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EXAMINATION OF THE INFLUENCE OF CHEMICAL COMPOSITION ON PROPERTIES OF Al-Si ALLOYS AS CAST AT ROOM AND ELEVATED TEMPERATURES

RAZISKAVA VPLIVA KEMIČNE SESTAVE NA LASTNOSTI ZLITIN AlSi PRI SOBNI IN POVIŠANI TEMPERATURI

Darko Vuksanović[1], Snežana Rakočević[2], Kata Kovačević[3], Snežana Tripković[4], Branka Bošnjak[1]

[1]University of Montenegro, Faculty of Metallurgy and Technology, Cetinjski put bb, 81000 Podgorica, Serbia and Montenegro
[2]University of Montenegro, Library of Technical Faculties, Cetinjski put bb, 81000 Podgorica, Serbia and Montenegro
[3]Institute for Ferrous Metallurgy, 83000 Nikšić, Serbia and Montenegro
[4]H. K. "Petar Drapšin", 11400 Mladenovac, Serbia and Montenegro
darkov@cg.ac.yu

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Good strength makes the Al-Si cast alloys suitable for wide application also at elevated temperature. These alloys have a widespread use in automobile industry, primarily for components of internal combustion engines. It was found that the individual content of alloying elements and their interaction influence to a great extent the microstructure and the mechanical characteristics of examined alloys. In the multi-phase microstructure at particles of intermetallic phases microcracks are generated and cause a brittle fracture surface with small ductile inserts.

Key words: cast Al-Si alloys, mechanical properties, microstructure, fracture morphology, intermetallic phases

Zaradi dobre trdnosti se lite zlitine AlSi uporabljajo tudi pri povišani temperaturi. Zlitine se mnogo uporabljajo v avtomobilski industriji, predvsem za dele motorjev z notranjim zgorevanjem. Ugotovljeno je bilo, da vsebnost posameznih elementov in njihova interakcija močno vplivata na mikrostrukturo in lastnosti zlitin. V mikrostrukturi iz več faz razpoke v intermetalnih fazah ali ob njih povzročajo krhek prelom z majhnimi vložki duktilne dekohezije.

Ključne besede: lite zlitine Al, mehanske lastnosti, mikrostruktura, mikromorfologija preloma, intermetalne faze

1 INTRODUCTION

Cast aluminium silicon alloys play a significant part in the increasing interest for aluminium and its alloys. These alloys are intended also for use at elevated temperature, for this reason, significant efforts are aimed to the improvement of their heat resistance and stability at elevated temperature.

In this paper alloys with a large number of alloying elements are discussed with relation to alloys of standard composition. In industry the presence of different non controlled elements makes more difficult to obtain alloys with suitable composition and properties.

In the investigated alloys the silicon content varied from hypoeutectic to hypereutectic levels and inoculation was applied to improve the properties. As modifier, a strontium based prealloy was used which, apart from the inoculation effect, has also the role of dimension stabilizer at elevated temperature.

The experimental work consisted of the determination of the chemical composition, as cast mechanical properties at room temperature and at the temperature of 250 °C and 300 °C as well as of observations of microstructure and of fracture morphology.

2 EXPERIMENTAL

The alloys were prepared in an electric resistance furnace with melting in a carbon crucible. The chemical composition was determined with a X-RAY quantometer calibrated for this type of alloys.

For the testing of mechanical properties at room and the temperature of 250 °C and 300 °C three types of samples and test bars were used, depending on the type of testing. The testing of mechanical properties consisted of the determination of tensile strength, relative elongation and hardness at room and elevated temperatures, as well. Tensile strength and relative elongation were determined with the machine "1195 INSTRON" in Aluminium Plant in Podgorica, whereas the tests at elevated temperature were carried out using the AMSLER tensile testing machine MG EMC in Ltd Company "Petar Drapšin" in Mladenovac. Brinell hardness was determined using the standard procedure.

The microstructure and the fracture morphology were examined in the electron probe microanalyser.

3 RESULTS AND DISCUSSION

The chemical composition testing of the investigated alloys is in **Table 1**. It covers a large range of compo-

Table 1: Chemical composition of examined alloys
Tabela 1: Kemična sestava raziskanih zlitin

Alloy No	Si (%)	Cu (%)	Be (%)	Fe (%)	Mo (%)	Ni (%)	Co (%)	Mg (%)	Mn (%)	Sr (%)
1.	10,90	1,40	0,25	0,50	0,20	0,834	0,40	0,881	0,154	0,048
2.	11,30	1,32	0,25	1,20	0,45	0,598	0,75	1,275	0,256	0,050
3.	13,79	1,34	0,25	1,23	0,20	1,142	0,60	1,430	0,268	0,040
4.	12,68	1,25	0,25	0,86	0,25	0,655	0,60	1,370	0,258	0,045
5.	11,00	0,98	0,25	0,62	0,20	1,049	0,90	1,071	0,177	0,040
6.	12,63	1,32	0,25	0,73	0,20	0,360	0,35	1,290	0,109	0,048
7.	12,10	1,23	0,25	0,77	0,25	1,031	0,70	0,799	0,326	0,050
8.	10,70	1,20	0,25	0,43	0,45	0,644	0,90	1,350	0,197	0,050
9.	12,50	1,32	0,25	1,04	0,20	1,023	0,50	1,400	0,169	0,055
10.	11,55	1,20	0,25	0,59	0,33	0,606	0,50	1,420	0,170	0,045
11.	11,02	1,20	0,25	0,44	0,25	0,737	1,00	0,791	0,109	0,040
12.	10,88	1,31	0,25	0,61	0,25	0,440	0,75	0,805	0,165	0,050

sitions with a great number of alloying elements. The silicon content is in the range from 10,9 % to 13,79 % and the content of other alloying elements at a level, which allows to discern the effect of microstructural phases with a significant influence on alloys properties. The mechanical properties at room temperature are given in **Table 2** and the properties at the temperatures of 250 °C and 300 °C are given in **Tables 3 and 4**.

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.	244	0,8	128
2.	201	0,5	124
3.	167	0,5	125
4.	203	0,3	121
5.	196	0,3	128
6.	204	1,3	121
7.	264	0,5	138
8.	216	0,3	132
9.	217	0,8	128
10.	191	0,8	124
11.	271	1,0	138
12.	231	0,8	124

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.	164	1,40	124
2.	199	1,30	120
3.	170	1,40	128
4.	180	1,40	123
5.	194	1,70	123
6.	192	1,53	128
7.	225	1,00	120
8.	200	1,00	128
9.	202	1,20	138
10.	187	0,80	130
11.	230	1,40	120
12.	210	1,10	118

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.	150	1,70	125
2.	185	1,40	135
3.	161	1,45	135
4.	170	1,50	130
5.	186	1,80	125
6.	181	1,70	135
7.	202	1,20	120
8.	191	1,40	135
9.	197	1,40	130
10.	180	1,45	135
11.	212	1,20	123
12.	199	1,45	128

The mechanical properties as cast alloys at room temperature show different values of given characteristics and reflect the effect of the chemical composition of alloys. By tensile tests no yield point ($R_{0,2}$) was discerned due to the brittle fracture of tensile specimens. It should be noted that in terms of application, the absence of yield strength is without significant influence on the use of the alloys.

The mechanical properties at elevated temperature of 250 °C and 300 °C are high and indicate to an adequate choice of chemical composition, primarily the addition of nickel and cobalt which improve the heat resistance. Characteristic for all alloys is the increased relative elongation at both elevated temperatures in relation to that at room temperature, sign of increased ductility at higher temperature.

For microstructural investigation alloys 3,7 and 11 were chosen because characteristic in terms of chemical composition and mechanical properties. The microstructure of the alloys is shown in **Figures 1-3**.

In alloy 3 with the highest content of silicon and iron the microstructure is hypereutectic (**Figure 1**) and it consists of primary particles of silicon, rod-like iron based particles, α-solid solution, eutectic, in which also

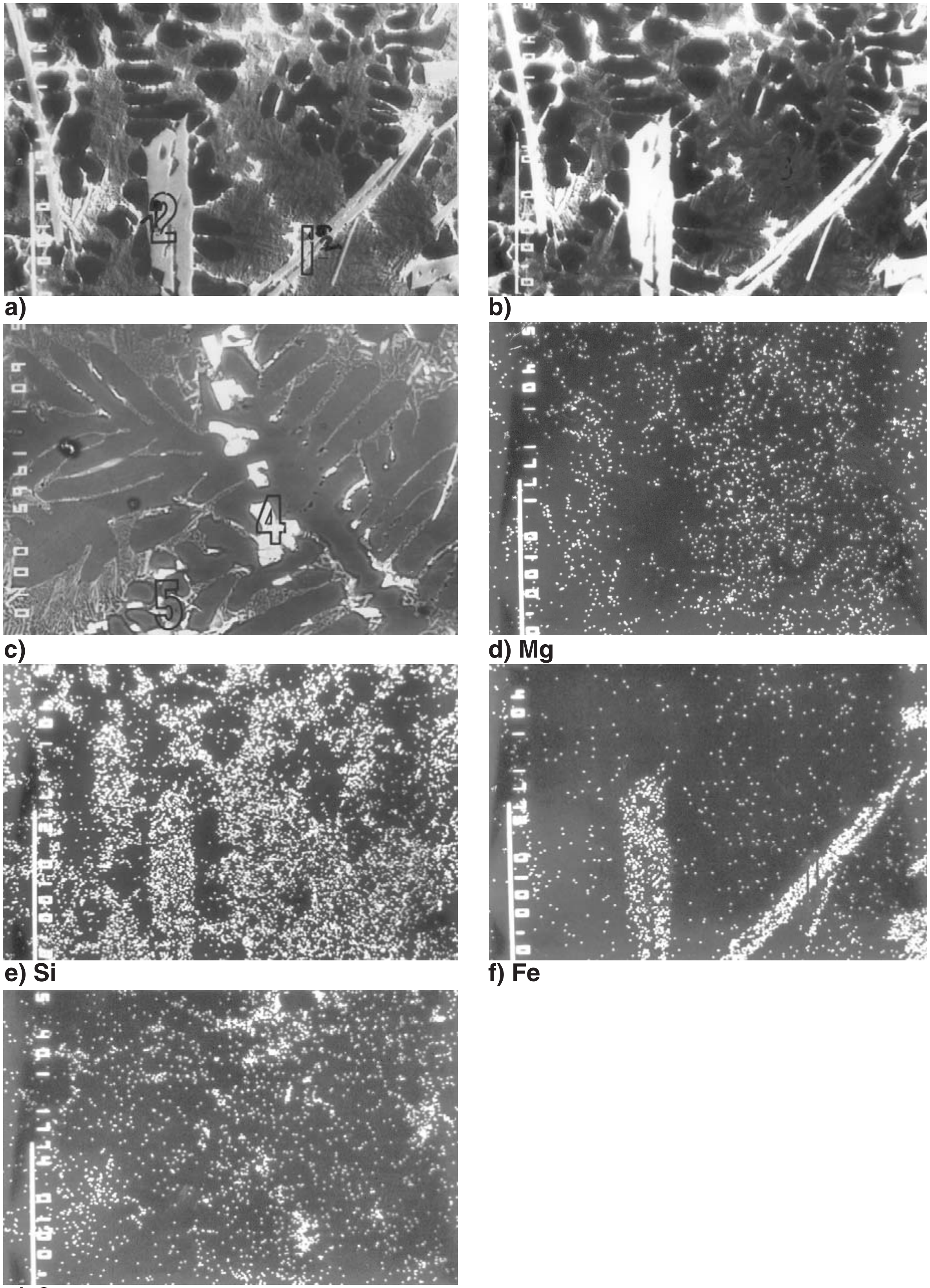

Figure 1: Microstructure of the as cast alloy 3 (a, b, c). Etched with 0.5 % HF, magn. 400 x (a, b) and 600 x (c). X mapping of elements: d-Mg, e-Si, f-Fe, g-Cu. Marks: 1-Fe_3SiAl_{12}, 2-$Fe_2Si_2Al_9$, 3-Mg_2Si, 4-$Cu_2Mg_8Si_6Al_5$, 5-$CuAl_2$

Slika 1: Mikrostruktura lite zlitine 3 (a, b, c). Jedkano z 0,5 % HF, pov. 400-kratna (a, b) in 600-kratna (c). Specifična rentgenska slika za elemente: d-Mg, e-Si, f-Fe, g-Cu. Označbe: 1-Fe_3SiAl_{12}, 2-$Fe_2Si_2Al_9$, 3-Mg_2Si, 4-$Cu_2Mg_8Si_6Al_5$, 5-$CuAl_2$

particles of the phase $Cu_2Mg_8Si_6Al_5$ are found (mark 4). Primary silicon particles are mostly of irregular shape, while the phase $Cu_2Mg_8Si_6Al_5$ is found as cluster of particles, in dendrites or in the form of greek letters (**Figure 1**). From the copper distribution it is concluded that the phase $Cu_2Mg_8Si_6Al_5$ (mark 4) is mostly an eutectic constituent, while, in dendrites at grain boundaries the phase $CuAl_2$ is found (mark 4).

Iron is found in form of rods of different size and different iron content. **Figure 1** shows that in some rod-like particles the iron content is higher and that leads to the conclusion that several iron containing phases are present in the alloy, probably the phases Fe_3SiAl_{12} (mark 1) and $Fe_2Si_2Al_9$ (mark 2) and $FeSiAl_5$.

In the multi-phase eutectic particles of the Mg_2Si phase (mark 3) with irregular shape or in the form of greek letters are found (**Figure 1**). The presence of copper, to a certain extent, as phase $CuAl_2$ (mark 5) cannot be excluded, also. The microstructure of the alloy 7 (**Figure 2**) is typically hypereutectic with a multi-phase eutectic. In the near surface region the microstructure consists of fine and globular dendrites of α-solid solution (sign 6), a dual eutectic (α-solid solution + Si) and a multi-phase eutectic.

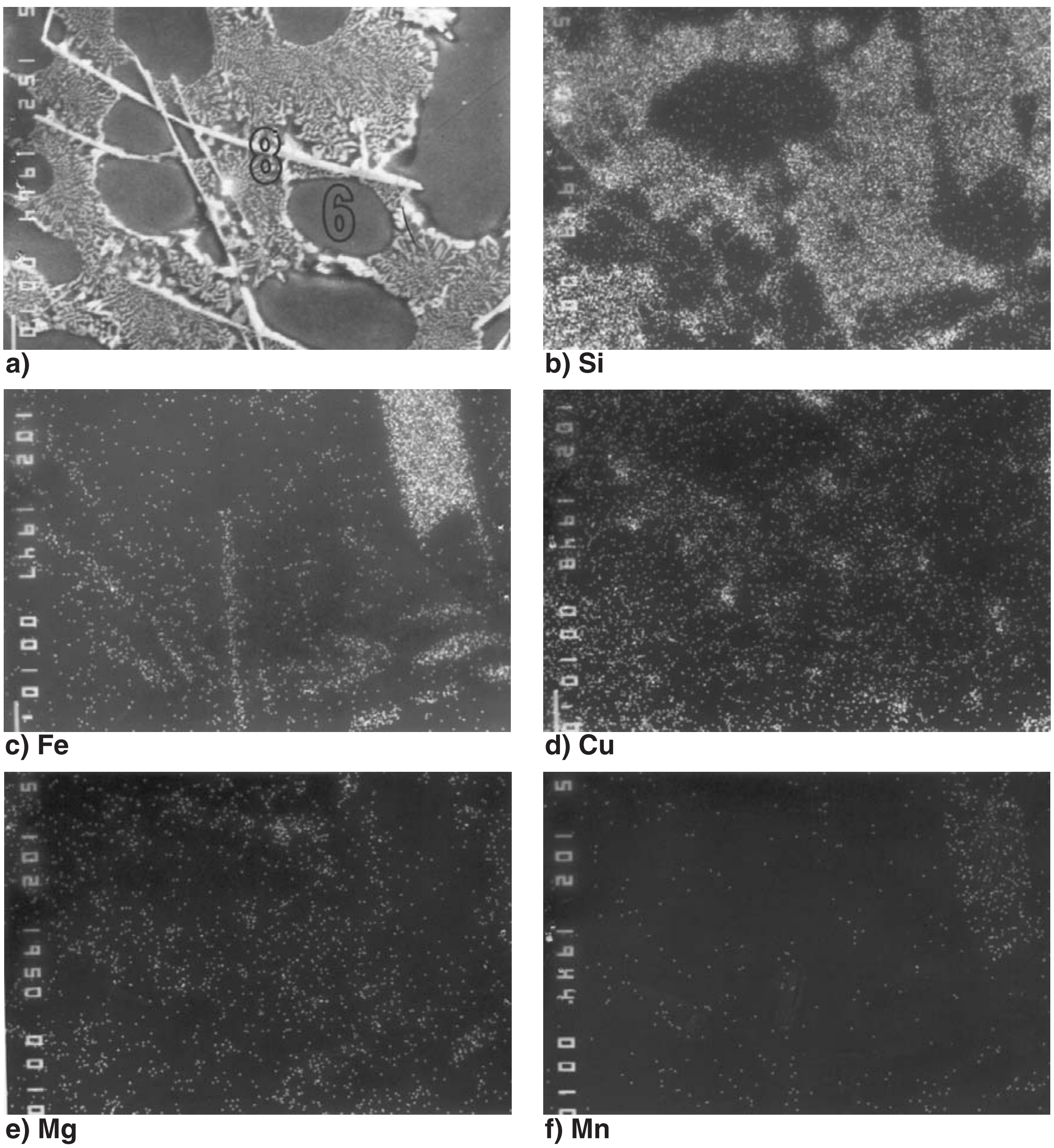

Figure 2: Microstructure of the as cast alloy 7. Etched with 0.5 % HF, magn. 1500 x (a). X mapping of elements: b-Si, c-Fe, d-Cu, e-Mg, f-Mn. Marks: 6-α solid solution, 7-FeMn, 8-$FeSiAl_5$

Slika 2: Mikrostruktura lite zlitine 7. Jedkano z 0,5 % HF, pov. 1500-kratna. Specifična rentgenska slika za elemente: b-Si, c-Fe, d-Cu, e-Mg, f-Mn. Označbe: 6-α solid solution, 7-FeMn, 8-$FeSiAl_5$

With addition of strontium silicon phases are modified primary and appear in form of particles of irregular shape at the boundary of eutectic areas (**Figure 2**). The eutectic consists of particles of phases $CuAl_2$ and Mg_2Si.

Long and thin rods are the b-phase containing iron (mark 8) and manganese (**Figure 2**). According to previous results and data in reference [1], this phase is active in the convertion of the $FeSiAl_5$ phase to a less deteriorating phase $(FeMn)Al_3$ and it is especially significant by an iron content above 0,45 mas % and the ratio Fe:Mn 2:1, which was achieved in some of the investigated alloys.

The microstructure of the alloy 11 is shown in **Figure 3**. Due to the low iron content rod-like particles of b-phase are absent. The microstructure consists mostly of dendrites of α-solid solution and eutectic. Iron and copper are found in the eutectic as a more elements phase of the type AlCuFeNi. Dark Mg_2Si particles are also found in eutectic areas.

According to literature data and the previous research[2] phases with molybdenum, cobalt and nickel were also expected in some of the investigated alloys.

Previous results [3] have shown that the brittleness of Al-Si alloys is decreased if the addition of cobalt is sufficient for the formation of the $(CoFe)_2Al_9$ phase. The

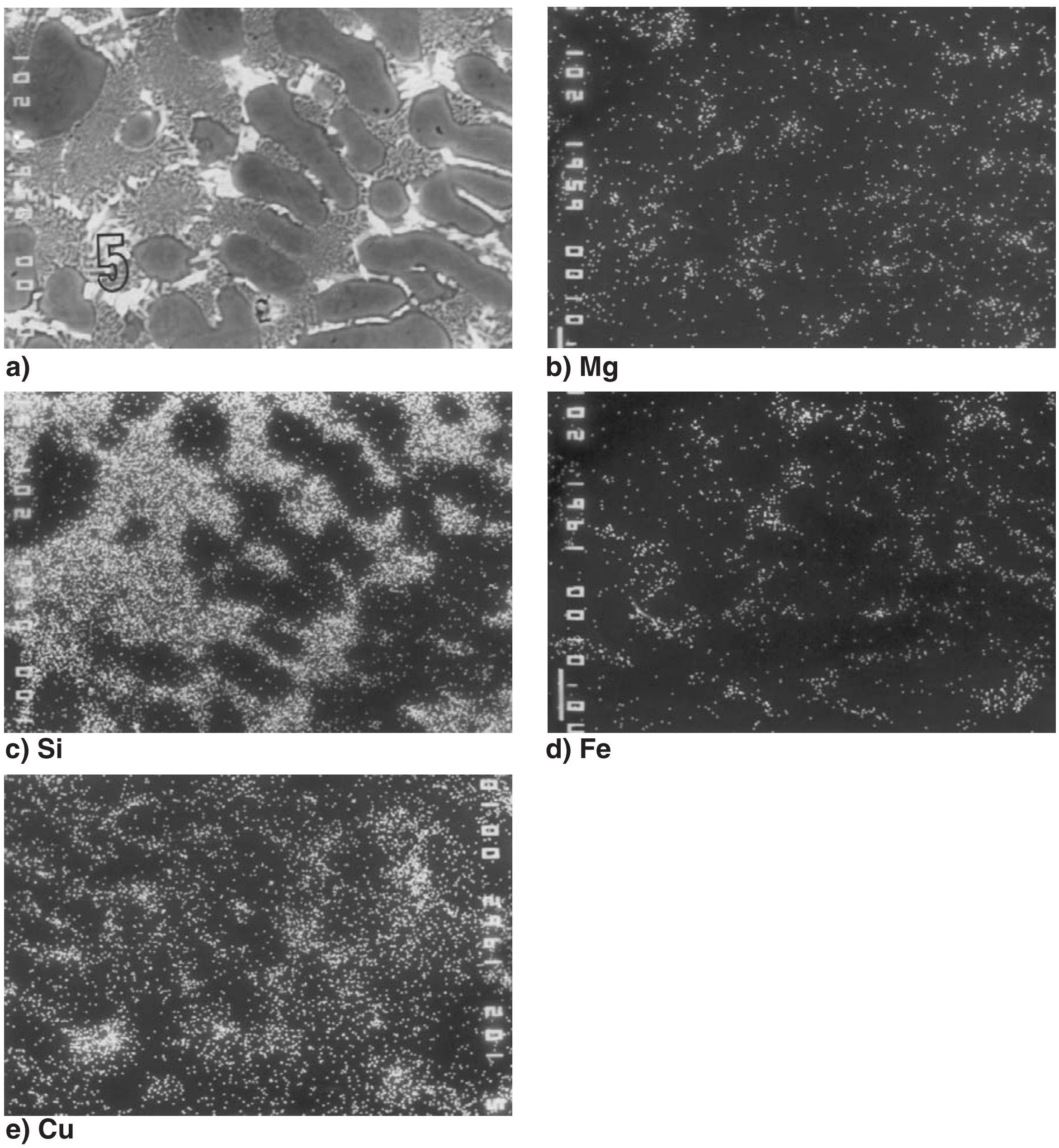

Figure 3: Microstructure of the as cast alloy 11. Etched with 0.5 % HF, magn. 1000 x. X mapping of elements: b-Mg, c-Si, d-Fe, e-Cu
Slika 3: Mikrostruktura lite zlitine 11. Jedkano z 0,5 % HF, pov. 1000-kratna. Specifična rentgenska slika za elemente: b-Mg, c-Si, d-Fe, e-Cu

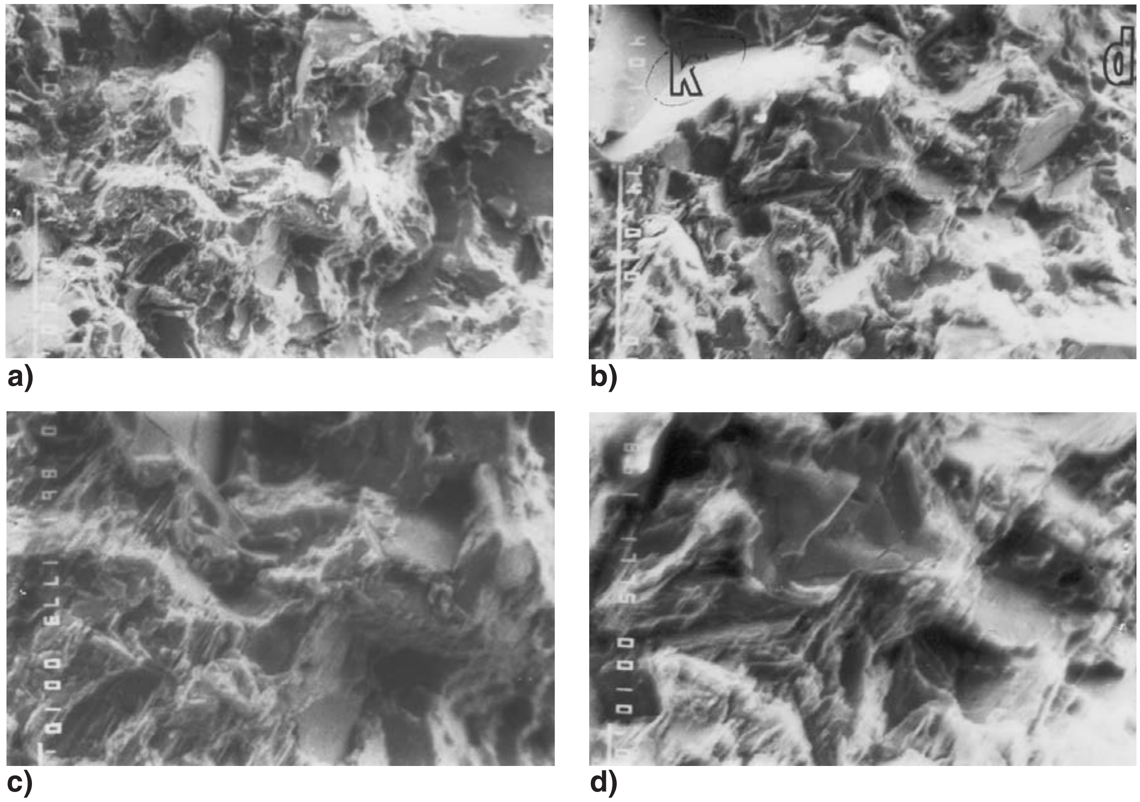

Figure 4: SEM micrograph of the fracture of the as cast alloy 3, magn. 400 x (a, b) and 860 x (c, d). Testing temperature 250 °C, k-brittle fracture, d-ductile fracture

Slika 4: SEM-posnetek preloma lite zlitine 3, pov. 400-kratna (a, b) in 860-kratna (c, d). Temperatura preizkusa 250 °C, k-krhki prelom, d-duktilni prelom

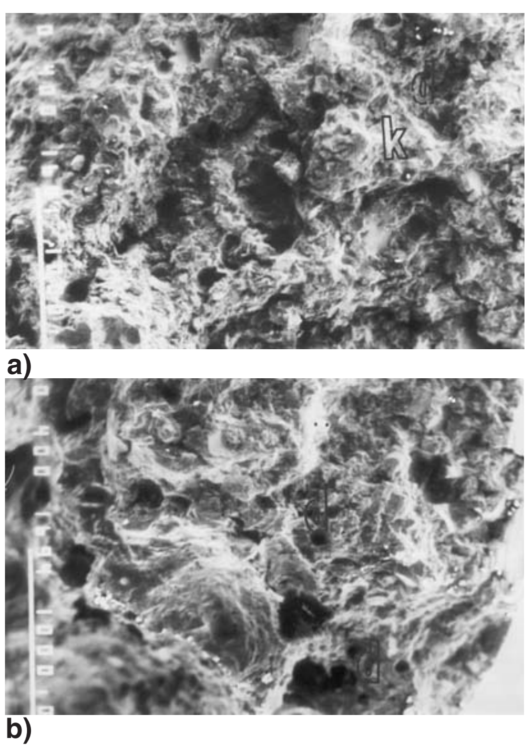

Figure 5: SEM microfraph of the fracture of the cast alloy 7, magn. 40 x. Testing temperature 20 °C (a) and 250 °C (b)

Slika 5: SEM-posnetek lite zlitine 7, pov. 40-kratna. Temperatura preizkusa 20 °C (a) in 250 °C (b)

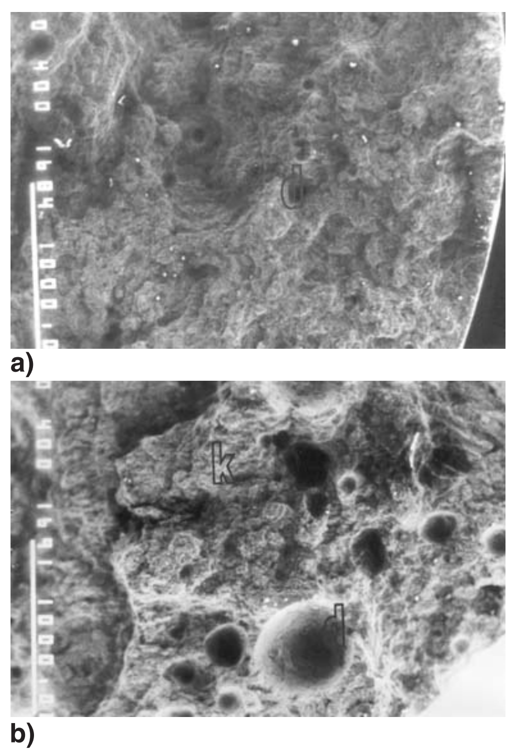

Figure 6: SEM micrograph of the fracture of the cast alloy 11, magn. 40 x. Testing temperature 20 °C (a) and 250 °C (b)

Slika 6: SEM-posnetek preloma lite zlitine 11, pov. 40-kratna. Temperatura preizkusa 20 °C (a) in 250 °C (b) presence of nickel to 1 mas % in solid solution can result in displacement of the equilibrium and the formation of the dual eutectic $FeAl_3$ + Co_2Al_9. Thus, the quantity of the formed phases depends strongly on the cobalt and nickel content, since these elements do not bind with silicon to intermetallic phases.

For molybdenum, it is reported [4] that it is bound to ternany AlFeMo or quaternany AlFeMoSi phases which displace the equilibrium. No data on the morphology and the corrosion behaviour of these phases were found.

The fracture surfaces of alloy 3 fractured at 250 °C consist of areas of transcrystalline and intercrystalline brittle fracture (**Figure 4 and 5**) as well as sporadic inserts of ductile fracture with typical dimples. The brittle fracturing is due mostly to the cracking of primary silicon particles, however, it can be also triggered by the presence of the iron phase which, because of its rod-like shape and size is a potential place for the initiation of micra cracks.

The presence of areas of ductile decohesion in a still predominantly brittle surface of the alloy 11 in **Figure 6** is due probably to the absence of the primary rod-like brittle b-phase.

4 CONCLUSION

Based on experimental results it is concluded that the mechanical properties at room and elevated temperatures depend on the chemical composition of the alloys. Each alloying element and their combination significantly affect the microstructure and the mechanical properties. Qualitative analysis shows that the microstructure consists of great number of phases with complex chemical composition. The fracture of all alloys is brittle with inserts of ductile decohesion. At increased temperatures the alloys have good mechanical properties, which are different for different alloys and depend on the chemical composition, especially the content of nickel and cobalt.

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