ARCHIVES
of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 13
Special Issue
1/2013
9–12

2/1

The Quality of Steel Castings in Terms of Precision Ceramic Mould Structure

R. Biernacki [a,]*, R. Haratym [b], J. Kwapisz [c]

[a] Warsaw University of Technology, Institute of Manufacturing Technologies, Narbutta 85, 02-524 Warsaw, Poland
[b] University of Ecology and Management, Wawelska 14, 02-061 Warsaw, Poland
[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

Received 21.01.2013; accepted in revised form 08.05.2013

Abstract

In the opinion of metrologists, technologists and trybologists surface microgeometry is one of the most important factors affecting the performance characteristics of the machine parts (resistance to wear, sliding and lubricating properties, durability and tightness of joints, fatigue strength, corrosion resistance, etc.).
The analysis was made of the ceramic mould elements structure influence on the microgeometry of steel castings surface and their dimensional accuracy. To assess the structure of the ceramic mould previous studies made with usage of computer tomography where used, those studies highlight the ceramic mould structure anisotropy and its properties.

Keywords: Lost wax casting, Casting surface microgeometry, Ceramic mould structure

1. Introduction

Key issues considered for precision casting associated with the quality of castings are mainly the surface micro-geometry, dimensional accuracy and quality parameters of the material from which the casting was made. Studies of surface micro-geometry and dimensional accuracy of castings were made and are presented in this article.

Casting surface should have as low as possible Ra, generally from 1 to 5 mm and a high surface load capacity tp_{50} determined for Rmax = 50% [1, 2]. Surface load capacity should be comparable with the surface made in the machining process. It is important for the exploitation, because the top layer of precision casting generally between 100 and 200 μm is much more resistant to abrasive processes, corrosion, etc. This on the other hand increases casting lifetime as high as 100% in relation with similar part made by machining.

Evaluation of precision casting surface is difficult because according to surface metrology it is porous surface [1, 2]. Typically, studies of determining the casting surface were associated with the pressure of the liquid metal H_c in the casting set (usually sprue height does not exceed 360 mm) and solidification module. Such studies have been conducted on the escalator castings with solidification modules m_K from 0.1 mm to 0.9 mm [3]. Analyses carried out on steel castings and ductile iron clearly shows the impact of H_c and m_K on the value of the basic metrology parameter for microgeometry surface - Ra [3, 4]. The microgeometry study did not include measurements of castings where m_K module is relatively small and includes the value from 0.1 to 0.4 mm, and the ceramic mould structure makes recognition of properties anisotropy of the ceramic form as a significant, given the parameters of the casting surface microgeometry and their dimensional accuracy specified by the parameter of dimensional tolerances $\Delta L_{6\sigma}$, where

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

and the average value of the measured parameters

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

Parameters measured during the studies were achieved for an unusual ceramic mould assembly (Fig. 1 and Fig. 2), where portion of ceramic mould is separated by a horizontal "empty space" and different portion is formed in the block (which create a network of castings). This leads to difficulties in determining the actual shrinkage of the casting [5]. It is not possible to separate the free shrinkage, restrained shrinkage and mixed shrinkage.

These parameters significantly affect the value of $\Delta L_{6\sigma}$, as emphasized in the [6].

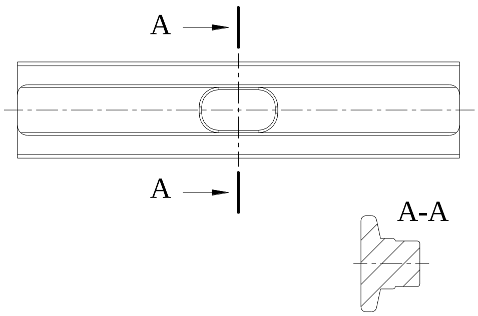

Fig. 1. Casting number 1 - Low-alloy cast steel.

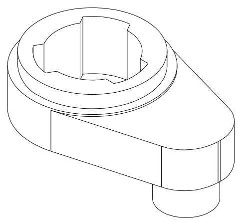

Fig. 2. Casting number 2 - Carbon steel.

Recognition of the influence of anisotropy parameter of ceramic mould properties on Ra and $\Delta L_{6\sigma}$, is an additional factor in the study. Casting used in study were chosen to include all types of sintering deformation of ceramic moulds presented in [7], which the numerical size depends to a large extent on the anisotropic properties of the ceramic mould.

2. Evaluation of dimensional accuracy and surface quality of examined steel castings

2.1. Research Methodology

Two castings were chosen - cast number 1 (Fig. 1) made of low-alloy steel of composition: C - 0.3% Cr - 0.5% Mo and 0.2% and casting number 2 made of carbon steel (about 0.4%) with a polygonal hole for subsequent dragging (Fig. 2).

Casting number 1 was made by pouring in to ceramic moulds which were on carts with capacity of 9 to 15 sets. Carts were part of the furnace zone. Ceramic mould temperature during pouring of molten metal depended on casting setting on the cart and was in the range from 650 to 850 °C.

Cast number 2 was made by the individual pouring liquid metal in to ceramic mould outside of the furnace after removing them from the cart. Ceramic mould temperature during pouring of molten metal was about 600 to 700 °C.

The temperature of the melted metal before pouring casting number 1 was approximately 1580^{-20} °C, and for casting number 2 about 1550 °C.

The surfaces of castings for the determination of Ra were measured in the relevant sectors (18 measurement areas) presented respectively for casting number 1 in Fig. 3, and for casting number 2 in Fig. 4. Sample results are shown in the summary table 1.

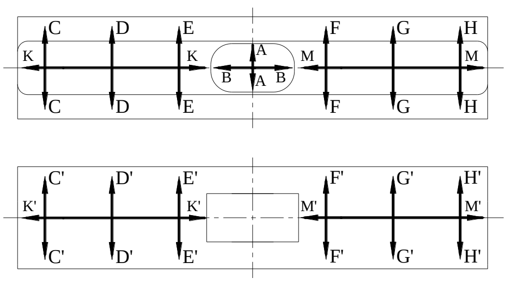

Fig. 3. Cast number 1 with marked measuring areas Ra

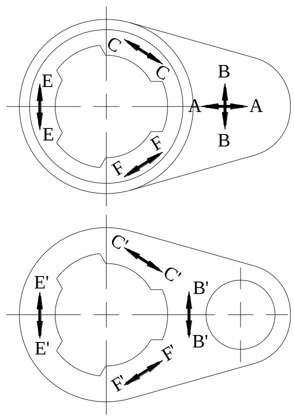

Fig. 4. Cast number 2 with marked areas for measuring Ra

Table 1.
Sample Ra measurements for casting number 1 (example)

Layer number (from sprue)	Outer surface							
	K-K	C-C	D-D	E-E	M-M	H-H	G-G	F-F
1	6,25	4,7	4,95	5,73	5,62	5,16	4,8	5,58
1	4,48	3,21	3,74	3,83	4,72	4,76	4,68	4,95
2	4,83	3,58	4,86	4,28	4,67	5,26	4,78	4,44
2	5,47	5,6	5,54	5,8	5,86	5,61	6,02	5,46
3	5,63	4,73	5,19	5	4,81	4,83	4,57	5,04
3	5,39	5,36	5,45	5,41	5,19	4,88	5,16	5,67
4	5,63	6,13	5,02	5,94	4,98	5,76	5,66	5,64
	Inner surface							
	K'-K'	C'-C'	D'-D'	E'-E'	M'-M'	H'-H'	G'-G'	F'-F'
1	4,64	4,16	3,39	3,31	4,23	4,28	3,67	4,18
1	5,78	4,31	4,54	4,24	3,92	4,71	5,3	4,87
2	5	4,65	5,86	3,91	6,27	5,37	3,89	4,76
2	4,68	4,91	4,86	4,89	4,9	4,78	4,42	4,97
3	4,92	5,18	5,03	4,87	5.39	5,78	5,19	4,82
3	4,51	5,68	5,25	4,79	5,14	5,5	5,69	5,07
4	4,93	5,69	5,06	4,71	4,25	4,83	4,27	4,51
4	5,13	4,65	4,59	5,97	5,7	4,99	5,29	4,62
5	5,77	4,39	4,58	5,06	4,67	4,09	5,52	5

For castings number 1 (Fig. 1) about 360 measurements were taken for the determination of Ra, with 10 levels, on which were castings (Fig. 5). Castings were removed from the two sets.

For castings number 2 (Fig. 2) examinations were performed in 13 measurement areas. Castings were spread over 7 levels (Fig. 6). 310 measurements were taken globally.

Fig. 5. Picture of castings set number 1

Fig. 6. Picture of castings set number 2

Measuring section for both castings ranged from 1.5 to 5 mm. Dimensional accuracy assessment was carried out only for number 1 casting by the selected measuring points (Fig. 7). 450 measurements were taken, and based on them dimensional deviation $\Delta L_{6\sigma}$ was calculated. Similarly, for the assessment of surface microgeometry value of $\Delta Ra_{6\sigma}$ and $x_i(Ra)$ was determined.

2.2. Results

2.2.1. Evaluation of microgeometry

Measurements of microgeometry for casting number 1 allowed obtaining the following results:

1) The average value for the whole measured population
$\overline{x}$ = 5,33$^{\pm 0,47}$ μm;
2) Deviations from the average $\Delta Ra_{6\sigma}$:
- for the external surface (far from the sprue) result was
$\Delta Ra_{6\sigma}$ = 3,27$^{\pm 0,5}$ μm;
- for the inner surface (located on the joint runner and sprue) result was
$\Delta Ra_{6\sigma}$ = 4,60$^{\pm 0,5}$ μm.

Measurements of microgeometry for casting number 2 allowed obtaining the following results:

1) The average value for the whole measured population
$\overline{x}$ = 4,70$^{\pm 0,51}$ μm;
1) Deviations from the average $\Delta Ra_{6\sigma}$:
- for the external surface result was
$\Delta Ra_{6\sigma}$ = 4,48$^{\pm 0,45}$ μm;
- for the inner surface result was
$\Delta Ra_{6\sigma}$ = 4,82$^{\pm 0,45}$ μm.

2.2.2. Evaluation of dimensional accuracy

For *Lnom* dimension (Fig. 7) it was possible to obtain for the whole population: $\overline{x}$ = 89,95 mm and $\Delta L_{6\sigma}$ = 0,64$^{\pm 0,11}$% *Lnom*;

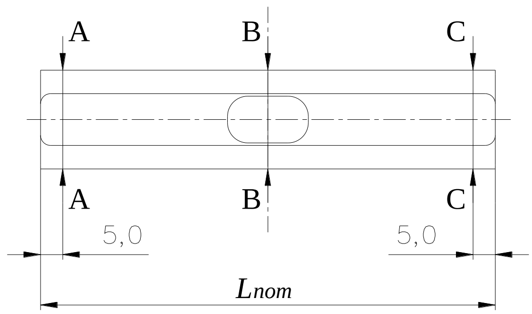

Fig. 7. Casting number 1 - dimensions included in the linear measurements

For the dimensions A, B and C (Fig. 7) it was possible to obtain:

- Dimension A-A:
$\overline{x}$ = 19,26$^{\pm 0,08}$ mm; $\Delta L_{6\sigma}$ = 0,27 mm (1,4 % nominal dimension *Lnom*);

- Dimension B-B:

$\overline{x}$ = $19{,}28^{\pm 0{,}09}$ mm; $\Delta L_{6\sigma}$ = 0,30 mm (1,57 % nominal dimension *Lnom*);

- Dimension C-C:

$\overline{x}$ = $19{,}20^{\pm 0{,}10}$ mm; $\Delta L_{6\sigma}$ = 0,34 mm (1,76 % nominal dimension *Lnom*);

3. Summary

Considering the surface microgeometry (Ra parameter):

1) The lowest values of $\Delta Ra_{6\sigma}$ = $3{,}27^{\pm 0{,}5}$ µm were obtained for the external surface (ends) of castings number 1, located on the left and right from the sprue. These areas are in a stable, in terms of wall thickness, area of the ceramic mould, as shown in Fig. 8a.
2) The highest values of $\Delta Ra_{6\sigma}$ = $4{,}60^{\pm 0{,}5}$ µm were obtained for casting surface number 1 located in front of sprue, where the ceramic mould is much thicker, and thus deformation during sintering of the ceramic mould, marked "pww" [7], are the greatest.
3) Similar dependencies were observed for the cast number 2. It should be noted that the ceramic mould shaping casting (with a slightly higher solidification modulus) increases the value of Ra (the majority of mould of compact shape – Fig. 8b).

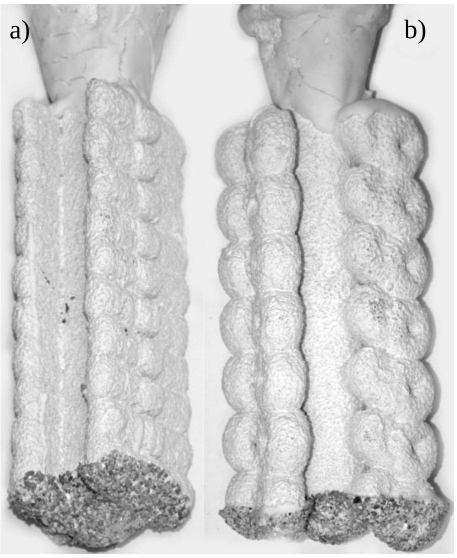

Fig. 8. Pictures of ceramic moulds a) with castings set number 1, b) with the castings set number 2

Analysis of dimensional accuracy of the casting number 1 showed very high accuracy of L dimension (Fig. 7) which was no more than $\Delta L_{6\sigma}$ = 0,75% *Lnom*. It is due to observed in the ceramic mould sintering deformation values for the predominant area with the thinnest walls of ceramic mould. Value of sintering is consistent with the diagram indicated in [7] described with the symbol "ns". Other dimensions, because of their small volumes, and differences in thickness of the ceramic mould has a low accuracy. Close to thin walls average dimensional deviations were 1.48% of nominal dimension, and in the case of maximum wall thickness and sintering process described with the symbol "pww" [7] - average dimensional deviations were 1.76% of nominal dimension.

Reference

[1] Wieczorowski, M., Cellary, A., Chajda, J. (2003). *Characterization of surface roughness*. Poznan University of Technology Publishing.

[2] Tomasik, J., Haratym, R. (2000). Precision casting surface micro geometry. III Polish Foundry Congress, Warsaw.

[3] Haratym, R. (1992). Evaluation of precision castings surface quality using the stepped model. XVII Symposium Warsaw University of Technology Institute of Foundry, 1992.

[4] Tomasik, J., Haratym, R. & Myszka, D. (2008). The influence thermo - physical parameters of ductile iron investment casting manufacturing on their surface geometry in ecological aspect. *Archives of Foundry Engineering*. 8(spec. 2).

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

[6] Skarbiski, M. (1965). *Castings dimensional accuracy*. WNT, Warsaw.

[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 Engineering*. 5(15).