THE COOLING EFFECT OF CASTING MOULDS AND ITS EFFECT ON MICROSTRUCTURE OF ALUMINUM ALLOYS

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Abstract

Material properties in cast condition are largely influenced by its structure. Here you can influence, for example the speed of solidification, or metallurgical operation. In the case of aluminum alloys, casting into moulds with a low cooling effect of vaccination is commonly used material. Submitted work deals with the influence of the cooling effect of common foundry moulds achieved microstructure of casting alloys on the base of Al-Si. Used moulding materials were mixed with inorganic and organic binders. Other types of materials have been significantly different cooling effects - metal and plaster form.

Keywords: Aluminum alloy, cooling effect, microstructure, casting

1. INTRODUCTION

The use of aluminum for casting production is largely due to the obtained mechanical properties of the finished component. It is known that with the increasing thermal load of the given workpiece these properties are significantly reduced. However at the same time it is necessary to pay attention also to the material expansion throughout the all range of the used temperature interval. This question is partly solved in the presented contribution. It looks for the relationship between microstructure and properties obtained as cast which shall decide about the use of the given material.

Generally it can be stated that the material grain size, i.e. the grain fineness of microstructure, directly depends on achieved mechanical properties of the casting. With the increasing grain size they are decreased.

During intensive cooling the great overcooling of the melt occurs under the equilibrium crystallization temperature at which even less favourable nuclei activate. It results in obtaining of fine-grained structure without any metallurgical interventions [1, 2]. This mechanism of grain refinement is typical for thin-walled castings. For castings with thicker walls and especially when casting in sand moulds the cooling intensity is considerably smaller and therefore the material is of coarse-grained structure. In these cases the refinement of primary grains is achieved by inoculation, i.e. by introduction of nuclei or such matters from which these nuclei will be formed. Hypoeutectic aluminum alloys are inoculated with titanium or with combination of titanium and boron. The effect of inoculation on casting properties is always less than the effect of rapid cooling. This method is used in practice basically always despite the fact that most of the production of castings from aluminum alloys is cast into permanent metal moulds. The contribution deals with the relationship between the cooling effect of the mould, obtained microstructure and achieved thermophysical properties of the cast part.

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.

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

For investigation of the influence of the cooling effect of the metallic mould on selected properties of the casting alloy we studied the hypoeutectic aluminum alloy of the Al-Si (AlSi10Mg) type the exact chemical composition of which is shown in **Table 1**. This material is commonly used for production of castings in disposable and permanent moulds by gravity casting or with application of elevated pressure [3]. It is thus possible to produce castings with different dimensions and wall thickness [4]. The material was melted in an electric resistance furnace, and it was not metallurgically modified in any way.

For checking the influence of cooling effect on microstructure and thermophysical properties different types of material were chosen for manufacture of moulds which are commonly used in foundry practice. Thus the test castings were obtained by casting in 3 chosen types of moulds. In the first case the material was poured in a metal mould (in the text marked with the letter A) which was made of ordinary carbon steel (0.80 wt.%). This mould was used both without preheating - temperature 24 °C (in the text marked with the number 1) and with preheating - temperature 300 °C (4). Furthermore a unit bentonite mixture (B) was used for manufacture of moulds. It was prepared from the quartz sand (ŠH35), 8 weight parts of bentonite (Keribent) and water that was used in the content of 1.83 % (1) and 2.28 % (4). The cooling effect of bentonite mixture is directly dependent on the water content with the growing content of which the cooling effect of the mould increases. For manufacture of the third type of moulds a self-setting mixture (ST-mixture) with water glass (E) has been used. It was prepared from the quartz sand (ŠH35), 4 weight parts of water glass with module M = 2.37 and the binder was monoacetin. Thanks to its low price and environmental certificate as compared with organic binders this material belongs among the materials with high application potential4. Moulds of this material were used in the undried state (1) and dried one - 120 °C/1 h (4).

Test castings of a roller type (ø 50 mm, height 50 mm) were obtained by gravity casting into open moulds, casting temperature was 650 °C in all cases. From the central part of obtained castings the samples for metallographic and dilatometric analysis were prepared. Thermal analysis was used for determination of thermophysical properties of aluminum alloys. The material thermal expansivity (linear changes) is characterised typically by the length expansion coefficient according to:

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

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 of 25 °C up to 350 °C with constant heating and cooling rate (15 K/min), with holding time of 30 min at the maximum temperature (isotherm) in the protective argon atmosphere (purity 99.999 % Ar). The dilatometric analysis was carried out for central part of the samples.

3. EXPERIMENTS AND DISCUSSION

Microstructure was analysed on the central parts of the test casting for suppressing the influence of the cooling effect in a different direction from the mould wall. Microstructure of the material which was cast in the metal mould without preheating is given in **Fig. 1**. It is evident from the picture that the dendritic segregation of the primary α occurred and on the base of its size the considerably finer-grained structure can be expected than in the case of the casting obtained from the preheated metal mould (**Fig. 2**).

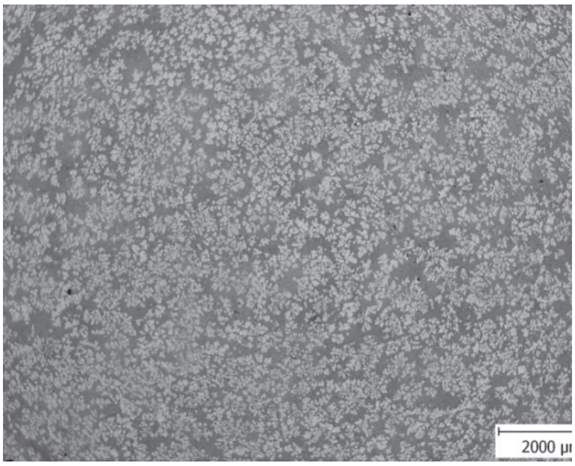

Fig. 1 Microstructure of the sample A1 - mould temperature 24 °C

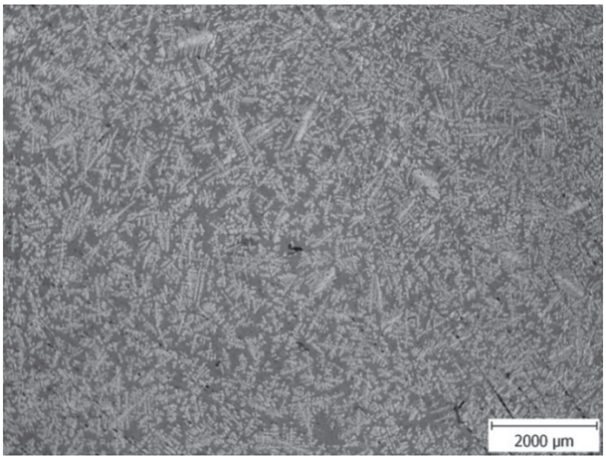

Fig. 2 Microstructure of the sample A4 - mould temperature 300 °C

On the contrary, based on the size of dendritic cells the significantly coarser-grained structures can be expected in castings cast in moulds of the unit bentonite mixture (**Figs. 3, 4**). When comparing the achieved microstructure the influence of the increased water content in the mixture isn't evident (**Fig. 4**). On the contrary, in these cases the significantly porous structure caused by increased release and subsequent decomposition of water vapour is evident. Microstructure of the alloy obtained by casting in the ST-mixtures with water glass is shown on **Figs. 5** and **6**. Also in this case, from the point of view of the grain size there is no considerable difference between the use of the undried mould (**Fig. 5**) and the dried one (**Fig. 6**).

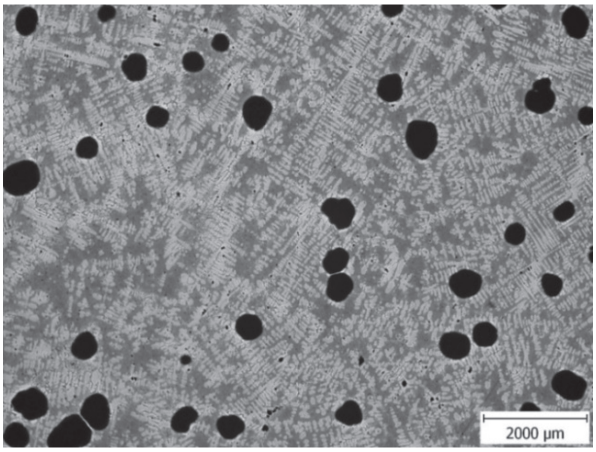

Fig. 3 Microstructure of the sample B1 - moisture of the mixture 1.83 %

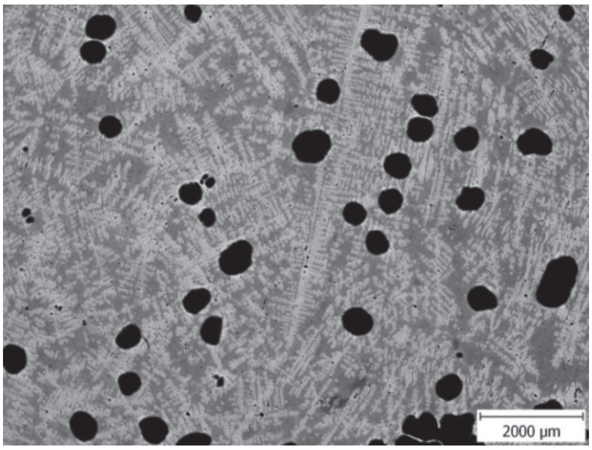

Fig. 4 Microstructure of the sample B4 - moisture of the mixture 2.28 %

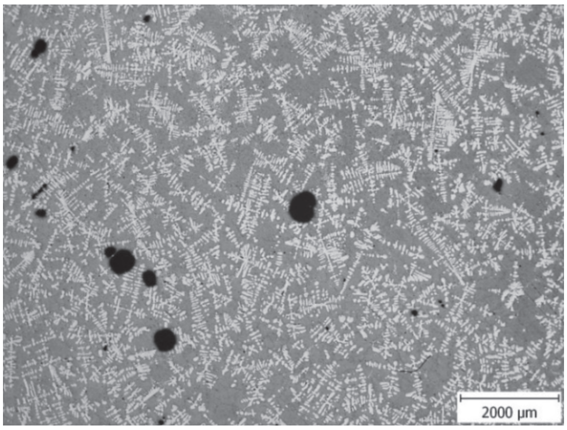

Fig. 5 Microstructure of the sample E1 - the undried mould

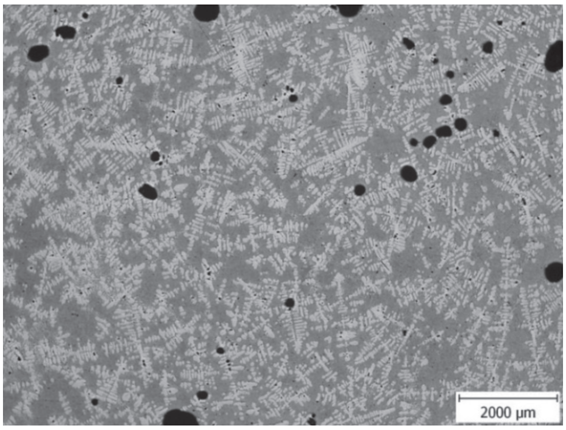

Fig. 6 Microstructure of the sample E4 - the dried mould

Small gas cavities can be observed in the structure. With the size of dendritic formations it is placed between the material obtained from the metal mould and that one from the mould of the unit bentonite mixture.

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 summarized in **Table 2**.

Table 2 Overview of thermophysical parameters of AlSi alloy

Specimen	**α_T x 10^6**	**l_{350}**
	(K^{-1})	(%)
A1	27.3736	0.86
A4	22.5674	0.72
B1	26.2069	0.86
B4	28.9744	1.02
E1	26.9513	1.31
E4	25.9262	0.88

The highest value of the coefficient of linear thermal expansion ($28.9744 \cdot 10^{-6}$ K^{-1}) in the studied interval (20 ± 5 °C up to 350 °C) has been reached for the material which was cast in the mould prepared from the unit bentonite mixture with higher moisture content. In this case the length change of 1.02 % has been recorded under temperature of 350 °C. The lowest value of the studied coefficient ($22.5674 \cdot 10^{-6}$ K^{-1}) has been obtained in the case of the sample which was cast in a preheated metal mould. In this case the lowest achieved length change (0.72 %) has been also recorded. The highest value (1.31 %) was then obtained for the material cast in a dried mould of the mixture with the use of water glass.

In the case of the use of metal moulds the higher degree of dilatation was monitored in the case of the finer-grained material (the mould without preheating). This phenomenon also occurred when expendable moulds prepared from the bentonite mixture with higher water content (B4) and the undried mixture with water glass (E1) was used.

On the other hand the highest value of the coefficient of linear thermal expansion was obtained for a sample cast in a bentonite mould with higher water content (B4) although from the studied materials the metal mould without preheating has the highest cooling effect (A1). This was verified by analyzing the microstructure.

4. CONCLUSIONS

The work was focused on evaluation of thermophysical properties and microstructure of AlSi10Mg aluminum alloy. Based on done experiments a significant influence of the choice of the moulding material on resulting structure of the casting has been proved. It decides on other properties and potential use of the cast part. With the dilatometric analysis of test samples a significant influence of the grain size (fine-grained structure) on studied thermophysical properties - the coefficient of linear thermal expansion and maximum length changes in the studied temperature interval - has been confirmed in all cases. On the other hand it failed to find the exact dependency between the achieved microstructure and determined thermophysical parameters.

Works in this field will continue for further checking the dependencies of the microstructure of cast materials and studied thermophysical properties. Attention will be paid to other processes influencing the grain size - inoculation and the choice of other types of materials usable for manufacture of moulds.

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REFERENCES

[1] MICHALCOVÁ A., VOJTĚCH D., SCHUMACHER G., NOVÁK P., PLIZINGROVÁ E. Effect of iron and cerium additions on rapidly solidified Al-TM-Ce alloys. Materiali in Tehnologije, Vol. 47, No. 6, 2013, pp. 757-761.

[2] WANNASIN J. et al. Grain refinement behavior of an aluminum alloy by inoculation and dynamic nucleation. Acta Materialia, Vol. 61, No. 10, 2013, pp. 3897-3903.

[3] BOLIBRUCHOVÁ D., SLÁDEK A., BRŮNA M. Effect of filtration on reoxidation process in aluminum alloys. Archives of Foundry Engineering, Vol. 10, No. 1, 2010, pp. 121-126.

[4] JELÍNEK P., MIKŠOVSKÝ F., BEŇO J. et al. Development of foundry cores based on inorganic salts. Materiali in Tehnologije / Materials and Technology, Vol. 47, No. 6, 2013, pp. 689-693.