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# THE CHARACTERISATION OF Al-Si ALLOYS IN A THERMALLY TREATED STATE

## KARAKTERIZACIJA ZLITIN Al-Si ZA UPORABO PRI POVIŠANI TEMPERATURI

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The aim of this investigation was to demonstrate the influence of thermal treatment on the general characteristics of alloys for elevated-temperature application. The investigated alloy represent a very complex system. For the thermal treatment the $T_6$ treatment was used.

Key words: Al-Si alloys, intermetallic phases, corrosion potential, polarisation resistance, corrosion current

Cilj raziskave je bil dokazati vpliv toplotne obdelave na splošne karakteristike zlitine za uporabo pri povišani temperaturi. Raziskana zlitina ima kompleksno sestavo. Uporabljena je toplotna obdelava $T_6$.

Ključne besede: zlitine Al-Si, intermetalne spojine, korozijski potencial, polarizacijska upornost, korozijski tok

## 1 INTRODUCTION

Al-Si alloys are characterized by a low coefficient of linear expansion, a high hardness and a good resistance to wear. For these alloys it is important to improve the elevated-temperature properties and the goal of this study was to determine the influence of alloying elements such as cobalt, nickel, molybdenum and iron. In the previous study (1) the general characteristics of Al-Si alloys in the cast state were presented. In this paper the properties of these alloys in a thermally treated state are investigated.

The experimental work consisted of the determination of the chemical composition and of the mechanical properties in the thermally treated state at room and elevated temperatures (250 and 300 °C), as well as the investigation of the fracture morphology and the determination of corrosion characteristics.

## 2 EXPERIMENTAL WORK

The chemical compositions for the two alloys is shown in **Table 1.** The $T_6$ thermal treatment consisted of a 6 hours isothermal annealing at 520 ± 5 °C, cooling in warm water (70 °C), 7 hours ageing at the temperature 205 ± 5 °C, and air cooling. This thermal treatment regime according to references 2, 3 and 4 is one of the most commonly used. The mechanical-testing consisted of the determination of the tensile strength ($R_m$), relative elongation ($A$) and hardness (HB) at room temperature and the temperatures of 250 and 300 °C.

The examination of the microstructure involved a qualitative and a quantitative analysis. The phases were identified by their morphological characteristics and their chemical behavior during selective etching (10,11). The fracture surface was investigated with scanning electron microscopy with the aim to establish the effect of the constituents on the fracturing process. The corrosion resistance was determined in a 0.51 mol NaCl solution at room temperature with tests consisting of the determination the corrosion-potential change as a function of time, $E_{corr} = f(\tau)$, the polarisation resistance, $|R_p|$, and corrosion current, $|j_k|$.

**Table 1:** Chemical composition of the examined 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 |

## 3 RESULTS AND DISCUSSION

The results of the mechanical-tests at room and elevated temperature are presented in **Tables 2, 3 and 4**. After thermal treatment the mechanical properties are improved when compared to these of the as cast alloys, while the mechanical characteristics at elevated temperature are after thermal treatment lower than those of the as cast alloys.

**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. | 212.19 | 1.2 | 110 |
| 2. | 239.37 | 2.2 | 99 |

**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. | 185.7 | 0.80 | 110 |
| 2. | 162.8 | 1.30 | 100.75 |

**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. | 174.5 | 1.5 | 104 |
| 2. | 159.2 | 1.3 | 107.3 |

The constituents of the microstructure and the related stereological parameters are shown in **Table 5**. Most of the constituents are found also after thermal treatment, since, the thermal treatment influenced mostly the volume share of intermetalic phases.The microstructure of alloy 1 is shown in **Figures 1 to 3** and for alloy 2 in **Figures 4 to 7**. The microstructure of alloy 1 in the thermally treated state is characterised by rounded and coarse particles of eutectic silicon (the value of $L_{max}$ of

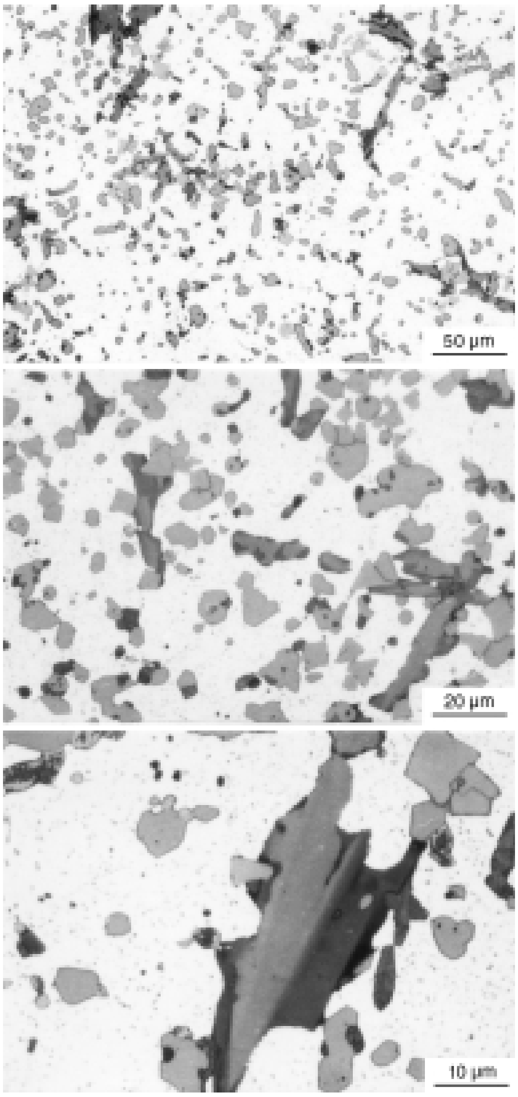

**Figure 1-3:** Microstructure of alloy 1
**Slike 1-3:** Mikrostruktura zlitine 1

**Table 5:** Type of $IMF_s$ present and the geometric parameter values determined by quantitative analysis
**Tabela 5:** Vrste intermetalnih spojin in njihovi geometrijski parametri, določeni s stereološko analizo

| Alloy No. | Phase type | $V_v$ (vol. %) | $L$ (µm) | $S_v$ (mm$^2$/mm$^3$) | $S_v/V_v$ (mm$^2$/mm$^3$) |
|---|---|---|---|---|---|
| | Eutectic Si | 11.91 | 3.487 | 136.59 | 1147.0 |
| | $Al_3Ni$ | 0.43 | 2.302 | 7.47 | 1737.8 |
| | $Cu_2Mg_8Si_6Al_5$ | + | + | + | + |
| 1. | $(FeMn)Al_3$* | 9.63 | 6.870 | 56.06 | 581.9 |
| | $(FeMn)_3Si_2Al_{15}$ | | | | |
| | AlFeMoSi | 4.09 | 5.190 | 31.50 | 770.7 |
| | $CuAl_2$ | + | + | + | + |
| | Primary Si | 1.09 | 21.58 | 2.03 | 185.3 |
| | Eutectic Si | 16.48 | 4.19 | 157.28 | 954.6 |
| | $Al_3Ni$ | 1.35 | 2.31 | 23.45 | 1732.1 |
| | $Cu_2Mg_8Si_6Al_5$ | 0.55 | 4.27 | 5.14 | 937.2 |
| 2. | $(FeMn)_3Si_2Al_{15}$ | - | - | - | - |
| | $(FeMn)Al_3$ + | | | | |
| | AlMnFeNi + | 2.87 | 6.39 | 17.98 | 625.94 |
| | AlFeMoSi | | | | |
| | $CuAl_2$ | - | - | - | - |

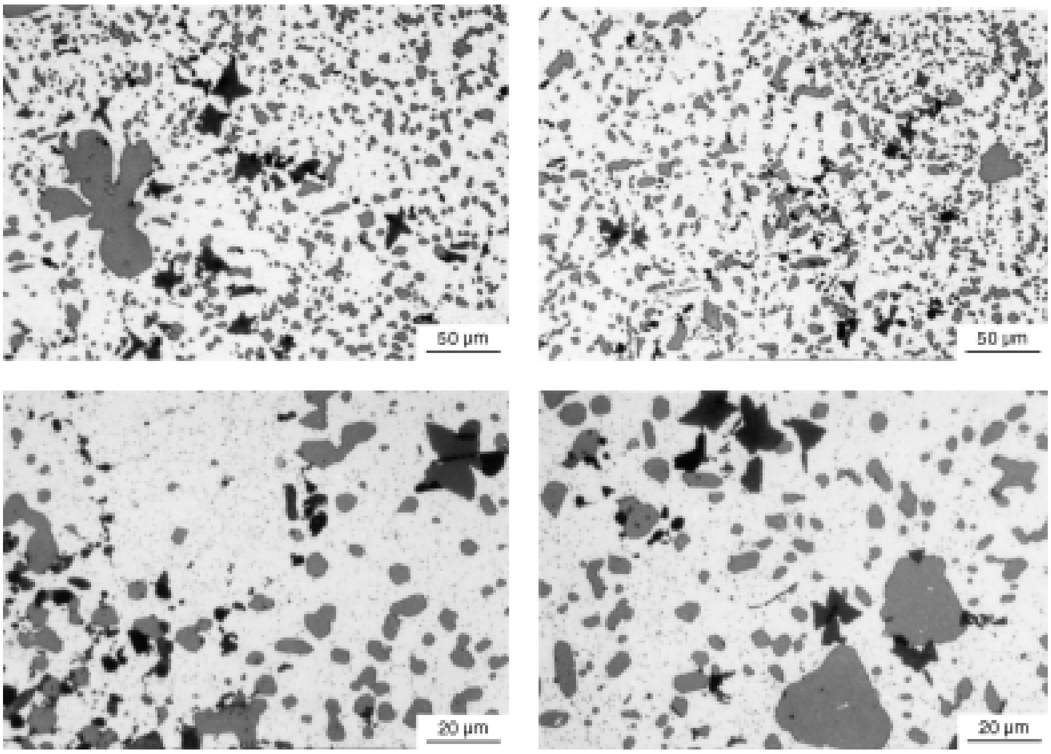


**Figure 4-7:** Microstructure of alloy 2
**Slike 4-7:** Mikrostruktura zlitine 2

aproximately 19 µm is for a factor of 5.4 greater than that for the same alloy in the cast state (**Figures 1-3**). The different nature of the undisolved phases with iron, as well as their quantity and dispersion are apparent. Coarse and partially rounded particles with a volume share of $V_v$ = 9.63 vol % have after etching an inhomogeneus coloration (**Figures 1-3**). This may lead to the conclusion that at the boundary area of the particles of the $(FeMn)Al_3$ phase is enriched in nickel and partially transformed in some of the phases based on nickel, f.i. AlCuNi or AlFeNi. The copper phases ($CuAl_2$ and $Cu_2Mg_8Si_6Al_5$) are almost entirely dissolved after heat treatment. The undissolved particles are small, rounded and rare (**Figure 3**).

The microstructure of the alloy 2 after thermal treatment consists of coarse eutectic silicon particles (*L* = 4.2 µm) (**Figures 4, 5**), and black particles (**Figures 6 and 7**). The number of primary silicon particles was three times smaller. It is not related to the thermal treatment but to solidification and due to the great propensity of silicon to liquation solidification. This conclusion is confirmed with the difference in the quantity of iron and nickel intermetallic phases.

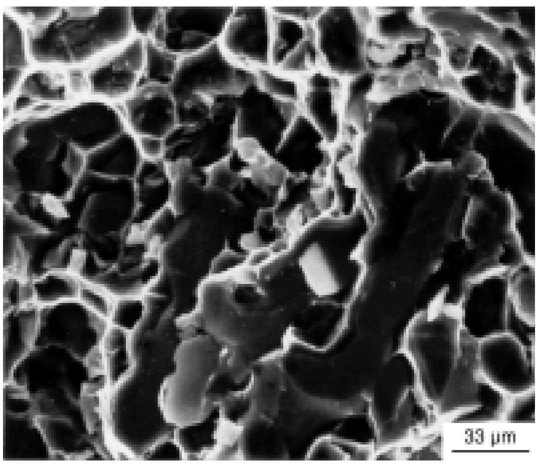


**Figure 8:** Fracture surface for alloy 1. Tensile-test temperature of 250 °C
**Slika 8:** Prelomna površina zlitine 1. Temperatura preizkusa 250 °C

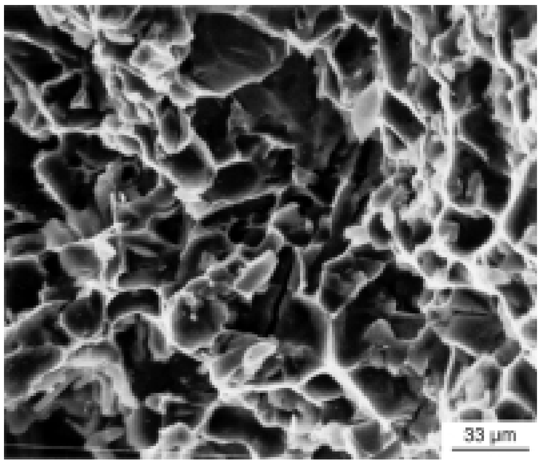


**Figure 9:** Fracture surface for alloy 1. Tensile-test temperature of 300 °C
**Slika 9:** Prelomna površina zlitine 1. Temperatura preizkusa 300 °C

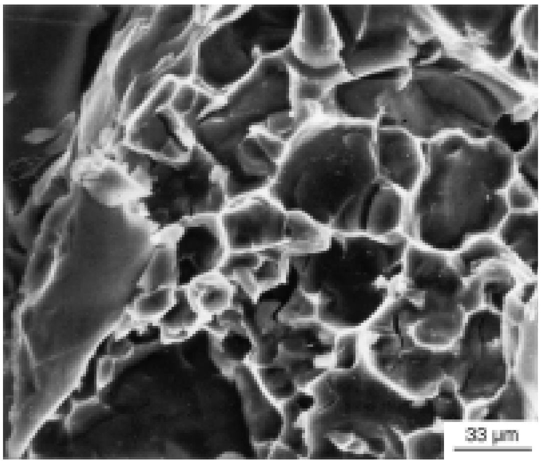


**Figure 10:** Fracture surface of alloy 2 at 250 °C
**Slika 10:** Prelomna površina zlitine 2 pri 250 °C

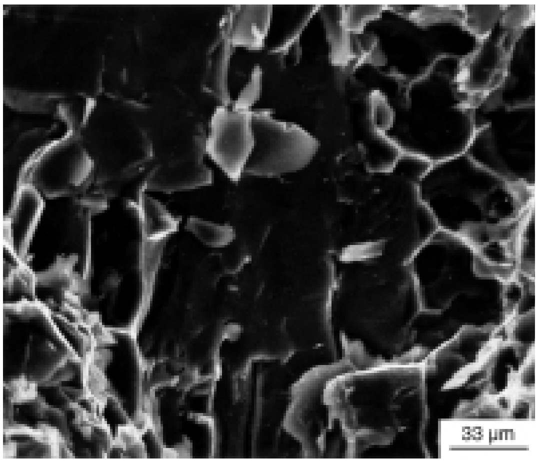


**Figure 11:** Fracture surface of alloy 2 at 300 °C
**Slika 11:** Prelomna površina zlitine 2 pri 300 °C

At isothermal annealing the phase $Cu_2Mg_8Si_6Al_5$ was partially dissolved and it volume share in the microstructure was diminished.

The fracture morphology of alloy 1 at elevated temperatures (250 °C and 300 °C) is shown in **Figures 8-11**. The fracture micromorphology after thermal treatment of the alloy 1 at 250 °C and 300 °C is similar to that in the as cast state, but with deeper and more numerous hollows due to the exstracted coorse eutectic silicon particles. The fracture starts on the larger particles at a lower deformation level and in this case the hollows evolve in greater deformation range than in the case small-particle fracture.

In some of the hollows particles of iron phases as well as some manganese and molybdenum phases were found (**Figures 8, 9, 11**). The coarse particles, probably the intermetalic phase $(FeMn)Al_3$), show a greater resistance to fracture (**Figures 10, 11**).

Some data on the corrosion-behavior of the heat treated alloy 1 in the 0.51 mol NaCl solution, obtained using corrosion potential vs. time method as well as the

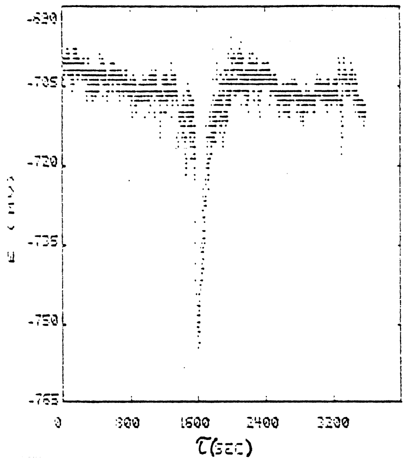


**Figure 12:** Change of corrosion potential in the 0.51 mol NaCl solution as a function of time $E_{corr} = f(\tau)$ for alloy 1. The potential after 3600 s is -691 mV relative to ZKE
**Slika 12:** Sprememba korozijskega potenciala v raztopini NaCl 0,51 mol v odvisnosti od časa $E_{corr} = f(\tau)$. Po 3600 s je potencial proti ZKE -691 mV

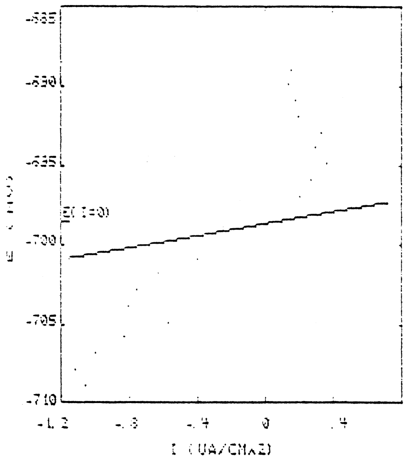

**Figure 13:** Polarisation resistance ($R_p$) and corrosion curent ($j_k$) in the 0.51 mol NaCl solution for alloy 1, scan velocity of 1 mV/s ($R_p$ = 9.65 kΩ, $j_k$ = 2.25 µA/cm$^2$)
**Slika 13:** Polarizacijska upornost ($R_p$) in korozijski tok ($j_k$) za zlitino 1 v raztopini NaCl 0,51 mol. Hitrost skeniranja 1 mV/s ($R_p$ = 9,65 kΩ, $j_k$ = 2,25 µA/cm$^2$)

**Table 6:** Values obtained from tests of the corrosion potential [$E_{corr} = f(\tau)$]
**Tabela 6:** Rezultati določanja korozijskega potenciala [$E_{corr} = f(\tau)$]

| Alloy No. | $E_{corr}$-start | $E_{corr}$-final | Concen-tration | Tempera-ture |
|---|---|---|---|---|
| 1. | -700 | -170 | 0.51 | 32 |

**Table 7:** Values obtained from tests of the polarisation resistance
**Tabela 7:** Rezultati določanja polarizacijske upornosti

| Alloy No. | $E_{corr}$ (mV) | $E(I=0)$ (mV) | $R_p$ (kΩ) | $j_k$ (µA/cm$^2$) | Concen-trat. NaCl (mol) | Tem-perat. (°C) |
|---|---|---|---|---|---|---|
| 1. | -692 | -701 | 1.9635 | 11.06 | 0.51 | 32 |

polarisation resistance ($R_p$) and corrosion-current ($j_k$) method are shown in **Tables 6 and 7**.

**Figures 12 and 13** present the change of the corrosion potential as a time function $E_{corr} = f(\tau)$ as well as the polarisation resistance ($R_p$) and the corrosion current ($j_k$) for alloy 1. The thermal treatment of alloy 1 leads to some structural changes that are not beneficial for the corrosion characteristics. **Table 6** presents the change in the corrosion potential towards negative values relatively to the as cast state. The value of the polarisation resistance is significantly reduced and the value of the corrosion current is increased (**Table 7**).

The examination shows that the thermal treatment's influence on the corrosion behavior was not beneficial and that excludes the use of this treatment for the preparation of corrosion-resistant alloys.

## 4 CONCLUSION

The thermal treatment has a beneficial influence on the mechanical-characteristics, but it has also a deleterious effect on the corrosion stability. Therefore, the proper choice of chemical composition and the production technology ares of great importance.

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