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Effect of overheating degree on the solidification parameters of AlSi17CuNiMg silumin

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Abstract

Melting technology, especially the temperature of overheating and pouring above the liquidus point T_{liq} as well as the cooling rate, determine alloy macro - and microstructure, and hence also casting performance properties. These parameters affect the solidification process and the formation of shrinkage cavities and porosity. So, it is important to choose the best parameters of the melting and pouring process, since on these parameters the process of crystal nucleation and growth as well as shaping of the alloy primary structure will depend. Hence it follows that the time-temperature treatment of molten alloys, hypereutectic silumins included, will also affect the solidification process. Therefore it is fully justified to examine in extenso the effect of overheating degree on parameters of the hypereutectic silumin solidification (T_{liq}, T_E, T_{sol}) and temperature of complex eutectic crystallisation (due to additions of Cu, Ni and Mg), the more that these effects have not been so far fully investigated and understood.

Keywords: Theoretical Backgrounds of Solidification Process, Modification, Hypereutectic Silumins

1. Introduction

As a result of the solidification process, hypereutectic silumins develop the structure composed of a soft dendritic aluminium matrix with large primary silicon crystals of a non-uniform distribution. A structure of this type has very disadvantageous effect on the mechanical properties and machinability of castings, and therefore the key issue in the application of Al-Si alloys is to reduce the size of primary silicon crystals and ensure their uniform distribution. This goal can be achieved through modification, refining and ultrasonic treatment [1÷3] of alloys, and also through overheating of melt before casting [4]. The obtained effect is due to the formation of a large number of the substrates, which initiate the heterogeneous nucleation of silicon crystals. In [5] one can find a reference to studies carried out on the structure of molten AlSi alloys and the effect it has on the alloy structure in solid state. The results of the investigations have shown that, while in hypoeutectic silumins the high degree of alloy overheating changes the alloy structure in a partly reversible mode, in hypereutectic silumins these changes are of a practically irreversible character.

2. Research methodology

The research methodology included melting and casting of alloys characterised by the following chemical composition: AlSi17, AlSi17Cu3, AlSi17Cu3Ni and AlSi17Cu3NiMg, subjected to modification with phosphorus. The above mentioned alloys were poured from six different temperatures, i.e. 710°C, 740°C, 780°C, 820°C, 860°C and 900°C, maintaining the same time-temperature conditions.

The effect of overheating degree on the solidification parameters of silumins was examined by an ATD thermal analysis using a Crystaldigraph PC apparatus. The test stand included a PT-600-PvG furnace, a Crystaldigraph recording unit, and a computer. The modification with phosphorus, added in an amount of 0,05 wt. %, was carried out with a Cu-P master alloy (~9,95% P). The refining was done with a „RAFGLIN-3", added in an amount of 0,3 wt. %. A general view of the stand for melting and casting of silumins is shown in Figure 1.

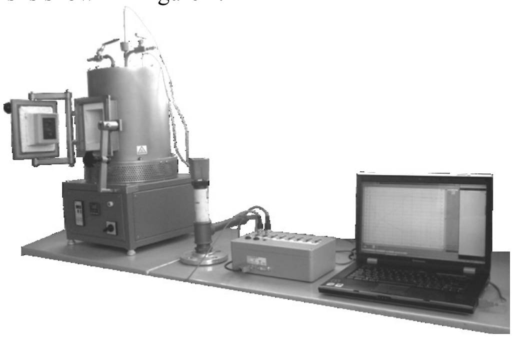
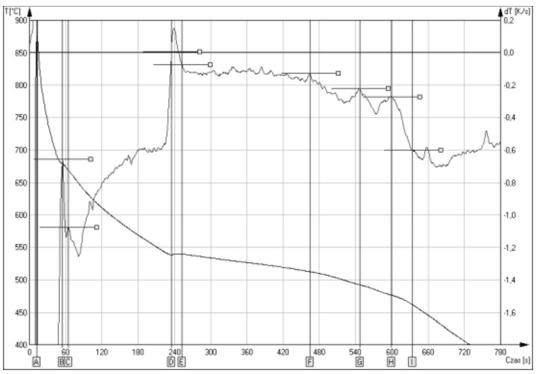


Fig. 1. A general view of the test stand

3. Results and analysis

Preserving similar melting and casting parameters, the examined silumins were poured into a standard probe, model QC4080, plotting the temperature curves in function of time (T=f(t)) and a temperature derivative over time (dT/dt = f`(t)). Figure 2 shows an example of the plotted thermal analysis curve.



[A]	12,0 [s]	875 [°C]
[B]	54,5 [s]	679 [°C]
[C]	64,0 [s]	669 [°C]
[D]	235,0 [s]	539 [°C]
[E]	252,5 [s]	540 [°C]
[F]	464,0 [s]	512 [°C]
[G]	47,0 [s]	492 [°C]
[H]	599,5 [s]	476 [°C]
[I]	634,5 [s]	462 [°C]

Fig. 2. The ATD thermal analysis curve with some characteristic points plotted for an AlSi17CuNiMg silumin after modification with 0,05% P

For all melts, the characteristic values of temperature were plotted in function of pouring temperature, as illustrated in Figures 3÷9.

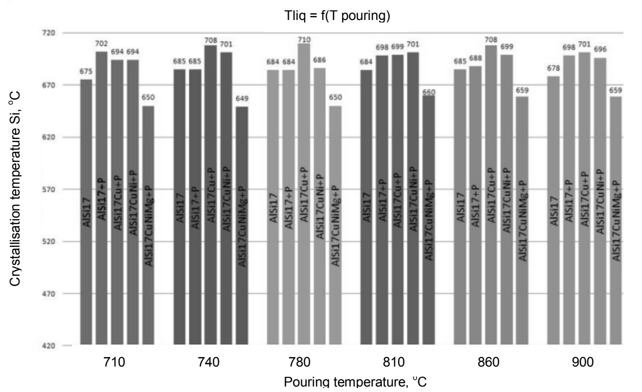


Fig. 3. Changes of temperature T_{liq} as a function of pouring temperature

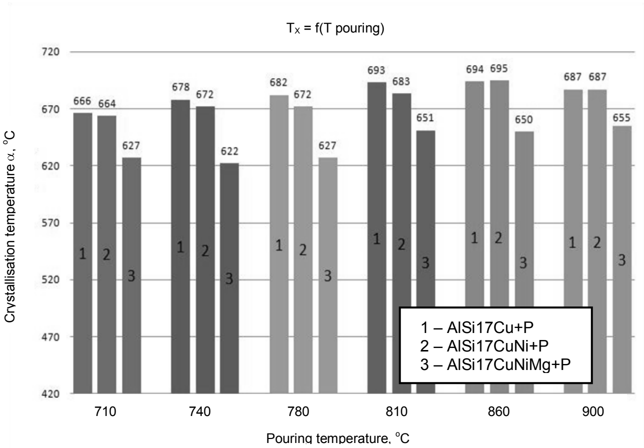


Fig. 4. Changes of probably pre-eutectic temperature T_X of the α dendrite crystallisation as a function of pouring temperature

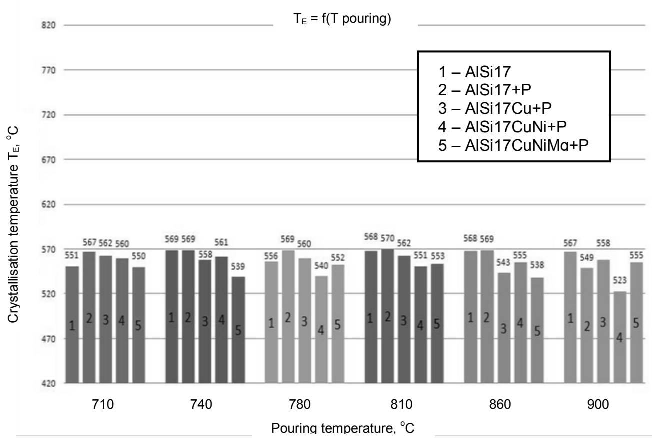


Fig. 5. Changes of temperature T_E as a function of pouring temperature

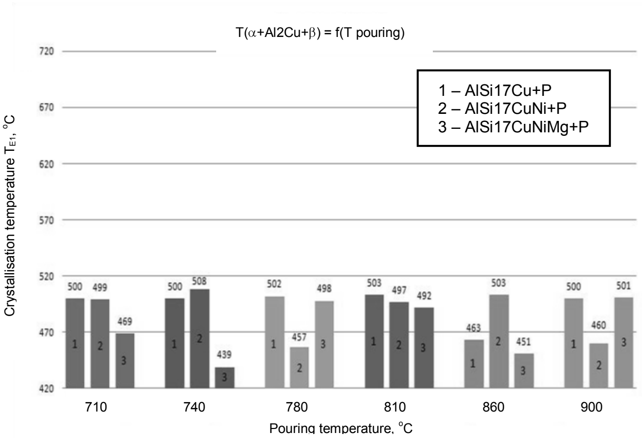


Fig. 6. Changes of temperature T_{E1} (the Cu containing eutectic) as a function of pouring temperature

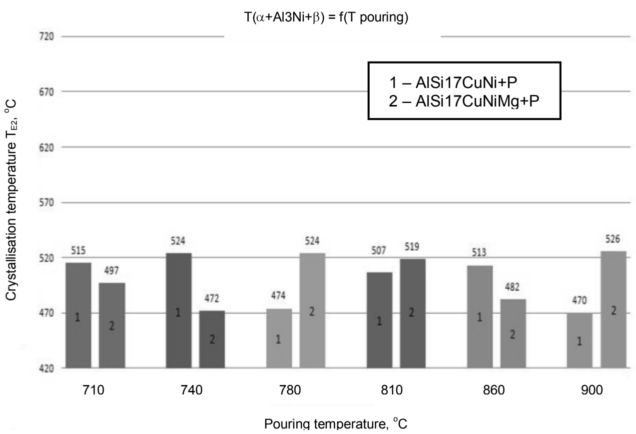


Fig. 7. Changes of temperature T_{E2} (the Ni containing eutectic) as a function of pouring temperature

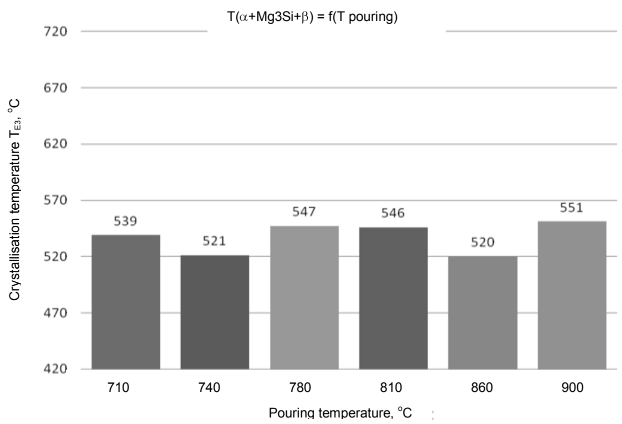


Fig. 8. Changes of temperature T_{E3} (the Mg containing eutectic) as a function of pouring temperature

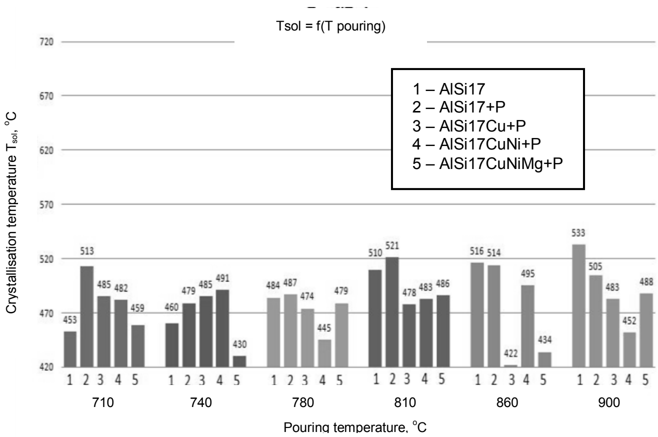


Fig. 9. Changes of temperature T_{sol} (the solidus) as a function of pouring temperature

4. Summary

To investigate the effect of overheating degree on the solidification parameters, an AlSi17 silumin was selected and subjected to the process of phosphorus modification made with a CuP master alloy, adding successively copper, nickel and magnesium in the form of AG10 alloy. The silumins were poured from the six selected temperatures, i.e. 710°C, 740°C, 780°C, 820°C, 860°C, 900°C. The basis for evaluation of the time-temperature parameters of molten alloy overheating was how well the pre-established conditions were kept at a stable and similar level during melting and pouring. The key issue was to observe the requirement of holding the alloy for the same lapse of time and pouring it from the preset temperature, measured with a TP202K-100 (NiCr-NiAl) mantled thermocouple. Maintaining the same conditions during alloy manufacture eliminated the inconsistencies and enabled detailed investigations of the true effect of the overheating degree on solidification parameters of the examined alloys. For this purpose, an ATD thermal analysis, carried out on a Crystaldigraph apparatus coupled with an ATD-QC 4080 standard thermal analysis probe, has been used. Having obtained the preset temperatures, the examined alloys were poured and respective solidification curves were plotted.

Since in hypereutectic silumins, the factor that is responsible for the modification effect is mainly the temperature T_{liq}, its values have been compared in function of the pouring temperature. Table 1 shows the obtained results.

Table 1.
Changes of temperature T_{liq} as a function of pouring temperature and the addition of alloying elements, i.e. Cu, Ni and Mg

Composition	Pouring temperature, °C					
	710	740	780	810	860	900
AlSi17	675	685	684	684	685	678
AlSi17+P	+27	0	0	+14	+3	+20
AlSi17Cu+P	+19	+23	+26	+15	+23	+23
AlSi17CuNi+P	+19	+16	+2	+17	+14	+18
AlSi17CuNiMg+P	-25	-36	-34	-24	-26	-19

As follows from Figures 3÷9, in most cases, the addition of modifier, i.e. of phosphorus, to the pure AlSi17 alloy raises this temperature by even 27°C . The effect of copper and nickel added to the alloy after modification is not so prominent as regards the value of the temperature T_{liq}. The addition of magnesium reduces quite considerably the temperature of the crystallisation of the primary silicon crystals (by even as much as 19°C÷36°C), compared to the temperature T_{liq} of pure AlSi alloy. From the theory of crystallisation it follows that magnesium added to silumins has no beneficial effect on the modification process. It is added mainly to facilitate the heat treatment.

Examining the solidification curves of silumins cast after the modification process, one can observe the presence of an additional thermal effect which, as has already been mentioned, can be responsible for the pre-eutectic crystallisation of the dendrites of aluminium solution. The said effect is visible only in alloys after modification and occurs irrespective of the introduced alloying additions and melt overheating temperature. An interesting phenomenon has been observed when the temperature of pre-eutectic solidification α (T_x) was compared in function of the pouring temperature (T_{zal}). The comparison is shown in Figure 4. From an analysis of this drawing it follows that the additions of copper and nickel have practically no effect on changes in the temperature T_x (it is comprised in the range of 664÷690°C). On the other hand, adding magnesium to AlSi17CuNi alloy reduces this temperature very definitely, i.e. by about 40°C . The same tendency has been observed in the case of all other pouring temperatures, which suggests that the element present in the composition of the eutectic, when the latter one is crystallising under the pre-eutectic conditions, can be magnesium.

Examining a relationship that is said to exist between the crystallisation temperature of α+β eutectic (T_E) and pouring temperature of the examined alloys, one can observe that the addition of phosphorus has no significant effect on changes in the value of the temperature T_E. Introduced to the base AlSi17 alloy, the additions of Cu, Ni, and Mg result in an insignificant (25°C at a maximum) drop of the crystallisation temperature of the α+β eutectic. Hence a conclusion follows that copper, nickel and magnesium reduce the crystallisation temperature of the α+β eutectic by about 15÷20°C .

Examining the overheating degree and melt composition effects on the crystallisation temperature of the ternary $\alpha+Al_3Ni+\beta$ and $\alpha+Mg_2Si+\beta$ eutectics, from Figures 7 and 8 no distinct tendency or relationship could be derived as regards alloy composition, pouring temperature and crystallisation temperature of the ternary eutectics. On the other hand, in the crystallisation of a ternary $\alpha+Al_2Cu+\beta$ eutectic (Figure 6), one can trace an interesting relationship, which in most cases assumes the form of a drop of the temperature $T_{\alpha+Al2Cu+\beta}$, reported for alloys of the final composition (as compared to the base AlSi17 alloy).

Examining a relationship between the solidus temperature (T_{sol}) of the examined alloys and pouring temperature, from Figure 9 one can conclude that in most cases the addition of a modifier considerably raises the temperature T_{sol}. The effect of copper and nickel additions on the temperature of the end of crystallisation is not so prominent. In alloy of the final composition (AlSi17CuNiMg), one can observe that, like in the case of the pre-eutectic crystallisation temperature of aluminium dendrites and the temperature T_{liq}, an addition of magnesium reduces the temperature T_{sol}, reducing also the whole range of the AlSi17CuNiMg alloy crystallisation temperatures (T_{liq}-T_{sol}).

The next important issue in the explanation of the effect of overheating degree on the solidification parameters of hypereutectic silumins is the examination of microstructure of alloys cast from different temperatures. This is, however, the problem left for the next study of a time-temperature treatment affecting the cluster structure of hypereutectic silumins.

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