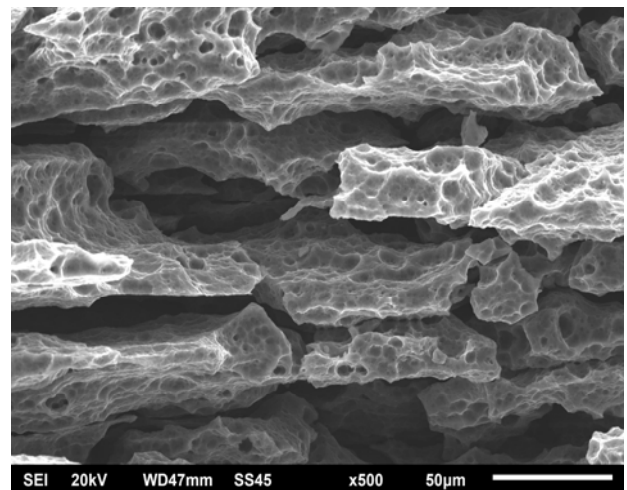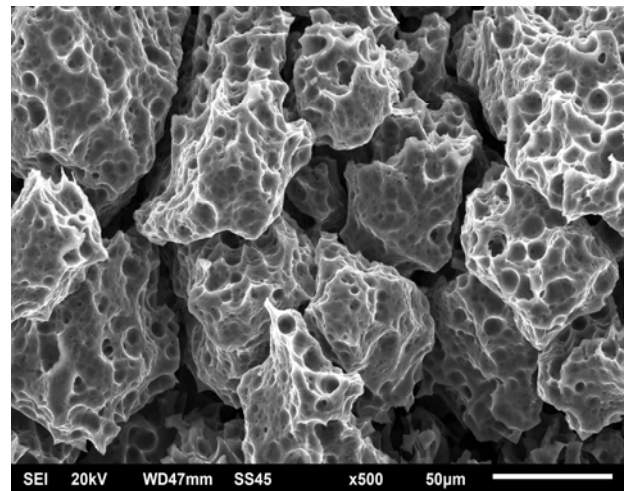

Figure 6. Surface morphology of the senzitized weld joint after the NAMLT test: a) weld metal; b) HAZ.
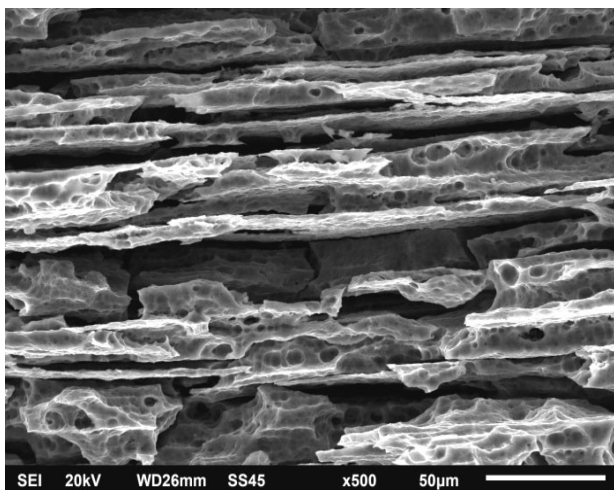
Figure 7. Surface morphology of the senzitized basma

Discussion

Although Al-Mg alloys are considered to have good corrosion resistance, Al-Mg alloys with (5-6) %Mg under certain manufacturing and service conditions may be prone to IGC and (SCC) [12, 30-31]. Additionally, corrosion resistivity of weld of these alloys, due to microstructural changes caused by filler (usually AlMg5) and weld thermal cycle, among other factors, is dependent on electrochemical properties of welding zones [6, 32]. NAML testing is a standard quantitative method [22] for testing of intergranular corrosion (IGC) susceptibility of Al-Mg alloys. In this test, it was used to determine the IGC susceptibility, comparing the mass loss of welded specimens with the mass loss of base metal. The mass loss of welded specimens was 106.8 mg cm^{-2} (Table 3). According to ASTM G67 the tested weld joints after sensitization treatment are susceptible to IGC. Since the nitric acid preferentially dissolves β-phase [22], high values of mass loss indicated that β-phase was precipitated in a relatively continuous network at grain boundaries. The other results, metallographic observation as well as SEM surface morphology, confirm that the mass loss is result of intergranular attack. Metallographic observation by SEM confirms these results showing continuous network β-phase at grain boundaries (Figures 2 and 3). This phase precipitated only at the grain boundary is responsible for the increased of IGC and SCC [4, 9, 11, 20-21].

Visual examination of the specimens after the 24h exposure to HNO$_3$ (Figure 4) and macroscopic observation (Figures 5) shown rough surface of all parts of the weld, as well as base metal. At higher magnification severe localized intergranular attack in all parts of the welds WM, FZ, HAZ and base metal can be seen (Figures 6 and 7). Surface morphology analyses of both welds and base metal specimens on the SEM, shown the separated grain due to dissolution of the continuous network of the β-phase particles around the grains. Preferential attack of the nitric acid caused that grains fall away from the specimens which resulted in relatively large mass losses. The large mass loss is according to this observation. Therefore, the welded specimens, as well as base metal after sensibilisation (100ºC/7 days) are susceptible to intergranular corrosion, since the mass loss is greater than 25 mg cm^{-2} [22]. Also, the mass loss in sensitized welded specimens in much greater than in non-sensitized specimens [30].

The results of mass loss shown that the higher sensitivity to IGC have sensitized welded specimens compared to sensitized

base metal. Since the welded specimen consists of weld and base metal, and the mass loss represent the sum of these, it can be concluded that the increase of the mass loss can be attributed to the weld metal. In other words, filler material is more sensitive to IGC in sensitized condition compared to AlMg6Mn alloy. Other authors also reported precipitation in Al-Mg-Mn alloy (5% Mg, 0.8 % Mn) at 100° C sensitization treatment and the presence of the metastable β'' phase [34].

Conclusion

The susceptibility to intergranular corrosion (IGC) of TIG welded AlMg6Mn alloy with AlMg5 filler wire was investigated after sensitization, according to ASTM G67.

Specimens of TIG welded joints and base metal were sensitized at 100°C for 7 days. Both of specimens shown high sensitivity to IGC. NAMLT results shown that the mass loss were 107.7 mg cm^{-2} and 70.7 mg cm^{-2} for welded specimens and the base metal, respectively. These results were attributed to continuously precipitation of β-phase at grain boundary. The higher sensitivity to IGC of welded specimens compared to base metal was caused by high sensitivity of weld metal, i.e. AlMg5 filler material.

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Uticaj senzibilizacije na koroziju tig zavarenog spoja Al-Mg legure

Ispitan je uticaj senzibilizacije na interkristalnu koroziju zavarenog spoja AlMg6Mn legure zavarene TIG postupkom. Korišćene su metode skenirajuće elektronske mikroskopije (SEM) i test gubitka mase -NAMLT. Izvršeno je zavarivanje ploča AlMg6Mn legure debljine 8 mm. Kao dodatni material je korišćena žica S-AlMg5. Uzorci su senzibilizovani na 100°C u trajanju od 7 dana. Pokazano je da su zavareni spojevi osetljivi na interkristalnu koroziju nakon senzibilizacije. Gubitak mase u NAMLT testu je bio 70.7 mg/cm^2. Povećanje osetljivosti na interkristalnu koroziju je pripisano izraženom kontinuiranom taloženju Mg-faze duž granica zrna za vreme senzibilizacije.

Ključne reči: **Al-Mg-Mn legure, TIG zavarivanje, interkristalna korozija, senzibilizacija.**