APPLICATION OF 3D SCANNING TO EVALUATING THE QUALITY OF CERAMIC FORMS

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Abstract

One of the most crucial parameters having deciding influence on the quality of multilayer ceramic forms used in precision casting process of aircraft blades, is their thickness. Traditional measuring methods ensure a possibility of quantitative determining the factor only after inundating the form with liquid metal and breaking it. This article shows the results of the research which aim was to implement the non-destructive method using 3D scanning in order to determine thickness of forms. Three different kinds of ceramic materials and binders were selected and were put on wax model kits. Finally, 7-layers forms were made. Model sets and every of applied layers were scanned with 3D scanner. The results of scanning are generated as stl. files, which means that they describe geometry of the surface. After applying two scans on each other and processing them with the use of software dedicated for scanner, the empty space visible between measured surfaces determine the thickness of each layer and consequently the whole covering. The solution is very profitable as it allows to detect faulty forms and exclude them from subsequent stages of production. It allows to reduce the unnecessary spending which are really enormous in the case of such product.

Keywords: Metallurgy, 3D scanning, aircraft vanes, ceramic forms, thickness

1. INTRODUCTION

The process of precise casting of blades, being critical parts of aircraft engines, is carried out in many individual processes, including making wax model, creating wax model sets and multi-layered ceramic mold, wax liquation, mold firing, mold basking, inundating, post-casting mechanical treatment and 100% quality control of final products .The evaluation of the quality of wax models and ceramic forms is only visual. Quality of these semi-finished products have influence on the quality of the finished, many times more expensive product, because of the usage of the Inconel alloy to the air blades. The aim of the research was to find a solution which in the perspective can reduce production costs and that would eliminate defected model sets and/or ceramic forms before the pouring stage. 3D scanning method, which is a very flexible tool for determining the shapes and dimensions of the researched elements, turned out to be the best solution. The most useful type of scanning for this type of research is the structural light method [1]. It works in such a way that patterns in shape of stripes are projected onto the tested element. The light source is a special projector. Displayed image is visible on the tested element, and all shapes deform the projected pattern. Dedicated software analyzes changes in shape and creates a point cloud on this basis, where each point corresponds to the pixel of the camera [2]. The higher resolution of the device, the more accurate results are possible to obtain, was demonstrated by Derejczyk and Siemiński at scientific research [1]. Then, thanks to the appropriate software, the point cloud is processed into a .stl extension file and that is grid of triangles. The 3D scanning method has been applied in many fields of science and engineering, including aerospace industry, as evidenced by the work of Kachel, Kozakiewicz, Łącki and Olejnik [3], in which it was presented how the use of 3D scanning led to obtaining a three-dimensional model of the MIG-29 aircraft. Another area in which 3D scanners are used is archeology and digitization of works of art [4]. 3D scanning is also a very helpful tool used in construction. Authors of the publication [5] presented the use of 3D scanning to collect data on the shapes and dimensions of existing buildings to facilitate the modernization of their structure. Analysis of the literature indicates that this method has many applications, and its flexibility and the type of results that it receives reveal that the spectrum of applications is almost unlimited. The use of this method allowed, after many attempts and methodology development, to evaluate the thickness of a multi-layer ceramic mold used for casting critical parts of aircraft engines.

2. METHODOLOGY

Two wax sets models were used in the research and two molds were made on them, referred later in the article as parallel (**Figures 1a, 2a**) and serial (**Figures 1b, 2b**), with different gating systems and arrangement of individual blade models. Such application of two different systems allowed to analyze the influence of the shape of the mold, made by hand on the diversification of its thickness. To make wax model kits, it is necessary to use specially prepared for this purpose materials consisting of 30-70% ordinary wax, 20-60% resin, 0-20% plastic and 0-5% other substances. The wax used for the tests was characterized by lack of solubility in water, green color and absence of smell. The melting point was 64.5 ± 14.5 °C, flashpoint above 200 °C and weight density 1.002 g/cm^3.

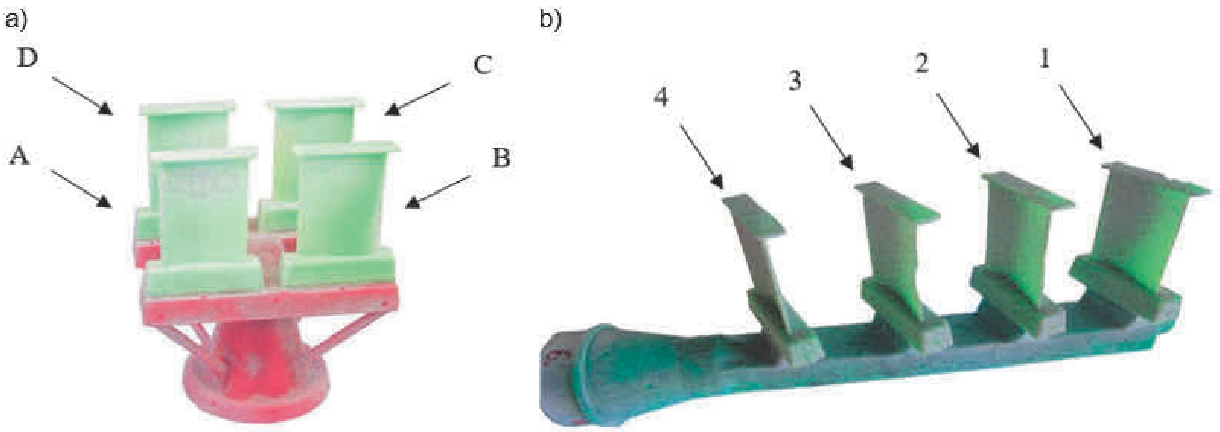

Figure 1 Waxed parallel model (a) and serial (b) sets with markings of individual blades

Then, multilayer ceramic forms were made on the model sets. They consisted of seven coverings, each of them was made from an bond, as well as a ceramic covering with different grain sizes for each layer. Two types of binders were used: ludox and hydrolyzed ethyl silicate. Ceramic aggregate was quartz. **Figure 2** presents multi-layered ceramic forms with the markings of individual blades as well as lines of cross-sections parallel to the bases of the blades.

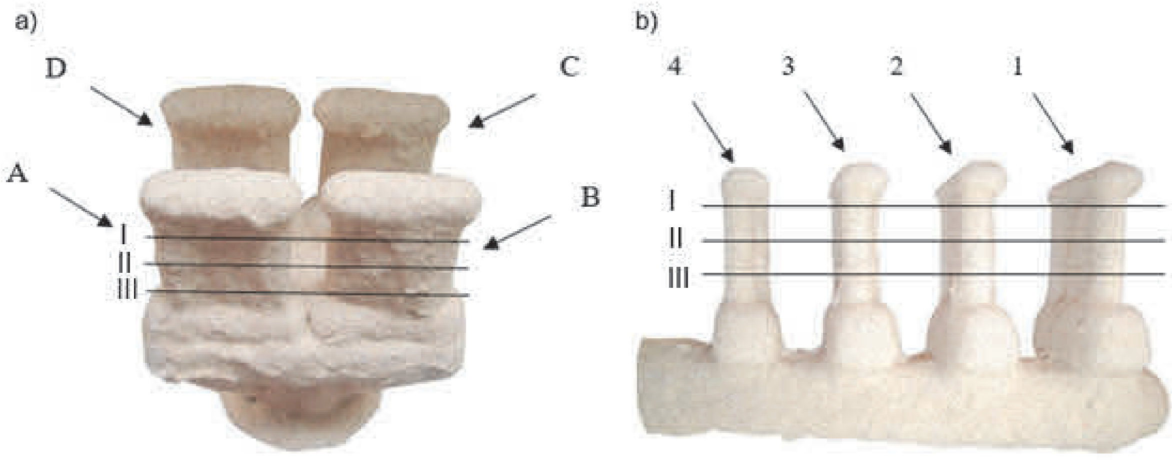

Figure 2 Parallel (a) and serial (b) forms together with the markings of individual blades and lines denoting cross-sections

In order to obtain accurate results of the mold thickness, two-stage tests were performed by 3D scanning. First step consisted in scanning wax models sets. Next, the appropriate number of ceramic mold layers was applied to the scanned element. After melting the wax in the autoclave, the mold was subjected to 3D scanning. An important stage of the process was to make the mold in such a way that it would not cover the entire model set, but left the wax fragment on the gating system. Thanks to this, it is possible to correlate the results of wax and mold scans very precisely. The beginning of the gating system, i.e. the part that is not covered by the form, is the same for both models. It gives the possibility to match the entire model sets by the local best fit function. It is very important that the uncoated part is not smooth, but it has characteristic elements such as, for example, wax drops or cavities, which significantly increase accuracy and eliminate possible matching errors.

3. RESULTS AND DISCUSSION

Research which was carried out according to the presented methodology allowed to obtain results in the form of 3D scans of the wax model sets (**Figures 3a, 3b**) and molds (**Figures 4a, 4b**).

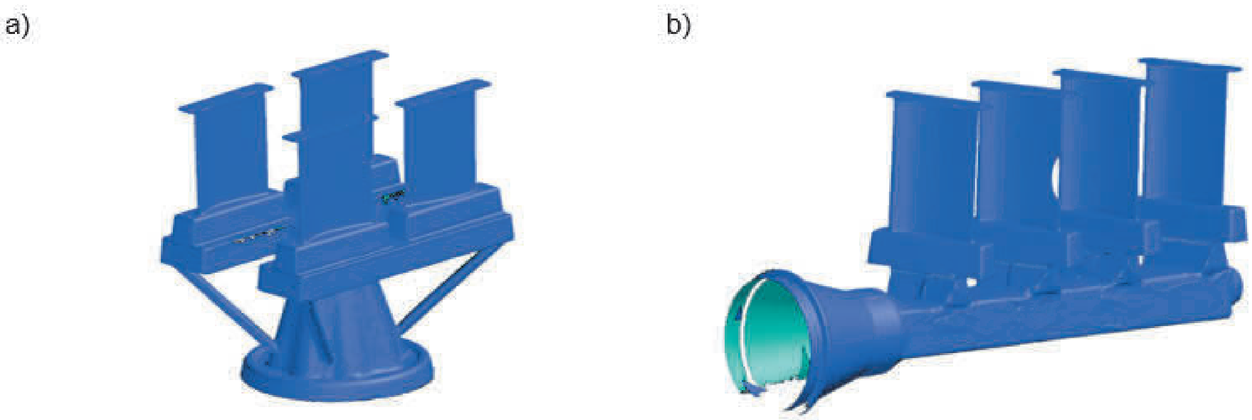

Figure 3 Scan results of the parallel (a) and serial (b) sets

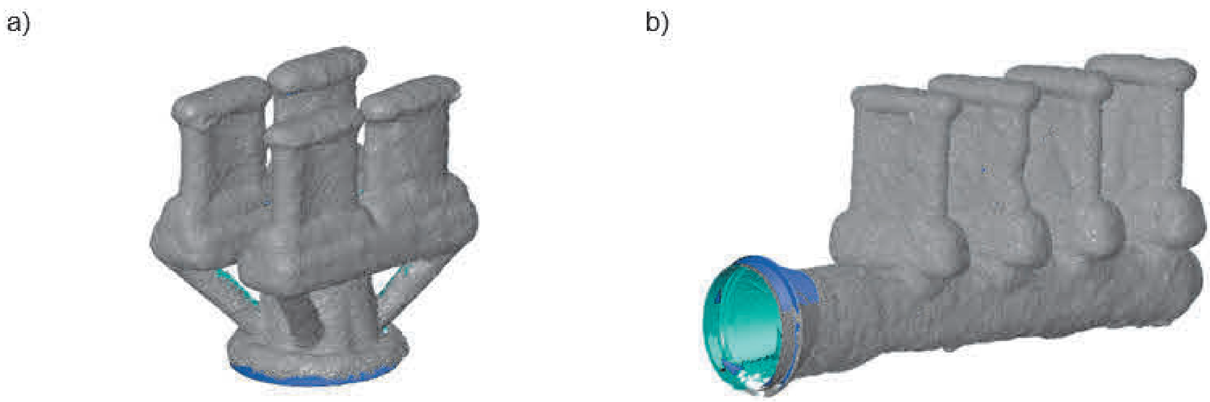

Figure 4 Scan results of the parallel (a) and serial (b) sets

After the model set and mold scans were applied to each other, the results of mold thickness were obtained. The images of which in the form of a color deviation map are presented in **Figure 5**.

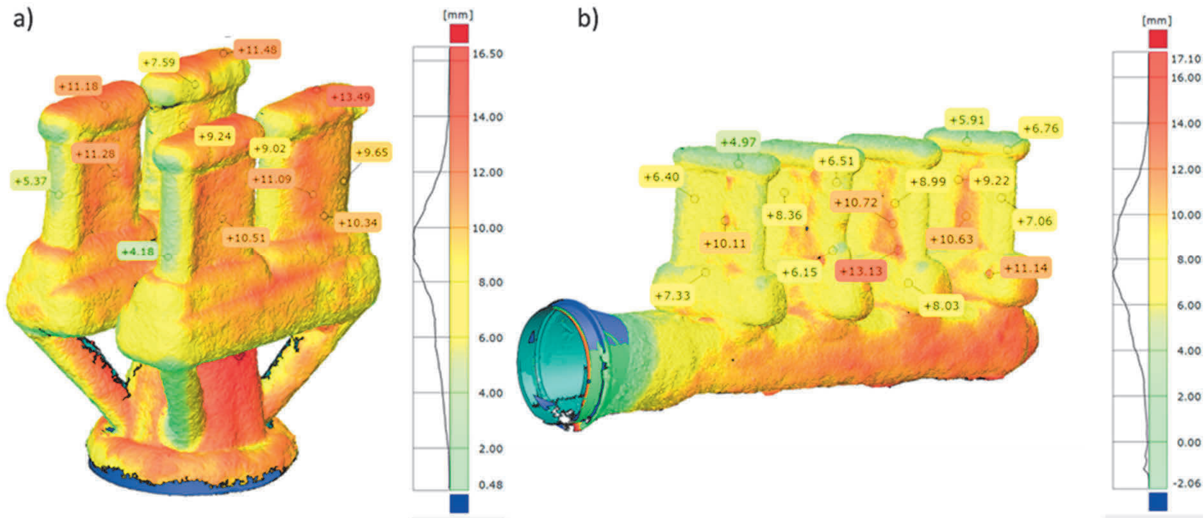

Figure 5 The results of the thickness presented in the form of a colorful deviation map with additional flags marked for parallel (a) and serial (b) molds

As can be seen in **Figure 6**, it is possible to fit two models in a very accurate way. In this case, the best local fit function was used, and the selected area included part of the wax model set that was not covered with the ceramic mold. The results oscillate around values not exceeding 0.03 mm, i.e. they are close to the accuracy that can be guaranteed by the 3D scanning method itself using high quality equipment. This means that this way of matching two models is nearly optimal.

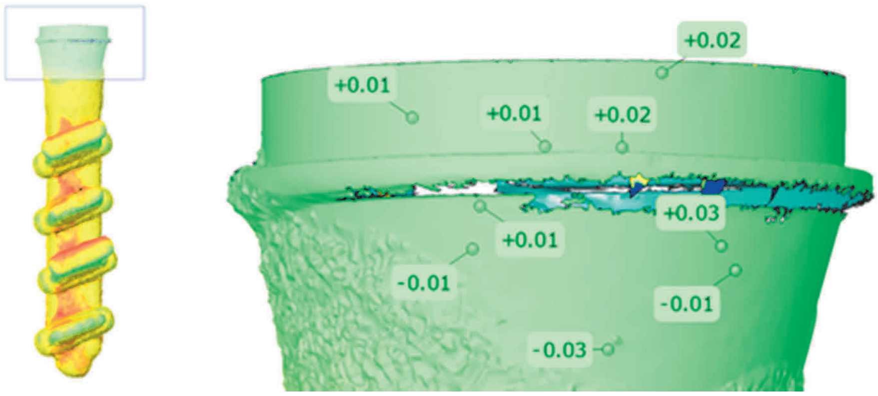

Figure 6 Presentation of the accuracy of matching two models

Then, a more detailed analysis of the results obtained was made. For molds, as presented in the research methodology, cross-sections were created, which allowed to analyze the changes in mold thickness on the blades at intervals of 25 mm (**Figure 7**).

Visible differences between the sections a) I and a) III indicate that the thickness of the mold varies significantly with the distance from the gating system. For the section a) I, the maximum value is 13.14 mm, the minimum value is 4.23 mm and the arithmetic average is 9.23 mm. For a) II, the aforementioned values are 12.63 mm, 3.89 mm and 9.02 mm respectively and a) III 11.76 mm, 4.78 mm and 8.96 mm respectively. In addition, large deviations in thickness are visible depending on the geometry of the blades in a given cross-section. In the case of cross-sections b) I, II, III, differences depending on the place of measurement in a given cross-section remain at the same level. For b) I, the maximum value is 11.29 mm, the minimum value is 4.11 mm and the arithmetic mean is 8.03 mm. As regards b) II, these values are in succession 13.47 mm, 3.12 mm and 8.45 mm, and for b) III 13.58 mm, 3.25 mm and 8.62 mm respectively.

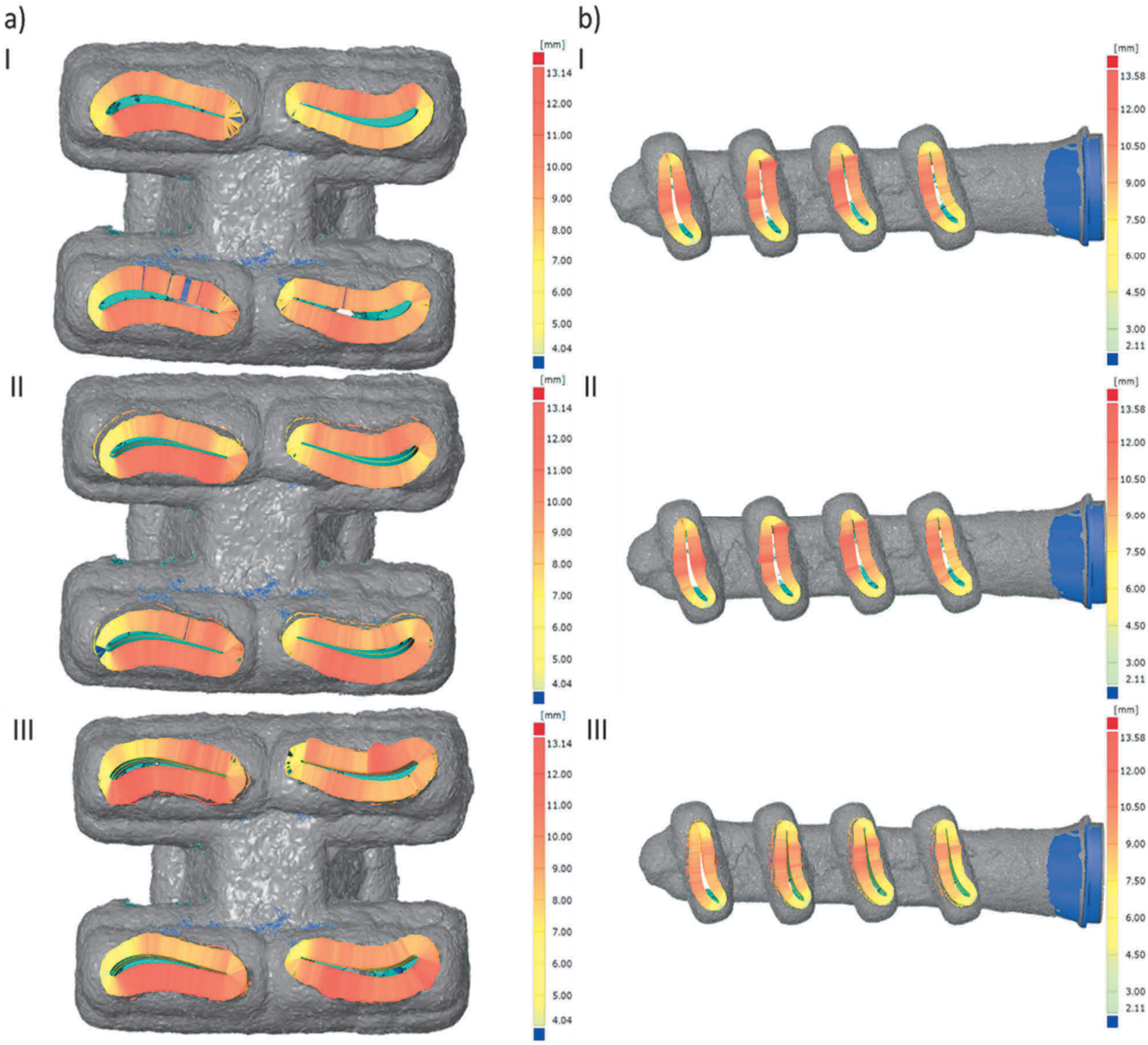

Figure 7 Mold thickness results in parallel (a) and serial (b) cross-sections

As part of the study, the average mold thickness for each blade was also analyzed. The results are shown in **Figure 8**.

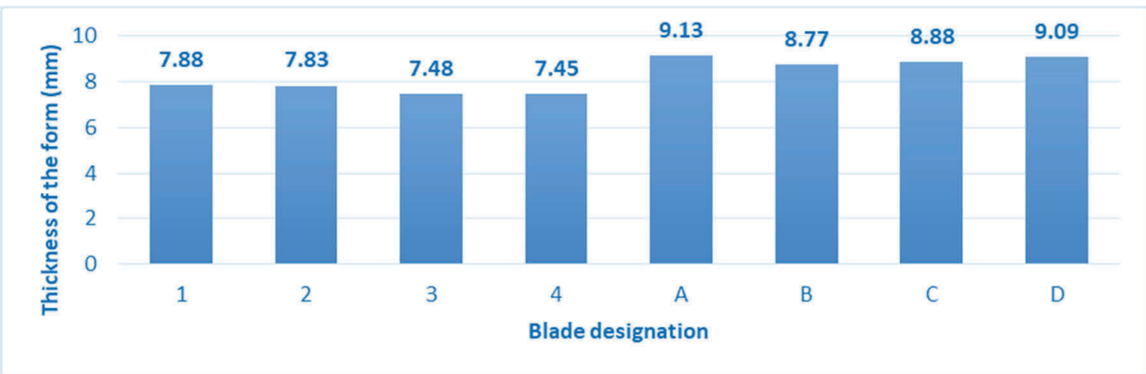

Figure 8 Average thickness of the mold for each blade

It can be seen, that the mold thicknesses differ from one another significantly. The differences associated with average thickness, as well as those visible in cross-sections, are so large that they can have a significant impact on the solidification of the metal inside the mold.

4. SUMMARY

Analysis of the results of research shows that by using the 3D scanning method one can easily get detailed quantitative information about the thickness of the mold. Due to the fact that the thickness is determined at virtually every point of the form and presented in the form of a color deviation map, it is very quick to locate key locations where the measurement showed deviations from the nominal value. Of course, the ability to analyze the obtained results is much greater, and in addition, all operations can be performed using free software, which is undoubtedly an important advantage of this method. Ability to assess the thickness of the mold before filling it with metal, i.e. at a crucial point from an economic point of view, gives great opportunities to streamline the entire production process. Further research is being carried out to determine the limit thickness of the mold at which casting defects will start to appear.

ACKNOWLEDGEMENTS

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