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FATIGUE PROPERTIES OF HIGH-STRENGTH Al-Zn-Mg-Cu ALLOYS WITH DIFFERENT LEVELS OF PURITY

UTRUJENOSTNE LASTNOSTI VISOKO TRDNIH ZLITIN Al-Zn-Mg-Cu Z RAZLIČNO ČISTOSTJO

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We have investigated the effect of iron and silicon impurities on the endurance limit (S_f) of wrought Al-Zn-Mg-Cu alloys. For four alloys with a similar base chemical composition and different iron and silicon contents we performed standard fatigue tests in the minimum and maximum loading range of R = -1. The fatigue fracture surface was investigated in the region of the crack initiation. We have shown that the greater the iron and silicon levels the lower the endurance limit of the alloys at ambient temperature.

Key words: high-strength aluminium alloys, fatigue properties, Fe impurity, Si impurity, intermetallic particles

Raziskan je bil vpliv vsebnosti nečistot (železo in silicij) na časovno nihajno trdnost. Standardni preizkusi utrujenosti so bili opravljeni po metodi največje in najmanjše napetosti z R = 1 za štiri zlitine s podobno osnovno kemijsko sestavo in različno vsebnostjo železa in silicija. Prelomna površina je bila preiskana z vrstičnim elektronskim mikroskopom s poudarkom na področju začetka razpoke. Pri večji vsebnosti Fe+Si je bila nižja časovna nihajna trdnost.

Ključne besede: visoko trdne Al-zlitine, utrujenostne lastnosti, nečistoče (Fe+Si), intermetalne spojine

1 INTRODUCTION

High-strength aluminium alloys belong to the Al-Zn-Mg-Cu system. Zinc and magnesium in an aluminium solid solution increase the strength of worked and cast alloys [1,2]. These alloys have good casting properties; however, low ductility, lack of toughness and poor fatigue strength prevent their more widespread use. Barely soluble elements, such as iron and silicon, even though only present in small quantities have a predominantly negative influence on the properties and are, therefore, considered as impurities.

It was proved experimentally that the higher the iron and silicon content, the greater the quantity of insoluble intermetallic phases in the microstructure [1-6]. These phases increase the inhomogeneity of the microstructure and so decrease the fracture toughness [1,6-9], ductility [1,2,6], and, to a lesser degree, the mechanical properties in general [1,8,10].

Since these alloys are also used for structural elements that support alternating and impact loads, the aim of this investigation was to determine the influence of the presence of iron and silicon on the fatigue strength.

2 EXPERIMENTAL WORK

Four Al-Zn-Mg-Cu alloys with different levels of purity and similar amounts of alloying elements were investigated. Their compositions are shown in **table 1**.

The alloys were prepared in standard industrial conditions. The materials were cast, homogenised, pressed, forged and heat treated. Each casting was heat treated according to the procedure T6: solution annealing, quenching and artificial ageing, with the aim of obtaining the optimum mechanical properties.

The test specimens had a circular cross-section and a diameter of 10 mm. The tests were performed on a resonant pulsator that produced stresses by the oscillation of unbalanced masses. The test, as prescribed in the ASTM E 486 standard [11], for the endurance limit (S_f) was conducted for a number of cycles, typically 10^7

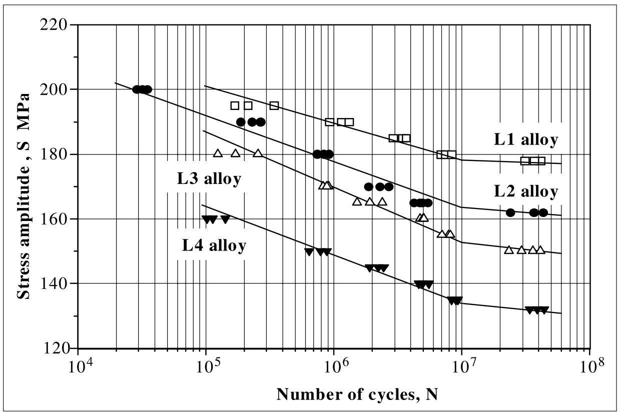

Figure 1: S-N curves of the investigated alloys /12/
Slika 1: Odvisnosti S-N za raziskane zlitine

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

Alloy name	Element, mas. %									
	Fe	Si	Ti	Cu	Zn	V	Cr	Mn	Mg	B	Zr
L1	0,16	0,09	0,015	1,55	7,30	0,007	0,18	0,29	2,26	0,003	0,13
L2	0,19	0,07	0,010	1,70	7,78	0,012	0,18	0,24	2,52	0,009	0,120
L3	0,24	0,08	0,020	1,57	7,35	0,004	0,17	0,26	2,31	0,002	0,120
L4	0,29	0,13	0,028	1,35	7,31	0,007	0,19	0,33	2,52	0,003	0,008

Table 2: Parameters of the statistical analysis of the S-N curves
Tabela 2: Parametri statistične analize odvisnosti S-N

Alloy	Mathematical function	Log C	m	Variant	Standard deviation	Dispersion
L1	$S_f = C.N^m$	2,3923	- 0,0192	1,0721	1,4925	1 : 2,79
L2	$S_f = C.N^m$	2,4465	- 0,0325	1,0900	1,5613	1 : 3,13
L3	$S_f = C.N^m$	2,4403	- 0,0355	1,0267	1,2796	1 : 1,88
L4	$S_f = C.N^m$	2,3798	- 0,0348	1,0359	1,3300	1 : 2,08

or 10^8. Altogether, 71 round specimens were investigated for all four alloys.

To better understand the behaviour of these alloys under conditions of variable loads, the fracture surface was examined in the scanning electron microscope and the different intermetallic phases were identified using EDAX analysis with special attention paid to the fracture surface near the crack initiation point.

3 RESULTS

The dependence of stress amplitude on the number of cycles for the four investigated alloys is shown in **figure 1**.

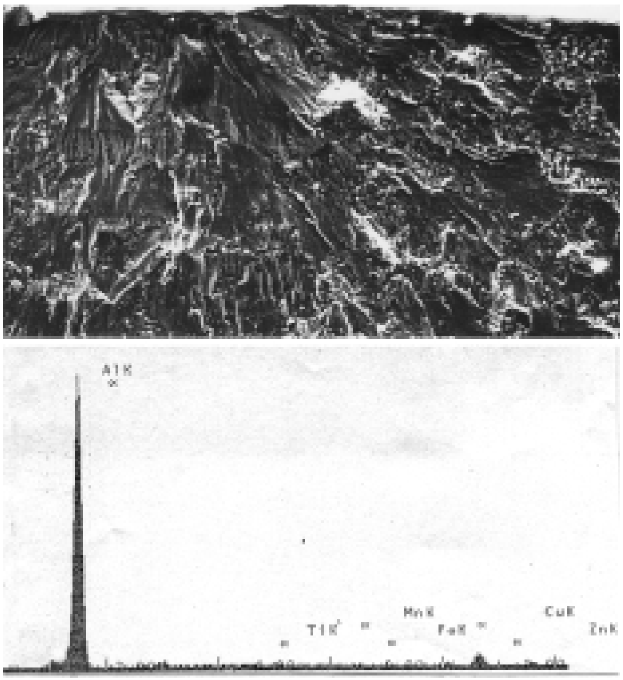

Figure 2: Fracture initiation surface and EDS spectrum in the crack-initiation area of the L1 alloy
Slika 2: Področje začetka preloma in spekter EDS. Zlitina L1

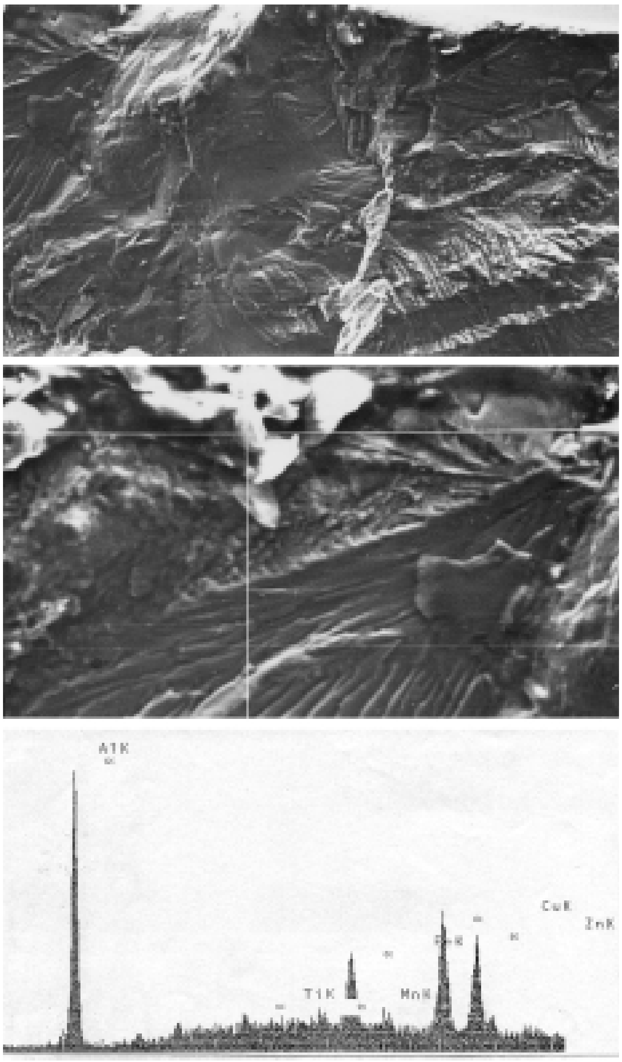

Figure 3: Fracture initiation surface, intermetallic particles and EDS spectrum in the crack-initiation area of the L2 alloy
Slika 3: Področje začetka preloma, zrna intermetalne spojine in spekter EDS. Zlitina L2

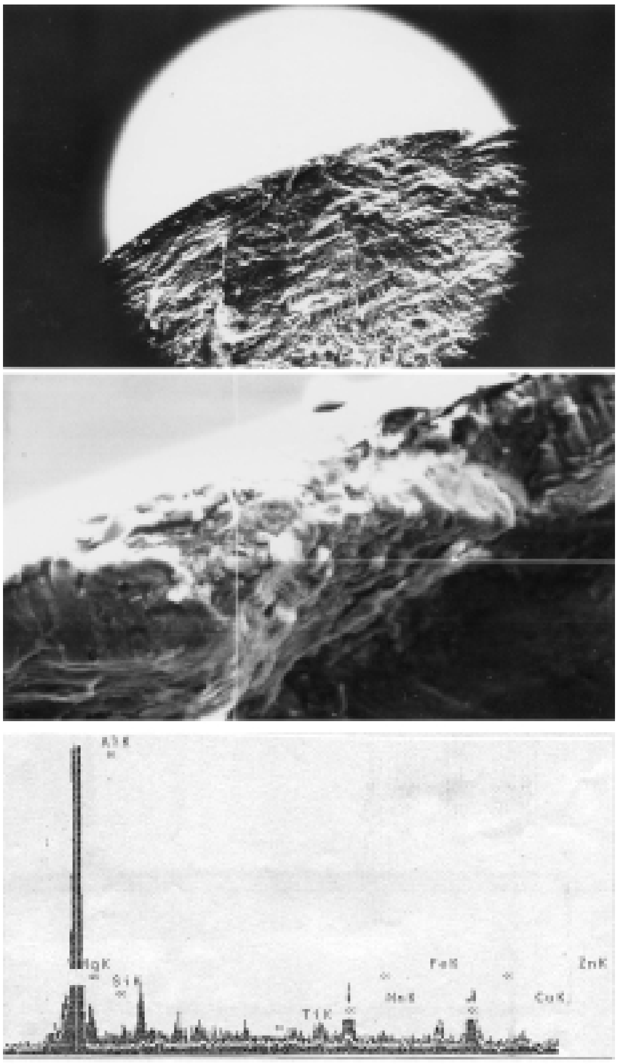

Figure 4: Fracture initiation surface, intermetallic particles (probably Mg_2Si) and EDS spectrum in the crack-initiation area of the L3 alloy
Slika 4: Področje začetka preloma, zrna intermetalne spojine (verjetno Mg_2Si) in spekter EDS. Zlitina L3

In **table 2** the data relating to the statistical analysis of the curves in **figure 1** are shown. An SEM picture and EDAX spectra are shown in **figures 2 to 5**.

4 DISCUSSION

The greatest endurance limit (S_f) at 10^7 cycles of 178 MPa was obtained for the L1 alloy with the lowest content of Fe and Si, whereas the lowest fatigue strength endurance limit of 132 MPa was found for the L4 alloy with the highest content of Fe and Si. Since the amount of alloying elements is similar and they are found in the alloy in a form that could not directly affect the fatigue behaviour, we conclude that the reduction in the endurance limit is caused by the higher impurity content, in other words, the increased amount of insoluble intermetallic phases containing iron and silicon.

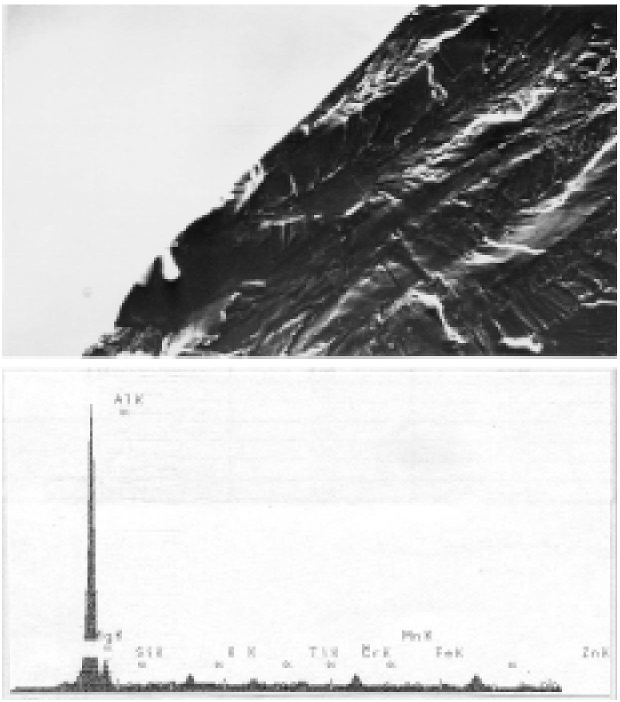

Figure 5: Fracture surface and EDS spectrum in the crack initiation area of the L4 alloy
Slika 5: Področje začetka preloma in spekter EDS. Zlitina L4

It was reported that the share of insoluble particles of intermetallic phases increases in proportion to the amount of iron and silicon [1-6]. The greater the number of such particles in the plastically deformed zone the more the local plasticity and fracture resistance are affected and so the crack propagation rate increases [1,8,10,13-15]. Consequently, the heterogeneity introduced to the microstructure by the intermetallic particles affects, to a great extent, the fatigue behaviour of the alloys.

The analysis of the fatigue fracture surfaces did not show conclusive results, since in the crack-initiation area of the alloys L1 and L4 no particles of intermetallic phases were found using the SEM. Such particles were found on the initial fracture area of the alloys L2 and L3 and identified as $(CuFeMn)Al_6$ and Mg_2Si. It seems, therefore, very probable that similar intermetallic particles were lost from the fracture of specimens L1 and L4 or that they remained on the sister fracture surface of the specimen.

Qualitative microstructural analysis can be used for a reliable analysis of the composition and a determination of the stoichiometry of intermetallic phases. In this case we calculated it on the basis of the intensity of the EDS spectra 1-4, considering the chemical composition of the alloys and relevant references [1,2,4,16] on phases in alloys of the same or similar type and composition. As a result, the phases are defined as the most probable.

5 CONCLUSION

The results of this investigation show that the greater the iron and silicon content in an Al-Zn-Mg-Cu alloy the lower is the endurance limit. On two of the fracture surfaces examined we found particles of intermetallic phases with SEM analyses at the crack-initiation point. We can conclude that the decrease in the endurance limit is due to these phases, which decrease the local ductility and strength of the alloys.

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