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Analysis of the Geometric Accuracy of Wax Models Produced Using PolyJet Molds

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Abstract: The article presents an analysis of the geometric accuracy of wax models produced using PolyJet molds. Photopolymer resin was used to make the molds, and the surface of the model was finished in a gloss mode in the 3D printing process. This allows you to obtain a smooth surface of the molded part model. The geometric accuracy of the models was determined by measurements with the GOM ATOS scanner and analysis of the measurement results in relation to the base model made in the 3D-CAD program. Accuracy analysis was the basis for determining the wear of the mold wear when making subsequent models.

Keywords: 3D printing; geometric accuracy; PolyJet mold; rapid tooling

1 INTRODUCTION

One of the basic concepts used in the area of methods for supporting and rapid production preparation is Rapid Prototyping - RP [1]. This concept refers to the rapid production of models in unit or low-volume production, based on computer-aided capabilities and the use of three-dimensional computer models made in the CAD environment and 3D printing [2, 3]. The benefits of using this type of solutions are based on the possibility of physically presenting the product or visualizing the product to potential buyers. The offered opportunities allow for a significant reduction in investment risk, which in turn is important for the development strategies of companies in the production area [4, 5]. The development of this type of solutions is related to mastering the possibilities offered by additive technologies, leading to a situation in which they can be successfully used to produce technological tools in the Rapid Tooling - RT [6-8] process and ready-made Rapid Manufacturing - RM products [9].

Taking into account the process of introducing new products to the market, it is worth noting that rapid prototyping techniques can be useful at each stage of the process [10]. Direct production of prototypes presenting the visual, geometric or ergonomic properties of products using additive methods offers many benefits [11]. A problem may arise when it is necessary to create a functional model or technological prototype. Such a model should be manufactured using the final selected manufacturing technique and the final selected material, so that the properties of such a model are as close as possible to the final product. Using techniques used in mass production to produce models on a unit scale is not very profitable due to the high cost of preparing production tools [12, 13]. The aviation industry uses proven technologies, especially in the production of aircraft engine parts. In the case of blades of hot parts of aircraft engines, one of the basic manufacturing methods is precision casting from heat-resistant alloys. For this purpose, wax models made in mass production by injection into metal alloy molds are used. In order to test new design solutions for turbine blades, the production of metal injection molds for the production of wax models is very expensive. For this reason, the use of molds based on the Rapid Tooling process from polymer materials using the PolyJet method [14, 15] is an application for the quick and economically effective production of prototype models. Molds of this type enable the production of wax models in numbers ranging from several dozen to even several hundred pieces. However, it is necessary to analyze the wear of the mold cavity, which, due to thermal and mechanical influence, wears out earlier than molds made of metal alloys. One of the methods for assessing mold cavity wear is measuring the geometric accuracy of wax models using optical scanning, which is presented in this article.

2 PREPARATION OF RESEARCH MODELS

The preparation of research models consisted of several stages. It started with the preparation of a 3D-CAD model of the blade, the wax models of which were made of wax. Then, a mold was designed for low-pressure wax injection, which includes a channel for supplying liquid wax, a cylindrical container with a piston for low-pressure injection, and venting channels. A 3D-CAD model of the mold was also created, which was then transformed into an STL model intended for production using additive technology. The MJT – Material Jetting process and PolyJet technology were chosen to produce the molds.

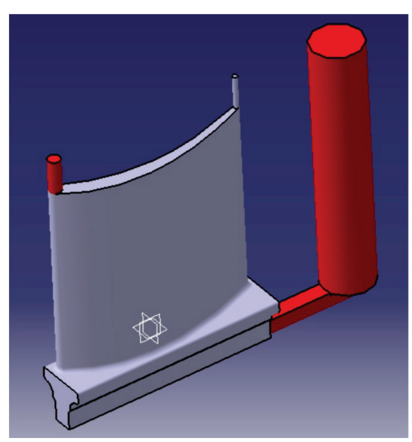

Figure 1 3D-CAD model of blade

In the process of producing the mold model, the Objet EDEN 260 device was used, based on the PolyJet technology solution. The starting material in the printing process was a liquid photopolymer called RGD720 (Stratasys, USA), which guarantees high stability of dimensions and shapes of the created models. The single layer thickness of the printing process was 16 microns and the Glossy finishing mode was used for finishing. With such selected parameters, it was possible to obtain a very smooth surface of the model immediately after printing, which allowed for easier demoulding (removing the cast models from the mold) in the later stages of the experiment. A view of the manufactured mold and the wax model of the blade is shown in Fig. 2.

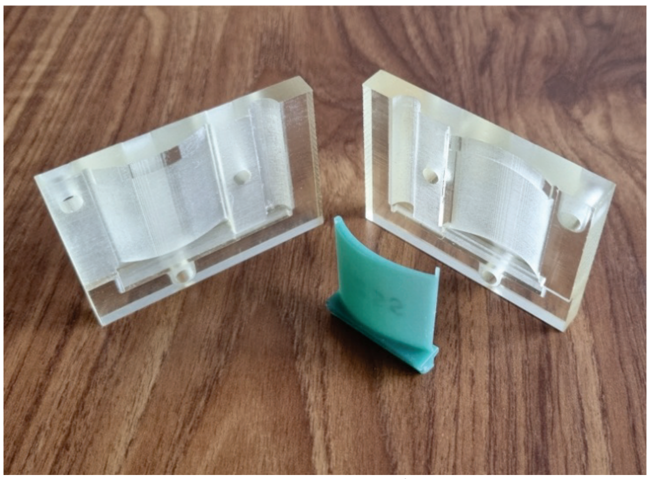

Figure 2 Mold and wax cast of the blade

Figure 3 View of the wax heating furnace

The next step was to cast the blade model from wax using a mold printed in PolyJet technology. One cycle of the casting process took approximately 180 minutes. It consisted of several stages: heating and removing the mold from the oven, pouring wax into the mold, cooling it and demoulding it. Fig. 3 shows a photo of a wax heating furnace.

The mold was filled with KC 6052D casting wax, which was heated in an oven to 100 °C and then poured into the mold to obtain a wax model of the blade. Fig. 4 shows a graph of wax temperature changes during the casting process.

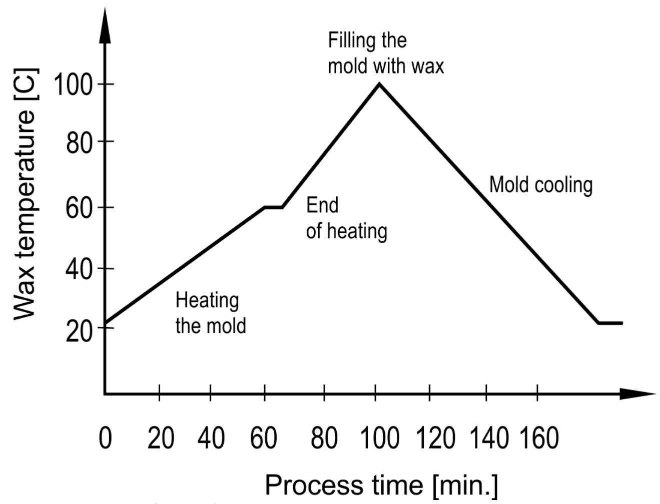

Figure 4 Graph of temperature changes during the casting process

Before the casting process, the two parts of the mold were connected using three screws with nuts, which ensured the stability of the connection of the mold elements during the pouring process. The view of the mold with a filled cavity is shown in Fig. 5.

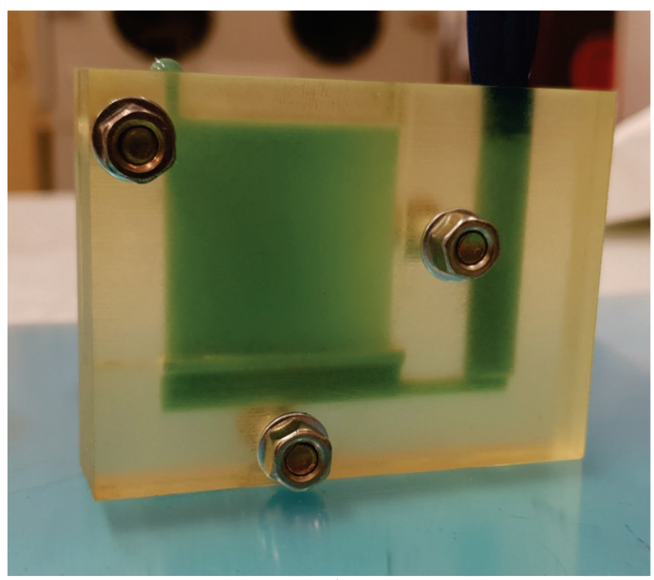

Figure 5 Mold filled with wax

After the mold had cooled down, its parts were separated and the cast wax model was removed. The mold cavity and adjacent surfaces were cleaned before the next casting process. In this way, 100 research models were made to assess the wear of the mold cavity as subsequent pieces of casting were made.

3 RESULTS OF MEASUREMENTS OF THE GEOMETRY OF WAX MODELS OBTAINED BY LOW PRESSURE MOLDING

The shape change was examined using a coordinate measurement technique based on the structured light scanning process. During the research, no measurements of the mold cavity were made because it would have been necessary to scan two parts and then assemble them in software. Such a process would introduce additional errors in the interpretation of the results. A map of deviations from the nominal dimension was made by superimposing the scanned model on the reference model. Using the indicated method, the geometry of the moldings obtained in the low-pressure forming process. Measured was made using the Atos II Triple Scan scanner with structured light illumination (Fig. 6). Measurements of the blades were made from two sides (inner and outer), but due to the volume of the article, the measurement results of only one side are presented.

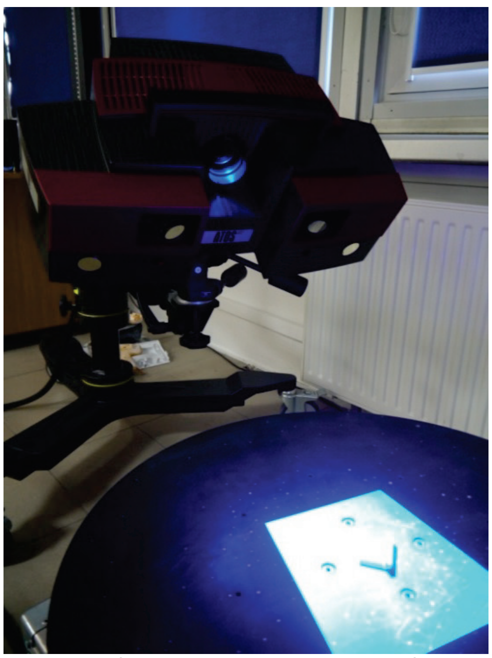

Figure 6 Scanning process using Atos II Triple Scan

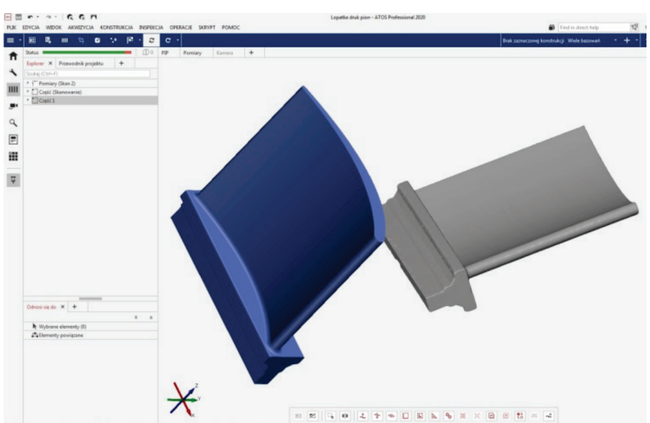

Figure 7 Overlaying models of the measured object on the nominal STL model in Atos Professional

Then, using the Atos Professional software, the mesh of the model obtained as a result of scanning was superimposed on the mesh of the nominal model and an analysis of the deviations of the dimensions of the actual model from the nominal dimension was carried out (Fig. 7).

The following drawings show views of deviation maps for subsequent models obtained in the low-pressure forming process using a mold obtained in the incremental process (Figs. 8 - 17). Measurements were performed on every tenth model for the research cycle of producing 100 wax casts.

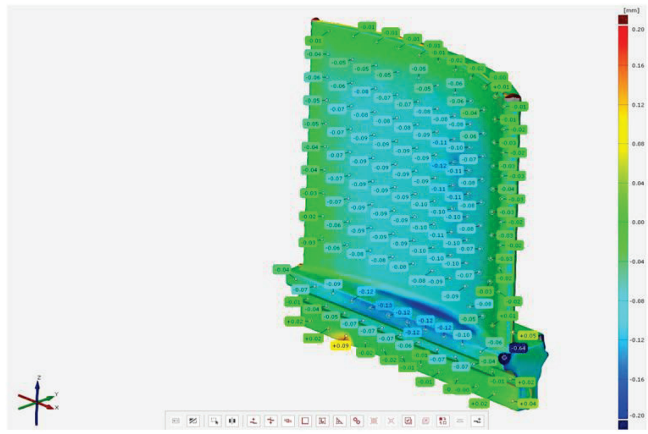

Figure 8 Analysis of the measurement results of the wax model of blade no. 10

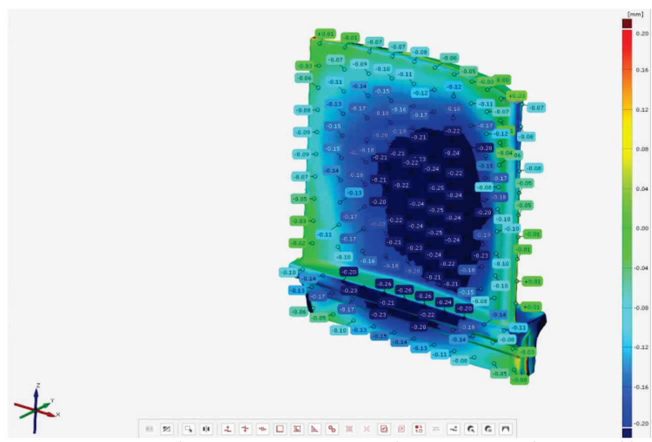

Figure 9 Analysis of the measurement results of the wax model of blade no. 20

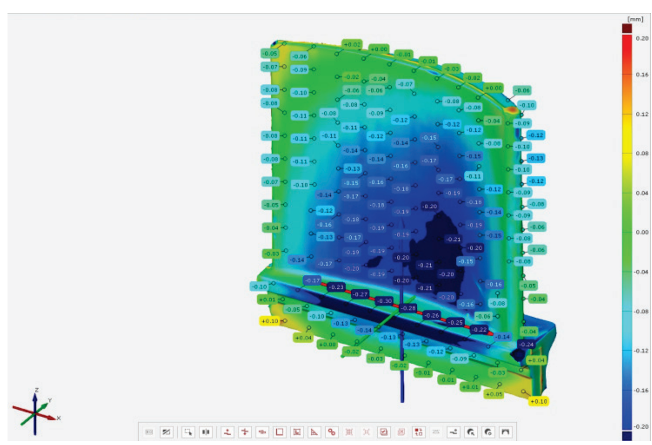

Figure 10 Analysis of the measurement results of the wax model of blade no. 30

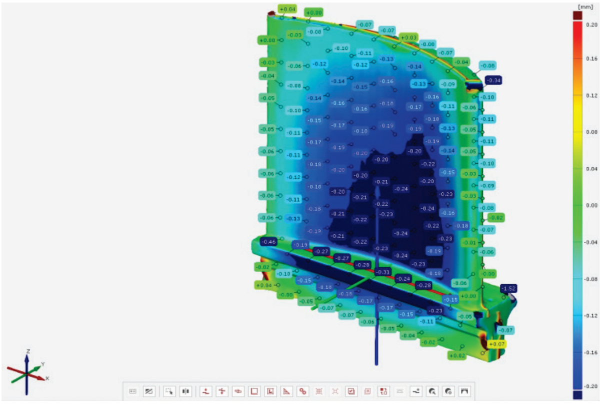

Figure 11 Analysis of the measurement results of the wax model of blade no. 40

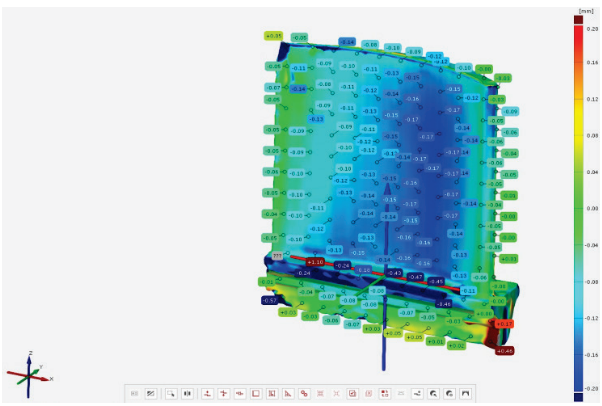

Figure 12 Analysis of the measurement results of the wax model of blade no. 50

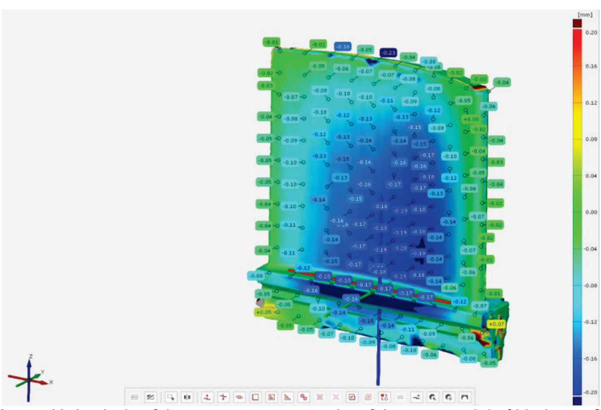

Figure 13 Analysis of the measurement results of the wax model of blade no. 60

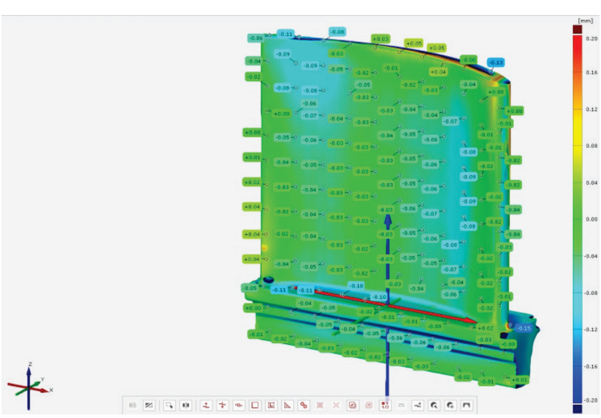

Figure 14 Analysis of the measurement results of the wax model of blade no. 70

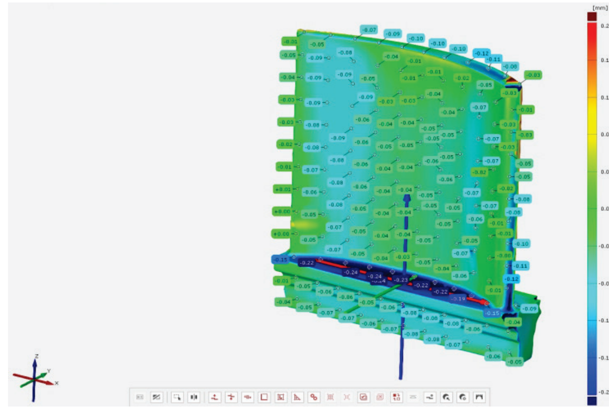

Figure 15 Analysis of the measurement results of the wax model of blade no. 80

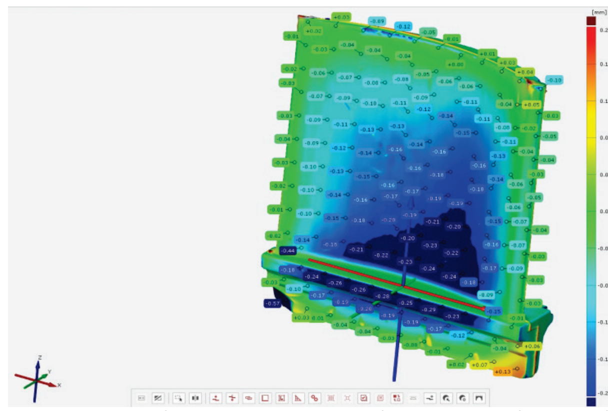

Figure 16 Analysis of the measurement results of the wax model of blade no. 90

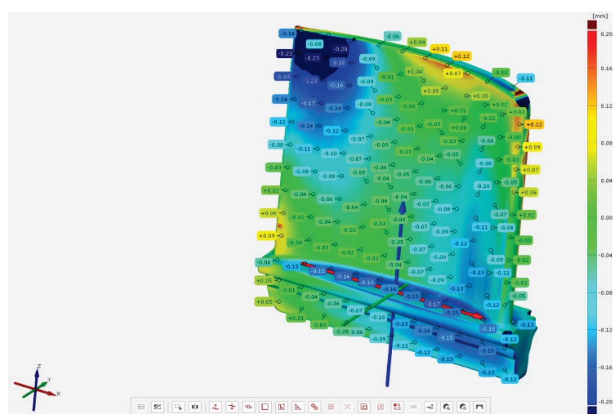

Figure 17 Analysis of the measurement results of the wax model of blade no. 100

4 CONCLUSIONS

During the low-pressure molding process using a mold obtained in the additive process, greater ease in the mold filling process was noticed, despite the use of wax filled with particles of other phases (composite wax). The general analysis of the obtained models allowed us to notice again a significant predominance of negative deviations from the nominal dimension. The shrinkage of the model is probably due to material shrinkage.

In the case of the first ten cast models, analysis of the deviation map allowed for the conclusion of a high regularity of deviations from the nominal dimension: the deviations were one-sided and evenly distributed on both sides of the blades. Deviations on the outer surface were up to -0.1 mm. Such regularity of model inaccuracies can be treated as an advantage, because in such a case, rescaling the mold by a given value would allow for easy compensation of shrinkage and obtaining precise models.

From model 60, positive deviations from the nominal dimension were noticed near the side parts of the model (corners) on both sides of the model. Positive deviations in the indicated places appeared on subsequent models, so they probably result from mold damage. From the 70th model implemented, a negative effect of heating the silicone mold before the molding process was noticed, affecting its deformation. From that moment on, elements stiffening the form were used. Therefore, the dimensional accuracy of the models improved, which can be seen by analyzing the measurement results, mainly for the internal part of samples no. 70 and 80.

In the case of models 70 and 80, a slight improvement in dimensional accuracy was also noticed on their external surfaces, resulting from stiffening the structure with additional elements. In the case of these samples, a negative deviation was noticed on the outer part of the blade in the place where the blade inclination angle changed from negative to positive. In this area, the shrinkage is the greatest, therefore, as the number of molding cycles increases, it is in this area of the surface that the greatest inaccuracy should appear. This shows that the shape of the blade has a significant impact on the direction of deformation resulting from shrinkage. The inaccuracy of the obtained models, even after 100 processes, did not generally exceed –0.2 mm on the curve surfaces (external and internal), which proves that the obtained models are quite accurate compared to other methods enabling obtaining models for precision casting processes. Additionally, the low value of deviations may indicate that the surface of the socket model showed quite good resistance to abrasive wear caused by flowing wax. Damage to the mold was related to small tears during demoulding in mold elements with a narrow cross-section - around the side lines of the blades.

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