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Shape Accuracy of Iron Precision Castings in Terms of Ceramic Moulds Physical Properties Anisotropy

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Abstract

While analyzing shape accuracy of ferroalloy precision castings in terms of ceramic moulds physical anisotropy, low-alloy steel castings ("cover") and cast iron ("plate") were included. The basic parameters in addition to the product linear shape accuracy are flatness deviations, especially due to the expanded flat surface which is cast plate. For mentioned castings surface micro-geometry analysis was also carried, favoring surface load capacity tp50 for R_{max} = 50%.

Surface load capacity tp50 obtained for the cast cover was compared with machined product, and casting plate surface was compared with wear part of the conveyor belt. The results were referred to anisotropy of ceramic moulds physical properties, which was evaluated by studying ceramic moulds samples in computer tomography equipment Metrotom 800.

Keywords: Ceramic moulds physical anisotropy, Precision castings

1. Introduction

Influence of ceramic moulds properties on casting quality, especially those creating a set of castings in the ceramic mould, it is considered as a network of relationships between individual elements, which currently does not allow for accurate computer simulation of occurring physical phenomena's [1]. An example can be difficulties associated with accurate evaluation of metal shrinkage during solidification due to the variable cross-sections and different mould porosity throughout the whole mould volume. In this case it is possible to speak about structural ceramic mould (CM) anisotropy and the anisotropy of the properties associated with the variable CM structure. Evaluation of anisotropy and its role in shaping castings is described in several publications [2, 3, 4, 5].

2. The evaluation method of ceramic mould significant parameters affecting its anisotropy

The main parameters used for ceramic mould performance evaluation are: density and porosity distribution in the whole CM volume. The porosity affects the basic technological parameter –

CM permeability (ability to remove gas after filling mould with molten metal).

Computer tomography was used to carry out on examination of ceramic mould samples cut from different mould parts as shown in Figure 1.

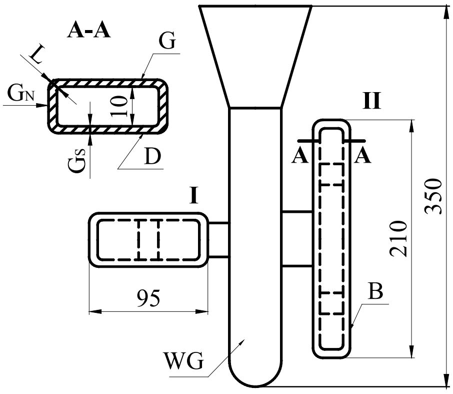


Fig. 1. Ceramic mould used in the research

Mould porosity evaluation was performed using three methods:

1) analyzing, with usage of appropriate method, the density change in different ceramic mould areas - Figure 1

2) counting the pores shown in the pictures from the computer tomography (using planimetry) – it was possible to obtain an average porosity of about 12% (PR1) - Figure 2,

3) using the mercury porosimetry, which makes it possible to characterize the ceramic mould material by showing porosity surface area changes in function of pore diameter - Figure 3.

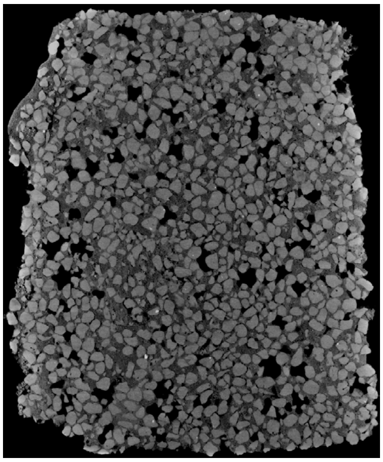


Fig. 2. The pores in the CM (picture from Computer Tomography)

Figure 2 shows selected cross section through the form. Several images of CM cross sections were obtained. On their basis dark spots planimetry was performed and their planimetred surface was referenced to the total cross-sectional area. Estimated porosity value was 12%. Porosity was later compared with the change of density at various CM locations.

Evaluation of CM density change based on samples taken from various CM areas

CM density evaluation was performed on several samples cut from various CM areas. After the weighing, they were coated with a thin layer of resin and then immersed in a solution of sodium silicate located in a graduated cylinder with precise scale. Volume of samples t has been estimated this way. Obtained for the side surfaces B (Fig. 1):

- The upper surface of CM - B side wall density was equal to 2.08 g/cm^3,
- The central area of CM - B side density was equal to 2.09 g/cm^3,
- For the lower surface of CM - B side density was equal to 2.11 g/cm^3.

Furthermore, measures of the surface G and D perpendicular to the sprue (section A-A in Figure 1) gave results:

- the surface G had density equal to 2.12 g/cm^3,
- the surface D had density equal to 2.04 g/cm^3.

Furthermore, it was found that in the L points, along CM length, the thickness L is smaller than the thickness G_S by approximately 1.2 - 2 mm. In addition, the G_N thickness is smaller than the thickness of G_S by approximately 1 mm. Ceramic mould density variations was estimated by comparing the obtained results with porosity obtained during CM evaluation which was averaging around 12%. Based on the data considering CM production process, and weighing multiple batches of filling material for the production of numerous CM sets it was found that the filling material account for 80% of the total CM weight, and the liquid ceramic slurry is around 20% of CM. Performing analytical calculations using the above findings, it was estimated that CM density calculation results are consistent with the results obtained in the production environment.

Mercury porosimetry in assessing the porosity CM

Ceramic mould porosity evaluation was conducted on the porosimeter Auto Pore II 9220 Micrometrics. Liquid penetrating CM components sample was mercury. Mercury contact angle in the capillary tube containing the test sample has a surface tension γ = 485 dynes/cm. The contact angle of the sample material by liquid mercury is θ = 130 deg, the maximum pressure in the chamber P_i is up to 145 MPa.

Evaluation of pores is based on the following equation:

$$r_i = \frac{-2\gamma\cos\theta}{P_i}$$

where r_i – is the radius of pore.

The results of the investigation are shown in Figure 3. On the basis of several sample measurements total CM porosity was obtained, and is equal from 24 to 28%.

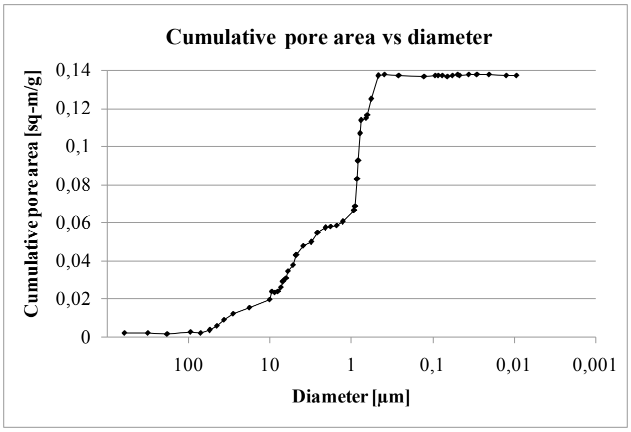


Fig. 3. Changes in porosity surface area in a function of pore diameter

3. Ceramic mould deformation studies and casting (flatness evaluation)

Deformation evaluation was performed on the ceramic mould internal walls and plate castings with dimensions 195x77 and 10 mm thickness. A ceramic mould set reproducing the casting is shown in Figure 4.

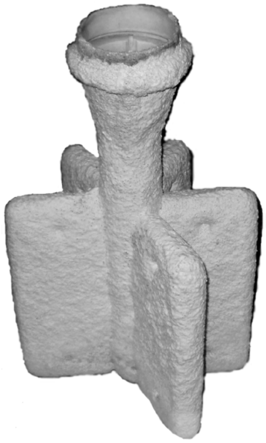


Fig. 4. Ceramic mould set for ceramic "plate" casting

Examination of mould flatness reproducing flat casting plate surface and other castings - Figure 5a – was performed on coordinate-measuring machine ZEISS Calypso 4.6.10.00. Typical (theoretical) flatness deformation is shown in Figure 5b.

Fig. 5a. “Cover” casting

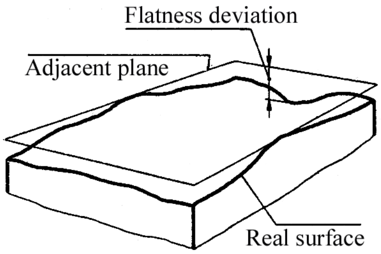


Fig. 5b. Flatness deviation

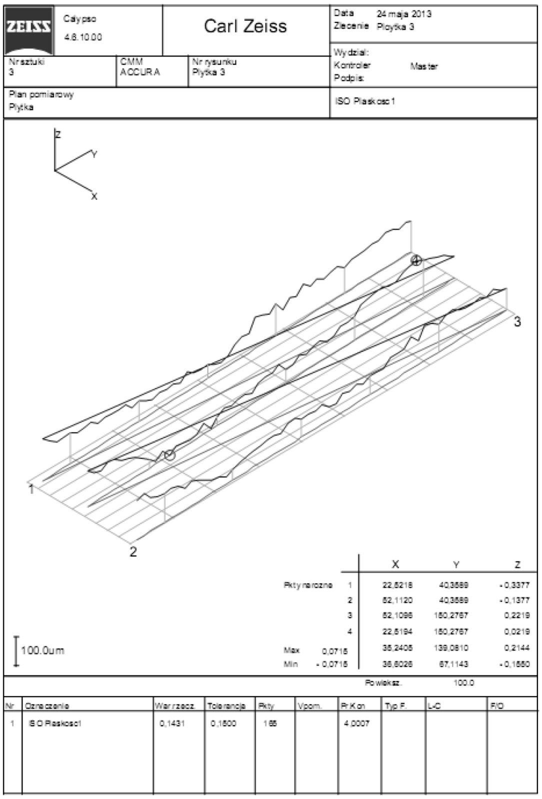
The measurement results are shown graphically in Figure 6 and analytically in Table 1.

Table 1.
The results of casting flatness measurement

	Result of flatness P [mm]
1.	Casting from Figure 5a – P_{avg}=0,07 mm
2.	“Plate” casting 195x77 – P_{avg} = 0,15 mm
3.	Ceramic mould surface B and D – P_{avg} = 0,24 mm

P_{avg} relates to the average flatness value in the assessment of the 5 measured objects.

Flatness was estimated after the analysis of several hundred data points, which significantly reduced measurements uncertainty [6].



Calypso
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Carl Zeiss

Data 24 maja 2013
Zlecenie Plytka 3

Nr sztuki
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CMM
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Nr rysunku
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Wydzial:
Kontroler Master
Podpis:

Plan pomiarowy
Plytka

ISO Plaskosc1

		X	Y	Z
Pkty narozne	1	22,5218	40,3589	- 0,3377
	2	52,1120	40,3589	- 0,1377
	3	52,1096	150,2767	0,2219
	4	22,5194	150,2767	0,0219
Max	0,0716	35,2405	139,0810	0,2144
Min	- 0,0716	36,6026	67,1143	- 0,1660

Powieksz. 100.0

Nr	Oznaczenie	War.rzecz.	Tolerancja	Pkty	Vpom.	Pr.K.on	Typ F.	L-C	F/O
1	ISO Plaskosc1	0,1431	0,1600	165		4,0007			

Fig. 6. Sample flatness evaluation of plate casting replicated in CM from Figure 4 Coordinate-measuring machine Zeiss Calypso

4. Analysis of the ceramic mould surface and casting

The results of the measurements are shown in Table 2. The results of "cover" casting measurements made from ferroalloy - Figure 7 and data reflecting surface state of "plates" made from low-alloy chromium-nickel containing 0.15% molybdenum casting. Plates made in CM marked the index B (Fig. 1).

Table 2.
The results of plate casting surface micro-geometry measurements (Ra parameter evaluation and tp50 for R_{max} = 50%)

Mn	Result R_a (μm)	Result tp_{50} (%)
1.	Casting replicated by part of mould B_G: $6.5^{+2.15}_{-2.07}$	$46.8^{+3.2}_{-5.3}$
2.	Casting replicated by part of mould B_D: $5.19^{+1.34}_{-1.36}$	$50.1^{+5.9}_{-4.9}$
3.	Plate casting in abrasive friction condition $R_a$avg: $4.67^{+2.44}_{-2.02}$	$52.7^{+9.4}_{-9.2}$

5. Conclusions of research results

Changing the density of ceramic moulds (CM) depending on the location was different. In the total volume, especially for the surface perpendicular to the sprue, density ranged from 2.04 g/cm^3 to 2.12 g/cm^3. For the side surfaces on the whole sprue height it was possible to observe changes in the range from 2.08 g/cm^3 to 2.11 g/cm^3.

CM porosity averages about 12%, including a study made by mercury porosimetry method, from which pores less than 2 microns should be ruled out. These pores have practically no effect on the filtration of gases through the ceramic mould wall after filling with liquid metal.

Analyzing the results of the „cover” casting flatness evaluation can be concluded that they vary depending on tested object from 0.05 to 0.11 mm and the effect of CM anisotropy is small.

However, considering casting plates flatness arranged in CM vertically (Fig. 4), we have also anisotropy in the construction of CM set. Area attached with sprue has a thickness of about 5 mm, which is larger than the CM cavity reproducing cast. This leads, in accordance with the recommendations [1], to stiffen the sprue structure - casting "plates". The result is less flatness of casting surface than observed on single surface CM cavity - Table 1.

Analyzing "plates" casting surface micro-geometry described by the parameter Ra we can see that on the upper surface (CM density is approximately 2.08 g/cm^3) we have $Ra = 6.11^{+2.15}_{-0.07}\ \mu m$ and visibly different value of $Ra = 5.19^{+1.34}_{-1.36}$ for the lower surface (CM density around 2.11 g/cm^3).

Surface load capacity expressed by tp50 for the bottom surface of the plate is equal to $tp50_{max}$ = 56% and significantly higher than tp_{50max} = 50% for the upper surface of the plate (where the mould has a lower density).

Value tp_{50max} = 56% is also higher than the average value of tp_{50} for cast plate after operation in abrasive friction condition which is equal to $tp50_{max}$ = 52.7%.

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