Study regarding the Printing of Metric Threads on a FDM 3D printer

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Abstract: *3D printers are well known and widespread in several fields, such as architecture, design, mechanical and industrial engineering, constructions, medical, food, clothing, etc. The 3D printer has become a device almost as familiar as the paper printer. The technologies used for 3D printing are diverse and adapted to the functional requirements of the printed product as well as to the material used for printing correlated with the necessary costs. Printers with FDM (Fused Deposition Modeling) technology are an affordable segment in terms of both price and use, making this type of printer very popular with regular consumers, who use it most often to replace common worn or damaged components. This study focuses on the possibility of printing Metric type threaded surfaces on FDM type printers. The study presents experimental results and conclusions regarding the attempt to obtain these surfaces on printers and includes some recommendations towards printing such parts.*

Keywords: *3D printing, FDM, ABS, threaded surfaces*

1 INTRODUCTION

Threaded surfaces are a basic solution in terms of removable assemblies due to the attributes they possess, amongst which one might mention here the ease of operation, adaptability to the shape of the part, interchangeability, etc. The fact that threaded surfaces can be used to transmit movement as well as a sealing solution makes them more important as a type of surface in all sorts of domains.

The manufacturing of threaded surfaces by conventional methods includes processing with kinematic generators (turning, milling, etc.) respectively with materialized generators (tapping, rolling, etc.). The groups of materials from which the threaded parts are made are multiple and include plastics.

When it comes to manufacturing threaded components out of plastics, some methods are commonly used, like cutting, plastic injection, forming, etc. Most of these methods require additional adjustment of the threaded surface to match the parameters of the thread standard. On the other hand, at times, the workpiece that is threaded is manufactured through another method hence increasing the steps needed to obtain the final threaded part.

Threaded surfaces can be part of main piece or they can be added as inserts.

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In recent years, 3D printers have developed very rapidly as an additive manufacturing method [1][3][5][7][9][13], from the simplest, those of the FDM (Fused Deposition Modeling) type that use filaments, to the most complex, that print metal and composite materials [1][6][10].

The 3D printing method is most commonly known for its capability of producing intricate design of parts which are very difficult if not impossible to create by using other manufacturing methods such as subtractive or formative processes.

FDM printers, which have become accessible to most people work with different types of plastics (ABS, PLA, Nylon, etc.) and have had a big popularity. The 3D printers based on plastic filaments includes an ecologic component if the plastic filament is obtained from recycled materials, as indicated in [12][8][4][11][2]. Similar studies are undergoing worldwide and aim at reducing the impact on the environment that plastic by recycling it in the form of filaments or other such products needed for 3D printing.

For these reasons, the current study focuses on thread manufacturing using the FDM type of printer.

In the vast majority of cases, 3D printers work on the basis of a 3D CAD model. The model represents the piece that needs to be obtained, in its final form. For this purpose, a numerous number of software commercially available can be used as long as they offer the possibility to generate the model in a format understandable for the 3D printer's software. There also is CAD software capable of directly communicating with the 3D printer hence skipping the model export step.

At the export operation of the CAD model, attention must be given at the tolerance factor of the model to corelate it with the specifications of the 3D printer. Otherwise the printing piece could be compromised precision wise.

Once the CAD model is loaded into the printer's software, it is "sliced" according to a certain direction and according to user-defined parameters, thus obtaining successive sections of the model, similar to slicing a pineapple. By overlapping these slices, depending on the principle according to which the printer works, the 3D part is formed.

For models that contain cavities or console like structures, some extra material may be needed to support the overhanging geometry.

In case of FDM printers, the raw material in the form of wire/filament is pulled into the heated nozzles of the printer, which turn it into a flowing material. This semi-liquid material is then deposited, layer after layer, onto the printing surface, according to every layer's contour obtained during slicing.

This way of obtaining the model, although it copes successfully for most of the parts, in terms of threaded surfaces, it represents a challenge. The character of difficulty is given by the 3D helix shape of the thread coil which, by the technique described above, is created from successive segments added to the model. This makes the coil a discontinuous surface, regardless of the direction in which the piece is printed. Theoretically this would not be problematic if all printing parameters remained the same throughout the process; however, this is not possible given the positioning, the control of the extruded material, its temperature, the adhesion between the successive layers deposited and other such process-specific variables. These variables are the more difficult to control as the printer is in the mid and low range, in terms of performance. Due to these details and to the non-compliant parts obtained after printing during day-to-day activity, it was decided to develop this study which aims to establish correlations between printing parameters so that the threaded surfaces obtained can be used as such, without any further alteration, after the 3D printing process.

2 EXPERIMENTAL PREPARATION

The printing process has been conducted on a CubeProTrio printer from 3D Systems with the following main characteristics:

- maximum build size: 285.4 x 270.4 x 230 mm;
- layer thickness: 70, 200, 300 μm;
- print tolerance:
  X and Y axis ±1% dimension or ±0.2 mm, whichever is greater.
  Z axis ± half the processed Z resolution;
- print speed extruded volume: 15 mm/sec and polymer dependent.
- number of printing heads available: 3
- number of printing heads used for this study: 1
- printing platform type: thermo-resistant glass
- slicing software: CubePro V1.105

Acrylonitrile Butadiene Styrene (ABS) filament has been chosen as printing material.

The slicing software of the printer only accepts *.STL files so this had to be the file format in which the CAD model had to be exported.

To be able to make a comparison on the printer's capability, two types of threads have been chosen to be printed: one consisting of a larger diameter and bigger pitch, i.e. M12x1.75 and one with a smaller diameter and smaller pitch, i.e. M6x1. Both threads were applied externally on screw like parts to ease the post-printing analysis. The drawing of the two parts is shown in figure 1. The head of the screw like part was modeled square to shorten the printing time and to optimize the use of printing material.

When it comes to choosing the 3D modeling software precautions must be taken because for threaded surfaces, most of the commercially available software does not effectively model the thread's helix. They only record it as a feature and recognize it later for example when making the 2D technical drawing of it.

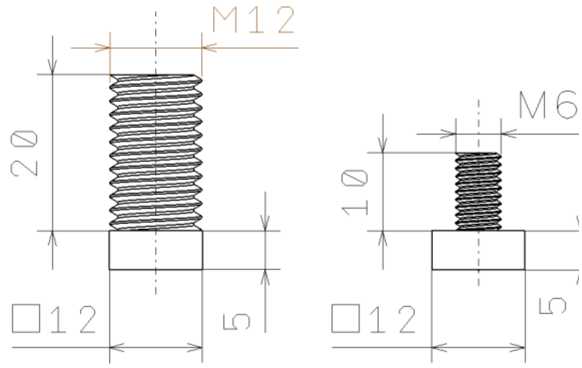

Fig. 1. Drawings of the two threaded pieces that were printed

It is for this reason that in most of the cases, the thread's helix must be modeled. This is usually achieved by revolving the thread's cross-sectional profile along a directing curve and adding or subtracting the resulting feature.

This in turn increases the overall manufacturing cycle and it is sometimes prone to error.

To overcome these issues, for this study, the Autodesk Fusion 360 software has been used. This software offers the possibility to choose between a represented or an effectively modeled threaded surface. By using the Thread command the threaded surface is generated according to the ISO standard implemented in the software's database.

If the threaded surface is obtained by effectively modeling it on the piece, when creating the 2D drawing, the threaded surface is represented as shown in figure 1 and not according to the technical drawing standards. As a general recommendation, this feature of the software is to be used when the modeled piece will be 3D printed.

Autodesk Fusion 360 was also used for converting the 3D model to *.STL file needed for the printer's slicer.

The settings of the slicer were chosen as such to reflect two printing capabilities of the 3D printer:

- one Standard implemented in the slicer software by the printer's manufacturer

- one enhanced, based on the results obtained in the first case. The printing parameters used for the Standard mode are shown in Table 1.

At first the M12 piece was prepared for printing. Following printing, the profile and pitch of the thread were assessed by means of a feeler gauge.

Table 1. Printing parameters for the Standard mode

Printing configuration - Standard	
Layer resolution	200μm
Print strength	Strong
Print pattern	Cross

Pattern fill spacing	4 mm
Top surface layers	6 layers
Bottom surface layers	4 layers
Outer walls	2 layers

Afterwards the printed piece was tested on how it matched with a nut as an assembly operation. Based on these results the enhanced printing configuration was devised and the process was repeated for the new printing configuration. The results are presented in the following section.

3 EXPERIMENTAL RESULTS

The *results* of the first printed piece, using the Standard configuration of the printer (Table 1), can be seen in the figures 2 and 3. The printing time for this instance was 52 minutes.

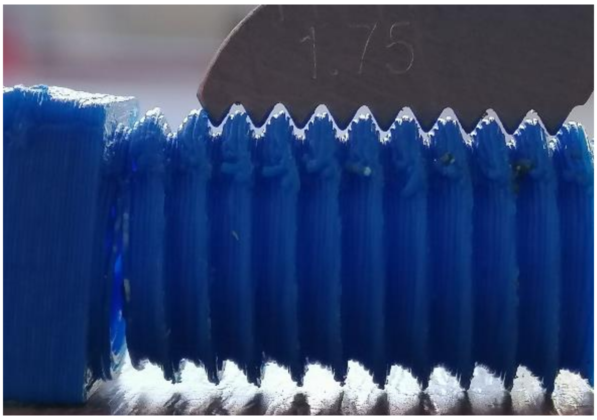

Fig. 2. Assessment of the printed piece with the feeler gauge

Fig. 3. Assessment of the printed piece by assemblying it with a matching nut

Although assembly with the nut was possible, it can be seen from Figure 2 that the pitch is not constant over the whole checked length (there is a slight deviation). In figure 2 it can also be seen that the thread profile is wavy due to the filament used which had a cylindrical section. This profile may change the strength and assembly behavior. Also, due to the small thickness of the walls, in the connection area of the thread with the head of the screw, the piece broke (fig.4).

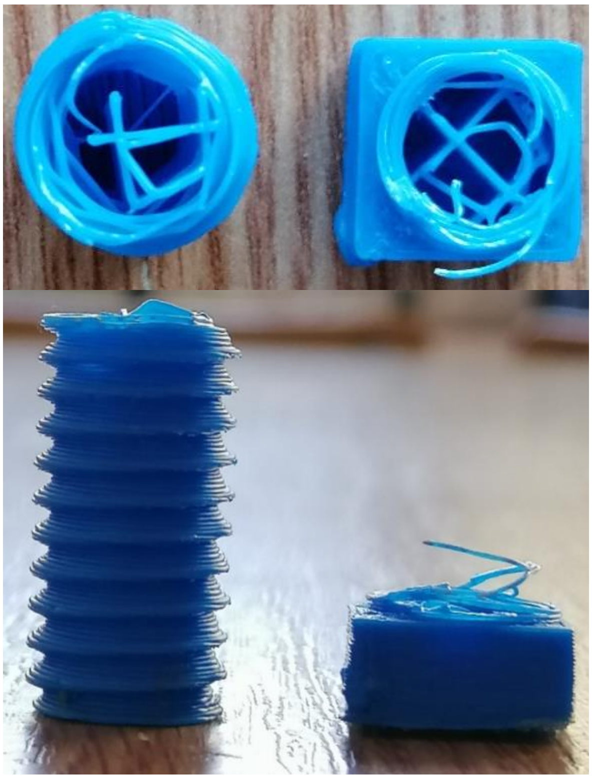

Fig. 4. Internal structure of the sectioned piece

Based on these initial results, it was decided to modify the printing configuration to overcome the problems recorded. The layer resolution was altered to obtain a much smoother thread profile. Also, the number of the layers in the outer walls was increased for the same purpose. The filling strength pattern, and spacing were modified as well to overcome the weak resistance of the piece. Table 2 was introduced to reflect all these changes.

Table 2. Printing parameters for the enhanced mode

Printing configuration - Custom	
Layer resolution	70μm
Print strength	Almost Solid
Print pattern	Diamonds
Pattern fill spacing	6 mm
Top surface layers	8 layers
Bottom surface layers	6 layers
Outer walls	6 layers

The printing time recorded for this instance was 2 hours and 19 minutes and the results are shown in figures 5 and 6.

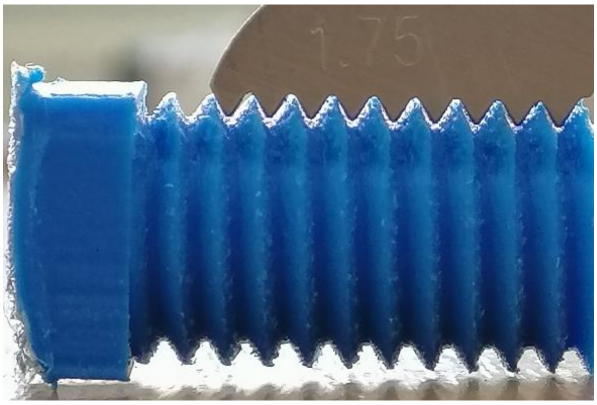

Fig. 5. Assessment of the printed piece with the feeler gauge

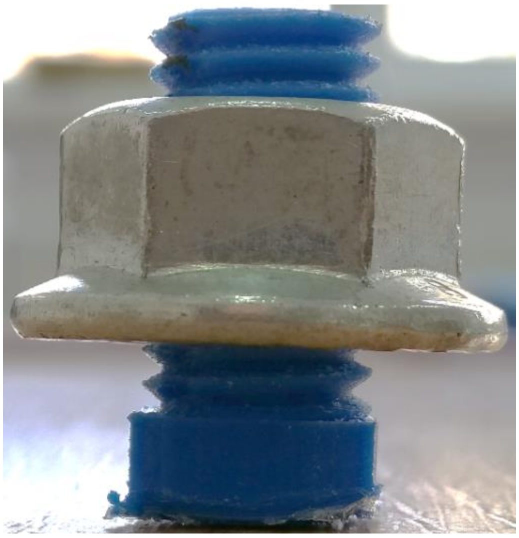

Fig. 6. Assessment of the printed piece by assembling it with a matching nut

Assembly with the nut was possible and it can be seen in figure 5 that the pitch is relatively constant over the entire length checked.

In figure 5 it can also be seen that the profile of the thread is much closer to that of the ideal thread and this is due to the small thickness of the section layer, which was of just 0.07 mm.

In the connection area of the thread with the screw head, the part is much more robust due to the high degree of filling of the part, as shown in figure 7.

Fig. 7. Part filling for the Custom printing setup

Figure 8 shows the protrusions left over from the successive passage of the print head from one deposited layer to another.

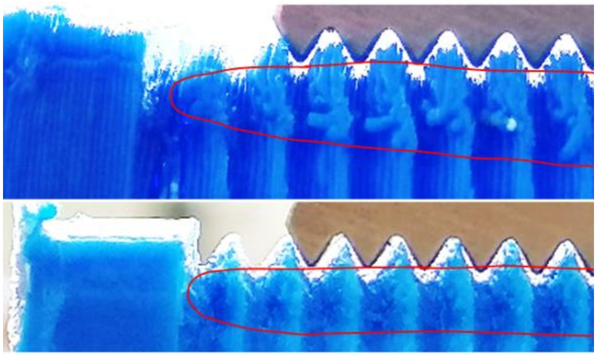

Fig. 8. Printing protrusions comparison

In the case of Standard printing, these protrusions are much more obvious but given the depth of the thread profile and the size of the pitch relative to them, they do not influence the function of the thread. However, it is recommended that after such results, an assembly with a steel counterpart to be made to run the threads off of the protrusions.

The afore mentioned protrusions can become problematic for smaller threads. In the lower image shown in figure 8, on the piece printed with a better setting, the printing protrusions are unnoticeable.

By using the configuration presented in Table 1, the second piece (M6x1) has been printed. The printing results can be seen in figures 9 and 10. The printing time in this case was 30 minutes.

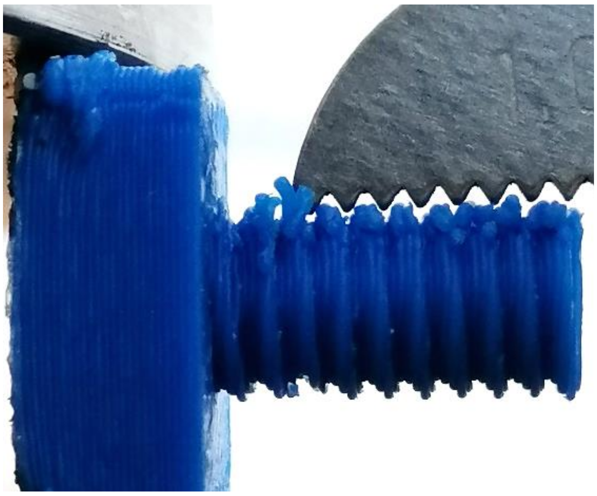

Fig. 9. Assessment of the printed piece with the feeler gauge

After printing, the consistency and the profile of the thread were checked on the piece with the help of the feeler gauge (fig.9). Great deviations from the profile and from the thread pitch were observed due to the large thickness of the deposited layer, compared to the thread parameters.

The assembly with the nut was not possible in this case mainly due to the printing protrusions shown in Figure 10, which formed with each passage of the printer to a new section.

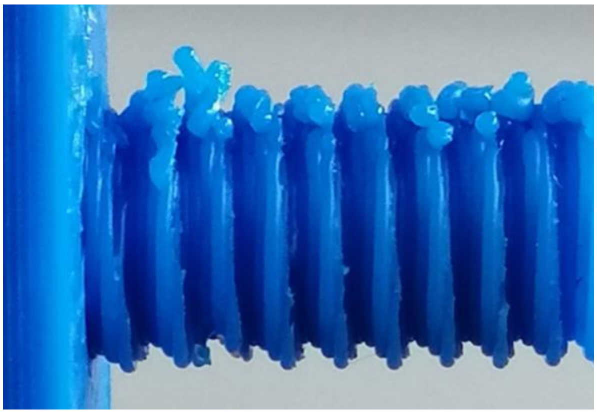

Fig. 10. Detailed view of the printed thread M6x1

In such cases as the one presented in figures 9 and 10, if the steel nut is forced to join the thread of the screw, it can act as a die-stock and reshape the helix of the thread rendering it totally out of shape but creating the impression that the nut is matched. When removing it the damage to the helix can be clearly seen, so it is not recommended.

Following the results presented above, it was decided to change the print settings so as to remove the disadvantages, using the print parameters shown in Table 2 with the following amendment: the number of layers of material deposited to form the outer walls of the part was set to 4 instead of 6, due to the small size of the threaded area section.

Figures 11 and 12 show the printing results.

Fig. 11. Assessment of the printed piece with the feeler gauge

Even if even in this case there were printing protrusions on the threaded surface (fig.11), they were much smaller and did not influence the assembling capacity of the printed part with the steel nut (fig.12). The thread profile and its pitch were also in accordance with those on the feeler gauge (fig.11). The print time for this configuration was 1 hour and 30 minutes.

Fig. 12. Assessment of the printed piece by assembling it with a matching nut

4. CONCLUSIONS

A first general conclusion resulting from this study is that by using the right settings, one can print metric threaded surfaces on FDM 3D printers.

For some printing configuration, the threaded surface does not meet the standard requirements, especially due to the thickness of the layer of material deposited and the area from one layer of material to the next. As a rule of thumb, it can be said that for large thickness of the layers, the resulting quality of the threaded surface is lower than in the case of smaller layer thickness. On the other hand, the smaller the layer thickness, the greater the printing time needed for the same part. These observations generally apply to the most majority of 3D printers commercially available on the market, due to the way the surface is generated.

An evaluation of the printer's capability regarding the print quality of the threads is always required before printing the actual threaded part. This capability must be closely correlated with the thread parameters to be obtained.

Attention must be given to the time needed for the printing operation and to the quantity of material used during the operation. Even if such pieces are produced in a small number, some economical considerations can be taken into account when establishing the printing parameters.

The strength characteristics of 3D printed threads have not been assessed in this paper and it is a requirement for parts that are to be used in real assemblies as they are subjected to static and dynamic stresses. The printing settings in this case will have to be tuned accordingly.

The same evaluation process presented in this paper should be used for nut like parts because the internal thread could raise different challenges than the exterior one. The threaded surface becomes concave as opposed to convex on the exterior threads and this could render a printing configuration considered optimum for external threads as inappropriate for internal threads.

Due to the way the layers of material are deposited during printing on FDM printers, it is recommended to print threaded surfaces aligned to the Z axis to eliminate the scaffolding structure. If this direction is not available for the alignment of the threaded surface, the results could be very different.

3D printed plastic parts having threads could be used, if deemed reliable in plastic-plastic or metal-plastic assemblies.

Based on the results of this paper, other 3D helical surfaces could be printed and tested from the parameters and functionality point of view, not only for assembling purposes but also for movement transmission.

Other type of threads like square or trapezoidal could undergo a similar testing process to assess their manufacturability on 3D FDM printers.

REFERENCES

[1] Chaudhry, FN., Butt, SI., Mubashar, A., Bin Naveed, A., Imran, SH., Zhang, FP., (2019). Effect of carbon fibre on reinforcement of thermoplastics using FDM and RSM. *Journal of Thermoplastic Composite Materials*, DOI: 10.1177/0892705719886891.

[2] Cruz Sanchez, F.A., Boudaoud, H., Hoppe, S., Camargo, M., (2017). Polymer recycling in an open-source additive manufacturing context: Mechanical issues. *Additive Manufacturing*, vol. 17, ISSN 22148604, p.87-105.

[3] Ding, SJ., Kong, LY., Jin, YJ., Lin, JB., Chang, C., Li, HY., Liu, EQ., Liu, HT., (2019). Influence of the molding angle on tensile properties of FDM parts with orthogonal layering. *Polymers for Advanced Technologies*, vol. 31, issue 4, ISSN 1042-7147, p. 873-884.

[4] Exconde, M.K.J.E., Co, J.A.A., Manapat, J.Z., Magdaluyo, E.R., (2019). Materials selection of 3D printing filament and utilization of recycled polyethylene terephthalate (PET) in a redesigned breadboard. *Procedia CIRP – 29th CIRP Design Conference*, Portugal, 08.05.2019.

[5] Goh, WH., Hashimoto, M., (2018). Dual sacrificial molding fabricating 3D microchannels with overhang and helical features. *Micromachines*, vol. 9, issue 10, ISSN 2072-666X, DOI: 10.3390/mi9100523.

[6] Heidari-Rarani, M., Rafiee-Afarani, M., Zahedi, AM., (2019). Mechanical characterization of FDM 3D printing of continuous carbon fiber reinforced PLA composites. *Composites Part B-Engineering*, vol. 175, ISSN 1359-8368, DOI: 10.1016/j.compositesb.2019.107147.

[7] Lee, J.Y., An, J., Chua, C.K., (2017). Fundamentals and applications of 3D printing for novel materials. *Applied Materials Today*, vol. 7, ISSN 23529407, p. 120-133.

[8] Lehrer, J., Scanlon, M.R., (2017). The development of a sustainable technology for 3D printing using recycled materials. *Proceedings of the Mid-Atlantic Fall Conference.*, Pennsylvania, USA, 06.10.2017.

[9] Nurulhuda, A., Aqmaliah, SHSN., Ali, R., Yacob, S., (2019). Multi-Layered ABS scaffold fabrication via Fused Deposition Modelling (FDM) 3D Printing. *Journal of Mechanics of Continua and Mathematical Sciences*, vol. 4, ISSN 2454-7190, p. 131-138.

[10] Rahim, TNAT., Abdullah, AM., Akil, HM., (2019). Recent developments in Fused Deposition Modeling-Based 3D printing of polymers and their composites. *Polymer Reviews*, vol. 59, issue 4, ISSN 1558-3724, p. 589-624.

[11] Reddy, S., (2018). Design and development of mini plastic shredder machine. *IOP Conference Series: Materials Science and Engineering – 2nd International Conference on Advancements in Aeromechanical Materials for Manufacturing*, India, 13.07.2018.

[12] Zakirov, N., Tyagunin, A., (2019). The hardware-software complex for the processing of plastic waste to the filament for a 3D printer. *Proceedings of AIP Conference.*, Ekaterinburg, Russian Federation, 20.05.2019.

[13] Zhao, Y., Chen, YS, Zhou, YJ., (2019). Novel mechanical models of tensile strength and elastic property of FDM AM PLA materials: Experimental and theoretical analyses. *Materials&Design*, vol. 181, ISSN 0264-1275, DOI: 10.1016/j.matdes.2019.108089.

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