ANETA MAGER*, PAWEŁ SZYMAŃSKI **

DIMENSIONAL ACCURACY OF PMMA CASTING PATTERNS PRODUCED BY 3D PRINTING AFTER IMPREGNATION

The paper presents research regarding dimensional compatibility of 3D printed casting patterns after impregnation with the paraffin. Scope of the work included conducting the impregnation process of the studied model and comparative analysis of dimensions of the 3D printed PMMA models before and after impregnation. The research consisted of the following stages: measurement of a non-impregnated casting pattern using an optical scanner, impregnation of the pattern with a selected paraffin and repeated measurement after the impregnation. Dimensional deviations were determined by measurement of the patterns in axes x, y and z and additionally by superposition of geometries scanned before and after the impregnation.

Key words: Rapid Prototyping, Rapid Tooling, 3D Printing, impregnation of PMMA models, precision casting, additive manufacturing technologies

1. INTRODUCTION

Investment casting (also known as lost-wax casting) is one of the oldest and most popular methods for production of precise castings [3]. Because of a specific way of removal of a pattern from the mold cavity, this method allows to manufacture castings of very complex shapes and high dimensional accuracy. Owing to high costs of tooling (e.g. matrices or injection molds for manufacturing of patterns), this method is mostly used in series and mass production [6]. In case of piece production or small batch production, a similar method can be used, consisting in evaporating out the molded patterns in conditions of thermal processing of the mold before pouring the liquid metal into it. Casting patterns used in the evaporative-pattern casting can be obtained using additive manufacturing technologies (belonging to the group of Rapid Prototyping and Rapid Tooling techniques). Three-dimensional printing is one of these techniques, in

* Mgr inż.
** Dr inż. 

Institute of Materials Technology, Poznan University of Technology.
which a model is built by selective bonding of powdered material using a liquid adhesive. One of frequently materials used in this method is a poly(methyl methacrylate) – PMMA – liquid and transparent thermoplastic [4, 5]. Casting patterns produced by 3D printing are characterized by a significant porosity due to used manufacturing technique, which is why the impregnation process is required. Models produced out of this material require impregnation due to significant porosity [2]. With casting patterns, this operation is necessary to fill the space between grains of material with an impregnate preventing penetration of this space with liquid molding material during the molding process, which ensures obtaining castings of low surface roughness. Necessity of impregnation of PMMA casting patterns requires conducting a comparative study regarding a dimensional compatibility of models before and after the impregnation [1, 2, 7].

2. AIM AND RANGE OF RESEARCH

The research was performed in order to measure dimensional accuracy of disposable patterns (models) after impregnation. For measurement of the dimensional accuracy, scaled casting pattern of the F1™ gearbox casing element was selected (Figure 1), of dimensions: length 216.31 mm, width 164.05 mm and minimal wall thickness of 1.6 mm. The pattern was printed out of PMMA powder, with grain size of 30÷80 μm and layer thickness of 120 μm.

Characteristics of selected physical and mechanical properties of poly(methyl methacrylate) – PMMA are presented in the Table 1.

Measurements of dimensions of PMMA pattern of gearbox casing element were performed in the ITA company (located in Poznan) and in the Division of Metrology and Measurement Systems at Poznan University of Technology. A comparative analysis of geometry of casting pattern was performed using an ATOS II coordinate optical scanner, produced by GOM company. First, the non-impregnated pattern was scanned. After performing an appropriate number of scans, obtained point cloud was transformed into a triangular mesh allowing to
generate a digital surface model of measured casing, which was then measured in $x$, $y$ and $z$ axes (Figure 2).

![Fig. 2. A view of model, measurement axes indicated](image)

### Table 1

<table>
<thead>
<tr>
<th>Physical properties of PMMA</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.19</td>
<td>g/cm$^3$</td>
</tr>
<tr>
<td>Strain at yield stress</td>
<td>1.3</td>
<td>%</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>3.6</td>
<td>MPa</td>
</tr>
</tbody>
</table>

### 3. RESEARCH COURSE

The casting pattern (element of the gearbox casing, Figure 1) was impregnated using the C$_{23}$H$_{48}$ paraffin. Impregnant properties are shown in Table 2.

### Table 2

<table>
<thead>
<tr>
<th>Properties of the paraffin</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting temperature</td>
<td>52-60</td>
<td>°C</td>
</tr>
<tr>
<td>Density</td>
<td>900-910</td>
<td>kg/m$^3$</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>0.3</td>
<td>%</td>
</tr>
</tbody>
</table>

Process of impregnation of the casting pattern was carried out by immersion in a liquid wax mixture of temperature of 70°C±5°C. To remove the surplus of
the impregnant from the surface of the pattern, it was subjected to heating in the Nabertherm chamber furnace, in temperature $75^\circ\text{C}\pm5^\circ\text{C}$.

According to the procedure described above one retaked the measurements of model after it’s impregnation. Results of measurements are shown in Table 3.

![Points of dimensional deviations of model surfaces](image)
<table>
<thead>
<tr>
<th>Casting model dimensions</th>
<th>Before impregnation [mm]</th>
<th>After impregnation [mm]</th>
<th>Difference [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>x axis</td>
<td>216.314</td>
<td>215.799</td>
<td>0.515</td>
</tr>
<tr>
<td>y axis</td>
<td>164.052</td>
<td>163.807</td>
<td>0.245</td>
</tr>
<tr>
<td>z axis</td>
<td>162.849</td>
<td>162.65</td>
<td>0.199</td>
</tr>
</tbody>
</table>

All indicated dimensional deviations prove the shrinkage being result the model impregnation.

Generated geometries were superimposed to compare them and determine dimensional deviations. Selected views of model surface with indicated measurement points are presented in the Figure 3. The highest dimensional deviations occurred in areas marked by dark colors.

4. CONCLUSIONS

Performed experiments and conducted studies have proven the following:

- The wax paraffin is an efficient impregnating material for PMMA 3D printed casting patterns.
- Impregnation caused a reduction of overall dimensions of studied pattern, which is caused by paraffin shrinkage during solidification process.
- Linear shrinkage of the impregnated model in x axis is approx. 70% higher than in y and z axis which is caused by the model construction (bars inside model inhibited shrinkage of the impregnant).
- The measured dimensions deviations after superimposing of the models geometries before and after impregnation, confirm occurrence of impregnant shrinkage effects.
- The tests show that there is a need to consider of paraffin shrinkage during castings projecting with the use of printed PMMA casting models.
- The use of other impregnants requires each time dimensional compatibility tests.
REFERENCES


DOKŁADNOŚĆ WYMIAROWA DRUKOWANYCH MODELI ODLEWNICZYCH Z PMMA PO ZABIEGU IMPREGNACJI

Streszczenie

W artykule przedstawiono badania zgodności wymiarowej drukowanych modeli odlewniczych po ich impregnacji parafiną. Zakres prac obejmował impregnatację badanego modelu oraz analizę porównawczą wymiarów wydrukowanych modeli z PMMA przed zabiegiem impregnacji i po nim. Najpierw mierzono niezaimpregnowany model skanerem optycznym, następnie impregnowano go wybraną parafiną i powtórnie mierzono. Odchyłki wymiarowe wyznaczono na podstawie pomiarów modeli w osiach x, y, z oraz dodatkowo, nakładając na siebie zeskanowaneetry modelu przed zabiegiem impregnacji i po nim.

Słowa kluczowe: Rapid Prototyping, 3DP, impregnatia modeli PMMA, odlewanie precyzyjne