THE INFLUENCE OF THE COOLING EFFECT OF THE MOULDS ON THE QUALITY OF CASTINGS FROM ALUMINUM ALLOYS

Petr LICHÝ, Jaroslav BEŇO, Ivana KROUPOVÁ, Filip RADKOVSKÝ, Roman KŘENEK

VSB - Technical University of Ostrava, Department of Metallurgy and Foundry Engineering, Ostrava, Czech Republic, EU

Abstract

The quality of cast components is largely dependent on the structure of the casting. With the achievement of optimal fine grain structure, without any internal or surface defects, it is possible to obtain sufficient mechanical properties of the casting. This effect can be achieved using mould with a higher cooling effect. The aim of this paper consists in evaluation of quality of the cast components from selected aluminum alloys using microstructure analysis and evaluation methods of physical properties of castings. Samples from selected materials have been prepared by casting into the casting moulds with various cooling effect in order to achieve different conditions of solidification and cooling of the test samples.

Keywords: Aluminum alloy, cooling effect, microstructure, casting

1. INTRODUCTION

By selection of an appropriate type of alloy it is possible to significantly affect the mechanical properties of the produced castings, which are, however, also largely influenced by the structure and possible defects or internal inhomogeneity of the material. These properties of the cast part can be influenced by the method of casting, by heat treatment or by the following metallurgical processing. The finer structure is achieved, the higher are the resulting strength characteristics of the material. This fact was confirmed also in earlier studies [1, 2]. In practice, a simple way to achieve the desired structure is commonly used by an application of suitable preparations containing nuclei of crystallisation. In this way it is possible to obtain high quality fine grained structure also in the castings cast into disposable moulds with lower cooling effect, made e.g. from sand mixtures. This structure can be then expected also in large thick-walled castings in their full volume. This way of inoculation is normally used not only for graphitising iron alloys [3], but also for alloys of non-ferrous metals (e.g. magnesium and aluminum). In the case of aluminum alloys for example preparations based on AlTi5B1 is commonly used [4, 5].

In the case of crystallisation nuclei, which are added deliberately to the melt from the outside, their application is limited by the cooling effect of the mould. It plays a predominant role at formation of the primary structure, particularly in the case of casting smaller, thin-walled castings. In such case use of metallic mould appears to be the most efficient, in particular in combination with the application of external pressure (positive pressure and holding pressure) during casting or during solidification. It is generally known that by using the method of processing the metal in the semi-solid state (thixocasting) with application of high pressure we obtain a completely different microstructure, which is not dendritic anymore. These methods can be used only on special machines. The aim of this paper is to study the effect of cooling effect of the metallic mould on the microstructure and thermo-physical properties of selected aluminum alloy.

2. MATERIALS AND METHODS

For investigation of the influence of the cooling effect of the metallic mould on selected properties of the casting alloy we studied the Al based alloy (AlSi10Mg), the exact chemical composition of which is shown in **Table 1**. It is an alloy of the Al-Si type, the chemical composition of which is close to eutectic. This material is commonly used for production of castings in disposable and permanent moulds by gravity casting or with application of elevated pressure. It is thus possible to produce castings with different dimensions and wall thickness. The material was melted in an electric resistance furnace, and it was not metallurgically modified in any way. The test castings were prepared by gravity casting and cast into the open metallic mould, which was made of ordinary carbon steel (0.80 wt.% C), with top-loading at the casting temperature of 650 °C. For comparison of the influence of the cooling effect of the mould, the material was cast into a mould without pre-heating (20 °C) and with pre-heating of the mould (100, 200, 300 °C). Afterwards, the samples for evaluation of metallographic microstructure were prepared from these castings (observed on the etched thin section at 100x magnification) and for dilatometric analysis.

Table 1 Chemical composition of AlSi10Mg (wt.%)

Al	Si	Fe	Mg	Mn	Ti	Cu
88.2	10.82	0.284	0.464	0.188	0.0094	0.0022

Thermal analysis was employed for determination of thermo-physical properties of aluminum alloys. The material thermal expansivity (linear changes) is characterised typically by the length expansion coefficient according to:

$$\alpha_T = \frac{l_T - l_{To}}{l_{To}(T - T_o)} = \frac{1}{l_{To}}\left(\frac{dl}{dT}\right) \quad (1)$$

where:

α_T - length expansion coefficient,

l_{To} - sample length at the reference (e.g. laboratory) temperature,

l_T - sample length at the experimental temperature,

T - experimental temperature,

T_o - reference (e.g. laboratory) temperature,

dl - sample length change,

dT - temperature difference.

Changes of properties of aluminum alloy samples were observed with the aid of DIL 402C/7 dilatometer made by Netzsch GmbH at the temperature interval 25 °C up to 350 °C with constant heating and cooling rate (15 K/min) in the protective argon atmosphere (purity 99.999 % Ar). The dilatometric analysis was carried out for the edge parts of the samples (marked with subscript *E*) and central part of the samples (marked with subscript *C*), respectively.

3. EXPERIMENTS AND DISCUSSION

3.1 Metallographic analysis

For metallographic analysis we purposefully selected the central part of the test castings, in which the cooling effect of the mould was suppressed the most. Metallurgical analyses of individual samples are summarized in **Figs. 1** to **4.** From the micrographs of the obtained microstructure of the studied samples we can see evident influence of pre-heating of metallic mould on the resulting cast microstructure of the final cast test sample. Although distinct grain boundaries are not apparent, since this material is close to the eutectic composition, it is possible to see the structure refinement in the morphology and distribution of α-phase. With the increasing temperature of pre-heating of metallic mould the size of the segregated formations increases, while the most significant difference is observed between the temperature of 20 °C (**Fig. 1**) and 300 °C (**Fig. 4**)

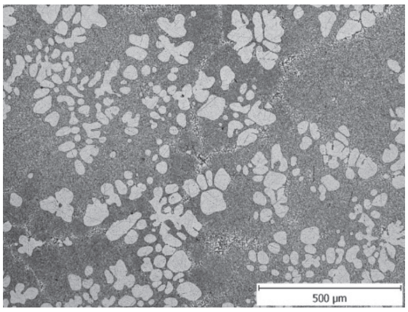

Fig. 1 Central part of the casting, mould temperature 20 °C

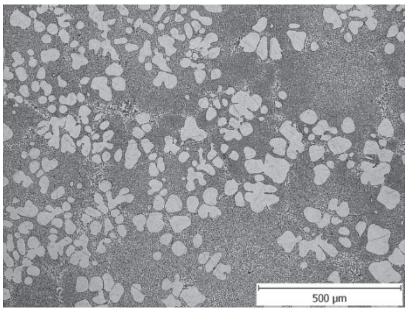

Fig. 2 Central part of the casting, mould temperature 100 °C

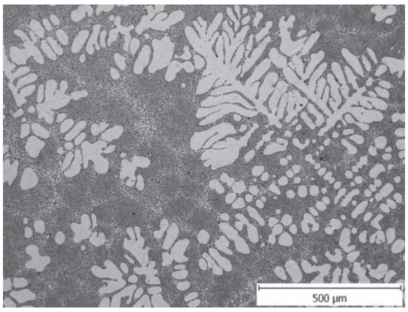

Fig. 3 Central part of the casting, mould temperature 200 °C

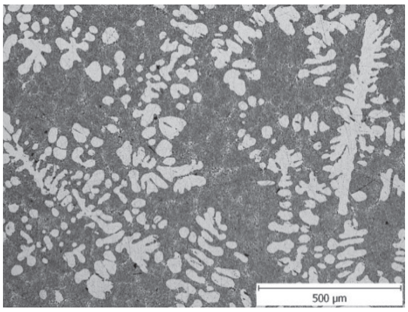

Fig. 4 Central part of the casting, mould temperature 300 °C

3.2 Dilatometric analysis

Thermal expansion of the material is an important parameter, particularly in the case of using cast parts for thermally stressed components. It influences the dimensional stability of structural elements under different degrees of heat loads, which determines their uses for different operational applications. The samples measuring 5 x 5 x 23 mm for dilatometric analysis were obtained from the central part of the test castings. The resulting values of the maximum expansion at T = 350 °C (max l_{350}) and coefficients of linear expansion in the temperature range studied (α_T) are summarised in **Table 2.**

On the basis of the obtained results it is possible to observe the influence of the degree of pre-heating of the metallic mould on the resulting structure of the test casting. With the increasing temperature of the mould pre-heating the cooling effect of the mould decreases, which affects the character and size of the segregated phase resulting in affecting the behaviour of the material with the increasing temperature load. Character of the microstructure (**Figs. 1-4**) is closely correlated with the degree of dilatation of the test sample. It is evident from the obtained results that the higher is the cooling effect of the mould, the finer is the microstructure of the test sample and thus the degree of dilatation is higher.

Table 2 Thermo-physical properties of selected samples

Sample	A	B	C	D
max l_{350} (%)	0.86	0.84	0.74	0.72
α_T x 10^{-6} (K^{-1})	27.3736	25.1546	22.4209	22.5674

Note: A = without pre-heating; B = pre-heating at 100 °C; C = pre-heating at 200 °C; D = pre-heating at 300 °C.

The maximal degree of relative expansion was observed in the sample, which was cast into a non pre-heated mould (**Table 2, Fig. 5**), i.e. where the maximum cooling effect was ensures (A: 0.86 %). Conversely, the lowest degree of thermal expansion was observed in the samples with the maximum temperature of pre-heating of metallic mould (C: 0.74 % and D: 0.72 %). These findings are confirmed also by the values of the coefficients of linear expansion (for the sample A: 27.3736 x 10^{-6}, for the sample D: 22.5674 x 10^{-6}).

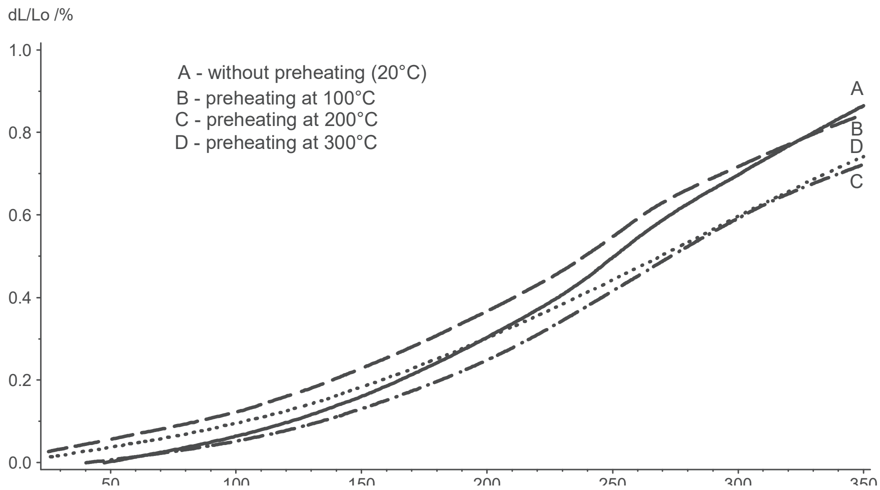

Fig. 5 Dilatometric characteristic of studied samples

From the results of carried out experiments is evident that application of various mould with different cooling effect can substitute addition of inoculate agents. It is evident, that with the lowest size of the grains (with increasing cooling effect, it means bigger temperature difference between the mould and solidified casting) the relative expansion increase.

CONCLUSIONS

Mechanical properties of the cast components, which are largely influenced by the structure and possible defects or internal inhomogeneity of the material, can be influenced by the manner of casting, or by the following metallurgical processing. For the use of the given casting for thermally stressed parts the degree of dilatation under thermal load is also of crucial importance, which determines the dimensional stability of the given parts or of the service life of whole unit. In the case of the studied alloy AlSi10Mg the cooling effect had a positive impact on the microstructure of the cast samples, but it had also a negative impact on the behaviour of the cast components under thermal load. In this paper we investigated the impact of the cooling effect of metallic (permanent) moulds. Further works we will pay attention to the use of non-permanent (sand, gypsum) moulds.

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