Analysis of Impact of the Multilayer Ceramic Moulds Quality on the Steel Precision Castings Dimensional Accuracy

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Abstract

Results of analysis presented in this paper were based on analysis of casts made especially for this research purpose and related to actual cast – industrial. The evaluation of the dimensional accuracy of casts was made in relation to the pressure of the liquid metal with consideration of the ceramic mould temperature. Ceramic moulds used in these analyses were made from crystalline quartz with an aqueous colloidal silica binder containing polymers (KK), and ethyl silicate (KE).

Keywords: Lost wax casting; Dimensional accuracy; Multilayer ceramic mould; Ceramic mould expansion

1. Introduction

Analysis of the precision casts dimensional accuracy made with usage of investment casting is carried out by many researchers. In papers [1] to [5] the dimensional accuracy was evaluated by analysis of all casts produced globally by investment casting. This applies to mass manufacturing of casts produced from cast steel and other materials.

Analysis of accuracy in these publications concerns the evaluation of dimensional changes in different production phases, during preparation of patterns, ceramic moulds and making final casts. Especially highlighted was the impact of dimensional deviations of ceramic mould on final cast tolerances.

2. Analysis of impact of the multilayer ceramic moulds (FC) quality on the steel precision casts dimensional accuracy

Analysis includes studies of the temperature distribution in the cross-sections of the multilayer ceramic mould and the evaluation of expansion of ceramic moulds in various research options.
2.1. Studies of the temperature distribution

Research methodology presented in Fig. 1. Thoroughly describes a method on cross-section of sprue (WG).

![Diagram of temperature distribution in the cross-section of the multilayer ceramic mould (FC) during annealing and cooling after pouring liquid metal into FC cavity.](image)

Similar measurements were conducted on a ceramic mould (FC-O) reproducing the casts. In this case, the three thermocouples were used to measure No. 2, No. 4 and No. 6. For measurement of ceramic mould temperature, thermocouple made from NiCr-Ni was used, and for measuring of the liquid metal temperature PtRh-Pt thermocouple was used.

It was found that about 2 min. after pouring liquid carbon steel into the mould cavity, the thickness of the inner wall of the cast exceeded 1.5 mm. The method of pouring liquid metal from FC was used. FC outside wall temperature exceeded 900 °C (in the case of the upper level of the tank filler). The measurement was performed with thermocouple marked as 6(t) in Fig. 1.

2.2. Analysis of ceramic mould expansion

Expansion of the mould (FC) typically made on the basis of crystalline quartz – SiO₂

In order to make FC the colloidal silica binder - Ludox and Ekosil was used together with ceramic SiO₂ (coarse ceramic particle and ceramic slurry (CMC)). A typical representative graph is shown in Fig. 2. - testing was performed on a dilatometer made by Rigaku-Denki company (samples heating speed 2 °C/min).

![Graph of thermal expansion of FC made from KK and KE binder and SiO₂](image)

**Tests of expansion of samples FC dilatometer under load**

The applied loads correspond to the pressure of the liquid steel acting on FC, measured locations includes horizontal distance from the surface of the pouring basin 70 mm, 160 mm and 300 mm, giving the test load on FC sample, estimated as 0.0046 \(\frac{MN(1)}{m^2}\), 0.016 \(\frac{MN(2)}{m^2}\) and 0.030 \(\frac{MN(3)}{m^2}\). Relevant references in the chart in Figure 3 (1, 2, 3).
Evaluation of dimensional accuracy of industrial casts in different levels

An evaluation of dimensions of casts "Kurbel" made of carbon steel, where the chemical composition of the material was as follows: carbon from 0.4 up to 0.6 %, Mn – 0.5 to 0.8 %; Si – 0.2 to 0.40 %. Casts diameters were measured (Figure 4). The average outside diameter - D of exerting bush from cast for the two upper levels sets was $\bar{X} = 33.30$ mm with dimensional gap ($D_{\text{max}} - D_{\text{min}}$) was 0.20 mm for n - 20 pieces of measured casts.

Similarly, the measurements of the two lower levels were made for D which give the average dimension $\bar{X} = 30.16$ mm with R = 0.17 mm.

Generally, in practice, the dimensional analysis is performed for the entire population of produced casts. In that case, for the obtained measurements the following results have been achieved: $\bar{X} = 30.23$ mm and the total gap range for all of castings would be $R = 0.30$ mm.

Hence the conclusion is that there is a possibility to narrow production tolerances of casts by separation of the two upper levels or two lower levels of casts.

The observed regularity is reflected in the dimensions of the ceramic mould cavity. For example, for the upper level when the FC temperature is close to the 960 °C expansion deviations are minimal (Fig. 2), moreover FC dimensional changes due to liquid metal pressure are low (references 1, 2, 3, from Fig. 3). Thus, on the upper level measurements gap range was $R = 0.2$ mm in comparison to the total population where $R = 0.3$ mm.

3. Summary of analysis results

The research methodology presented in the previous section applies to casts which weight up to 250 grams and are mass-produced using the pattern segments. In such cases, the pattern sets are made by forming pattern clusters containing the WG element accompanied by patterns located periphery around WG.

For castings which weight approximately 150 grams, with an average solidification module of about 0.3 to 0.4 cm, it is possible to mount them in sets of several different types of casts. Casts which require increased dimensional accuracy should be mounted on the two upper or two lower levels. This significantly improves tolerance of casts made without increasing the manufacturing costs.

With a global consideration of all casts, for carbon steel cast and moulds FC-SiO$_2$ it’s possible to get process tolerances $T_u = 0.8$ to 0.9% $L_{\text{nom}}$, which is reflected in literature [1] to [5].

After the selection is made, which take into account choice of levels, for small carbon steel casts we can obtain manufacturing tolerances estimated for $T_u = 0.6$ to 0.7% $L_{\text{nom}}$ without increasing manufacturing cost.

References


