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3D PRINTING TECHNOLOGY AS A TOOL IN FABRICATION OF ELEMENTS FOR WHEEL MODEL

Abstract
This paper illustrates an experience related to the use of 3D printing technology during the fabrication of elements for a supporting arm. The arm was a part of a test stand designed for an investigation of rotating wheels in contact with the ground. One of the crucial elements of a supporting arm is the hub, which was originally made from aluminium, however it was decided to replace it by the one made from ABS using 3D printing technology. The author decided to describe difficulties encountered during fabrication of the hub, together with a set of recommendations for future use of 3D printers.

Key words
3D printing, fused deposition modelling, wheel, hub, supporting arm

Introduction

Through the year's aerodynamic analysis of vehicles was mainly focused on race cars. In construction of everyday life models aerodynamic has gained popularity since 1970s when peak oil crisis appeared. Organization of the Petroleum Exporting Countries (OPEC) proclaimed an oil embargo and prices of fuel raised. Dependency of different vehicle components on fuel consumption shows that biggest influence is connected with aerodynamic drag - 40%, the second most important factor is rolling resistance – 23% [1]. What is interesting 15% of car aerodynamic drag is connected with wheels, which is the third contributor to the aerodynamic drag [2]. To perform an investigation of rotating wheels in contact with the ground, an experimental test stand was designed and built at the Institute of Turbomachinery at Lodz University of Technology. The main elements of the stand constructed as presented in Fig.1. Road conditions were imitated by use of polyurethane belt installed on three rollers. The driving roller, connected with the motor, acts as an element responsible for delivering the movement to the belt to achieve a given linear velocity. A passive roller was located on the opposite side of the stand, and there was an additional middle roller to support the wheel model placed centrally on the belt. All three rollers were fixed together with bearings to an aluminium frame. A multi-ribbed belt transmits the power with 2:1 speed ratio from the electric motor to the active roller [3,4].

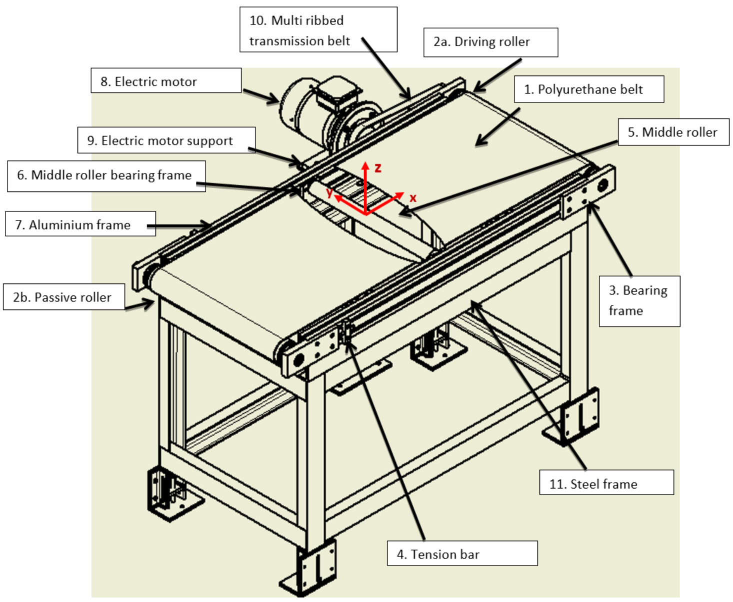

Fig. 1. Moving ground test stand
Source: [3]

Another important element of the test stand was measuring arm (see Fig.2.) responsible for preserving the position of the wheel on the belt.

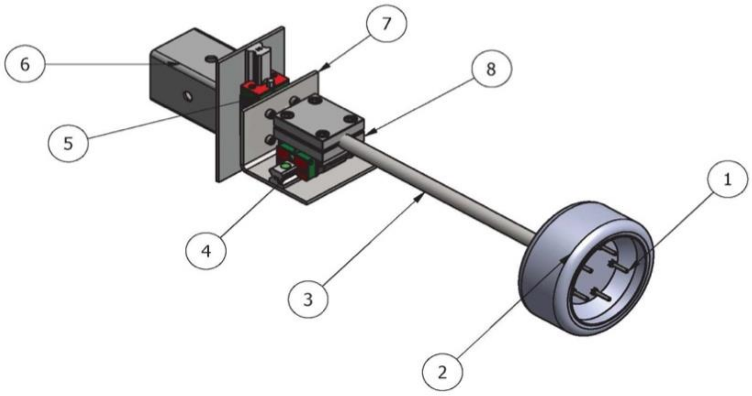

Fig. 2. Measuring arm
Source: [5]

The supporting arm consists of a rotating hub (1), a wheel model (2), an axle (3), two rails (4, 5) with a vertical (7) and horizontal (8) guideway, and a mounting sub-assembly (6) for connection to the aluminium frame. The axle is fixed and supported by two bearings. In this, construction, the wheel model rotates by means of friction transferred from the belt at the place of contact [4].

The hub was originally made from aluminium. The shape was obtained with use of lathe, then mounting holes were drilled (see Fig.3a, Fig.3b. and Fig.3c.). After the first tests, it became visible that the wheel was not centred on the axle because the mounting holes were not perfectly aligned on the hub (difference around 0.5 mm). Since the misalignment was due to human error, either a more precise way of marking and drilling should be applied, or a different way of manufacturing. The Institute offered the possibility of using 3D-printers, so it was decided to print a hub. Placing the hole with a computer eliminated human error and thereby increased the precision of the model.

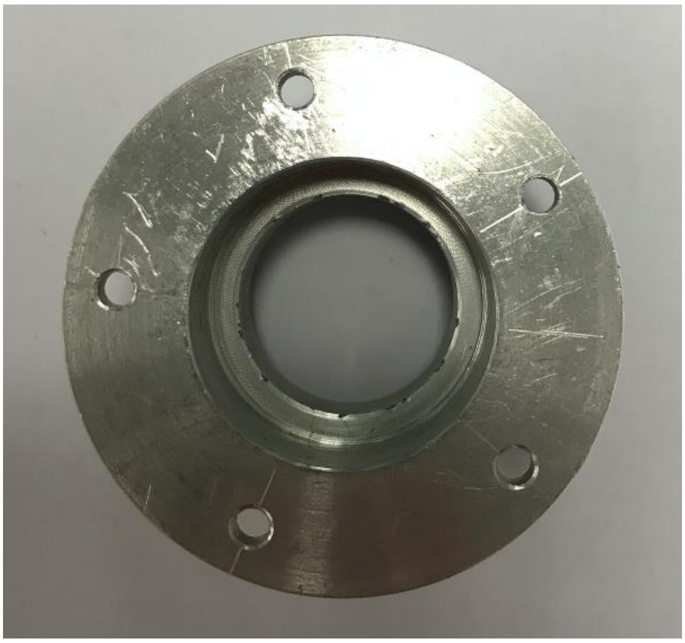
Fig. 3a. Hub made from aluminium
Source: Author’s

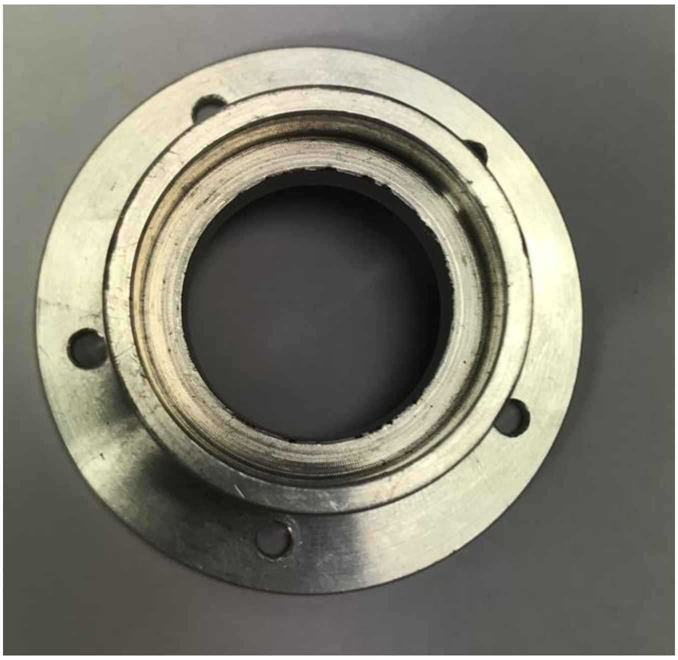

Fig. 3b. Inner part of aluminium hub
Source: Author's

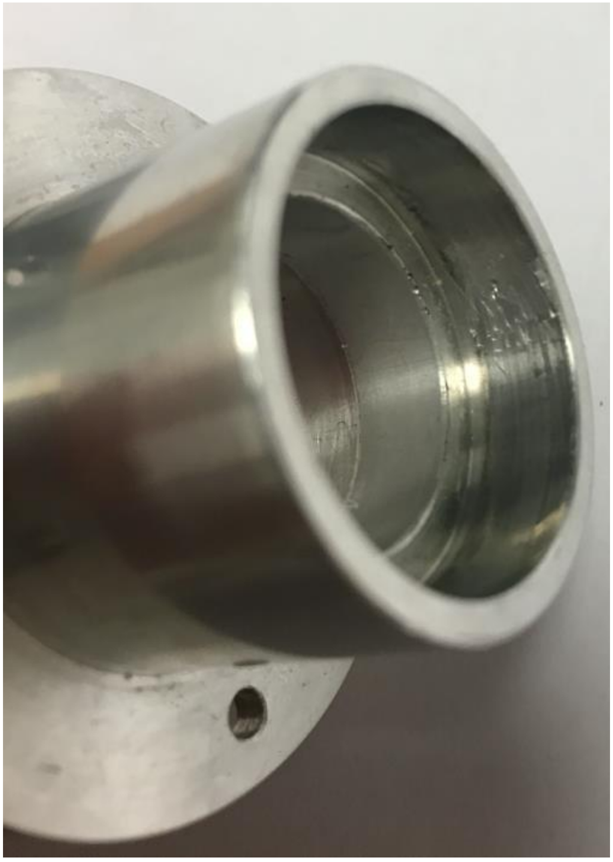

Fig. 3c. Inner part of aluminium hub
Source: Author's

Materials and methods

To create the hub, a Zortrax M200 3D printer was used (see Fig.4. for details and specification) together with Z-ABS material [6]. 3D printer that was used works in FDM (fused deposition modelling) technology which means that it prints the model with use of molten polymer imposed layer by layer [7,8]. In described work Z-ABS material was applied as the one used by 3D printers that were accessible in the Institute (FDM printers). Selection of this material and technology was also related to its simplicity (construction of the printer, printing process), availability on the market, low price, possibility of long storage of material and treatment of printed objects. However, the author is aware that this material is relatively flexible and has high shrinkage level and some port of the problems that occurred during preparation of the hub may be related to the properties of the material itself.

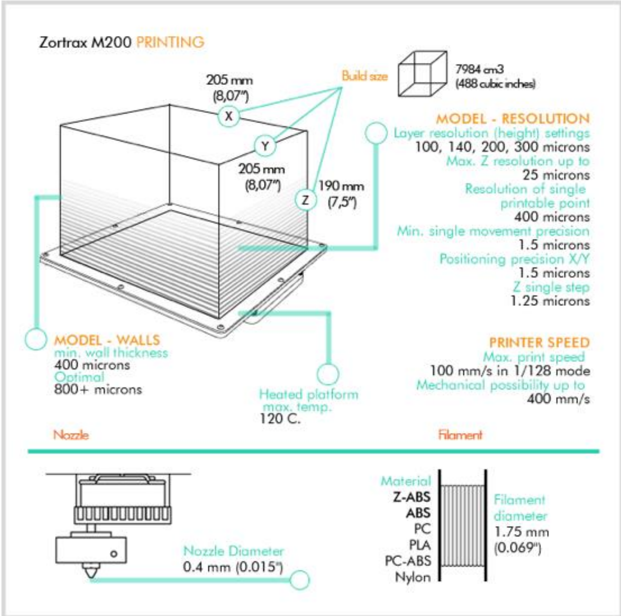

Fig. 4. Zortrax M200 3D printer
Source: [9]

A 3D CAD model of the element was created with use of Solidworks and exported to the Z-Suite software (provided by the manufacturer of the printer) to generate the code base on which printer could create the object. It is important to take into consideration resolution setup of the model during conversion to a universal file format, which is the standard file type used by rapid prototyping systems. After creating the model in a CAD software environment, it is necessary to save it as an STL (STereoLithography) file, which converts round objects into triangles. Depending on the resolution parameters, the quality of the conversion may differ [7,10,11]. That is why it is essential to select the highest possible resolution to obtain as round shape of the model as possible, remembering that the increase of resolution also increases the file size, leading to longer processing times.

At the preparation stage, the code was set to a layer thickness of 0.19 mm. Infill was selected as medium, and the angle for the supporting material as 20°. Speed and seam were marked as normal. Based on those settings, the code for the printer was generated and a simulation of the printing element was made. The set of parameters used for this simulation are presented in Table 1.

Table 1. Printer settings

Material Type	Z-ABS
Layer Thickness	0.19 mm
Quality	High
Seam	Normal
Infill	Medium
Supporting Angle	20°
Surface Layers Top	6
Surface Layers Bottom	3
Fan Speed	Auto

Source: Author's

After selecting the print settings, the Z-Suite software generated code (zcode file extension) that was used by the printer to create the object. At this stage, it was possible to check basic settings that were selected and the amount of material that was be needed to print the object. An example of that information can be found in Table 2.

Table 2. Printer settings

Profile	Z-ABS
Estimated print time	1h 16 min
Filament usage in meters	5.11 m
Filament usage in grams	12 g

Source: Author's

It was also possible to observe a simulation of the printing process. It was helpful to monitor where the supporting material was generated because after finishing the printing process that material needed to be removed. Locating the object so as to reduce the creation of supporting material in difficult to access places is advised because it can very often be problematic. Fig. 5. shows an example of a simulated printing process, where visualisations show progress in the prints at 20% intervals of completion. The main element is marked as blue, and the supporting material as grey.

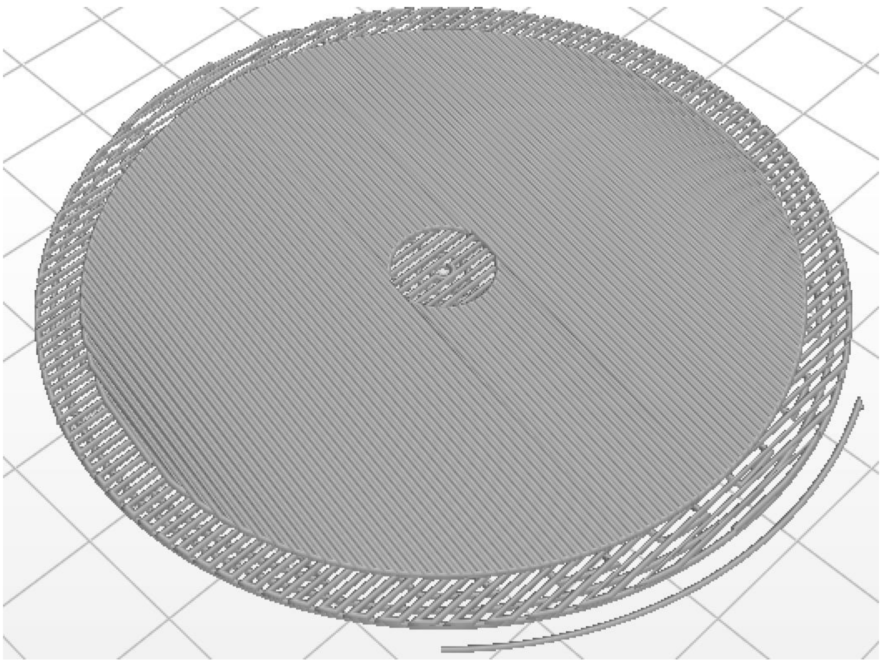

Fig. 5a. Simulation of printing process 0%
Source: Author's

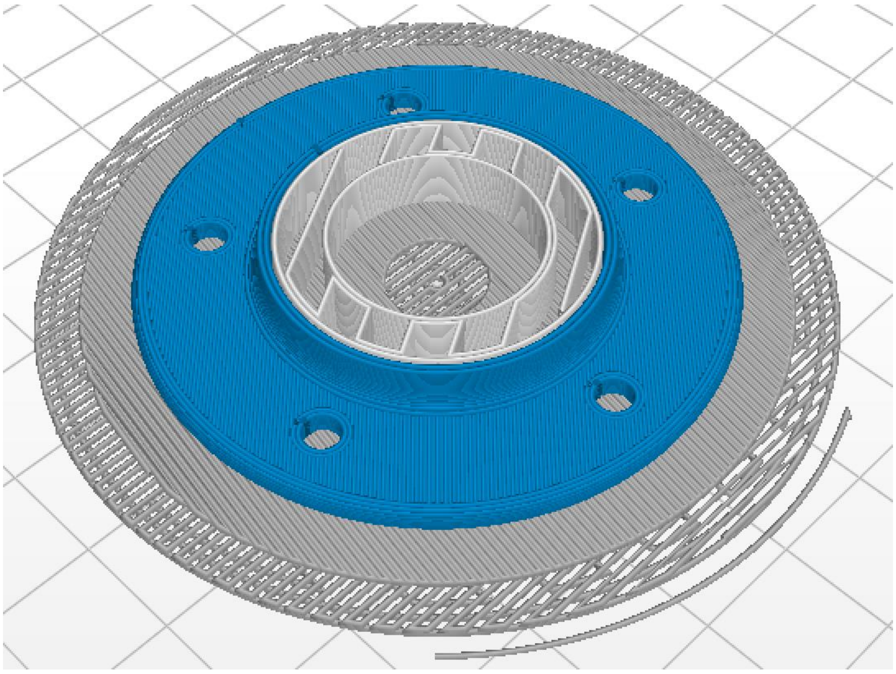

Fig. 5b. Simulation of printing process 20%
Source: Author's

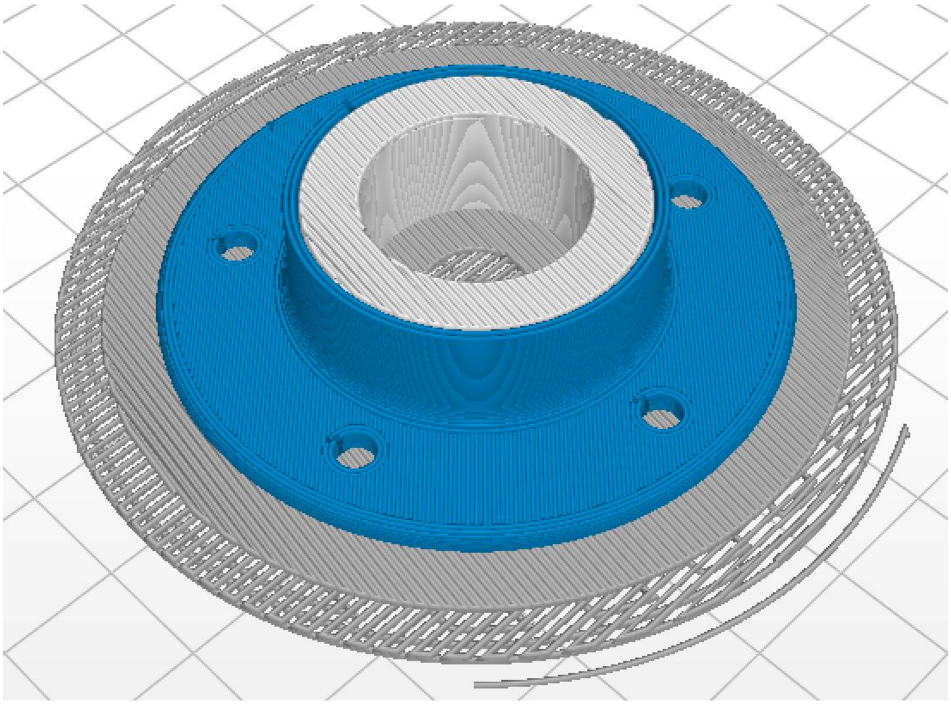

Fig. 5c. Simulation of printing process 40%
Source: Author's

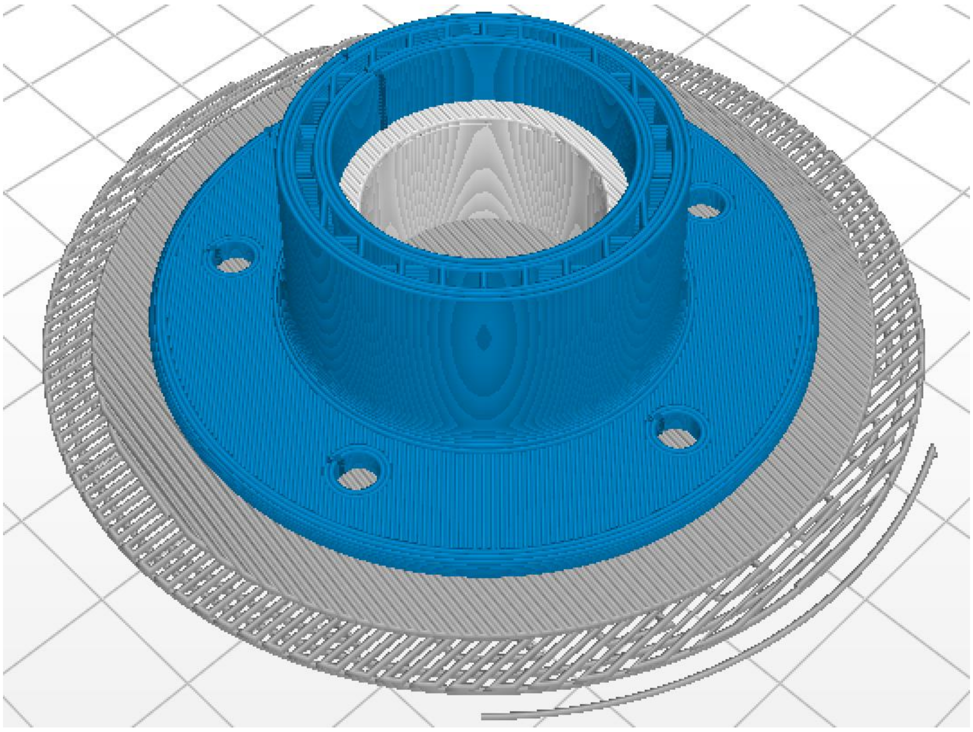

Fig. 5d. Simulation of printing process 60%
Source: Author's

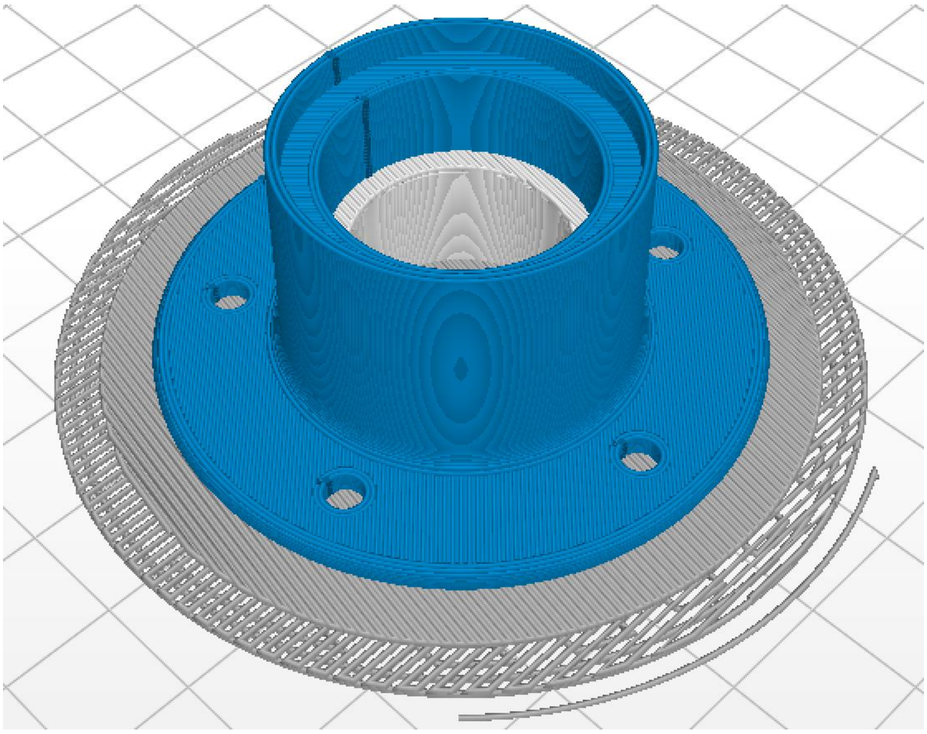

Fig. 5e. Simulation of printing process 80%
Source: Author's

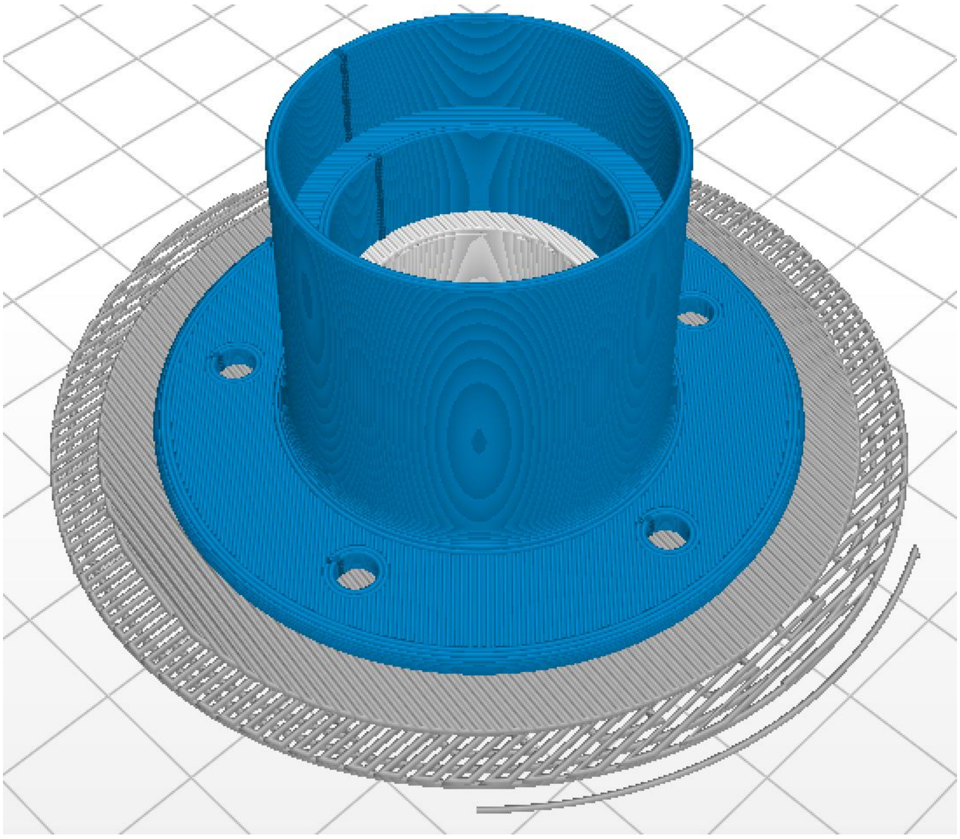

Fig. 5f. Simulation of printing process 100%
Source: Author's

Apart from the visualisation of printing process, the Z-Suite software provides information on how much material will be needed at each moment of print. Based on that it is possible to calculate at which stage printing process should be stopped if it is necessary to change the filament used for printing the model.

Results and discussion

After printing the hub, it was possible to distinguish the differences between the CAD model of the element and the result of the printing process. Although the printed hub holes diameter was equal to 2 mm, the mounting holes were designed to have a diameter of 3 mm. Due to the elastic deformation properties of the material, it was possible to use M3 screws, making it a tight fit, thereby ensuring an aligned fit of the wheel. However, there was a problem with fitting of the bearings. In the CAD model, the inner diameter of the hub was 30 mm, but the printed model had an inner diameter of 29.2 mm. Due to the previous experiences with the elastic deformation of ABS, it was decided to fit the bearings. The hub was first heated (around 70°C) to ensure that its temperature would not exceed the melting point, then the bearings were pressed in. The hub was deformed due to the excessive force needed to insert the bearings (see Fig. 6). Furthermore, during removal of the bearings from the hub, it was decomposed on to three elements, as shown in Fig. 7.

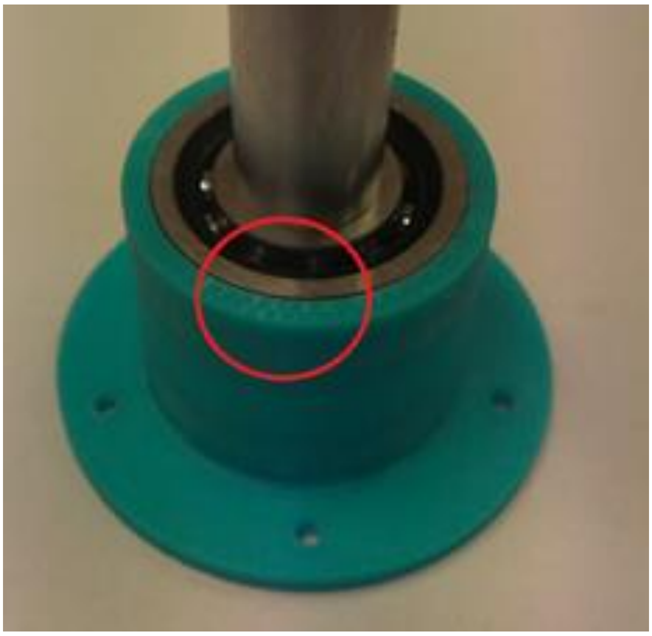

Fig. 6. Hub deformation
Source: [12]

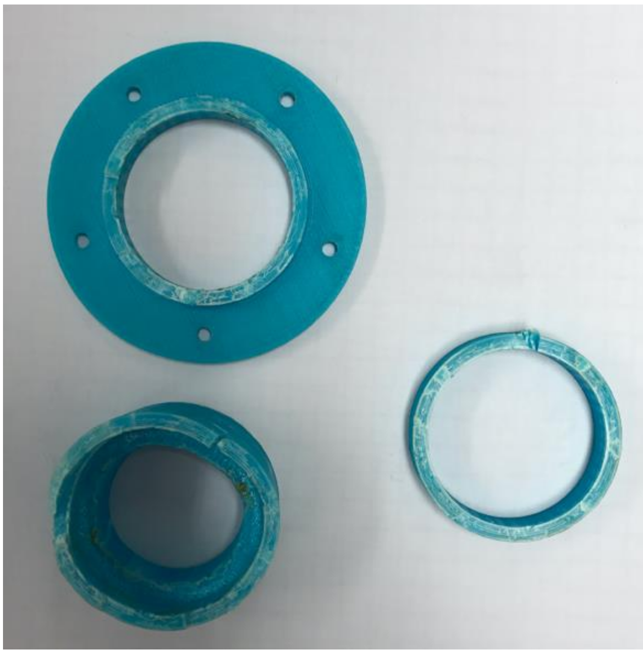

Fig. 7. Hub breakdown
Source: Author's

To eliminate the problem with the sizes of the printing holes and to find the hole size that best suits the bearing, a series of test rings were printed (see Fig. 8.). During this investigation, the programmed inner hole sizes were selected from 30 to 31 mm, with size steps of 0.2 mm. As a result of this investigation, it can be concluded that the difference with the actual sizes of the holes was linear: the actual hole size was about 0.8 mm smaller in diameter.

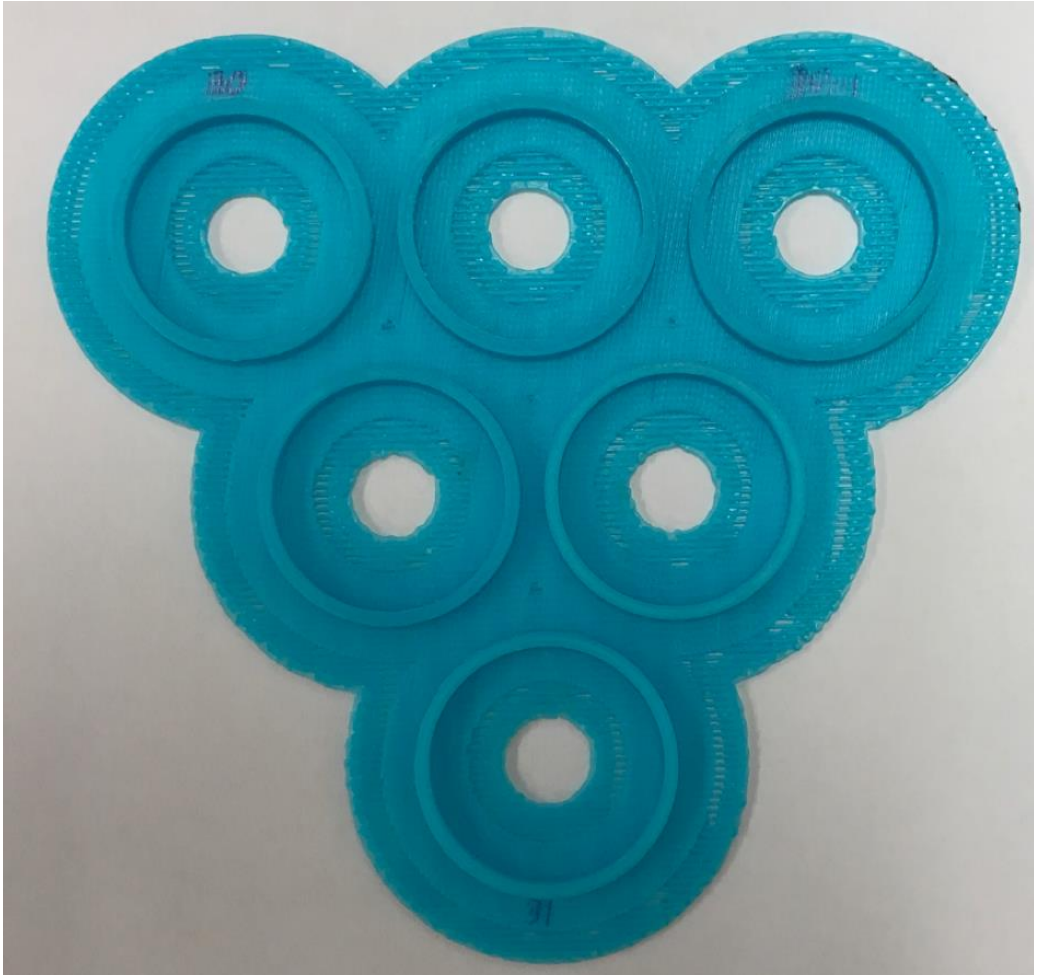

Fig. 8. Rings for hub internal diameter tests – gradually increased by 0.2mm
Source: Author's

Based on the test result presented above, it was decided to print the hub with a bearing housing size of 30.4 mm. The inner diameter of the ring between the bearings was enlarged to be able to remove the bearings more easily. The face with the mounting holes was made slightly thicker as it was deformed in the first hub. After creating the model (see Fig. 9), it can be concluded that the positioning of the bearings was perfect and the dimensions of the mounting holes were kept.

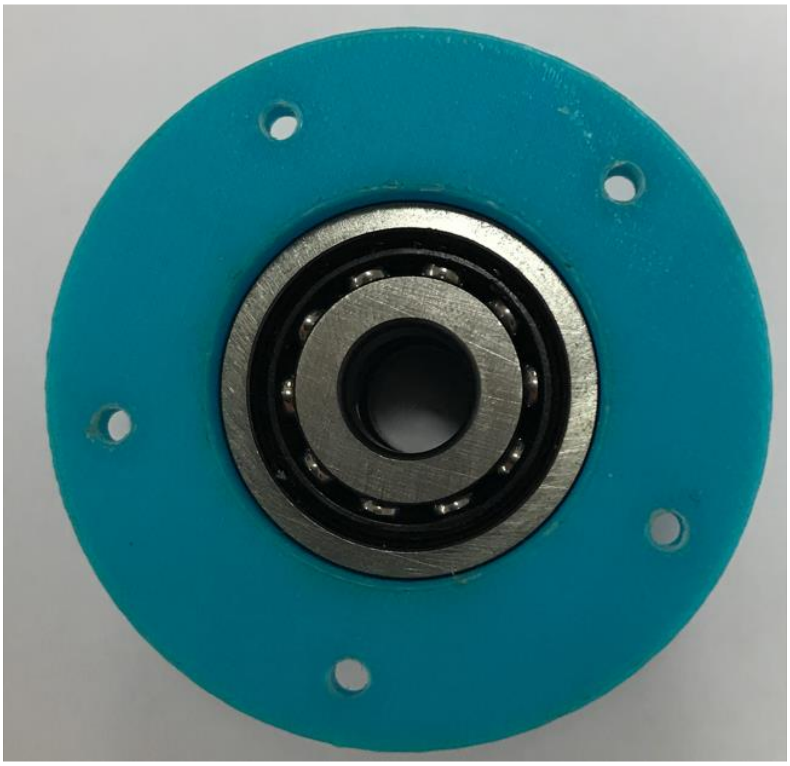

Fig. 9. Hub with bearings inside
Source: Author's

Summary

The problems described above give clear evidence that 3D printing is not an ideal solution despite the numerous advantages of this technology including possibility to create complex geometry, variety of materials, ability to influence the final shape of the object and high precision. After performing a set of tests with different hub sizes, it can be concluded that 3D printer that was used has difficulties with the creation of smooth and round elements/surfaces. The supporting material was also problematic. To print the hub, support material was added to make a bottom layer for the print, and support for the ring in the middle region of the hub. The support layers were made of the same material as the hub, and were attached to the hub more loosely than the hub material itself. Removing this material was difficult, and it may have led to the deformation of the hub when using excessive force. Also, if the surface on which the support material is attached has a rougher structure than the rest of the hub, it may need extra trimming afterwards. Part of the problems described in the above paper are common for almost all 3D printing techniques, but some port of them are limited only to the particular 3D printing technology and particular group of materials. The author is aware that polymers including ABS are relatively flexible and have high shrinkage level. Those disadvantages can be eliminated by use of SLS (Selective Laser Sintering) or SLM (Selective Laser Melting) printing techniques together with materials based on metal powders. Finally, it can be recommended to use 3D printing technology for fabrication of prototypes for preliminary and final investigations. Advantages of this manufacturing method gives a wide range of possibilities in modification of the object and selection of technique and material, however it is important to choose material and printing technology suitable for the application.

Acknowledgements

The author would like to express his appreciation towards Bas Hoogterp and Paweł Pietrzak, two students of Lodz University of Technology, which were contributed in the presented work. The special gratitude is directed to Michał Kulak, PhD of the Institute of Turbomachinery at Lodz University of Technology, his knowledge and experience was invaluable during the above work.

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