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Al-Si COPPER ALLOYS FOR BEARINGS

LEŽAJI ZLITIN AlSi Z BAKROM

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The AlSi10Cu1 bearing alloy was developed as an alternative to aluminium alloys containing Sn and Pb. The alloy is intended for low-speed bearings which work under high pressures. Their main use is in freight traffic.

The aim of this work was to determine the influence of alloy's treatment on its structure and mechanical properties. The influence of a modifier, its optimal concentration, the effect of time on the modifier concentration in the molten alloy and the cooling rate of the casting were determined. The morphology of the β particles and the interparticle spacing, λ_β, were evaluated as the basic structural parameters and the ultimate tensile strength, the reduction of area and the elongation were evaluated as the basic mechanical parameters.

Sr has the most significant effect as a modifier. Its optimal concentration was in the range 0.015-0.02%. The effect of the modifying did not change with regard to the microstructural parameters in this concentration range and at cooling rates of 0.6-12 Ks^{-1} untill 24 hours after the modifier was added. When the cooling rate was higher than 14 Ks^{-1}, the β phase modifies even without the addition of a modifier.

Key words: Al-Si alloys, casting, modifying, modifier, cooling rate

Zlitina AlSi10Cu1 je bila razvita kot alternativa zlitinam aluminija z Sn in Pb. Zlitina je namenjena za ležaje, ki delajo z velikim bremenom pri majhni hitrosti. Glavna uporaba je prevoz tovora.

V tem delu je opisan vpliv obdelave zlitine na mikrostrukturo in mehanske lastnosti. Določeni so bili: vpliv modifikatorja, njegova optimalna koncentracija, vpliv časa na koncentracijo modifikatorja v staljeni zlitini in hitrosti ohlajanja ulitkov. Morfologija β-delcev in razdalja med delci λ_B sta osnovna parametra mikrostrukture, raztržna trdnost, kontrakcija in raztezek pa so temeljni mehanski parametri.

Stroncij ima največji modifikacijski vpliv. Njegova optimalna koncentracija je v območju 0,015-0,02 %. Učinek modificiranja je bil konstanten v tem območju koncentracije in pri hitrosti ohlajanja 0,6-12 Ks^{-1} do 24 ur po dodatku. Pri hitrosti ohlajanja nad 14 Ks^{-1} je bila β-faza modificirana tudi brez dodatka modifikatorja.

Ključne besede: zlitine Al-Si, litje, modifikacija, modifikator, hitrost ohlajanja

1 INTRODUCTION

The conventional process of crystallization for the eutectic, silicium - β phase, in the primary Al-Si alloy results in the creation of flake-shaped crystals. The morphology of this β phase has a significant influence on the mechanical properties of Al-Si-based alloys. The change of the crystals' shape requires the transformation of their growth-unit from flake to fibre (in metallographic section from needle to globular morphology). The result is a change in the fracture micromechanism from the splitting of brittle β phase to α-matrix ductile fracture. This change is associated with an increase in the strength and plastic properties of the alloy.

The change of the β phase's shape can be realized by the addition of a modifier, a higher cooling rate or by superheating of the melt.

Sources in the literature suggest a number of modifying elements such as Li, Be, Na, Ca, Rb, Sr, Sb, Pb and Bi. But due to the limited efficiency and the toxicity of most of them only Sr and Na were chosen for modifying tests with the AlSi10Cul alloy.

Na, as a modifier, has a more significant influence an improving the mechanical properties than Sr, but it is more difficult to achieve the reguired Na content and its effect as a modifier is very short livrd.

Both the amount and homogenity of the modifier are very important. If the quantity of modifier is less than optimum, then the microstructure is either not modified or is insufficiently modified. If the amount of modifier is more than optimum, brittle phases (e.g. $SrAl_2Si_2$), blisters and shrinkage porosity can appear[1].

There are various opinions with respect to the optimum Sr-modifier concentration in the literature. Eearly studies recommended 0.03-1% Sr in the melt[1,2], more recent studies suggest 0.01-0.02%; increasing the Sr content beyond about 0.015% results in a coarsening of the β phase and a deterioration of the mechanical properties[3].

The modifying effect of Sr is not permanent. The melt's time at the pouring temperature effects the burnout (loss by burning), decreasing the modifier concentration. According to the literature, the modifying effect of Sr lasts 1-2 hours[1], or 3-4 hours with an initial Sr concentration of 0.03%[4]. The burnout of Sr can be

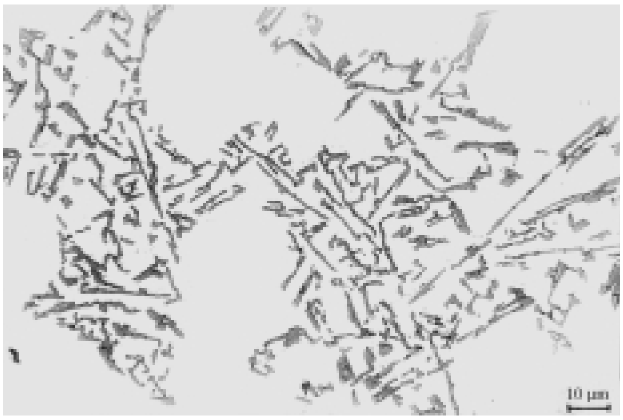

Figure 1: Cooling rate 2 Ks^{-1}, without modifier, etched 0.5% HF
Slika 1: Hitrost ohlajanja 2 Ks^{-1}, brez modifikatorja, jedkano z 0,5 % HF

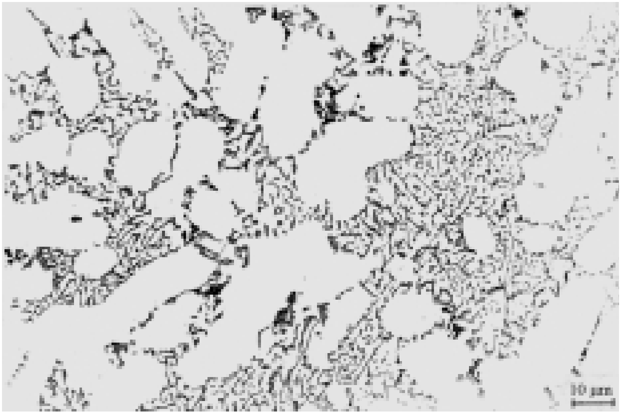

Figure 3: Cooling rate 18 Ks^{-1}, without modifier, etched 0.5% HF
Slika 3: Hitrost ohlajanja 18 Ks^{-1}, brez modifikatorja, jedkano z 0,5 % HF

inhibited by the addition of 0.05-0.2% Be, in such cases the modifying effect can last more than 10 hours[1,2].

The cooling rate has a significant influence on the modification process. The result of a high cooling rate is the appearance of a large number of crystallization centres, the growth of a number of β particles, and a decrease in the interparticle spacing and modification of the β phase. But at the same time there is an increase in the structural inhomogenity with the appearance of "over-modified islands" which contain fine β particles (ϕ less than 1 µm) and blowholes. Low cooling rates result in a coarse β phase as well as blowholes.

2 EXPERIMENTAL

The aim of the experiments was to study the parallel influences of the initial modifier's concentration, its decrease in the melt and the cooling rate of the casting on the structural and mechanical parameters of the castings.

The composition of the material used in our experiments, in addition to the Al, was (in wt.%): 10.1 Si, 1.1 Cu, 0.23 Fe, 0.35 Mg, 0.25 Mn, 0.05 Ca, 0.1 Zn and 0.11 Ti.

The alloy was melted in a graphite crucible (ϕ125x155 mm), in an electric resistance furnace, the weight of the charge was 2 kg. The pouring temperature was 760 °C. The oxide layer, or dross, was removed to clean up the surface of the melt before casting. Lumpy (up to 5 mm) AlSiSr10 master alloy containing 8.35% Sr, wrapped in Al foil, was used as the modifier. The melt was cast without modifier, immediately after the modifier was added, or 2, 4, 6, 8 and 24 hours after adding the modifier. The cooling rate was varied from 0.03 to 18 Ks^{-1} using various metallic dies, sand moulds or cooling the castings in a furnace.

The 0-24 hour period between adding the modifier and casting resulted in a gradual decrease of the Sr content in the castings and in the dross. The modifying effect of the Sr on the structural and mechanical properties was maintained accross the whole range of holding times in the castings up to 0.003% Sr after 24 hours. As a result of a more intensive dross removal the

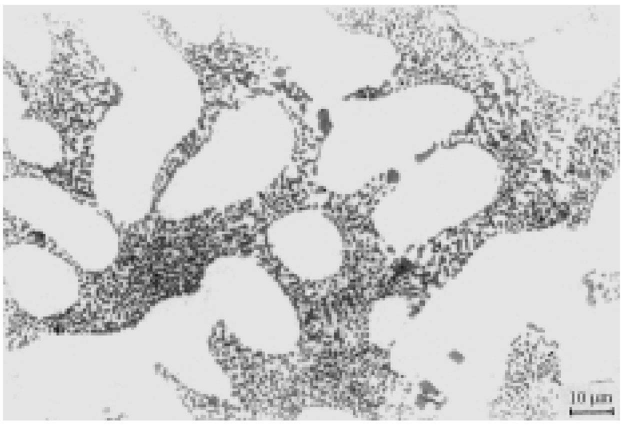

Figure 2: Cooling rate 2 Ks^{-1}, 0.015% Sr, etched 0.5% HF.
Slika 2: Hitrost ohlajanja 2 Ks^{-1}, 0,015 % Sr, jedkano z 0,5 % HF

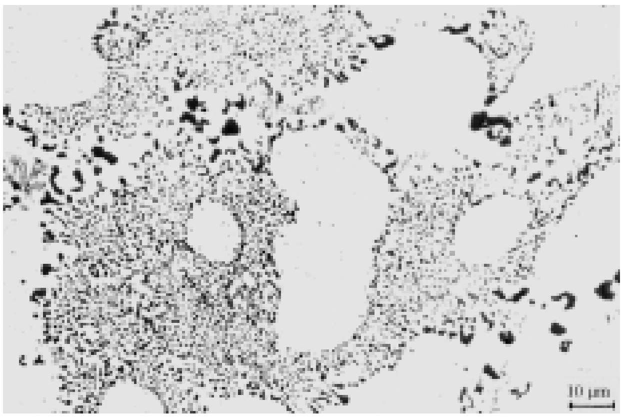

Figure 4: Cooling rate 2 Ks^{-1}, initial Sr content 0,015%, cast 24 hours after modifier applying, etched 0.5% HF
Slika 4: Hitrost ohlajanja 2 Ks^{-1}, začetna vsebnost stroncija 0-0,15 %, lito 24 ur po dodatku modifikatorja

Table 1: The influence of the modifier content and cooling rate on the shape of β phase

Tabela 1: Vpliv količine modifikatorja in hitrosti ohlajanja na obliko β faze

cooling rate Ks^{-1}	0 % Sr	0.003 % Sr	0.01 %Sr	0.015 % Sr	0.05 % Sr	0.075 % Sr	0.2 % Sr	0.35 % Sr
18	P	P	P	P	blowholes, P			
14	III	P	P	P				
8	II-III	III	III	III				
2	II	II-III	II-III	III	III	III	III	III
0.6	I	II-III	II-III	III	blowholes			
0.03	V	V-III	V-III	V-III				

Note: P very fine or fibre shaped, I - needle shaped, II - globular/ needle shaped, III - globular particles, IV - globular coarse particles, V - angular particles

Table 2: The influence of the modifier content and cooling rate on the interparticle spacing (λ_β), μm

Tabela 2: Vpliv količine modifikatorja in hitrosti ohlajanja na razdaljo med izločki (λ_β), μm

Cooling rate Ks^{-1}	0 % Sr	0.003 % Sr	0.01 % Sr	0.015 % Sr	0.05 % Sr	0.075 % Sr	0.2 % Sr	0.35 % Sr
18	1.6	1.5	1.1	1	blowholes, less than 1			
14	3.0							
8	3.5			2				
2	10	6.6	4.2	3	3	3	3	3
0.6	21			4		blowholes		
0.03	57				21			

Table 3: The influence of the modifier content and cooling rate on tensile strength (R_m), MPa

Tabela 3: Vpliv količine modifikatorja in hitrosti ohlajanja na raztržno trdnost (R_m), MPa

cooling rate Ks^{-1}	0 % Sr	0.003 % Sr	0.01 % Sr	0.015 % Sr	0.05 % Sr	0.075 % Sr	0.2 % Sr	0.35 % Sr
18	200			230	blowholes			
14								
8	190			210				
2	164		174	187	188	185	138	135
0.6	124		blowholes					
0.03	96							

Table 4: The influence of the modifier content and cooling rate on elongation and reduction of area (Z), %

Tabela 4: Vpliv količine modifikatorja in hitrosti ohlajanja na raztezek (A_5) in kontrakcijo (Z), %

cooling rate Ks^{-1}	0 % Sr	0.01 % Sr	0.015 % Sr	0.05 % Sr	0.075 % Sr	0.2 % Sr	0.35 % Sr
18	4 (5.5)		6.7 (4.5)	blowholes			
14							
8	3		5 (5)				
2	3 (4.2)	4.7 (4.2)	5 (8.7)	5.6 (7.3)	4 (4)	3 (4)	3 (4)
0.6	0.7 (1.3)	blowholes					
0.03	1.8 (1.1)						

Sr content decreased to 0.0015% after 24 hours, this amount of modifier was insufficient to maintain the modifying effect, which resulted in a needle-shaped morphology of the β phase in about 95% of the casting volume and a deterioration of the mechanical properties.

The tensile tests were made in accordance with STN 42 0310 (Slovak technical standard, R_m - ultimate tensile strength, A_5 - elongation and Z - reduction of area were evaluated), the morphology of the β phase, according to STN 42 0491, and the interparticle spacing (λ_β)[5] were evaluated at the point of fracture and at the lower and upper ends of the tensile-test samples.

3 SUMMARY AND CONCLUSIONS

1. A cooling rate above 14 Ks^{-1} results in a modification of the β phase without a modifier. A reduction of the cooling rate results in the growth of the number of needle-shaped β particles which ie related to a decrease in the mechanical properties. In the case of a cooling rate of 2 Ks^{-1}, which corresponds with the cooling rate using a sand mould, the morphology of the β phase is needle shaped with larger needles observed with a slower cooling rate.
2. With a cooling rate of 2 Ks^{-1}, and a Sr content higher than 0.015%, complete modification of the β phase and optimum mechanical properties were observed. Additional Sr, up to 0.35%, did not affect the structural characteristics but the mechanical properties decreased. An Sr content of less than 0.01% results in the needle-shaped β phase.
3. In the case of an extremely low cooling rate (0.03 Ks^{-1}) it is possible to archieve precipitation of the β phase in the form of coarse globules by adding more than 0.015% Sr. The mechanical properties of this structure were not evaluated because of the high porosity of the castings.
4. An initial Sr content of 0.015% in the AlSi10Cu1 alloy results in a complete modification of the β phase, with an improvement of the mechanical properties and a modifying effect lasting 24 hours with cooling rates of 0.6-18 Ks^{-1}.

ACKNOWLEDGMENTS

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