Analysis of the influence of selected Slicer parameters on the mapping accuracy in the FFF method

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Abstract: The methodology and measurement results of the machine part produced directly from the 3D-CAD numerical model are presented. Representative additive techniques based on polymer processing were used. The accuracy of replication of CAD numerical models was assessed in terms of both external surface analysis and part volume.

Keywords: additive manufacturing, parts manufacturing, PLA, accuracy analysis, computer tomography.

Analiza wpływu wybranych parametrów Slicera na dokładność odwzorowania w metodzie FFF

Streszczenie: Przedstawiono metodykę oraz wyniki pomiarów części maszyny wytworzonej bezpośrednio z modelu numerycznego 3D-CAD. Zastosowano reprezentatywne techniki addytywne bazujące na przetwarzaniu polimerów. Dokonano oceny dokładności replikacji modeli numerycznych CAD zarówno w ujęciu analizy powierzchni zewnętrznych, jak i objętości części.

Słowa kluczowe: techniki addytywne, produkcja części, PLA, analiza dokładności, tomografia komputerowa.

Polymer composites are currently the most widely used model materials in additive manufacturing processes [1–4]. These materials have been widely used in many additive technologies, including thermoplastic modelling processes with the use of, among others, FFF technique (Fused Filament Fabrication). The major problem with the use of these materials to produce details for a specific purpose is, first of all, incomplete material data published by manufacturers, but also the layered structure of models. Since the material is applied or sintered layer by layer, this layered structure is visible on the model. Especially in the FFF method, the heights of the printed layer are much bigger compared to other methods. Filling the interior of the printed element with the material depends on the user's preferences and settings in the program; however, it is certain that the user is not able to check the internal structure of the 3D printout directly. It is purposeful to conduct research to expand knowledge in this field [3–5].

The accuracy of polymer models obtained by 3D printing method (FFF), made with different layer heights and different filling densities, was investigated. Comprehensive research was carried out not only in the assessment of external surfaces, but also in terms of the models volume using computed tomography, which allows to identify defects in the internal structure of details in a non-invasive way. Non-destructive testing using industrial tomography is becoming more and more common in industry. X-ray computed tomography allows obtaining layered images of the examined object. It uses composite projections of an object from different directions to create cross-sectional (2D) and spatial (3D) images. In industry the CT method is used to determine the geometry and tolerance of products, the results analysis of production performed directly with CAD models, defectoscopy, performing volume measurements, determine the amount of the so-called volatile material that has not been removed during processing and reverse engineering [1,6, 7,8].

EXPERIMENTAL PART

Materials

The polymers used in the study and their symbols are listed in Table 1.The most commonly used material is polylactide acid (PLA), due to its ease of use, biodegradability and durability [9,10]. Due to the low thermal expansion, it allows the production of large models without shrinking and warping of the model, therefore it is also suitable for the production of small parts due to its low melting point.

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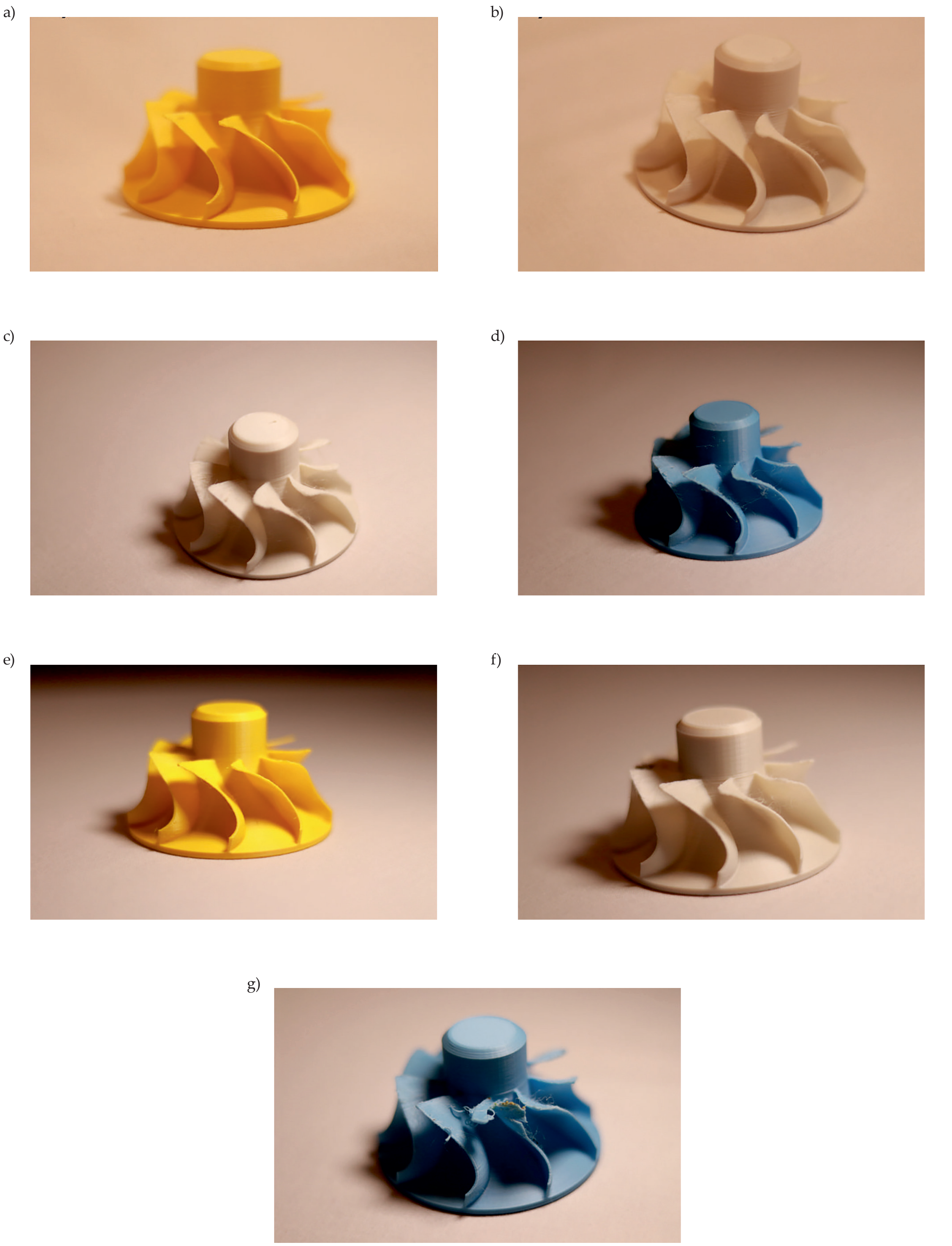

Fig. 1. Research models of a polymer compressor rotor produced with the use of additive techniques: a) 0.2 mm/20%, b) 0.15 mm/20%, c) 0.1 mm/20%, d) 0.05 mm/20%, e) 0.1/40%, f) 0.1/70%, g) 0.1/100%

T a b l e 1. Technical specification and physical properties of the Noctuo Ultra PLA filament

Filament diameter	1.75 mm
Density	1.30 g/cm^3
Print speed	< 120 mm/s
Vicat softening point	60°C
Melting temperature	150–170°C
Charpy notched impact strength	7 kJ/m^2
Flexural modulus	2650 MPa
Elongation at break	19%
Flexural strength	64 MPa
Tensile modulus	2600 MPa
Yield point	47 MPa

Model manufacturing

Manufacturing a model using the FFF method consists in melting the material (filament) in a heated head. The 3D printing process of models using the FFF technique was carried out on a Prusa MK3s printer [11–13]. The research model was a turbocharger rotor with complex blades geometry and the machining of which in CNC centres is time consuming. A total of 7 models were printed (Fig. 1). Four models were made with the following layer dimensions: 0.2 mm, 0.15 mm, 0.1 mm, 0.05 mm and the filling density of 20%. The remaining three were models with a layer dimension of 0.1 mm and a filling density of 40, 70 and 100%.

Methods

Geometry and structure

X-ray computed tomography (CT) was used to determine geometry and structure of research models. Due to the tests carried out on industrial computed tomography, volumetric data was obtained, onto which a 3D-CAD model was applied. A colored map of the printed objects dimensional and shape deviations in relation to the CAD model was obtained. The research was performed with the use of the Zeiss METROTOM 1 industrial computer tomograph, which makes it possible to perform tests on elements made of plastics and 65 metals. The working space allows you to measure elements with maximum dimensions of 165 × 140 mm. The device allows you to carry out a dimensional analysis of the tested object, wall thickness analysis, and defectoscopy analysis of internal structures. The tomograph was equipped with an X-ray tube with a maximum voltage of 160kV, and the size of the flat detector was 2500 × 2500 active pixels. During the measurements, the lamp power was 600 W, the X-rays passed through a prefilter made of 2 mm thick aluminum (Al2), and the exposure time was 300ms. During one projection, the device took 2000 photos.

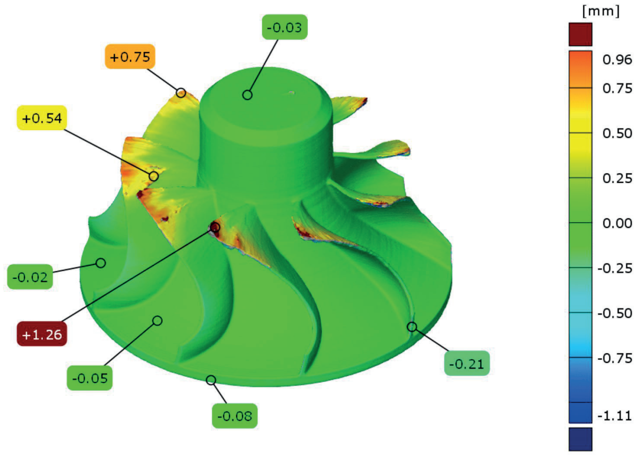

Fig. 2. Comparison of the print surface with a 0.1 mm high layer in relation to the CAD model

RESULTS AND DISCUSSION

Figure 2 shows a deviation map for the turbocharger rotor model made with a layer 0.1 mm high.

The greatest dimensional deviations are in the upper part of the blades. This phenomenon occurs on each of the printed models, but the greatest deviations occur in the model shown in Figure 2. This is because the blades are thin-walled elements, and their geometry is very complicated. The slope of the blade profile in relation to the working plane is large, which means that the individual layers in the upper part of the blade are applied almost in the air, which makes it rise in the direction of the Z axis. All rotor models have shrunk during the printing process as a result of the temperature gradient. The hot filament pressed through the nozzle cools down very quickly after it comes into contact with the previously applied layer. The whole process is intensified by the fan used to cool the head. Figure 3 shows the X-Y plane cross-section of the rotor dimensions deviations made with a 0.05 mm high layer from the CAD model with the deviation flags at selected points.

Figure 4 shows a profile located on the rotating surface of the rotor core, which was used to make cross-sections that allow to collect information on the distribution of deviations from the CAD model depending on the layer height used.

For better visualization, an approximation of the measuring section length of 10 mm was adopted. The obtained results were cumulated in the diagram presented in Figure 5.

This clearly indicates that surfaces with large radii of curvatures mapping a printout made with a layer 0.2 mm high, show the greatest deviations. The amplitude of the deviations is approx. 0.1 mm. This is due to the specificity of the incremental method. The higher the layer, the more difficult it is to reproduce a curvilinear surface. Densifying the number of print layers results in a more accurate representation of the surface curvature.

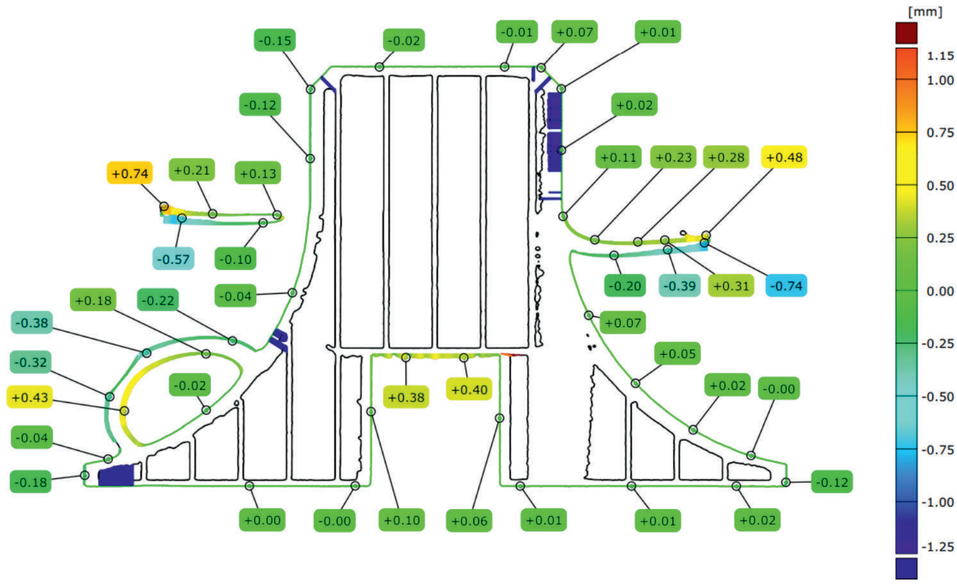

Fig. 3. Inspection cross-section in the XZ plane on a printout with a 0.05 mm high layer

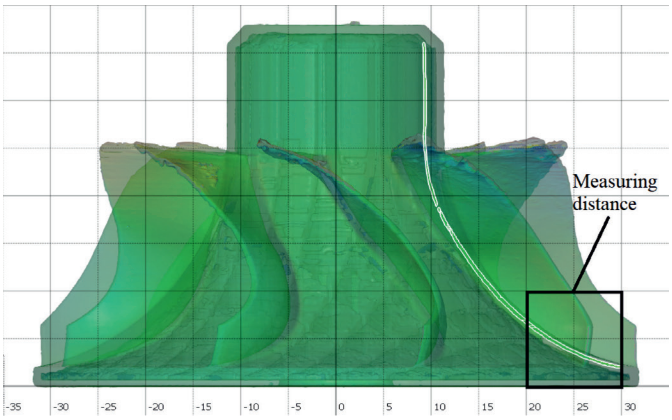

Fig. 4. Profile of the cross-section of the rotor core with the marked measurement section

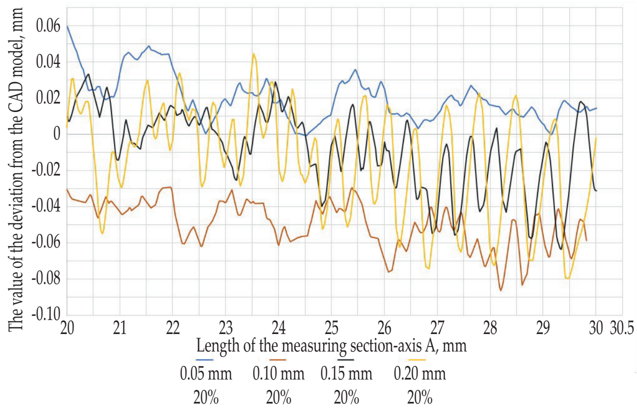

Fig. 5. Graph of the deviation value from the CAD model on the section profile of the rotor core

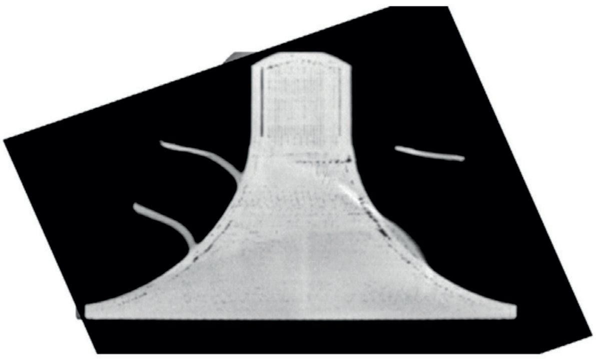

Fig. 6. Air voids visible on the X-Y plane section on the volumetric data

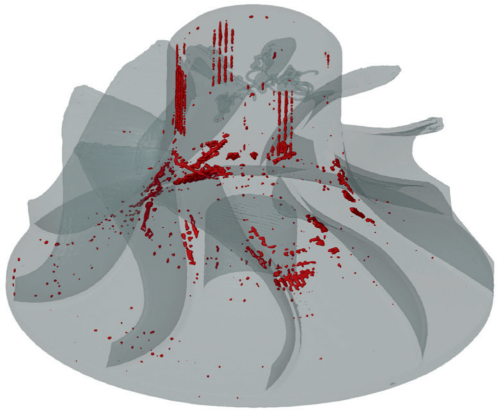

Fig. 7. Internal defects in the form of air voids on a model made with a 0.1 mm high layer and a filling density of 100%

Tests performed with the use of a computer tomography allow not only to perform a geometric analysis but, above all, to inspect hidden defects inside the object. Having the volumetric data of all the printed models of the turbocharger rotor, it was possible to analyze the occurrence of internal defects in the form of closed air pores. The most important research model was the rotor made with a layer 0.1 mm high and a filling density equal to 100%, because theoretically it should not contain defects in the form of empty air bubbles.

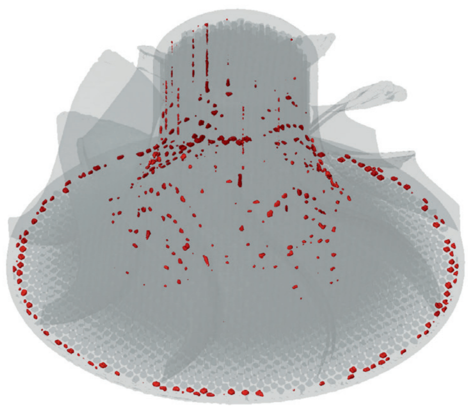

Fig. 8. Internal defects in the form of air voids on a model made with a 0.1 mm high layer and a filling density of 70%

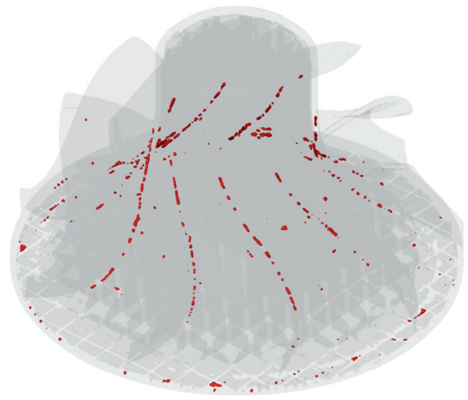

Fig. 9. Internal defects in the form of air voids on a model made with a 0.2 mm high layer and a filling density of 20%

T a b l e 2: The defects number and volume of the turbocharger rotor printouts

	3D models						
	0.05 mm 20%	0.1 mm 20%	0.1 mm 40%	0.1 mm 70%	0.1 mm 100%	0.15 mm 20%	0.2 mm 20%
Defects number	53	46	123	464	685	108	332
Defects total volume, mm^3	1.7	1.77	8.74	34.94	40.80	4.62	12.46
Rotor total volume, mm^3	34791.4	34696.8	34776.9	34737.3	34484.0	32704.1	34333.1

When inspecting the rotor inside, numerous defects in the form of empty air spaces were observed. Most of them are located just below the core surface. Empty air bubbles were created as a result of closing the gaps by making the full outer contours of the rotor core contour, which can be seen on the X-Y plane cross-section shown in Figure 6.

After all defects were filtered out, the actual image of defects in the volume of the rotor model made with 100% filling density was obtained (Fig. 7).

Due to the fact that not all the models made were printed with a filling density equal to 100%, an empty air space with a volume of up to 0,3 mm^3 was considered a disadvantage. After conducting such an analysis, the data contained in Table 2 was obtained.

It shows that with increasing layer height and filling density, the number of volume defects increases. Some of disadvantages result from the accuracy of 3D printing in the FFF method. These defects are caused by the lack of filament filling in the gaps where the printing nozzle did not move. These are places where several paths meet or where filament extrusion ends. In models where the full volume was not used, the number of defects is much higher. Some of the defects arose due to the closing of the air spaces after division with a filling grid. It is most clearly visible on the model with a filling density of 70% (Fig. 8), where there are numerous defects on the circumference of the rotor, which arose as a result of closing the space divided by the filling grid by the upper full contour external layers.

The long, narrow air channels visible at the top of the rotor core are due to poor optimization of the fill printing paths. On models made with a layer 0.15 mm and 0.2 mm high, defects appeared at the point where the blades joined the core (Fig. 9).

They result from the layer height used. The higher the layer, the more problems the printer has to completely fill in the gaps, which in turn causes the formation of closed spaces filled with air.

CONCLUSIONS

The conducted research was aimed at determining the influence of the layer height change on the accuracy of the CAD model mapping using the FFF method. This method is very popular in the industry [14–16], and is more and more often used to produce parts for a specific purpose. Using this technology, the most popular thermoplastic material – polylactide – PLA, was used to balance the models of turbocharger rotors. The external surfaces of the tested models analyses prove that the FFF method is not suitable to produce thin-walled products with a large inclination angle in relation to the working platform. The rotor blades were deformed in the direction of the Z axis, sometimes to a significant extent. Due to the change in the layer height, during the manufacturing of a product with a lower layer, the obtained model was characterized by a more accurately reproduced surface. The deviations resulted from the very specificity of the incremental FFF method. Visible layers are an indispensable element of this type of incremental method. Lowering the layer four times in relation to the layer. 2 mm high resulted in a reduction of the deviations amplitude by almost a half.

Tests performed with the use of a computer tomography allowed to obtain an image of the made models interior of the turbocharger rotor. Due to this, the defects in the form of closed air spaces were located and it was possible to quantify them. Most of these defects arose in places where the lines of the filling fibres meet the first contour of the outer contour. It can be observed that the number of volume defects increases with the increase of the filling density. The height of the printed layer contributes to this, but to a much lesser extent. The material used, its quality, and the shape of the model also have an influence on the formation of internal defects.

The next stage of research will be making models with a filling density equal to 100%, but with the use of parallel lines, and not the grid pattern as in this case. To confirm the thesis that the change in the height of the printed layer has an impact on the increase in the defects occurrence in the form of air voids, it would be necessary to make prints with different layer heights and with complete filling.

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