The Influence of Technological Parameters on the Properties of Castings Produced by the Vacuum Assisted Pressure Die Casting Method

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Abstract

The paper presents the results of investigations concerning the mechanical properties of the AlSi9Cu3 alloy castings in correlation with the most significant parameters of the vacuum assisted high pressure die casting technology. Experiments were designed and carried out according to the 2³ factorial design. There were found the regression equations describing the influence of the plunger velocity in the second stage of injection, the die temperature, and the injection temperature on the tensile strength and the unit elongation of the examined alloy. It was found that the main parameter affecting the increase in mechanical properties is the plunger velocity in the 2nd stage of injection. The highest mechanical properties of castings (Rm exceeding 280 MPa, and A5 at the level of 9%) are achieved (in the examined range of changes) for the plunger velocity in the second stage of injection equal to 4 m/s, the die temperature of 210°C, and the injection temperature of 640°C.

Keywords: Innovative foundry technologies, Aluminium alloys, Vacuum assisted high pressure die casting, Mechanical properties of pressure castings

1. Introduction

High pressure die casting (HPDC) is the one of the most effective casting technologies and it is applied for mass production of the high quality castings made of aluminium, magnesium, and zinc alloys, as well as of the low-melting alloys. Pressure castings are characterised by the excellent smoothness of the raw surface, the high dimensional and shape accuracy, and good mechanical properties. The advantages of the HDPC technology include also the refined structure of castings, the defect-free surfaces, small machining allowances, the possibility of obtaining the intricate thin-walled castings, and the low production costs [1-4]. The main defect occurring in pressure castings is their gas porosity, and – as far as castings of intricate geometry are concerned – both the shrinkage and the gas porosity. The presence of blowholes in castings is related to the character of liquid metal flow during the first and the second stages of filling the pressure die. During the first stage, an occlusion of gaseous phase present in the injection sleeve takes place, while during the second phase the air trapped in the die cavity is occluded or absorbed. The airtight walls of the metal die along with a very short injection time result in the minimal effectiveness...
The VERTACAST machine was equipped with the horizontally parted two-cavity pressure die designed for casting soleplates of clothes iron (Fig. 1). A casting selected for examination should meet the requirements adequate for items working within the range of elevated temperature, exceeding 100°C. The good quality of castings, and particularly their low gas porosity, is the main criterion of their acceptance.

Eight injection sequences were carried out in order to determine the influence of negative pressure in the die cavity on the mechanical properties of castings, a series of castings being produced during each of them.

![Fig. 1. The examined cast soleplate of clothes iron](image)

The optimization studies were planned and carried out according to the $2^3$ factorial design applying the following independent variables and their ranges of change:

<table>
<thead>
<tr>
<th>The independent variable, $X_i$</th>
<th>Centre point, $X_{i0}$</th>
<th>Range of change, $\Delta X_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$ – plunger velocity in the $2^{nd}$ stage of injection, m/s</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>$X_2$ – die temperature, °C</td>
<td>180</td>
<td>30</td>
</tr>
<tr>
<td>$X_3$ – injection temperature, °C</td>
<td>670</td>
<td>30</td>
</tr>
</tbody>
</table>

Two quantities describing the mechanical parameters of castings were assumed as the dependent variables (responses): the tensile strength and the unit elongation. The coding of variables was done according to the following formula:

$$x_i = \frac{X_i - X_{i0}}{\Delta X_i}$$

(1)

The realised experimental design is presented in Table 2 in details. It includes all combinations of variables at the lower and the upper level. For each point of the design the same number of equivalent measurements were taken.

The following quantities were accepted as constant during the experiment:
- total volume of castings (two soleplates cast together) with gating system and overflows, equal to $V_i = 373$ cm$^3$;
- the diameter of the injection plunger, $d_i = 58$ mm;
- the plunger velocity in the first stage of injection, $v_i = 0.3$ m/s;
- the (relative) negative pressure in the die and in the shot sleeve, $p = -0.5$ atm. ;
- time of molten metal suction through the feed tube, $t_z = 18$ s;
– the degree of injection chamber filling, equal to 60%;
– the machine clamping force, \( N_c = 2000 \text{ kN} \),
– the total area of gates for both soleplate castings, equal to \( \Sigma f_w = 2\times75 \text{ mm} \times 1.5 \text{ mm} = 225 \text{ mm}^2 \);
– the average casting wall thickness \( d = 5 \text{ mm} \).

The examinations concerning the mechanical properties of castings were carried out for the standardized tensile bars with length-to-diameter ratio of 5:1, according to the PN-EN 10002-1:2001 Standard, by means of the ZWICK-1488 testing machine. The data obtained from the test were used to determine the characteristic quantities \( R_m \), \( A_s \) (Table 3) for specimens representing all the combinations included in the design of the experiment.

### Table 2. The applied design of experiment

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Plunger velocity in the 2nd stage of injection</th>
<th>Die temperature</th>
<th>Injection temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre point</td>
<td>3</td>
<td>180</td>
<td>670</td>
</tr>
<tr>
<td>Range of change</td>
<td>1</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Upper level (1)</td>
<td>4</td>
<td>210</td>
<td>700</td>
</tr>
<tr>
<td>Lower level (-1)</td>
<td>2</td>
<td>150</td>
<td>640</td>
</tr>
</tbody>
</table>

#### Table 3. Average results of tensile strength \( R_m \) and unit elongation \( A_s \) of the EN AB 46000 alloy

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Tensile strength ( R_m ) MPa</th>
<th>Standard deviation ( \sigma(R_m) ), MPa</th>
<th>Elongation ( A_s ), %</th>
<th>Standard deviation ( \sigma(A_s) ), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>271.20</td>
<td>5.03</td>
<td>7.83</td>
<td>1.12</td>
</tr>
<tr>
<td>2</td>
<td>248.30</td>
<td>5.44</td>
<td>5.65</td>
<td>1.24</td>
</tr>
<tr>
<td>3</td>
<td>254.30</td>
<td>4.17</td>
<td>6.41</td>
<td>0.99</td>
</tr>
<tr>
<td>4</td>
<td>223.60</td>
<td>4.53</td>
<td>4.89</td>
<td>0.89</td>
</tr>
<tr>
<td>5</td>
<td>281.70</td>
<td>5.82</td>
<td>8.85</td>
<td>1.05</td>
</tr>
<tr>
<td>6</td>
<td>251.30</td>
<td>6.04</td>
<td>6.26</td>
<td>1.16</td>
</tr>
<tr>
<td>7</td>
<td>257.30</td>
<td>5.38</td>
<td>6.89</td>
<td>0.92</td>
</tr>
<tr>
<td>8</td>
<td>236.50</td>
<td>3.97</td>
<td>5.25</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The factorial design applied during the experiment gives a possibility of determination of the incomplete quadratic equation describing the influence of the independent variables (plunger velocity in the second stage of injection, die temperature, and injection temperature) on the tensile strength and the unit elongation of the EN AB 46000 alloy castings. The general form of the equation is as follows:

\[
\hat{y} = b_0 + \sum b_ix_i + \sum b_{ij}x_ix_j
\]  

where: \( b_0 \), \( b_i \), \( b_{ij} \) – regression coefficients, \( x_i \) – independent variables, \( x_{ij} \) – interactions of the independent variables.

The results of the strength and the elongation measurements were statistically elaborated, finding first the variances of experimental data, next the values of the regression coefficients, which were in turn assessed with respect to their statistic significance, then the adequacy of the regression equations was checked. These calculations allowed to find two equations which describe the average tensile strength and the average unit elongation for the examined ranges of independent variables:

\[
\hat{R}_m = 253 + 13.1 \left( \frac{X_1 - 3}{1} \right) + 10.1 \left( \frac{X_2 - 150}{30} \right) - 3.68 \left( \frac{X_3 - 670}{30} \right)
\]  

(3)

\[
\hat{A}_s = 6.65 + 0.99 \left( \frac{X_1 - 3}{1} \right) + 0.69 \left( \frac{X_2 - 150}{30} \right) - 0.31 \left( \frac{X_3 - 670}{30} \right)
\]  

(4)

The equation 3 indicates that the tensile strength depends in a linear manner on all of the examined parameters of casting production, and is most strongly influenced by the plunger velocity in the 2nd stage of injection and the die temperature. The regression coefficients standing by the successive examined variables reveal that the influence of the plunger velocity on the \( R_m \) value is four times as large as the influence of the injection temperature, and by 30% greater than the influence of the die temperature. The influence of the examined independent variables on the tensile strength of castings is presented in Figure 1.

The positive values of coefficient by the \( x_1 \) and \( x_3 \) indicate that an increase in these parameters leads to the increase in tensile strength, while the negative value by the \( x_3 \) denotes its corresponding decrease. The lack of the interactions \( x_1x_2, x_1x_3, x_2x_3 \) in the equation 3 means that they are statistically insignificant.

The analysis of the obtained relationship (3) and the curves in Fig. 1 also reveals that an increase in plunger velocity in the 2nd stage of injection by 1 m/s results in the increase in \( R_m \) by about 13 MPa, and an increase in the die temperature by 30°C leads to the growth in \( R_m \) by about 10 MPa. On the other hand, the rise in the injection temperature equal to 30°C causes the drop in the tensile strength which amounts to about 4 MPa.
negative. An increase in the plunger velocity in the 2nd stage of injection results in an increase in elongation by about 1%, the rise in the die temperature by 30°C causes the growth in the A₅ value by about 0.7%, and an increase in the injection temperature by 30°C results in the drop in the unit elongation of about 0.3% (Fig. 2).

4. Final conclusions

1. The application of the 2³ factorial design allowed to determine the regression equations describing the changes in mechanical properties of the EN AB 46000 alloy castings in relation to the technological parameters of the casting process.
2. The tensile strength and the unit elongation of the EN AB 46000 alloy castings depend on all the independent variables in their examined ranges of change.
3. The main parameter affecting the mechanical properties of castings is the plunger velocity in the 2nd stage of injection. The obtained relationships indicate that an increase in the plunger velocity in the 2nd stage of injection by 1 m/s rises Rₘ by about 13 MPa, and A₅ by about 1%.
4. The highest mechanical properties (Rₘ exceeding 280 MPa and A₅ at the level of 9%) are achieved for the plunger velocity in the 2nd stage of injection equal to 4 m/s, the die temperature of 210°C, and the injection temperature of 640°C.

References


