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Non-ferrous Metals Precision Casting Shape Accuracy in Terms of Ceramic Moulds Anisotropic Material Properties

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Abstract

Shape accuracy analysis of aluminum alloy castings was made in function of ceramic mould properties. Taken it to account was anisotropy of those properties, including influence of ceramic mould properties on the porosity of castings.
Ceramic moulds strains, which occur in sintering phase, were evaluated with taking into account the design and production process.

Keywords: Castings shape accuracy, Lost wax casting, Ceramic mould anisotropy

1. Introduction

Precision castings produced by lost wax process, due to the extent of their use, primarily for the aerospace and defense industries, are high-quality products, which in many cases [1, 2] have greater reliability then the best products produced by other metal forming techniques. Quality of products is highly dependent on the shape and dimensional accuracy. Difficult manufacturing process of ceramic moulds in many cases is a barrier to obtain castings with high accuracy.

The process itself due to the multilayer ceramic moulds and usually complex pattern shapes, on which multiple ceramic layers are applied, and the impact of physical and chemical phenomena leads to the ceramic mould thickness variations and quantitative composition [3] (Fig. 1). In various layers of ceramic mould there is a differentiation of ratio between binder contained in the liquid ceramic mould material and the amount of loose ceramic material. Large influence on the ceramic mould layers have fluidization phenomena affecting the motion speed of the free-flowing ceramic material grains in liquid ceramic shell mould material during movement of set of patterns and then set of successive layers of hardened ceramic moulds. A significant role especially during applying the first ceramic material layer is wetting by the liquid ceramic shell mould material and speed of its dehydration on the base of ceramic moulds. This further on leads to the hardening and prevents from movement of the loose grains of ceramic material on the liquid ceramic mould material substrate. The process repeats during the application of successive layers, wherein the second layer is roughened ceramic mould layer. As a result, we finally obtain ceramic mould, which has an anisotropic structure, due to the thickness and physical properties [3, 4].

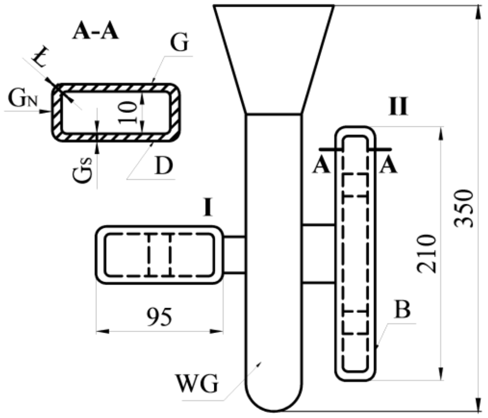

Fig. 1. Ceramic mould used in this research analysis

2. The accuracy obtained for AlSi alloy casting with different shapes and variable orientation in relation to the sprue axis

The accuracy of the casting (Fig. 2, 3, 4) were made after gathering set of measured castings, where in the measurement of each dimension was carried out three times to give 90 results globally, which reduced the measurement uncertainty [5] of the measured dimension. The results allowed us to determine the dimensional tolerances $\Delta L_{6\sigma}$ in accordance with the following formula:

$$\Delta L_{6\delta}{}^2 = \Sigma\delta_s + \sqrt{\delta_M{}^2 + \delta_f{}^2 + \delta_u{}^2}$$

and

$$\bar{x} = \frac{\sum_{i=1}^{i=n} x_i}{n}$$ where x_i - next casting dimension

The following results were obtained for casting number 1 (Fig. 2), for the dimensions:

a) A_1: $\Delta L_{6\sigma}$ = 0,11 mm; $\bar{x}$ = 13,33 mm;

b) A_2: $\Delta L_{6\sigma}$ = 0,20 mm; $\bar{x}$ = 13,43 mm;

c) B_1: $\Delta L_{6\sigma}$ = 0,17 mm; $\bar{x}$ = 33,40 mm;

d) B_2: $\Delta L_{6\sigma}$ = 0,21 mm; $\bar{x}$ = 33,25 mm;

e) C_W: $\Delta L_{6\sigma}$ = 0,16 mm; $\bar{x}$ = 21,23 mm;

f) D: $\Delta L_{6\sigma}$ = 0,42 mm; $\bar{x}$ = 43,72 mm;

g) F_G: $\Delta L_{6\sigma}$ = 0,32 mm; $\bar{x}$ = 58,14 mm;

h) F_D: $\Delta L_{6\sigma}$ = 0,40 mm; $\bar{x}$ = 58,16 mm;

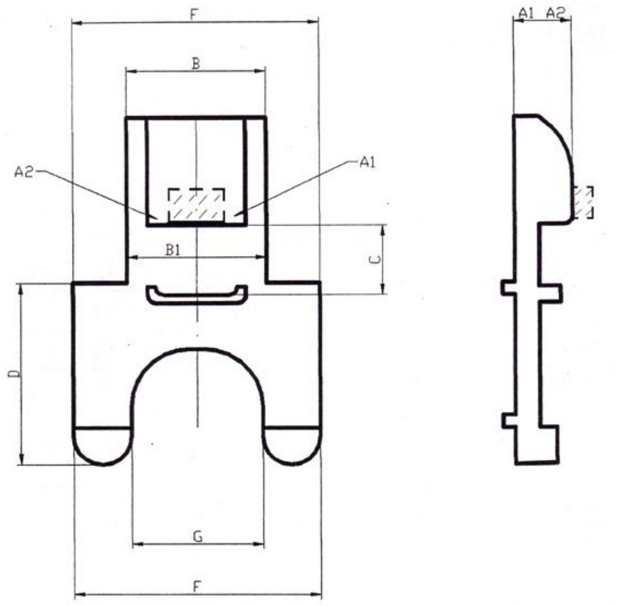

Fig. 2. Cast number 1 made from AlSi9

For casting number 2 (Fig. 3), the following results were achieved for the dimensions:

a) A: $\Delta L_{6\sigma}$ = 0,085 mm; $\bar{x}$ = 14,98 mm;

b) B: $\Delta L_{6\sigma}$ = 0,136 mm; $\bar{x}$ = 13,79 mm;

c) L: $\Delta L_{6\sigma}$ = 0,17 mm; $\bar{x}$ = 38,49 mm;

d) L_1: $\Delta L_{6\sigma}$ = 0,103 mm; $\bar{x}$ = 21,03 mm;

e) L_W: $\Delta L_{6\sigma}$ = 0,086 mm; $\bar{x}$ = 12,51 mm;

f) L_{W1}: $\Delta L_{6\sigma}$ = 0,060 mm; $\bar{x}$ = 10,07 mm;

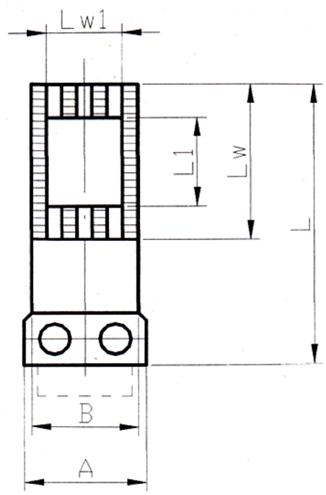

Fig. 3. Cast number 2 made from AlSi9 (dashed line present main runner to sprue)

For casting number 3 (Fig. 4) the following results were obtained for the dimensions:

a) c: $\Delta L_{6\sigma}$ = 0,208 mm; $\overline{x}$ = 26,53 mm;

b) d: $\Delta L_{6\sigma}$ = 0,126 mm; $\overline{x}$ = 13,04 mm;

c) e: $\Delta L_{6\sigma}$ = 0,119 mm; $\overline{x}$ = 13,05 mm;

d) f: $\Delta L_{6\sigma}$ = 0,076 mm; $\overline{x}$ = 6,55 mm;

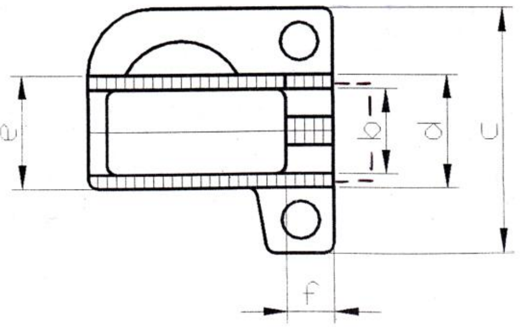

Fig. 4. Cast number 3 made from AlSi9

Process parameters related with the performance of castings:

a) Fig. 2 - Cast number 1: ceramic mould temperature during pouring of gravity - 350^{+50} °C, the temperature of liquid AlSi9 - 710^{+20} °C; sprue - ∅34, and height of set - 320 mm;

b) Fig. 3 - Cast number 2: pouring liquid metal in the process of backpressure, temperature ceramic mould when filling with liquid metal - $200^{\pm 20}$ °C, the temperature of liquid AlSi9 - $680^{\pm 10}$ °C, sprue - ∅25 (patterns with a sprue made from polystyrene), and height of set - 280 mm;

c) Fig. 4 - Cast number 3: Ceramic mould temperature during pouring of gravity - 320^{+20} °C, the temperature of liquid AlSi9 - 710^{+20} °C; sprue - ∅25, height of set - 320 mm; patterns made with polystyrene the same as for the cast from Fig. 3.

The distance between the layers in the casting set number 1 was approximately 20 mm, while for all the other castings 10 mm. Due to the small distance between the layers, which was 10 mm, ceramic mould sets are merged, creating a connected network of patterns and later for casting mould [6].

Visible merged ceramic mould construction (no space between layers) results in loss of separation between the layers of ceramic mould, since actual thickness of ceramic mould should be greater than 7 mm (i.e., for two layers of casting, the thickness of ceramic mould should be greater than the distance between the existing layers in the examined mould).

Evaluated castings were chosen in a special way in order to include three cases of the ceramic mould anisotropy properties on the porosity and deformation occurring during sintering. [7]

Significant impact on the value of the dimensional tolerances (the ability to fill complex ceramic mould shapes) has a wettability of mould by the liquid metal AlSi [8]. This can be seen frequently in an incompletely filled corner of castings, where the porosity of the mould is the smallest (a much larger amount of binder in relation to the loose ceramic material).

3. Analysis of research results

A fundamental role in determining castings dimensions play deformation of ceramic mould. Six sigma deviations $\Delta F_{6\sigma}$ of ceramic mold arise, which are estimated to be about 0.55% of $\Delta F_{6\sigma}$. Ceramic mould deformations which occur during sintering phase ΔF_S significantly influence on this value, whereas the effect on ΔF_S value has porosity variation in different places of the ceramic mould [7].

Analyzing the results presented in section 2 of article it is possible to observe that:

1) The location of casting (ceramic mould) against sprue has great significance (Fig. 1);

2) In the creation of the ceramic mould layers can be positioned freely (which mean, that there is a space between the layers of the ceramic mould), and the layers which are joined form the block mould, and castings form a network [6]. In case when the castings form a network it's not possible in accordance with the casting principles to extract free, mixed and moderated shrinkage.

Castings (Fig. 3, 4) were made in the moulds of the merged structure (block moulds). In these types of moulds the anisotropy of their properties plays a smaller role than in traditional sets of ceramic moulds.

Given the cast from Fig. 3 we are dealing with the smallest castings dimensional deviations. Ceramic mould deformation in accordance with [7] applies to such deformations marked with "www" and is for the aluminosilicate moulds in the range from 0.100 to 0.140% against cavity which recreates casting. However deviation $\Delta L_{6\sigma}$, for those casting averaged 0.62% of the nominal casting dimension.

For castings number 3 (Fig. 4) the deviation $\Delta L_{6\sigma}$ is on average 0.93%. The observed differences are mainly related to the stability of the AlSi liquid shrinkage.

Fluctuations in the casting shrinkage from Fig. 3 are estimated at about 0.1% of the nominal dimension of the casting, and the casting from Fig. 4 is about twice as large. The upper and lower moulds surfaces are formed by interlocking higher sintering deformation. These deformations are defined by symbol "pww" [7] and are about twice as high as other deformations of ceramic mould cavities.

The highest values of the dimensional inaccuracies of castings can be observed for casting number 1 (Fig. 2) made in the traditional SiO_2 - based ceramic mould. In this case, there are different kinds of sintering deformations described with symbols "www", "pww", and "ns" [7]. The smallest dimensional deviations of castings are for dimensions F, which average about 0.61% (mould deformation "ns"). The greatest deviation from 0.82% to 1.48% of the nominal dimension occurred for the dimensions defined by A1 and A2. These deviations have been shaped by major deformation during sintering of the ceramic moulds (symbol "pww").

4. Conclusions

1. Anisotropy of ceramic mould properties has a significant impact on the value of ceramic mould dimensional tolerances ΔF_C.
2. Design of the ceramic mould and the production process play an important role in achieving the smallest deviation of dimensional inaccuracy of precision casting $\Delta L_{6\sigma}$.

References

[1] Lorch D. (1998). Präzision aus dem Vakuum Aluminium feinguss mit Hoher Oberflächen gute und Massgenauigkeit. *Aluminium*. 64(5).

[2] Haratym, R., Biernacki, R., Myszka D. (2008). *Ecological investment casting in ceramic dies*. Warsaw University of Technology, Publishing House.

[3] Haratym, R., Lewiński, J., Biernacki, R. & Kowaluk, T. (2012). Anisotropy of ceramic moulds physical properties which affect environmentally friendly production of precision aluminium castings. *Archives of Foundry Engineerig*. 12(spec. 1), 53-56.

[4] Cileček, J. (1988). Production of precision castings made from copper alloys. *Archives of Foundry Engineering.* 5.

[5] Arendarski, J. (2003). *Uncertainty of measurements*. Warsaw University of Technology, Publishing House.

[6] Piwonka, T. S. & Wiest, J. M. (1998). Factors Affecting Investment Casting Pattern Die Dimensions. *Incast.* June.

[7] Haratym, R. (2005). Anisotropy of properties of ceramic molds in aspect of accuracy of castings made in the counter-pressure process. *Archives of Foundry*. 5(15), 2005.

[8] Haratym, R., Senkara, J., Sankowski, D. (2001). The impact of liquid aluminum alloys on ceramic moulds made with usage of silicate binders, Commission of Machine Building PAN (Polish Academy of Science) - Branch in Poznan. *Archives of Mechanical Technology and Automation*. 21.