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Complex silumins

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Materials

ABSTRACT

Purpose: The study presents the results of investigations carried out on silumins with additions of Mg, Ni, Cu, Cr, Mo and W. The silumins containing Mg, Cu and Ni are well-known and commonly used in construction of machines and equipment.

Design/methodology/approach: Additions of Cr, Mo and W have not been thoroughly investigated yet. They are considered a new family of innovative cast aluminium alloys.

Findings: In Al-Si systems they form silicides, like Cr_3Si, Mo_3Si, W_3Si and intermetallic phases of $Al1_3Cr_4Si_4$, $Al_{12}Mo$, $Al_{12}W$ and AlWSi. The silicides crystallise in cubic lattice of parameters similar to aluminium and silicon.

Research limitations/implications: Therefore they can act as crystallisation substrates and occur as separate phases. The examinations under the microscope and X-ray microanalysis of the linear and point distribution of elements confirmed the presence of the above mentioned phases. A combination of two elements, e.g. Cr and Mo, or Cr and W, was observed to cause the formation of complex silicide layers of Mo_3Si and $(Cr, Mo)_3Si$, or Cr_3Si as well as $(W, Cr)_3Si$.

Originality/value: The presence of the silicides has been indicated as a possible source of the refinement of α(Al) and β(Si) phases. The precipitations of these phases and of the intermetallic phases favour a high degree of the silumins hardening. A characteristic feature is the fact that nucleation and crystallisation of the successive phases takes place at the phase boundaries formed between the previously precipitated phase and solid solution α. The studies carried out so far have indicated that in complex silumins at high temperatures crystallise the silicides and peritectic phases of $Al_{12}W$, AlWSi, $Al_{12}Mo$ and $Al_{13}Cr_4Si_4$. Phases α or β are the next ones to crystallise, followed by complex eutectic α + β +Al(Si, Cr, Mo, W, Fe). Further crystallise the phases of Mg_2Si, Al_3Ni and Al_2Cu. The silumins presented here are characterised by high mechanical properties: $R_{p0,2}$=320-420MPa, R_m =400-520MPa, A_5=0.5-5.0% and elevated hardness of 145-210HB. Further investigations will be carried out to optimise the chemical composition of silumins and the precipitation hardening process parameters to produce alloys characterised by optimum combination of strength, ductility and hardness.

Keywords: Metalic alloys; Silumins; Silicides; Intermetallic phases; Proof stress; Ultimate tensile strength

1. Introduction

Complex silumins used most often in construction of machines and equipment have the following chemical composition: 2,00÷23,00% Si, 0,00÷4,00% Cu, 0,00÷1,50% Mg, 0,00÷1,50%Ni, 0,00÷1,30% Fe, 0,00÷2,00% Zn, 0,00÷0,10% Sn, 0,00÷0,55% Pb, 0,00÷0,20% Co, 0,00÷0,25% Ti. In raw condition or after precipitation hardening their mechanical properties are comprised within a range of the following values: $R_{p0,2}$ = 90÷260 MPa, R_m =1 50÷350 MPa, A_5 = 0,5÷5,0% and HB = 50÷110 [1].

The investigations carried out so far have indicated that the mechanical properties of silumins can be improved by introducing the additions of Cr, Mo or W. These are the elements characterised by high melting points, viz. Cr=1890°C, Mo=2625°C and W = 3410°C. The only way in which these elements can be introduced to silumins is in the form of "master alloys", like AlCr, AlMo, AlW, or their combinations containing 2÷5% of these elements. Hardening of silumins takes place through the formation of new phases and refinement of the dendrites in α(Al) phase and of crystals in β(Si) phase. These effects will take place either when the growth is impeded, or when new crystallisation substrates are provided. One of the conditions indispensable for the formation of crystallisation substrate and the phase growth is a consistency between the crystallographic lattice and its parameters, in most cases not exceeding the value of 25% (usually it is below 15%). Chromium, molybdenum and tungsten in Al-Si alloys form silicides of Cr_3Si, Mo_3Si and W_3Si, respectively. Tungsten is also prone to formation of complex phases of AlWSi [1-3].

Table 1 shows the type of the crystallographic lattice commonly encountered in aluminium, silicon, and silicides with the respective parameters.

Table 1.
The type of the crystallographic lattice, its parameters and the density of Al, Si, Cr_3Si, Mo_3Si, W_3Si

No.	Phase	Lattice	Parameters, Ä	Density, g/cm^3
1	Al	cubic	4,0414	2,6984
2	Si	cubic	5,4199	2,3283
3	Cr_3Si	cubic	4,6200	6,4500
4	Mo_3Si	cubic	4,8780	8,970
5	W_3Si	cubic	4,9100	—

In literature there is nearly no information on the characteristics of AlWSi phase. From the presented data it follows that the crystallisation substrates for phases α and β can be silicides. Irrespective of this, they can also occur as independent phases. As a consequence, their presence should cause hardening of silumins.

Therefore, the aim of this study was to investigate the effect of Cr, Mo and W on the microstructure of silumins and the resulting mechanical properties. Investigations were made on a hypereutectic silumin containing about 17,0% Si, on a nearly-eutectic silumin with 12,3% Si, and on a hypoeutectic silumin containing about 6,5% Si.

2. The results of investigations

Figure 2 shows the microstructure with measuring length (a) and a linear distribution of Si, Mg (b), Cr, Mo (c) and Ni, Cu (d) in hypereutectic silumin.

The microstructure shows that in the central part of the largest crystal there is a light- coloured zone of elevated chromium

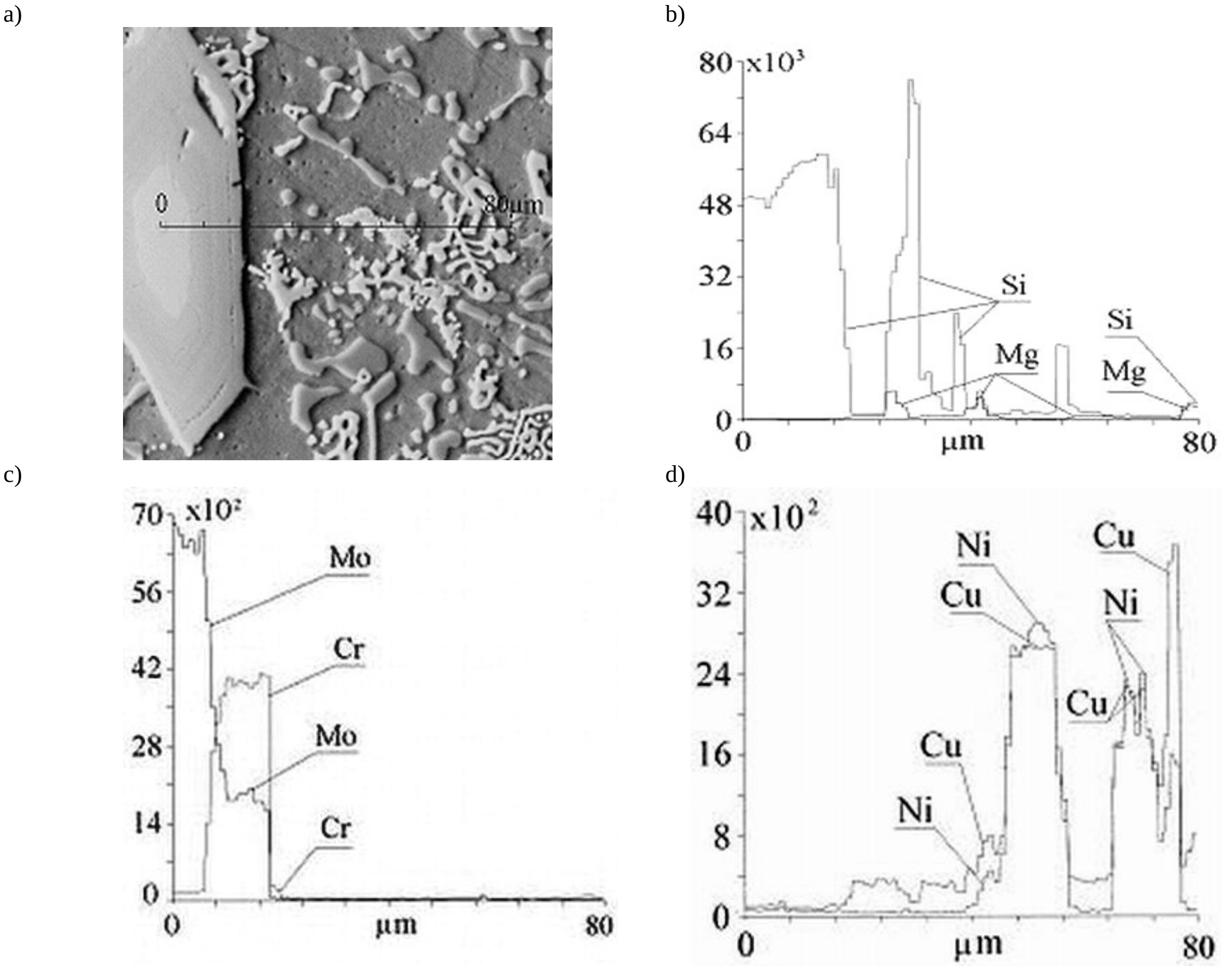
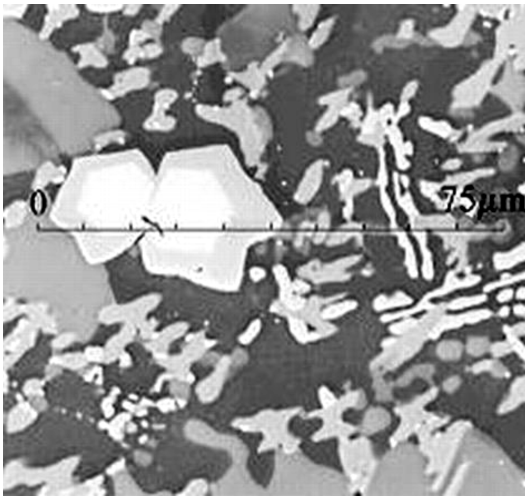
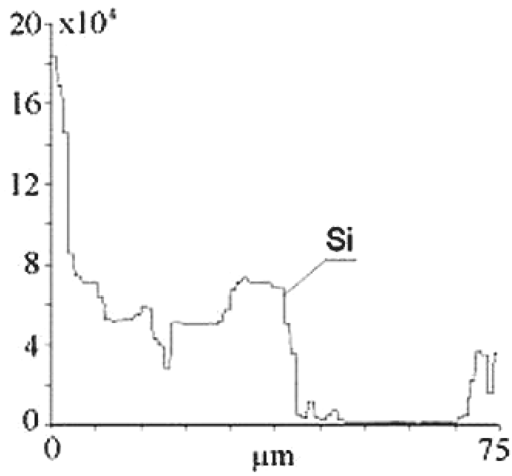


Fig. 1. Microstructure (a) and linear distribution of Si, Mg (b), Cr, Mo (c) and Ni, Cu (d) in AlSi17Mg1,3Ni3,5Cu3,8Cr0,5Mo0,4 silumin

a)



b)



c)

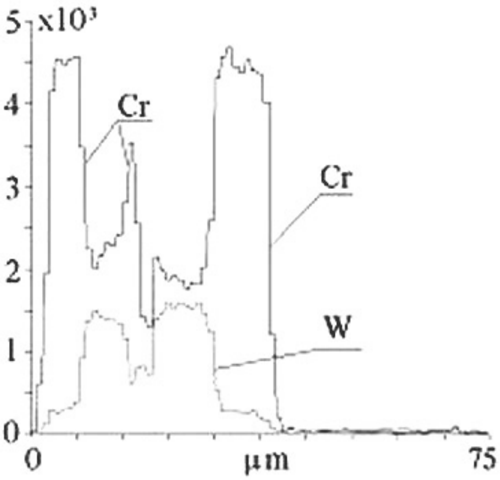


Fig. 2. Microstructure (a) and linear distribution of Si (b), Cr and W (c) in AlSi17,5Mg1,2Ni3,8Cu3,6Cr0,4W0,4 silumin

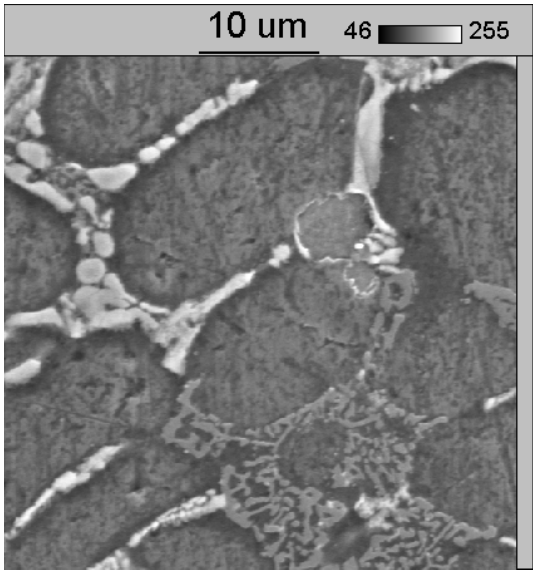
concentration and reduced concentration of molybdenum In all probability this is the phase composed of two silicides. In the central part there is Mo_3Si surrounded by a complex silicide of $(Cr, Mo)_3Si$ (b, c). At some distance from this phase there are fine precipitates of eutectic silicon, accompanied by the Mg_2Si phase (b). Between them there are precipitates of Al_3Ni and Al_2Cu phases (d).

Similar phases are formed when Cr and W occur simultaneously in silumin, as shown in Figure 2.

From the above it follows that in the external part of the examined phase, a silicide of Cr_3Si is present, while the internal part comprises a complex silicide of $(W, Cr)_3Si$.

The silicides in hypoeutectic silumins are much finer and assume a nearly-spherical shape. For example, Figure 3 shows microstructure (a) and a map of the distribution of Mg, Al, Si, Cr, Ni, Cu (b) in hypoeutectic silumin.

a)



b)

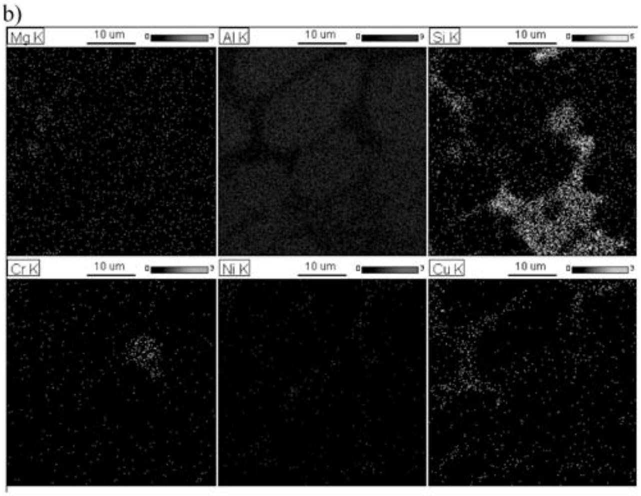
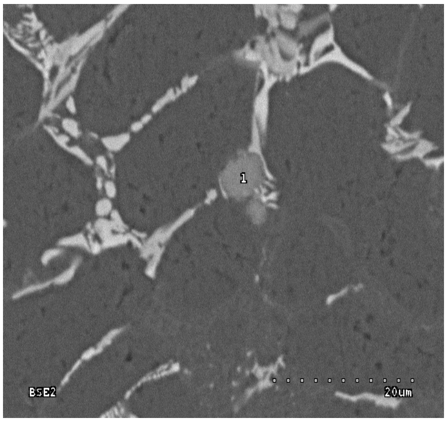


Fig. 3. Microstructure (a) and surface distribution of Mg, Al, Si, Cr, Ni, Cu (b) in AlSi6,5Cr0,3Mg1,2Ni1,5Cu1,4Fe0,45 silumin

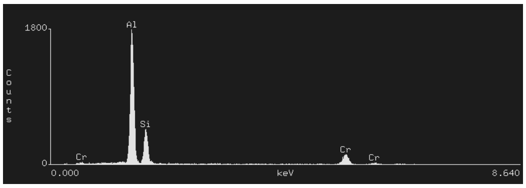
Figure 4 shows microstructure (a) from Fig. 3 (a) with marked phase no. “1” in which the point concentrations of Al, Cr and Si were locally analysed.

From Figures 3 and 4 (a, b) it follows that phase “1” is an intermetallic $Al_{13}Cr_4Si_4$ phase. It crystallises in cubic lattice of parameter 10,917 Ä and has the density of 3,40g/cm^3.

a)



b)



point 1 photo sample 1-01

Accelerating Voltage: 15 KeV   Take Off Angle: 35.621°
Live Time: 27 seconds   Dead Time: 4.09

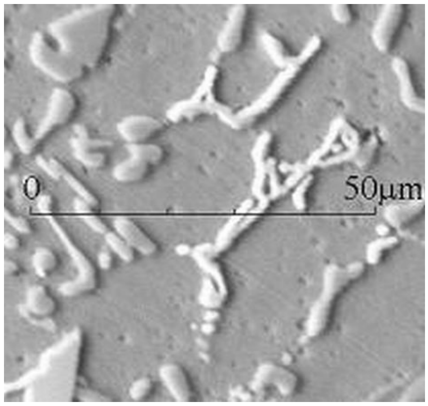
Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)
Al-K	0.4395	1.197	60.66	52.61	+/- 0.50
Si-K	0.1285	1.679	23.89	21.57	+/- 0.53
Cr-K	0.2277	1.134	15.45	25.82	+/- 0.95
Total			100.00	100.00	

Notepad

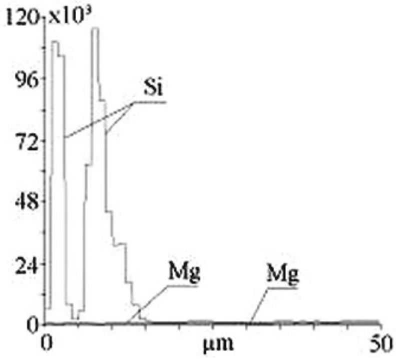
Fig. 4. Concentrations of Al, Cr and Si in a phase designated as phase no. “1”

Investigations have proved that single additions of Cr, Mo and W result in the formation of silicides of one type along with their respective phases formed with aluminium. In the presence of chromium, the Cr_3Si compound and, as proved above, the $Al_{13}Cr_4Si_4$ phase are formed. The addition of Mo or W causes, besides the formation of Mo_3Si or W_3Si silicides, also the crystallisation of $Al_{12}Mo$, $Al_{12}W$ and AlWSi phases of cubic lattice and very similar parameters, assuming the values of 7,5730 Ä and 7,5803 Ä, respectively. The density of these phases is 3,22g/cm^3 and 3,88g/cm^3, respectively. This is further confirmed by the data shown in Figure 5 for nearly -eutectic silumin.

a)



b)



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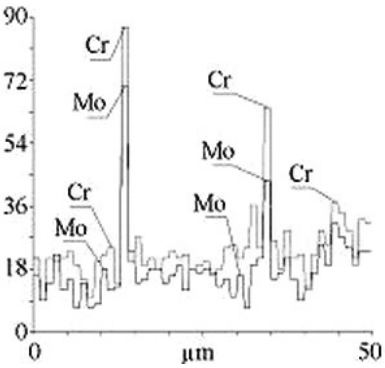

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d)

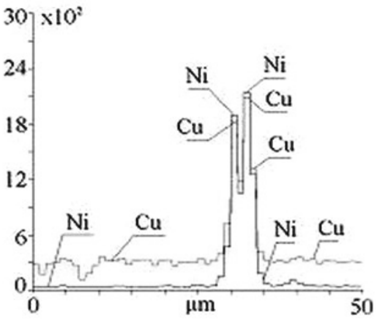

Fig. 5. Microstructure (a) and linear distribution of Si, Mg (b), Cr, Mo (c) and Cu, Ni (d) in nearly-eutectic AlSi12,3Mg1,5Cu2,5Ni2,8Cr0,4Mo0,5Fe0,25 silumin

From the investigations it follows that the site of nucleation and growth of the next phase is the phase boundary formed between the previously crystallised phase and solid solution α(Al). The investigations have also shown that at the highest temperature, in complex silumins crystallise the silicides and peritectic phases of $Al_{12}W$, AlWSi, $Al_{12}Mo$ and $Al_{13}Cr_4Si_4$.. Next to crystallise are the phases α or β and complex eutectic α + β + Al(Si, Cr, Mo, W, Fe). Further crystallises the eutectic containing Mg_2Si, Al_3Ni and Al_2Cu. Figure 6 shows example of the nucleation and growth of phases on the phase boundaries in hypoeutectic silumin.

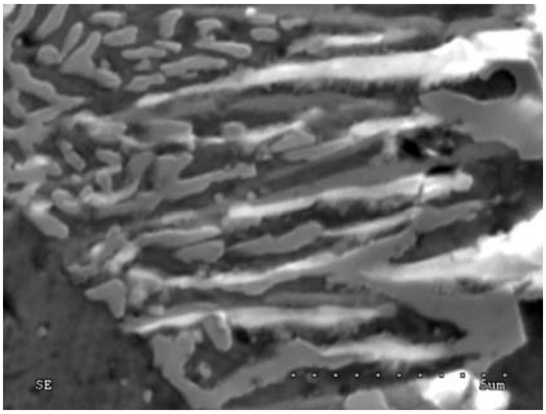

Fig. 6. Example of nucleation and growth of phases on the phase boundaries in hypoeutectic silumin

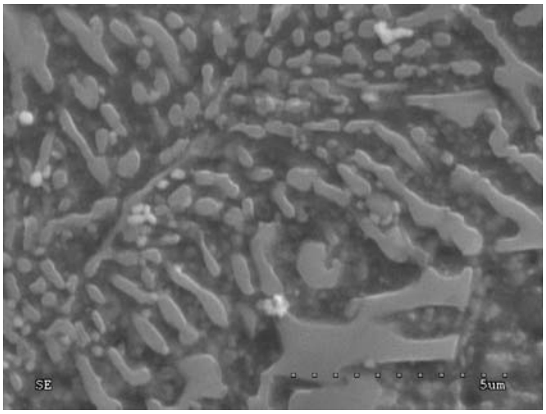

Fig. 7. Silicon precipitates in hypoeutectic, precipitation-hardened silumin

The additions of Cr, Mo and W refine silicon in silumins both untreated and heat treated. Examples of silicon precipitates found in precipitation-hardened hypoeutectic silumin are shown in Figure 7.

The above discussed complex silumins containing Cr, Mo, W, Mg, Ni and Cu are characterised by high mechanical properties comprised in a range of the following values: $R_{p0,2}$ = 320÷420 MPa, R_m = 400÷520 MPa, A_5 = 0,5÷5,0% and 145÷210 *HB*. The properties are due to the presence of the aforementioned refined phases.

3. Conclusions

From the data disclosed in this study the following conclusions follow:

- the alloying additions, i.e. Cr, W and Mo, introduced to silumins containing Mg, Cu and Ni result in the formation of silicides, like Cr_3Si, W_3Si, Mo_3Si and of the intermetallic phases, like $Al_{13}Cr_4Si_2$, $Al_{12}Mo$ and $Al_{12}W$,
- both the silicides and the intermetallic phases are responsible for strong alloy hardening and mechanical properties comprised in a range of the following values: $R_{p0,2}$=320-420MPa, R_m=400-520MPa, *HB* = 145-210, A_5 = 0,5-5,0%.

Acknowledgements

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