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

R. Haratym [a], *, **R. Biernacki** [b], **J. Kwapisz** [c]
[a] University of Ecology and Management, Olszewska 12, 00-792 Warsaw
[b] Warsaw University of Technology, the Faculty of Production Engineering, ul. Narbutta 85, 02-524 Warsaw
[c] Instituto Superior Tecnico, MIT Portugal, Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal
*Corresponding author. E-mail address: r.biernacki@wip.pw.edu.pl

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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 molds 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).

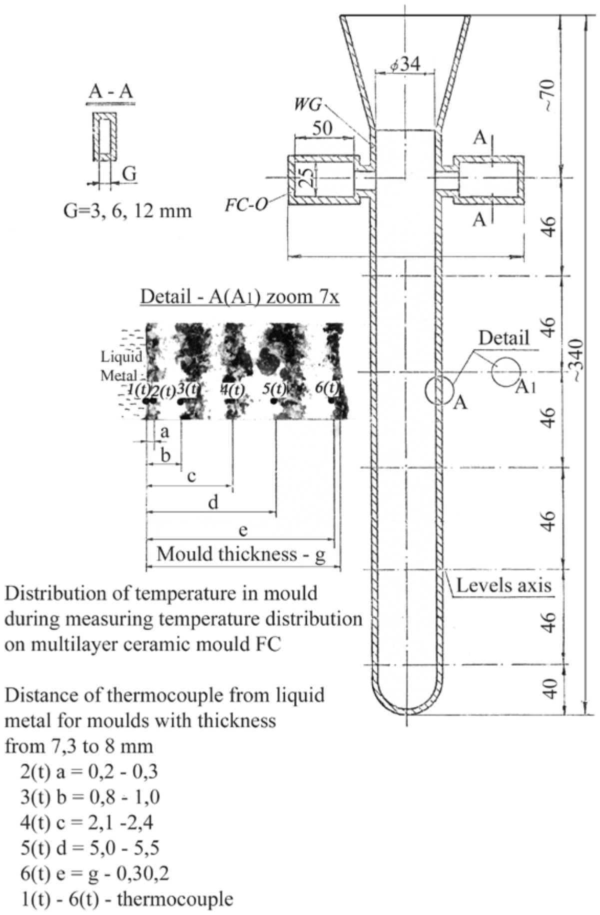

Fig. 1. Method of measuring temperature distribution in the cross section of the multilayer ceramic mould (FC) during the annealing and cooling after pouring liquid metal in to FC cavity

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 – SiO_2

In order to make FC the colloidal silica binder - Ludox and Ekosil was used together with ceramic SiO_2 (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).

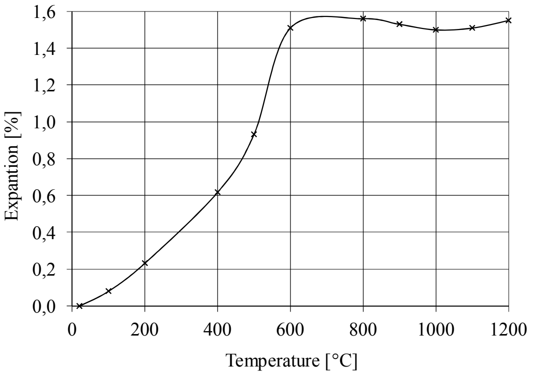

Fig. 2. Thermal expansion of FC made on from KK and KE binder and SiO_2

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).

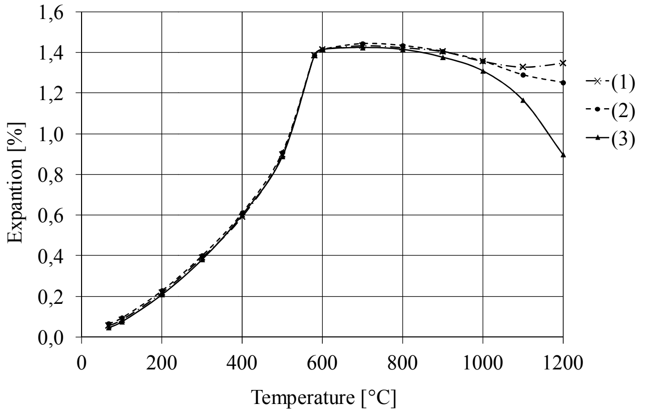

Fig. 3. The impact of load on FC sample in dilatometer on its thermal expansion. The sample on the basis of KK and KE binder and SiO_2

Measurement of the vertical FC temperature distribution along WG

In addition to measuring the FC temperature distribution in levels, temperature distribution measurements FC were made on actual industrial sets with the casts. A temperature measurement of FC containing 150 grams casts (set of castings Figure 4) was conducted on three levels. Measurements were made two minutes after pouring liquid metal into FC when the initial casting wall was formed. Laser pyrometer was used for this part of measurements.

Fig. 4. Carbon steel casts (approximately 0.5% C) in the industrial set after removing FC (next casting sketch)

Obtained for the upper level h = 70 mm from the surface of pouring basin the average temperature (for several measurements) - T_G = 930 °C, for the central level $h_2 \cong$ 160 mm - T_2 = 860 °C and for the lower level $h_3 \cong$ 300mm - T_D = 730 °C. These levels correspond approximately to the distribution of test casts shown in Fig. 1.

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 $\overline{X}$ = 33,30 mm with dimensional gap (D_{max} - D_{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 $\overline{X}$ = 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: $\overline{X} \cong$ 30,23 mm and the total gap range for all of castings would be R_C = 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_C = 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 cluster 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_w = 0,8 to 0,9% L_{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 $T_w \cong$ 0,6 to 0,7% L_{nom} without increasing manufacturing cost.

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