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MECHANICAL BEHAVIOR AND CORROSION PROPERTIES OF SOME AA6XXX ALUMINUM ALLOYS IN T5 TEMPER

The paper describes the mechanical and corrosion properties of three heat treatable extruded Al–Mg–Si aluminum alloys. The alloys were tested as T5 tempered (air-quenched directly on the press and artificially aged) after processing by the extrusion of semi-continuous cast and homogenized billets. The addition of small amounts of zirconium and manganese in the base AlMgSi0.7 alloy increased the strength, reaching 310 MPa of tensile strength and increased the corrosion rate by 15% in aqueous sodium chloride solution.

Key word: Extrusion, 6xxx Al alloys, Corrosion behaviour, Effect of zirconium and manganese.

Aluminum alloys are selected as construction materials in many fields because of their good mechanical properties and ability to resist corrosion. The AA6xxx aluminium alloys are materials of relatively high deformability and have been popular for a wide range of applications for a long time. These alloys are widely used for decoration, architectural sections, structural applications and in the automotive industry. The Al–Mg–Si alloy system offers a range of tensile properties from a yield strength of 48 MPa for AA6063 annealed temper to 395 MPa for AA6066 T6. The system offers the most useful combination of extrudability, strength, toughness and corrosion resistance characteristics of the whole aluminum alloy family [1–3].

Aluminum's ability to resist corrosion by atmospheric weathering has been well demonstrated by its application in agriculture, industrial and residential roofing, siding and other building materials for many years. The use of aluminum for storage tanks, tank cars, heat exchangers and other process equipment is ample evidence of its resistance to corrosion by chemicals and food products. Aluminum's resistance to corrosion both by fresh and salt waters can be shown by its many applications in ships, pleasure boats, irrigation pipe, heat exchangers, sewage disposal plants, rain carrying equipment, etc. Although aluminum is an active metal, its behavior is stable because of the protective, tightly adherent, invisible oxide film on its surface. Even when disrupted, this film begins to re-form immediately in most environments when oxygen or air is present. The oxide is present on the surface of the cast ingot and continually reforms after being disrupted by rolling, forging, drawing, extruding or other fabricating processes. As long as this oxide film is intact and continuous or can reform, if damaged, the aluminum metal will maintain its high resistance to corrosion. The oxide film is tenacious, hard and relatively insoluble and is therefore able to endure under a wide variety of environmental conditions.

All aluminum alloys and products are not equally resistant to corrosion.The addition of alloying elements modifies the properties and characteristics, such as the mechanical, electrical, thermal properties and corrosion resistance and new alloys are periodically introduced to satisfy the changing needs of the market [4–9].

EXPERIMENTAL PROCEDURE

Figure 1 shows the relations between the main alloying elements of the three investigated alloys. A typical 6082 alloy (AlMgSi1) contains approximately 2.4 % wt. of the main alloying elements with a balanced content of magnesium and silicon. Two other alloys are AlMgSi0.7 containing a small excess of silicon (related to magnesium). One of them (AlMgSi0.7Zr) contains zirconium and more manganese than the base AlMgSi0.7 alloy. The chemical composition of AlMgSi0.7Zr alloy was planned to provide higher strength in the T5 tempered condition.

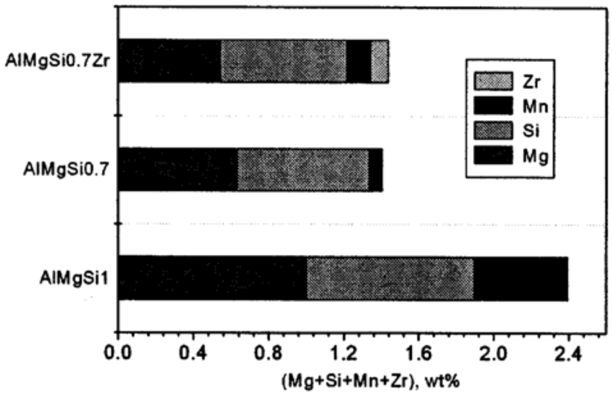

Figure 1. Principal constituents in the investigated Al–Mg–Si alloys

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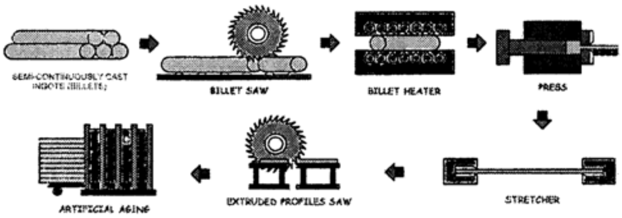

Figure 2. Thermo–mechanical processing scheme of extruded profil production

Figure 2 presents the thermo–mechanical processing scheme of extruded profile production. Semi–continuously cast billets of 200 mm diameter were homogenized for 12 hours at 570°C. The billets were heated in a pusher–type furnace, extruded at different temperatures in a hydraulic press with direct metal flow, air–quenched directly on the press, cooled to room temperature (cooling installation with ventilators), stretched and artificially aged. The temperature of the press container was 420°C and the billet temperature, T_{billet}, varied between 400°C and 520°C.

The mechanical properties and corrosion behavior of the profiles were investigated using standard methodology. "Instron" equipment was used to determine the tensile properties. The corrosion characteristics were determined by accelerated methods: monitoring of the corrosion potential (mV) vs time (open circuit potential); potentio–dynamic polarization (calculation of the values of the corrosion potential $E_{(I=0)}$, corrosion current (μA/cm^2), corrosion rate (mpy) and β_{anodic}, $\beta_{catodic}$ constants), linear polarization (calculation of the values of the polarization resistance (kΩ), corrosion current (μA/cm^2), corrosion rate (mpy) and corrosion potential $E_{(I=0)}$).

The corrosion tests were performed using a PAR–332 system (potentiostat–galvanostat model 273, MK–047 cell, software PAR SOFTCORR 352 II that completely automated fits experimental data). Two aqueous environments were used in the experiment: sodium chloride solution containing 29.8095 gr NaCl in 1dm^3 of distilled water (0.51 mol NaCl) and fresh natural water containing 8 mg/dm^3 of Cl^-.

RESULTS

The profile temperature essentially affects the final profile properties. The essence of hot working is that the deformation is carried out at a high temperature in order to reduce the yield stress to a value that enables high strains to be attained economically. But, if the exit temperature resulting from the initial billet temperature and the extrusion note is too close to the solidus temperature, the surface tears and roughens and is unacceptable. Figure 3 shows the influence of the billet temperature and extrusion ratio on the temperature of the extruded profiles, and Figure 4 shows the influence of the billet temperature on the extrusion pressures for the AlMgSi0.7(Zr) alloy.

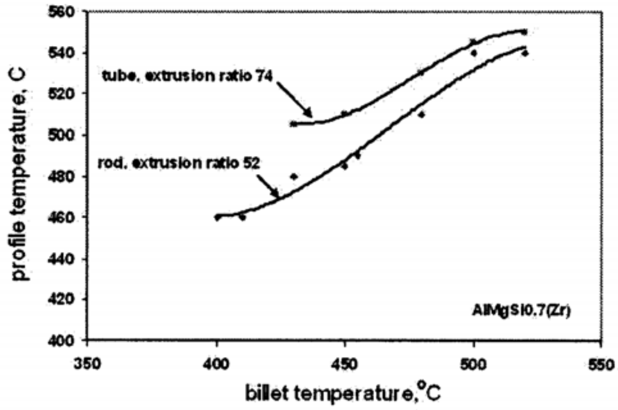

Figure 3. The influence of the billet temperature and extrusion ratio on the temperature of the extruded profiles for the AlMgSi0.7(Zr) alloy

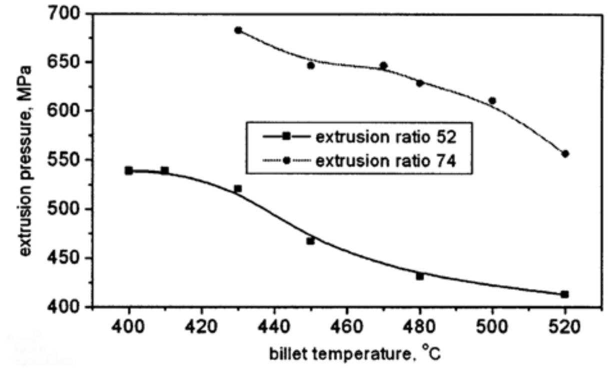

Figure 4. Influence of the billet temperature on the extrusion pressures for the AlMgSi0.7(Zr) alloy

The typical dependence of the profile temperature and extrusion pressure on the billet temperature and extrusion ratio is obvious.

A better quenching effect and greater strength of the profiles can be achieved at higher extrusion temperatures. Figure 5 shows the influence of the billet temperature on the tensile strength and elongation of the investigated alloys in the T5 tempered condition. The AlMgSi0.7(Zr) alloy is the most sensitive to the change of the billet temperature. The tensile strength increases from 240 MPa to 310 MPa within the selected range of T_{billet}. The other two alloys are less sensitive to the applied quenching procedure and show similar levels of yield stress.

The AlMgSi1 alloy shows the lowest strength after T5 tempering due to small quenching effects connected with relatively slow cooling rates for air quenching compared to water quenching which is recommended for the combination of main the alloying elements. This fact also explains the highest level of total elongation for the AlMgSi1 profiles.

Figure 6 illustrates the changes in the corrosion potential, E_{corr}, vs. time. The alloys show similar plots of

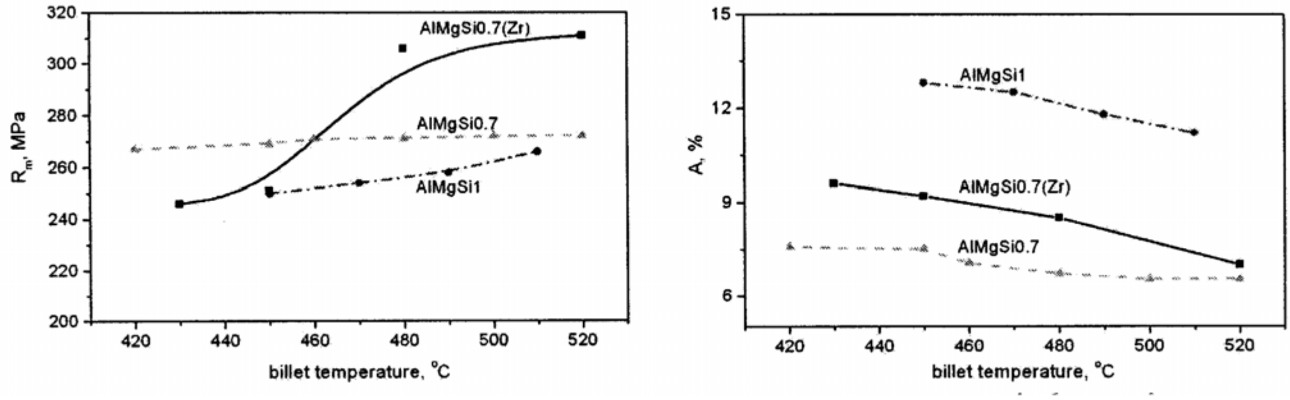

Figure 5. influence of billet temperature on the tensile strength and elongation of the investigated alloys in the T5 tempered condition.

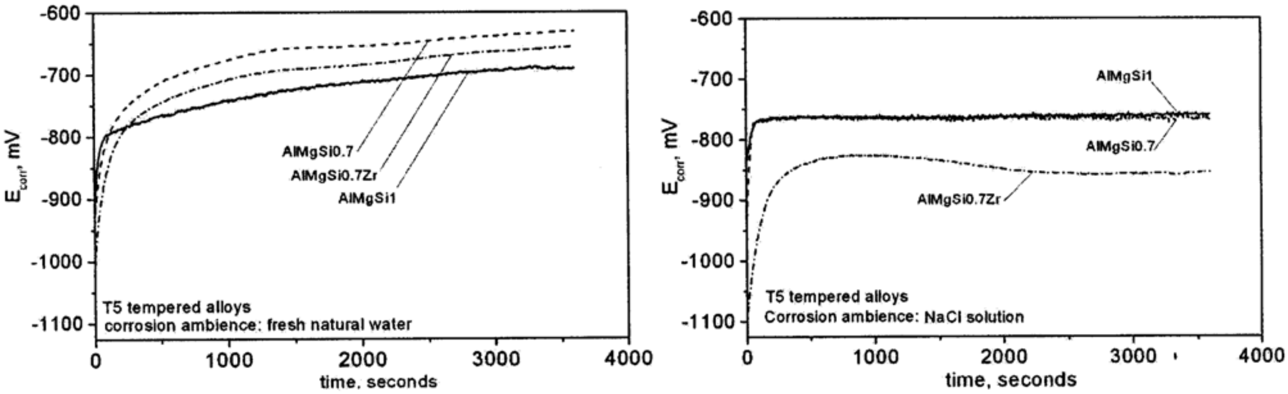

Figure 6. The corrosion potential of the tested Al–Mg–Si alloys in fresh natural water and 0.51 mol Na–chloride solution as a function of time

Table 1. Final values of the corrosion potentials of the tested alloys (E_{corr} vs. time – open circuit potential)

Corrosion ambience	E_{corr} after 3600 seconds, mV		
	AlMgSi0.7 T5	AlMgSi1 T5	AlMgSiZr T5
NaCl solution	–776	–757	–854
Fresh water	–630	–690	–655

E_{corr} vs time in fresh water. Alloy AlMgSi1, containing the highest percentage of alloying elements shows the lowest corrosion potential. The difference in E_{corr} for AlMgSi1 and the base AlMgSi0.7 alloy is almost 9% (60 mV), Table 1. The addition of small amounts of manganese and zirconium into the base AlMgSi0.7 alloy decreases the corrosion potential by 4% (25 mV). The base alloy AlMgSi0.7 and AlMgSi1 show almost equal changes in E_{corr} vs time in sodium chloride solution, Figure 6.b. The AlMgSi0.7Zr alloy has 10% (78 mV) lower levels of the corrosion potential.

Figure 7 shows the potentio–dynamic polarization plots and Table 2 lists some experimentally determined

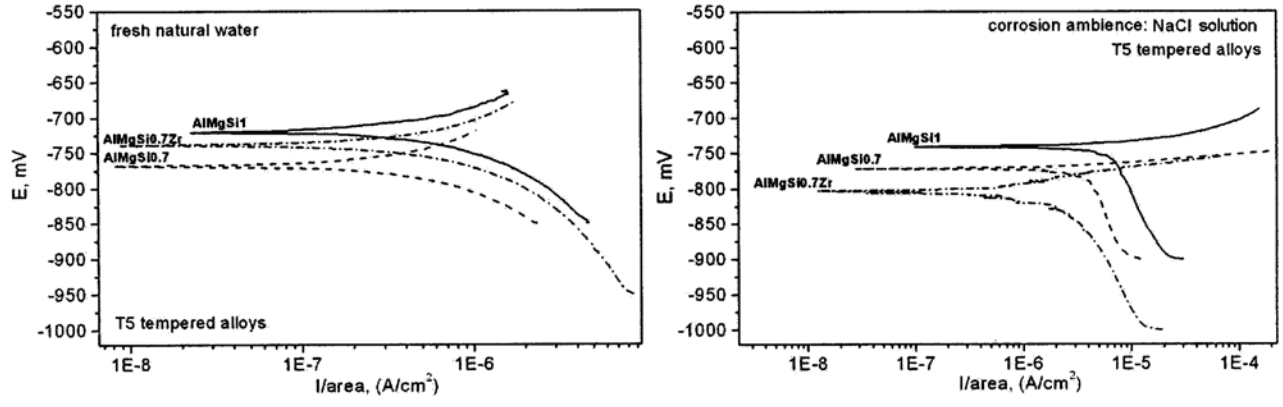

Figure 7. Potentio–dynamic polarization curves: (a) in fresh water, (b) in 0.51 mol NaCl

Table 2. Some results obtained during the potentio–dynamic polarization tests

	I_{corr} µA/cm^2	Corr rate mpy x10^{-3}	$E_{(i=0)}$ mV	β_{anodic}	β_{catod}
				V/ decade	
Corrosion ambience: sodium chloride solution					
AlMgSi0.7	3.068	49.28	–776.3	0.100	0.264
AlMgSi1	5.022	80.65	–745.7	0.100	0.244
AlMgSi0.7Zr	2.941	47.24	–805.3	0.097	0.313
Corrosion ambience: fresh water					
AlMgSi0.7	0.537	8.63	–767.1	0.100	0.100
AlMgSi1	1.126	18.09	–718.8	0.137	0.212
	1.615	25.94	–738.4	0.212	0.300

Table 3. Corrosion characteristics obtained by the linear polarization testing method

	R_{pol} kΩ	I_{corr} µA/cm^2	Corr r. mpy x10^{-3}	$E_{(i=0)}$ mV
Corrosion ambience: sodium chloride solution				
AlMgSi0.7	9.980	2.170	34.90	–819.2
AlMgSi1	8.376	2.593	41.64	–860.9
AlMgSi0.7Zr	8.581	5.530	40.64	–959.3
Corrosion ambience: fresh water				
AlMgSi0.7	20.22	1.074	17.25	–735.0
AlMgSi1	12.13	1.790	28.76	–847.2
AlMgSi0.7Zr	11.24	1.933	31.04	–903.0

characteristics such as the corrosion current I_{corr}, corrosion rate and constants β_a and β_c. The AlMgSi1 alloy has the highest value of the corrosion rate in sodium chloride solution. The AlMgSi0.7 alloys has similar corrosion rates but lower by almost 40% compared to the corrosion rate of the AlMgSi1 alloy. Comparison of the corrosion rates of the tested alloys in fresh water indicates that the base AlMgSi0.7 alloy shows the lowest corrosion rate. The addition of manganese and zirconium into the base AlMgSi0.7 alloy increases the value of the corrosion rate by three times.

The values of the polarization resistance, corrosion current, corrosion rates and $E_{(i=0)}$ experimentally determined during linear polarization in two aqueous ambiences are presented in Table 3. The highest values of the polarization resistance and $E_{(i=0)}$, as well as the lowest corrosion current and corrosion rate were obtained for the base AlMgSi0.7 alloy in both corrosion media. The presence of zirconium and manganese in the base AlMgSi0.7 alloy reduces the polarization resistance by 1.4 kΩ and unereases the corrosion rate by 5.74x10^{-3} mpy (~15%) in aqueous sodium chloride solution. The same behavior was formed in fresh water but the differences were more significant: the AlMgSi0.7Zr alloy had a lower polarization resistance and a higher corrosion rate by almost 40%.

CONCLUSION

The addition of small amounts of zirconium and manganese to the base AlMgSi0.7 alloy increases the strength of the material, reaching 310 MPa of tensile strength after T5 tempering, reduces the polarization resistance and increases the corrosion rate by 15% in aqueous sodium chloride solution. The differences in the corrosion rate are more significant in fresh water. The corrosion behavior of the investigated Al–Mg–Si alloys in fresh water and sodium chloride solution is satisfactory even though increase of the alloying elements content caused a small deterioration. The AlMgSi0.7(Zr) alloy has the most favorable combination of strength, ductility and corrosion properties. The alloys AlMgSi0.7 and AlMgSi0.7(Zr) offer a wide range of combinations of good mechanical and corrosion properties suitable for a wide range of profile applications.

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IZVOD

MEHANIČKE I KOROZIONE OSOBINE NEKIH AA6XXX LEGURA ALUMINIJUMA U T5 STANJU

(Naučni rad)

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U radu su opisane mehaničke i korozione osobine tri termički obradive Al legure tipa Al–Mg–Si koje su namijenjene presovanju. Legure su ispitivane u T5 stanju (kaljene direktno na presi vazduhom i vještački starene) u obliku profila presovanih od polukontinuirano livenih i homogenizovanih trupaca. Dodatak malih količina cirkonijuma i mangana u osnovu AlMgSi0.7 leguru uzrokuje povećanje zatezne čvrstoće do 310 MPa uz istovremeno povećanje brzine korozije u rastvoru natrijum hlorida za 15%.

Ključne reči: Presovanje, Al legure 6xxx, Korozija, Uticaj Zr i Mn.