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EFFECT OF AlTi5B1 AND AlSr10 ADDITIONS ON THE FLUIDITY OF THE AlSi9Cu3 ALLOY

VPLIV DODATKOV AlTi5B1 IN AlSr10 NA LIVNOST ZLITINE AlSi9Cu3

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This work studies the effect of the AlTi5B1 and AlSr10 additions on the fluidity and the solidification time of the AlSi9Cu3 casting alloy. The fluidity was investigated by determining the flow length in a spiral-shaped mould. The solidification time was measured with a thermocouple positioned at the ingate bottom. An individual pouring into the preheated (200 °C) metallic mould was done at different pouring temperatures ((640, 670, 700, and 710) °C). In all the cases, the fluidity was improved with the increasing pouring temperatures. An addition of the AlTi5B1grain refiner to the basic alloy reduced both the grain size and the fluidity, whilst the solidification time was similar to that of the basic alloy. On the other hand, an addition of the AlSr10 modifier refined the β_{Si} eutectic phase, increased the fluidity and prolonged the solidification time in comparison to the basic alloy. The fluidity was proportional to the solidification time. Thus, by carrying out a simple thermal analysis and determining the solidification time, it is possible to predict the fluidity.

Keywords: AlSi9Cu3 alloy, grain refinement, modification, fluidity, solidification time

V delu je predstavljen vpliv dodatkov AlTi5B1 in AlSr10 na livnost in strjevalni čas livne aluminijeve zlitine AlSi9Cu3. Livnost smo preiskovali z merjenjem dolžine toka taline v kovinski kokili s spiralno livno votlino, medtem ko smo strjevalni čas merili s termoelementom, ki je bil vstavljen na dnu lijaka. Talino smo pri različnih livnih temperaturah ((640, 670, 700 in 710) °C) ulivali v predgreto kokilo (200 °C). Livnost je v vseh primerih naraščala z naraščanjem livne temperature. Dodatek udrobnilnega sredstva AlTi5B1 k osnovni zlitini je zmanjšal tako velikost kristalnih zrn kot livnost, medtem ko je bil strjevalni čas podoben kot v osnovni zlitini. Dodatek modifikatorja AlSr10 je zmanjšal velikost evtektične faze β_{Si}, povečal livnost ter podaljšal strjevalni čas v primerjavi z osnovno zlitino. Livnost je bila sorazmerna strjevalnemu času, tako da lahko z enostavno termično analizo in določanjem strjevalnega časa napovemo livnost preiskovane zlitine.

Ključne besede: aluminijeva zlitina, udrobnjevanje, modificiranje, livnost, strjevalni čas

1 INTRODUCTION

Aluminium casting alloys are extensively used in the production of thin-walled castings. This is limited by the fluidity of the molten metal. Fluidity is defined as the ability of a molten metal to flow until it ceases due to solidification[1]. The fluidity is influenced by many factors that can be divided into metallurgical and mould/casting variables. The metallurgical factors are the composition, superheat and latent heat, the surface tension of the melt, oxide-film inclusions and the mode of solidification. The mould/casting factors are the heat-transfer coefficient at the interface, the mould temperature and the mould conductivity[2,3].

The most widely used test for measuring fluidity is the spiral test where fluidity is quantified by measuring the length of the molten-metal flow inside a spiral-shaped mould. The fluidities of pure metals and alloys differ due to different solidification mechanisms[4]. Pure metals and eutectic alloys have the highest fluidities. However, the fluidities of the hypereutectic Al-Si and Al-Mg alloys are better than those of the hypoeutectic and even eutectic compositions[5].

The effect of grain refining on the fluidity of Al-alloys depends on several factors: the type and amount of the grain refiner, the composition of the alloy, the holding time and the temperature within the furnace[6]. Tiryakioglu et al.[7] found that an addition of the mass fraction w = 0.04 % of Ti, in the form of an AlTi5B1 master alloy, to the A356 Al-Si alloy did not affect the fluidity measured in the sand spiral test. On the other hand, the fluidity was reduced with the additions of Ti below w = 0.12 %, whilst increased with the Ti additions above w = 0.12 %[8]. Kwon et al.[9] observed an increase in the fluidity when w = 0.03 % Ti was added to the A356 alloy. Lang[5] found that the fluidity was significantly increased with the additions of B, within the range of w = 0.04–0.07 %, to the Al-Si alloy.

The increases in the fluidities of the modified Al-Si alloys were expected only when the Si amount was close to the eutectic composition. However, Seshadri and Ramachandran[10] found that the fluidity of the modified AlSi12 alloy was reduced by 7 % within the sand mould and by 3 % within the iron mould. Venkateswaran et al.[11] studied the effects of the trace elements on the fluidity of the eutectic Al-Si alloy. The fluidity was decreased with the additions of Na, Na + Sr, Ti, Na + Ti, Na + Sr + Ti,

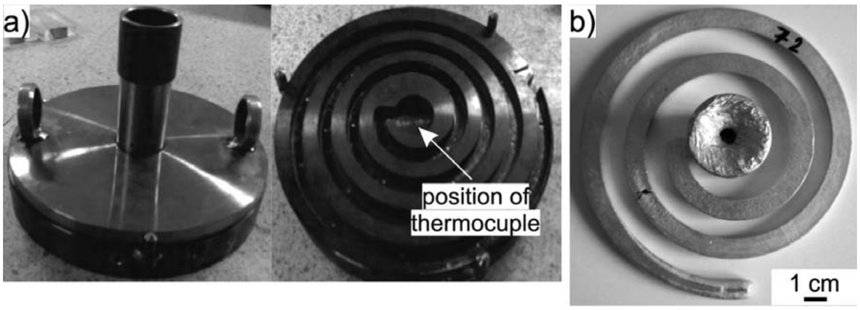

Figure 1: a) Metallic spiral mould and b) its fluidity sample
Slika 1: a) Kovinska kokila z livno votlino spiralne oblike in b) uliti vzorec

whilst it was increased with the additions of S, Sb, Sb + Ti, S + Ti. Kotte[12] found that with an addition of Sr to the Al-Si alloy, the fluidity was less reduced than with an addition of Na.

The purpose of the present study was to investigate the influence of grain refinement and modification on the fluidity and solidification time of the AlSi9Cu3 casting alloy. Thus, the main focus was on measuring the flow lengths and the cooling curves, and determining their mutual influence, which had not been yet investigated for the AlSi9Cu3 alloy. The solidification behaviour of the investigated alloy was also carried out using a simple thermal analysis.

2 EXPERIMENTAL WORK

The commercial AlSi9Cu3 alloy was melted in a Bosio EUP-K 20/1200 electrical resistance furnace, grain refined with an addition $w = 0.06$ % of Ti (the AlTi5B1 master alloy), or modified with an addition $w = 0.08$ % of Sr (the AlSr10 master alloy), heated to a pouring temperature and poured into a metal spiral mould. The fluidities of the basic, grain-refined, and modified alloys were tested at different pouring temperatures ((640, 670, 700, and 710) °C) by measuring the flow length inside the spiral mould, which was preheated to a temperature of 200 °C. The solidification time was measured using a NiCr-Ni thermocouple positioned at the ingate bottom. **Figure 1** shows the spiral mould and the shape of a fluidity specimen. The solidification behaviour of the investigated alloy was examined with a simple thermal analysis, when a sample was poured into a Croning measuring cell at a pouring temperature of (680 ± 5) °C. Light-optical microscopy work was done using an Olympus BX61 with the software Analysis Materials Research Lab 5.0.

3 RESULTS AND DISCUSSION

3.1 Solidification behaviour

Figure 2 shows a cooling curve with the characteristic temperatures of the basic AlSi9Cu3 alloy poured into the Croning measuring cell. The characteristic temperatures of the grain-refined and modified alloys are presented in **Table 1**. It can be seen that the minimum liquidus temperatures, $T_{\mathrm{L\,min}}$, of the basic and modified alloys were approximately the same, while $T_{\mathrm{L\,min}}$ of the grain-refined alloy was higher by about 5 °C. This is a characteristic of the strong grain refining that does not require significant undercooling before nucleation[13]. The recalescence during the primary crystallisation, ΔT_{L}, of the grain-refined alloy was also the lowest (0.5 °C). The eutectic reaction $\mathrm{L} \rightarrow (\alpha_{\mathrm{Al}} + \beta_{\mathrm{Si}})$ of the modified alloy took place at the temperature lower by about 6 °C than those of the basic and grain-refined alloys due to the addition of Sr[14], which caused the characteristic temperatures to drop. The solidification was completed with two eutectic reactions: $\mathrm{L} \rightarrow (\alpha_{\mathrm{Al}} + \mathrm{Mg_2Si})$ at temperature T_{E1} and $\mathrm{L} \rightarrow (\alpha_{\mathrm{Al}} + \mathrm{Al_2Cu}\text{-}\Theta)$ at temperature T_{E2}. The solidus temperature, T_{S}, was between 483.5 °C and 486.1 °C.

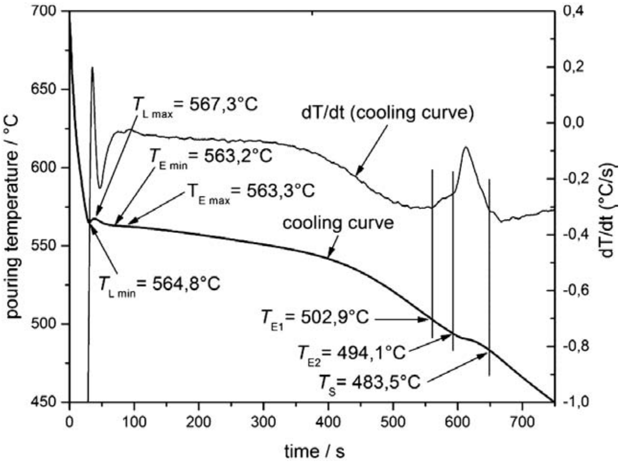

Figure 2: Cooling curve of the basic AlSi9Cu3 alloy poured into the Croning measuring cell. The marked characteristic temperatures: $T_{\mathrm{L\,min}}$ – minimum and $T_{\mathrm{L\,max}}$ – maximum liquidus temperature, ΔT_{L} – recalescence of the primary crystallisation, $T_{\mathrm{E\,min}}$ – minimum and $T_{\mathrm{E\,max}}$ – maximum eutectic temperature, ΔT_{E} – recalescence of the eutectic crystallisation $\mathrm{L} \rightarrow (\alpha_{\mathrm{Al}} + \beta_{\mathrm{Si}})$, T_{E1} and T_{E2} – eutectic temperatures, and T_{S} – solidus temperature.

Slika 2: Ohlajevalna krivulja osnovne zlitine AlSi9Cu3, ulite v merilno celico Croning. Označene karakteristične temperature so: $T_{\mathrm{L\,min}}$ – minimalna in $T_{\mathrm{L\,max}}$ – maksimalna likvidusna temperatura, ΔT_{L} – rekalescenca primarnega strjevanja, $T_{\mathrm{E\,min}}$ – minimalna in $T_{\mathrm{E\,max}}$ – maksimalna evtektična temperatura, ΔT_{E} – rekalescenca evtektičnega strjevanja $\mathrm{L} \rightarrow (\alpha_{\mathrm{Al}} + \beta_{\mathrm{Si}})$, T_{E1} in T_{E2} – evtektični temperaturi in T_{S} – solidusna temperatura.

Table 1: Characteristic temperatures of the basic AlSi9Cu3, grain-refined, and modified alloys
Tabela 1: Karakteristične temperature osnovne AlSi9Cu3, udrobnjene in modificirane zlitine

Temperature /°C	$T_{\mathrm{L\,min}}$	$T_{\mathrm{L\,max}}$	ΔT_{L}	$T_{\mathrm{E\,min}}$	$T_{\mathrm{E\,max}}$	ΔT_{E}	T_{E1}	T_{E2}	T_{S}
Basic	564.8	567.3	2.5	563.2	563.3	0.1	502.9	494.1	483.5
Grain-refined	571.6	572.1	0.5	564.5	564.6	0.1	506.8	498.8	486.1
Modified	566.3	568.6	2.3	557.2	557.7	0.5	503.6	497.4	486.5

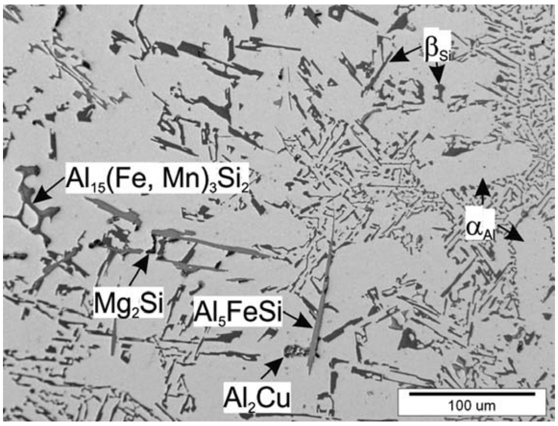

Figure 3: Light-optical micrograph of the modified AlSi9Cu3 alloy poured into the Croning measuring cell

Slika 3: Mikrostruktura modificirane zlitine AlSi9Cu3, ulite v Croning merilno celico

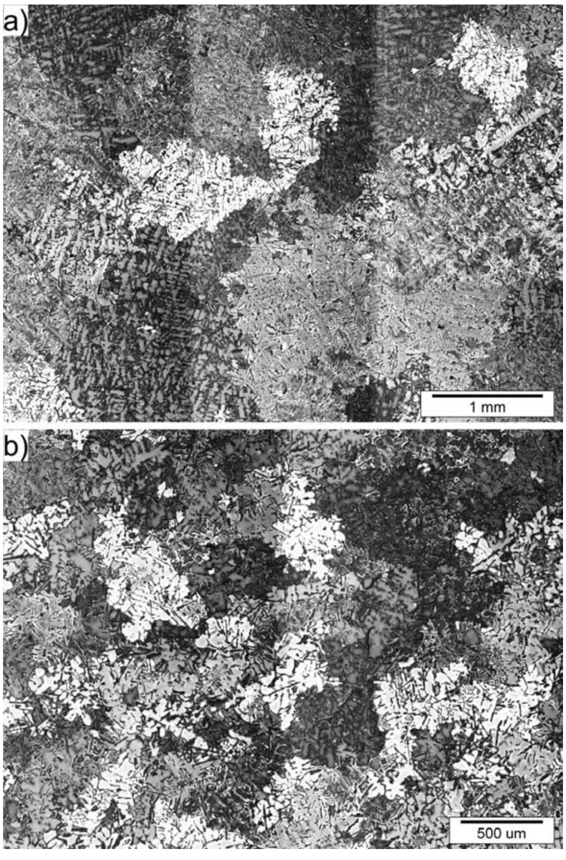

Figure 4: Light-optical micrographs using polarised light: a) basic alloy and b) grain-refined alloy

Slika 4: Mikrostruktura zlitine v polarizirani svetlobi: a) osnovna zlitina in b) udrobnjena zlitina

The microstructural constituents of the modified alloy were determined using a metallographic analysis, and were the same as in[15]. **Figure 3** shows the microstructure of the modified alloy. In addition to α_{Al} and β_{Si}, the $Al_{15}(Fe, Mn)_3Si_2$ and Al_5FeSi phases were also observed. The $Al_{15}(Fe, Mn)_3Si_2$ phase precipitated prior to the primary crystallisation of α_{Al}[15] and the stoichiometry of this phase usually changes during the cooling[16]. The Al_5FeSi phase was formed during the eutectic reaction[15], simultaneously with β_{Si}. The Mg_2Si and Al_2Cu-Θ eutectic phases were also observed.

Effects of the grain refinement and modification on the grain size and the size of the β_{Si} eutectic phase were metallographically examined. The average grain size was 911 μm in the basic alloy, only 507 μm in the grain-refined alloy and more than 1000 μm in the modified alloy (**Figure 4**). The average length of the β_{Si} eutectic phase was 49.5 μm in the basic alloy, 60.3 μm in the grain-refined alloy and only 17.4 μm in the modified

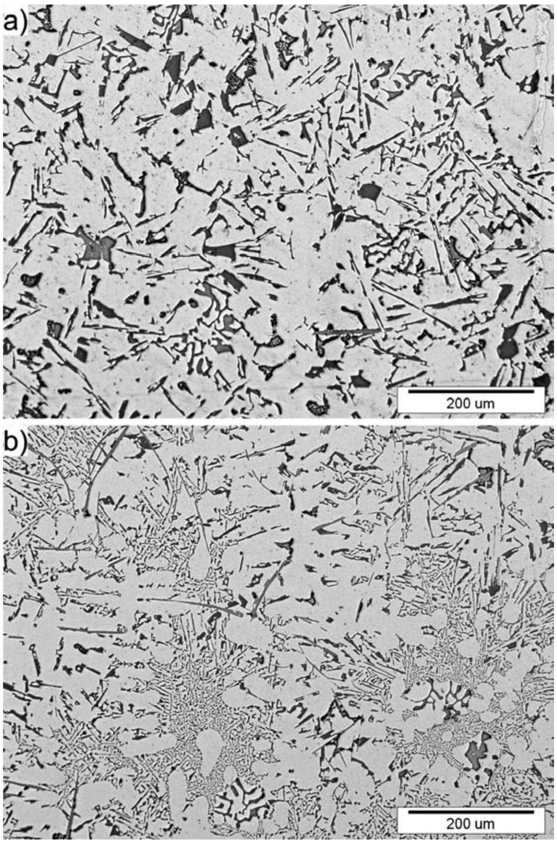

Figure 5: Light-optical micrographs of the: a) basic and b) modified alloys

Slika 5: Mikrostruktura: a) osnovne in b) modificirane zlitine

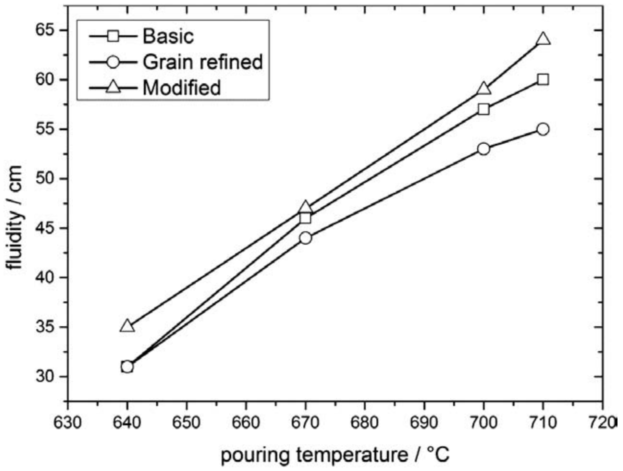

Figure 6: Effect of the pouring temperature on the fluidity of the basic AlSi9Cu3, grain-refined and modified alloys

Slika 6: Vpliv livne temperature na livnost osnovne AlSi9Cu3, udrobnjene in modificirane zlitine

alloy (**Figure 5**). These results showed that both the grain refinement and modification had been effective.

3.2 Fluidity and solidification time

Figure 6 shows the effect of the pouring temperature on the fluidity of the pure AlSi9Cu3, grain-refined and modified alloys. The fluidities of the basic and grain-refined alloy were the same at the pouring temperature of 640 °C, whilst the fluidity of the modified alloy increased by 4 cm. The cooling curves show that the solidification times of the basic and grain-refined alloys were also similar, whilst the solidification of the modified alloy took about 10 s more (**Figure 7a**). Furthermore, the fluidity of the modified alloy in comparison to the basic alloy was also increased by 1 cm or 2 cm at the pouring temperatures of 670 °C or 700 °C, and by 4 cm at 710 °C. The cooling curves also show these differences (**Figures 7b** to **7d**), indicating that the solidification times of the modified alloy were about 5 s longer at the pouring temperatures of 670 °C or 700 °C and about 10 s longer at 710 °C. The fluidity of the modified alloy was significantly reduced at the pouring temperatures of (670, 700 and 710) °C in comparison to the basic alloy, although the solidification times were similar (**Figures 7b** to **7d**). In all the cases, the fluidity was improved with the increasing pouring temperature because the nucleation and growth of the fine grains at the tip of the flowing metal in the test channel were impeded; hence, the fluidity length increased[17]. However, the fluidity of the modified alloy was the greatest, whilst the fluidity of the grain-refined alloy was the lowest at all pouring temperatures. This is related to the mechanisms of the grain refinement and modification. For instance, a large number of grains, formed due to the presence of a grain refiner, caused that the critical solid fraction required to stop the molten flow was reached earlier than in the

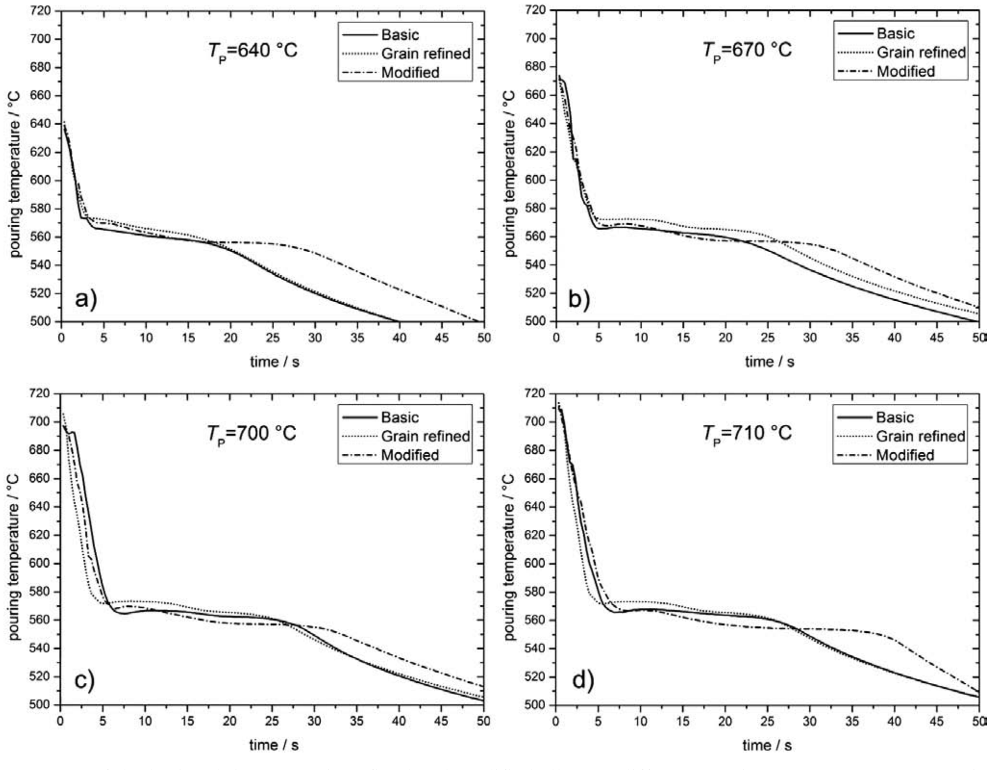

Figure 7: Cooling curves of the basic AlSi9Cu3, grain-refined and modified alloys at different pouring temperatures (T_P): a) 640 °C, b) 670 °C, c) 700 °C and d) 710 °C

Slika 7: Ohlajevalne krivulje osnovne AlSi9Cu3, udrobnjene in modificirane zlitine pri različnih livnih temperaturah (T_P): a) 640 °C, b) 670 °C, c) 700 °C in d) 710 °C basic alloy. However, the mechanism of the grain refinement did not influence the solidification time. The modification of β_{Si}, where the Sr atoms act as impurities and slow down the growth rate of the β_{Si} lamellas, extended the time of the eutectic reaction because the metal flow was stopped later than in the non-modified alloy.

4 CONCLUSIONS

This work revealed that the grain refinement and modification of the AlSi9Cu3 alloy influenced both the solidification morphology and fluidity. The average grain size of the grain-refined alloy was about 45 % smaller than in the basic alloy, whilst the β_{Si} eutectic phase in the modified alloy was about 35 % smaller. In all the cases, the fluidity was improved with the increasing pouring temperature. The fluidity of the modified alloy was the greatest, and the solidification time was the longest at all the pouring temperatures, whilst the fluidity of the grain-refined alloy was the smallest and the solidification time was similar to that of the basic alloy.

The results of this work clearly showed that the fluidity was proportional to the solidification time. It can thus be concluded that, for the investigated AlSi9Cu3, the fluidity can be predicted from the solidification time obtained with a simple thermal analysis. It is anticipated that the same could also be true for other aluminium casting alloys, which will be explored in our future work.

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