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AN INVESTIGATION OF TERMPERATURE-RESISTANT ALUMINIUM ALLOYS

RAZISKAVA TOPLOTNO OBSTOJNIH ALUMINIJEVIH ZLITIN

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Developments in modern technology have increased the interest in aluminium alloys for elevated-temperature applications. Al-Si alloys with additions of cobalt, nickel, molybdenum and iron represent a new temperature-resistant material. These alloys have a low thermal expansion coefficient (CTE) and a high hardness. The preparation of these alloys and the effect of specific alloying elements are presented. Special attention is paid to the temperature behaviour of the alloys. Mechanical properties at elevated temperature and the fracture and the corrosion resistance were investigated as well.

Key words: Al-Si alloys, modified state, intermetallic phases, fracture morphology

Moderne tehnologije povečujejo zanimanje za toplotno obstojne aluminij - silicijeve zlitine. Te zlitine s kobaltom, nikljem, molibdenom in železom so nova vrsta toplotno obstojnih materialov. Te zlitine imajo majhen temperaturni razteznostni koeficient in visoko trdnost. Izdelava in vpliv sestavnih elementov sta bila raziskana s poudarkom na lastnostih pri povišani temperaturi. Ugotovljena je bila tudi odpornost proti koroziji.

Ključne besede: zlitine Al-Si, modifikacija, intermetalne spojine, oblika preloma

1 INTRODUCTION

The goal of this investigation was to determine the effect of alloying elements in aluminium alloys on the properties that are important for their applications. The effects of single alloying elements as well as multiple alloying elements were investigated. The chemical composition was selected assuming that molybdenum and iron would improve the dimensional stability, while cobalt and nickel would increase the strength at elevated temperature. Nickel could also partially neutralise the effect of iron. The tests were performed from ambient temperatures up to 250 °C. However, based on the preliminary tests of the effect of molybdenum and iron (for the first time introduced as alloying elements in this system), the testing temperature was increased to 300 °C. Since the silicon content in Al-Si alloys can vary from a hypoeutectic to a hypereutectic content, it was necessary to use a suitable modification process. Using an alloy based on strontium, the successful modification and dimensional stability of these alloys at elevated temperatures were achieved. Also, the effect of the alloying elements on the corrosion resistance was determined. Only results obtained on cast alloys are reported.

2 EXPERIMENTAL

The chemical composition of the two investigated alloys is given in **Table 1**. The mechanical testing consisted of determining the tensile strength (R_m), the elongation (A) and the hardness (HB) at room temperature, 250 °C and 300 °C. The microstructural examination consisted of identifying the different phases, the characterisation of their morphology and their proportion in the microstructure. For the identification of a particular phase the method of selective efecting was applied [7,8].

The fracture surface was investigated by scanning electron microscopy with the aim of establishing the effect of the constituents of the microstructure on the fracturing process.

The corrosion resistance was determined in a 0,51 mol NaCl solution at room temperature. The tests consisted of determining the corrosion-potential change as a function of time $E_{corr}=f(\tau)$, polarisation resistance (R_p) and corrosion current (j_k).

3 RESULTS AND DISCUSSION

The results of the mechanical tests at room temperature are shown in **table 2**; the results for both the elevated temperatures are shown in **tables 3 and 4** have. The lower tensile strength and the higher hardness at room temperature indicate that alloy 1 has a less-formable microstructure than alloy 2. At higher temperatures alloy 1 exhibits a greater tensile strength and hardness, however, this is to be expected because of the higher alloying. It was not possible to establish a

Table 1: Chemical composition of the alloys
Tabela 1: Kemična sestava zlitin

Alloy No	Si (%)	Cu (%)	Be (%)	Fe (%)	Mo (%)	Ni (%)	Co (%)	Mg (%)	Mn (%)	Sr (%)
1.	11,70	1,28	0,25	1,23	0,55	0,68	1,00	1,33	0,38	0,046
2.	14,60	1,28	0,25	0,75	0,40	0,30	0,65	0,80	0,31	0,051

Table 2: Mechanical properties at room temperature
Tabela 2: Mehanske lastnosti pri sobni temperaturi

Alloy No	R_m (N/mm^2)	A (%)	HB (N/mm^2)
1.	179,71	1,0	124
2.	196,80	2,0	110

Table 3: Mechanical properties at 250 °C
Tabela 3: Mehanske lastnosti pri 250 °C

Alloy No	R_m (N/mm^2)	A (%)	HB (N/mm^2)
1.	200,5	1,45	148
2.	165,25	1,70	123

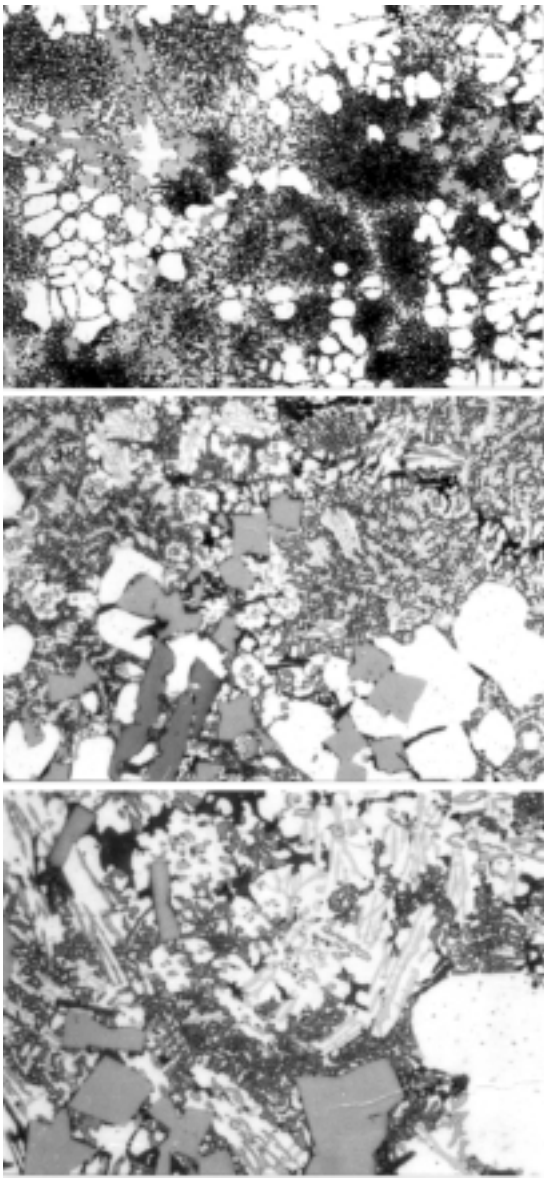

Figure 1, 2 and 3: Microstructure of alloy 1
Slike 1, 2 in 3: Mikrostruktura zlitine 1

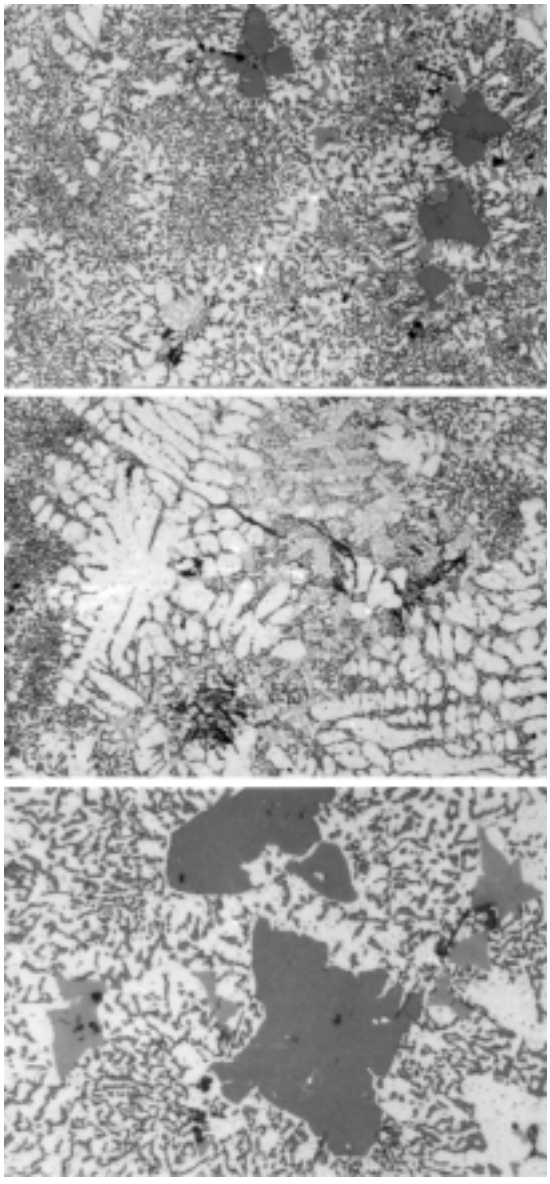

Figure 4, 5 and 6: Microstructure of alloy 2
Slike 4, 5 in 6: Mikrostruktura zlitine 2

Table 4: Mechanical properties at 300 °C
Tabela 4: Mehanske lastnosti pri 300 °C

Alloy No	R_m (N/mm^2)	A (%)	HB (N/mm^2)
1.	203	1,8	135
2.	150,55	1,2	125

reliable value for the yield strength at room temperature or the higher temperatures because of the brittleness of both alloys, which is confirmed by a very small elongation. The microstructures of alloys 1 and 2 are shown in **figures 1 to 6** and in **table 5**; where the

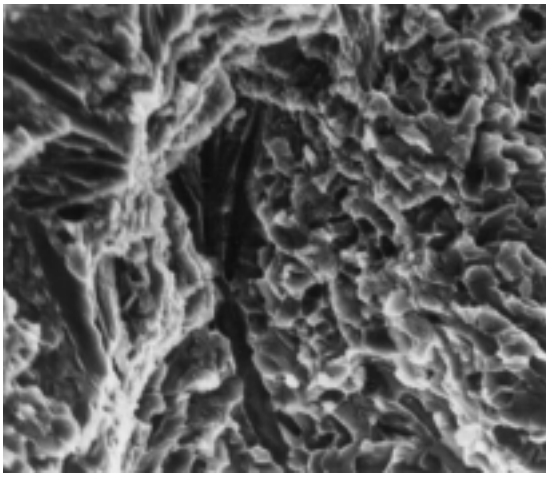

Figure 7: Tensile fracture surface of alloy 1 at 250 °C
Slika 7: Raztržni prelom zlitine 1 pri 250 °C

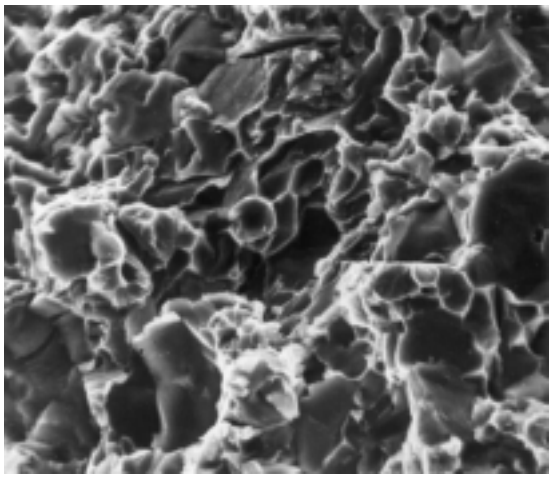

Figure 8: Tensile fracture surface of alloy 1 at 300 °C
Slika 8: Raztržni prelom zlitine 1 pri 300 °C

Table 5: Type of IMFs present and geometric parameter values as determined by stereological analysis
Tabela 5: Vrsta intermetalnih spojin in rezultati stereološke analize mikrostrukture

Alloy No	Phase type	V_v (vol. %)	L (μm)	S_v (mm^2/mm^3)	S_v/V_v (mm^2/mm^3)
1.	Eutectic Si	10,66	0,484	881,44	8269,8
	Al_3Ni	0,61	1,660	14,63	2409,2
	$Cu_2Mg_8Si_6Al_5$	5,46	1,000	217,44	3980,6
	$(FeMn)Al_3$*	6,71	4,760	56,40	840,8
	$(FeMn)_3Si_2Al_{15}$				
	AlFeMoSi	+	+	+	+
	$CuAl_2$	+	+	+	+
2.	Primary Si	2,85	13,82	8,26	289,5
	Eutectic Si	17,62	1,39	504,31	2862,5
	Al_3Ni	0,98	1,64	23,87	2443,9
	$Cu_2Mg_8Si_6Al_5$	3,16	1,85	68,23	2160,0
	$(FeMn)_3Si_2Al_{15}$	+	+	+	+
	$(FeMn)Al_3$ + AlMnFeNi + AlFeMoSi	2,04	6,64	12,29	602,1
	$CuAl_2$	+	+	+	+

Table 6: Corrosion potential of alloy 1 [$E_{corr} = f(\tau)$]
Tabela 6: Korozijski potencial zlitine 1

Alloy No	E_{corr} - start (mV)	E_{corr} - final (mV)	Concentration NaCl (mol)	Temperature (°C)
1.	-684	-691	0,51	32

Table 7: Polarisation resistance of alloy 1
Tabela 7: Polarizacijska upornost zlitine 1

Alloy No	E_{corr} (mV)	E(I=0) (mV)	R_p (KΩ)	j_k (μA/cm^2)	Conc. NaCl (mol)	Temperature (°C)
1.	-575	-630	9,65	2,25	0,51	32

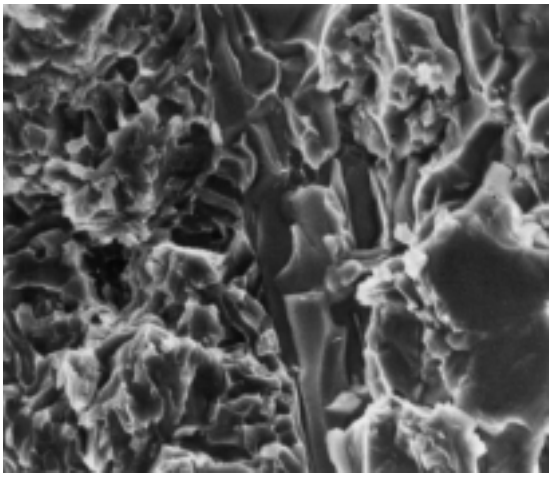

Figure 9: Tensile fracture surface of alloy 2 at 250 °C
Slika 9: Raztržni prelom zlitine 2 pri 250 °C

parameters of the stereological analyses of the microstructures of both alloys are given. The microstructure of alloy 1 consists of dendrites of solid solution and a dominant share of modified eutectic at the surface, while in the interior coarse particles of an intermetallic compound are also found. The size of the primary dendrites is in the range 0.4 to 0.7 μm. The eutectic consists mostly of small particles of the $Cu_2Mg_8Si_6Al_5$ phase and occasional particles of the Al_3Ni phase. The iron-containing intermetallic phase $(FeMn)Al_3$ is present as coarse polyhedral particles.

The microstructure of alloy 2 is shown in **figure 4 to 6**. It is similar to that of the alloy 1, however, the particles of the intermetallic phase containing iron are coarser and frequently have a dendritic shape. This phase is thought to be $(FeMn)Al_3$ or AlMnFeNi.

Nickel is found in both alloys in the Al_3Ni phase. In both alloys, magnesium and copper are found in the intermetallic compound $Cu_2Mg_8Si_6Al_5$. The fracture of the specimens tested at elevated temperature shows

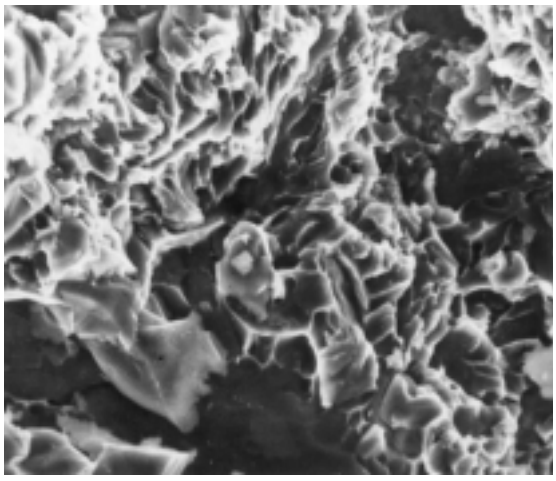

Figure 10: Tensile fracture surface of alloy 2 at 300 °C
Slika 10: Raztržni prelom zlitine 2 pri 350 °C

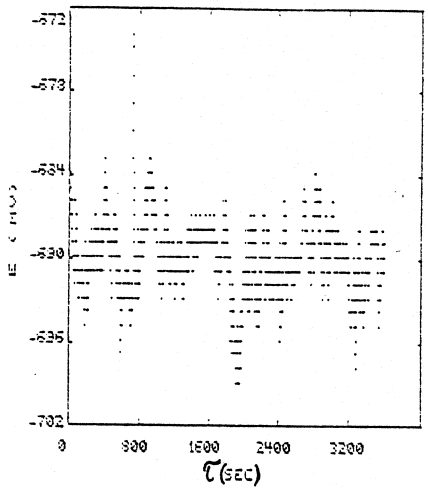

Figure 11: Change of corrosion potential in the 0.51 mol NaCl solution as a function of time $E_{corr} = f(\tau)$ for alloy 1. The potential after 3600 s is -691 mV relative to ZKE
Slika 11: Zlitina 1. Sprememba korozijskega potenciala v 0,51 mol raztopini NaCl v odvisnosti od časa. Potencial E_{corr} = -691 mV po 3600 s

dimpled areas (**Figure 7**) and microcracks with the initial points on the particles of polyhedric shape and with a smooth surface. Dimpled areas show the propagation to be in primary grains of α-solid solution. The fracture surface of alloy 2 is similar (**figures 8 and 9**). Most of the fracture consists of brittle facets in accordance with the very poor elongation.

Some points relating to the corrosion behaviour of both alloys are shown in **tables 6 and 7** and in **figures 11 and 12**. The corrosion potential, the polarisation resistance and the corrosion current are at acceptable levels.

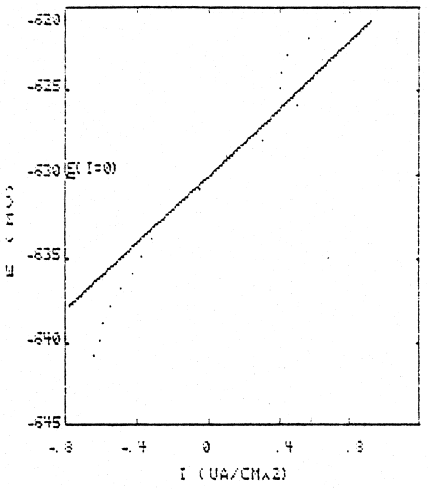

Figure 12: Polarisation resistance (R_p) and corrosion current (j_k) in the 0.51 mol NaCl solution for alloy 1, scan velocity of 1mV/s (R_p=9,65 KΩ, j_k=2,25 μA/cm^2)
Slika 12: Zlitina 1. Polarizacijska upornost (R_p) in korozijski tok (j_k) v 0,51 molarni raztopini NaCl. Hitrost snemanja 1mV/s (R_p=9,65 KΩ, j_k=2,25 μA/cm^2)

The corrosion characteristics for alloy 1 show that this alloy in the as-cast state is resistant to corrosion in the 0,51 mol NaCl solution.

4 CONCLUSION

The high tensile strength at elevated temperatures shows both alloys to be heat resistant. The poor elongation and the mostly brittle-fracture-type areas indicate the inherent brittleness that results from the solidification structure.

The beneficial effect of strontium as a modifier is also confirmed for both the hypoeutectic and the eutectic Al-Si alloys.

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