

# Application of stepped pattern in quality assessment of investment castings

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## Abstract

The article proves that the stepped pattern can be a versatile tool in examinations of casting quality, i.e. in determination of dimensional accuracy and surface microgeometry. Moreover, the pattern may be useful in evaluation of some important technological parameters used by investment casting technology, e.g. in evaluation of the anisotropy of the ceramic mould properties, which considerably affects errors of the dimensional deformation  $\delta fi$  at successive stages of the technological process of making ceramic moulds and investment castings. The results of the measurements of investment castings made in mixtures of the ceramic materials, like  $SiO_2$  and aluminosilicates – Molochite bonded with silicate binders, like colloidal silica, ethyl silicate, SIKOP [1], EKOSIL [2], were evaluated.

**Keywords:** Casting quality, Investment patterns, Stepped pattern

## 1. Introduction

The stepped pattern which has previously been tested for a long time at the Department of Foundry Engineering of the Warsaw University of Technology in evaluation of the casting surface roughness parameters is shown in Figure 1.

The pattern has been largely based on a method used by BICTA - British Investment Casting Trade Association. It ensures the results of investigations comparable in global scale of the manufactured investment castings, specially as regards castings of small and medium size, weighing up to 5kg and with maximum modulus of up to about 9 mm.

Besides an assessment of casting quality, the results of the investigations of the investment casting process made with a stepped pattern can serve in testing of new binders, ceramic materials, etc.

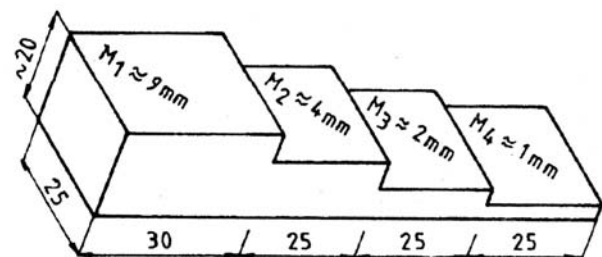


Fig. 1. Stepped pattern (SP) used in tests.

## 2. Investigations of the investment casting process using a stepped pattern

### 2.1. Assessment of the stepped pattern validity as a tool in evaluation of the surface quality of investment castings and ceramic moulds (CM)

The stepped pattern (Fig. 1) forming a part of the whole assembly is shown in Figure 2.

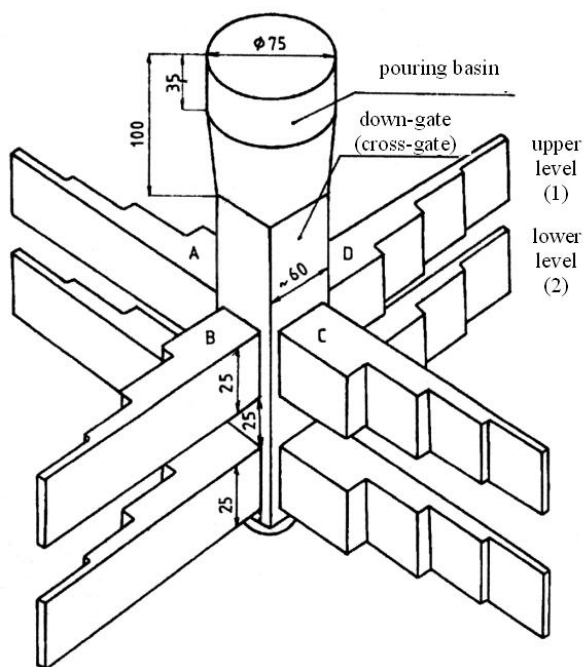


Fig. 2. Pattern assembly used in tests with marked elements of the gating and feeding system and with patterns.

The, shown in Figure 2, shape of the gating and feeding system enables making the necessary differentiation between the values of casting parameters. The flow of molten metal is practically the same at all levels. The metal is flowing from the down gate (DG) through the thickest element of the pattern (solidification modulus  $M_k \approx 1$  mm). As proved by numerous tests, the flow of metal in ceramic mould takes place without any disturbances (e.g. metal whirls).

The time of solidification of the individual wall sections in a stepped casting (Fig. 2) differs much more than it might result from the values of the solidification moduli ( $M_k$ ).

This is due to the fact that:

- the wall of the thinnest cross-section is solidifying in the lowest range of temperatures, that is, much more quickly than it would happen under the normal industrial conditions in a

self-supported mould, as it is located far from the down-gate which acts as a main source of metal feeding,

- the wall of the thickest cross-section is solidifying slowly because of its position close to the down-gate and overheating of the ceramic mould also situated close to the down-gate.

Hence the results of the investigations are of a more complex nature.

### 2.2. Examinations of surface quality of the investment steel castings

Tests and investigations were carried out on low-alloyed cast steel of the following composition: C – 0.18% to 0.22%; Si – 0.56% to 0.8%; Ni 1.5% on the average; Mn – 1.1% on the average; Cu – up to 0.34%; Cr – about 1.4% on the average; Al below 0.04%; and P and S below 0.02%.

Patterns were made from foamed polystyrene (characterised by special density) and from paraffin, stearin and Montana wax. The ceramic moulds were baked at a temperature of about 950°C for the time of 4 hours. The temperature of the ceramic moulds on pouring with molten metal was from 600 to 700°C; the temperature of molten metal poured into the ceramic moulds was  $1570 \pm 20^\circ\text{C}$ .

The values of the roughness index  $R_a$  in the examined castings (allowing for the uncertainty of measurements [4]) are:

I. self-supported moulds based on SIKOP binder and  $\text{SiO}_2$ ;

- a) modulus  $M_k = 1$  mm –  $R_{a,cr}$  from 1.60 to 2.8  $\mu\text{m}$ ;
- b) modulus  $M_k = 9$  mm –  $R_{a,cr}$  from 2.1 to 3.7  $\mu\text{m}$ .

II. self-supported moulds based on ethyl silicate binder, colloidal silica and  $\text{SiO}_2$ ;

- a) modulus  $M_k = 1$  mm –  $R_{a,cr}$  from 1.7 to 2.5  $\mu\text{m}$ ;
- b) modulus  $M_k = 9$  mm –  $R_{a,cr}$  from 2.3 to 4.4  $\mu\text{m}$ .

Castings were made simultaneously at levels (1) and (2) with pressure of molten metal column from 150 to 210 mm (Fig. 2).

The effect of molten metal pressure on  $R_a$  was nearly insignificant and amounted to about 0.7 mm for modulus  $M_k = 9$  mm.

### 2.3. Investigations of surface geometry parameters in castings made from aluminium alloys

Castings made from aluminium alloys are often used in airtight systems, where the investment casting, usually of a near-net shape, i.e. requiring no finishing treatment, may successfully cooperate with machined products. In this situation, the parameters used in evaluation of the casting surface microgeometry, applicable on other occasions ( $R_a$ ,  $R_z$ ,  $R_{max}$ ), are not suitable since in general assessment they allow for occasionally high peaks or deep valleys, revealed on a profilogram of the examined surface (Fig. 3).

Therefore, new parameters were proposed (Fig. 3 [3]), where the peak heights and valley depths are properly reduced. The new parameters  $R_{pk}$ ,  $R_{rk}$ ,  $R_k$  (according to DIN) are represented by Abbot curve (according to DIN).

The measurements of R were carried out on castings made in ceramic moulds based on EKOSIL binder and Molochite ceramic material.

For a dozen measurements, the mean values of  $Rpk_{cr} = 14.72 \mu m$  were obtained. Moreover, the coefficient of linear bearing capacity  $Mr_2$  (Fig. 3) was estimated; it is particularly suitable in forecasting of, e.g., the corrosion resistance (the higher is  $Mr_2$ , the higher is the resistance of the casting).

The studies were conducted using a modern profilometer, model Surtronic 3P, made by Taylor Hobson. The application of Abbot curve in evaluation of the microgeometry of casting surface was discussed in more detail in [6] and [7].

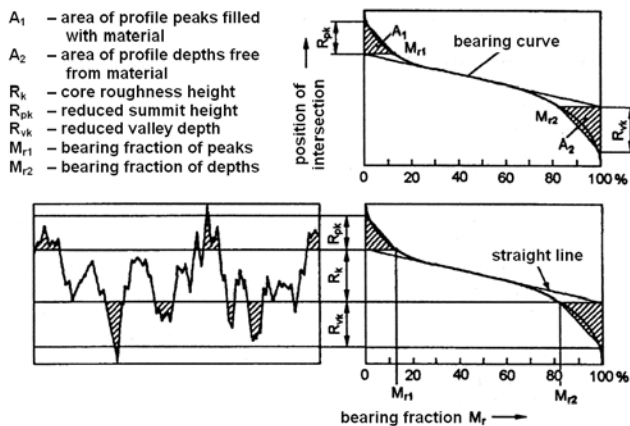


Fig. 3. The parameters of Abbot curve of the roughness profiles.

Moreover, evaluating the results of the measurements of parameters of the casting surface geometry, it is necessary to allow for the fact that usually  $Ra$  for castings made from aluminium alloys is lower by about 30% from the  $Ra$  obtained for a ceramic mould [8]. This is due to the fact that a very important role in the formation of casting surface microgeometry play the capillary phenomena [5]. At final stage of the ceramic mould manufacture (heat treatment), on the mould surface, numerous pits and capillary ducts of radius  $r$  are formed, their dimensions being from 50 to 100  $\mu m$  [8].

To make molten metal penetrate into the pores of a ceramic mould, the capillary should be larger than  $r$  calculated from equation (1) – [9], [10]:

$$r = \frac{2\delta \cos\theta}{h \cdot \rho \cdot g} \quad (1)$$

where:

- $\delta$  – surface tension (for aluminium alloys it ranges to about 850 mN/N – [11]),
- $\theta$  – wetting angle of ceramic mould material by molten aluminium alloys ( $141 \pm 5^\circ$  – [12]),
- $h$  – mean height of molten metal column in the ceramic mould (about 0.2 m),
- $\rho$  – density of molten aluminium alloy,
- $g$  – acceleration of gravity.

## 2.4. Evaluation of the anisotropy of ceramic mould properties

The configuration of the stepped pattern (Fig.1) and the way in which it is positioned in pattern cluster (Fig. 2) creates vast possibilities for evaluation of the anisotropy of properties of a ceramic mould made from this pattern cluster. The large flat surfaces, upper, lower and lateral, enable a large number of samples of orientation parallel and normal to the down-gate to be produced (Fig. 2). The anisotropy of the ceramic mould properties results from a non-homogeneous mould construction [13].

The anisotropy was examined on samples of the ceramic mould made with Ekosil binder and Molochite ceramic material. It is well visible when we compare the results of examinations of the dilatation of samples of the ceramic moulds, where the mean deformation on baking (contraction on baking) during the heat treatment and cooling of a ceramic mould amounts to:

- for samples of orientation parallel to the surface of the down-gate – 0.122%,
- for samples of orientation normal to the surface of the down-gate – 0.277%,

## 2.5. Evaluation of dimensional errors in casting wall thickness $\Delta L_{G\delta}$

The anisotropy of the ceramic mould properties results in considerable increase of the value  $\Delta L_{G\delta}$ , especially for the thickness of casting walls of orientation normal to the down-gate. Moreover, recent tendencies to increase the yield make the distances between the castings in a cluster smaller. Thus arranged castings form a grid where the possibilities of an effective forecasting of the dimensional accuracy are much more limited [14], [15]. To obtain data on the dimensional errors at the successive stages of the investment casting process, it is necessary to take a lot of measurements and use the methods of statistical analysis in their assessment. This requires large investment outlays for research and is a long-term process.

The application in research of stepped patterns gives over 50 samples (castings) from one cluster on which the thickness measurements can be made, ensures parallel orientation of the upper and lower wall (Fig. 1) and effectively reduces the uncertainty of measurements.

This, in turn, considerably reduces the cost of research and makes the measurements more reliable. In view of the fact that, at present,  $\Delta L_{G\delta}$  for the thickness quite often reaches from 1.5 to 3% of the nominal dimension at about 0.85%  $L_{nom}$  for linear dimensions, to counteract this phenomenon means a real challenge. It is therefore the aim of the studies made with the use of stepped patterns to find a prescription and make  $\Delta L_{G\delta}$  comprised (for the thickness values) in a range from 1.0 to 1.8% of the nominal dimension.

### 3. Conclusions

1. The application of a stepped pattern in the investigations of investment casting process enables the following:
  - a. effective evaluation of the parameters of the microgeometry of the casting and ceramic mould surface,
  - b. reliable evaluation of the anisotropy of the ceramic mould properties,
  - c. effective evaluation of the measurements of errors  $\Delta L_{G8}$  on casting wall thickness to reduce the value of  $\Delta L_{G8}$ ,
2. The application of a stepped pattern is expected to reduce the cost of testing the investment castings and improve their quality.

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