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Research paper

COMPARISON OF 3D PRINTED GEAR'S GEOMETRICAL CHARACTERISTICS

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Abstract: *A study of the influence of extruded material type and layer thickness on the surface roughness and the geometry accuracy on a 3D printed gear tooth profile is presented in this paper. A whole set of samples with the same geometric characteristics is printed from two types of materials (PLA and ABS plastic) and with different layer thickness: 0.1; 0.2; and 0.3 mm. The results of roughness testing and uniformity of the layer thickness are presented in this paper. By comparing the results of samples testing from PLA and ABS plastics with the same 3D printing parameters, a certain conclusions are presented at the end of the paper.*

Key words: *3D printed gears, geometry parameters, layer and surface roughness*

1. INTRODUCTION

It has not yet been investigated, how much geometric parameter of gears, 3D printed from plastic materials affect on their strength. The first step in this research is the production accuracy quantification of the printed gears. Since macrogeometry is most often controlled when checking the gears, for example, d_a – addendum and d_f - dedenum (root) circles, this paper is focused on the characteristics that are rarely examined, that is, the errors generating from the 3D printing process - Additive Manufacturing Technology (AMT). In order to measure the deviation of the nominal values of the thickness of the printed layers, as well as the roughness of the gear teeth surface, taking into account the influence of the material (ABS or PLA plastics), a series of specimens of gears with identical nominal geometry - made of ABS and PLA plastics, were made.

3D printing is an additive process for the production of three-dimensional, physical objects, of any shape, based on the digital computer model. Additive technology implies that the model is made by vertical material application, layer by layer. This kind of production dates back to the 1980s, but it has been protected for a long time by the patent, and there were only a few manufacturers of such devices, which were very expensive. Since the patent expired several years ago, there has been an expansion, primarily home-made 3D printers, and this technology has become more accessible.

Additive Manufacturing Technologies (AMT) is capable of building complex 3D objects by stacking up thin individual layers. By using this additive approach the degree of freedom regarding shape complexity is greatly enhanced compared to subtractive processes like turning or machining. AMT is largely used for manufacturing short-term prototypes (Rapid Prototyping), but it is also used for small-scale series production (Rapid Manufacturing) and tooling applications (Rapid Tooling) [1, 2]. Besides applications in engineering, RP is becoming more and more popular in medical applications, where patient – specific geometries are required (e.g., orthopedics, dentistry, and hearing aids) [5].

2. TESTING SAMPLES

For experiment, two types of samples were made. From the PLA plastics, a 3 × 2 sample (with a layer thickness of 0.1; 0.2 and 0.3 mm) was made – in order to determine the influence of the layer thickness on the surface structure of the prototypes. From ABS plastics, two more gears, with a nominal layer thickness of 0.3 mm were made - in order to determine the influence of material quality on the surface geometry by comparing them with appropriate samples from PLA plastics (Fig.1).

Fig.1. Specimens made from PLA and ABS plastic

The gear prototypes were fabricated from thermoplastic polymers. Most of the 3D printers (3DP) nowadays are able to work at temperatures of less than 300°C. The two temperature parameters for 3DP filament plastic materials are: Transition temperature (T_g) and Melting point temperature (T_m). Two of the most widely used materials for material extrusion 3DP are Acrylonitrile Butadiene Styrene (ABS, T_g = 110°C, not a true melting point) and Polylactic Acid (PLA, T_g = 60°C, T_m = 175°C) because of their dimensional stability and low T_g [3, 4].

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The technical specifications of the printed gears are: module m=4mm; pitch p=12,566mm; number of teeth z=23; pressure angle α=20°; tip diameter d_a=99,512mm; root diameter d_f=81,512mm; reference diameter $d=m\cdot z$=92mm; profile shift coefficient x = – 0,061mm.

For gears 3D printing, the 3D model was made in Autodesk Inventor software (Academic license), Fig.2. The model was exported in *.stl format, required for 3D printer software. The printing process with ABS plastic was performed with 3D printer *Makerbot Replicator 2X*, Fig.3.

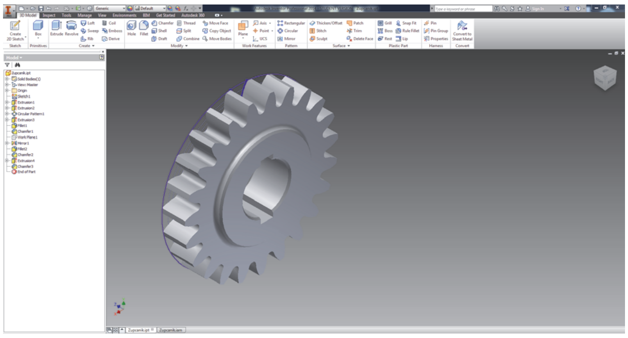


Fig.2. Gear 3D model – Autodesk Inventor

Fig.3. 3D printer - MakerBot Replicator 2X

The ABS gear prototypes were printed with the following parameters: Infill: 95%; Number of shells: 2; Layer thickness: 0,10 mm; 0,20 mm and 0,30, mm; extruder temperature 230°C; Extruding speed: 90mm/s.

2.1. Laboratory equipment

For determination of printed gear teeth surface quality the Mahr MarSurf SD26 device for surface roughness examination (Fig.4), and 3D microscope Xirox KH-7700 (Fig.5) were used.

Fig.4. Surface roughness examination Mahr MarSurf SD26

Fig.5. 3D microscope Xirox KH-7700

3. EXPERIMENTAL PROCEDURE

The aim of the experiments was to determine the influence of extruded material type and layer thickness on the surface roughness and the geometry accuracy on a gear tooth profile. The printing parameters, layer position and its printing angle were defined by previous experiments, published in paper [6].

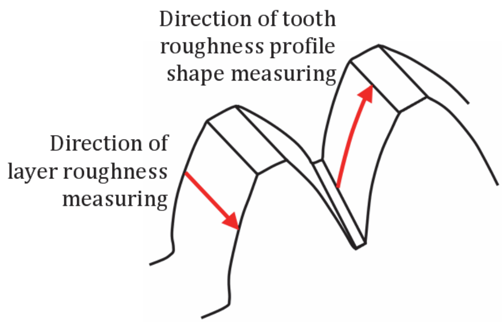


Fig.6. Roughness and profile shape measuring direction

The profile shape of outer printed layers was measured along lateral tooth line – parallel to the gear front surface, Figs.6 and 7. The roughness of printed layers was measured across printed layers – perpendicularly to the gear front surface, Figs.6. and 8.

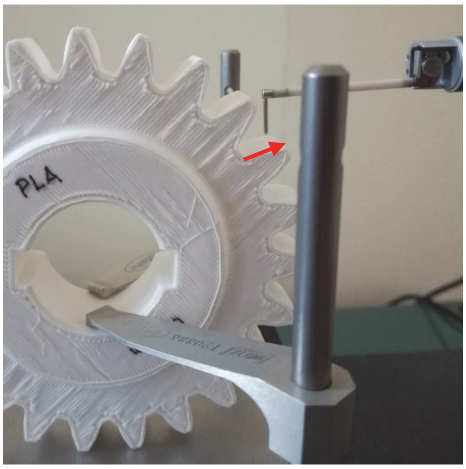


Fig.7. Profile shape direction measuring

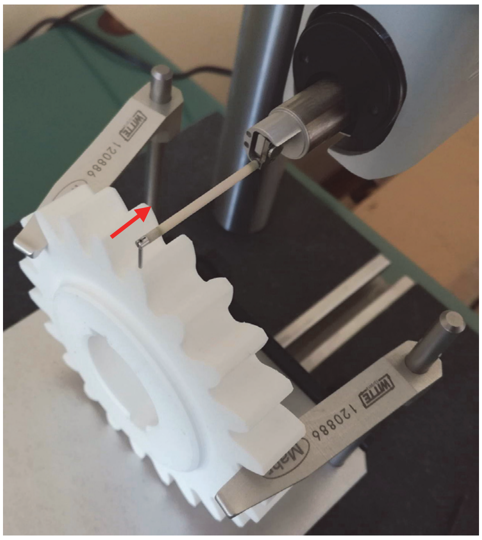


Fig.8. Roughness direction measuring

The examination parameters are shown in Tables 1 and 2.

Table 1.Parameters for profile shape measuring

Parameter	value
Traversing length	1,75 mm
Sempling length	5
Cutoff Lc	0,25 mm
Measuring speed	0,1 mm/s
Measuring interval	0,5 µm

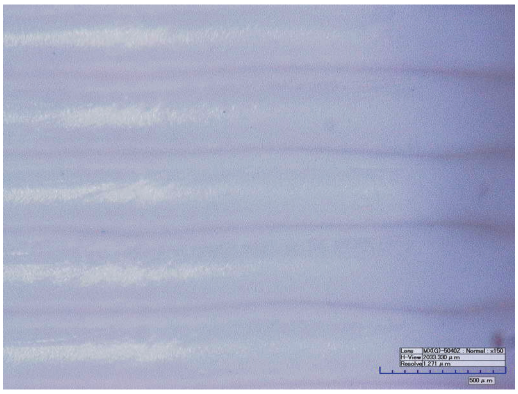
Table 2. Parameters for layer roughness measuring

Parameter	value
Traversing length	5,60 mm
Sempling length	5
Cutoff Lc	0,80 mm
Measuring speed	0,5 mm/s
Measuring interval	0,5 µm

For more accurate measuring of printed layers thickness, the 3D microscope was used (Figs. 5 and 9.).

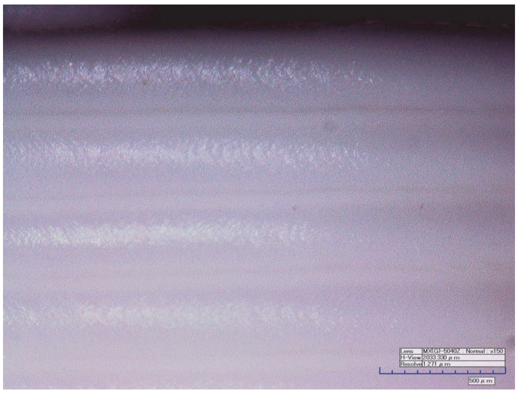
Fig.9. Measuring with 3D microscope

Some of microphotographys taken with magnification 150×, are shown on Figs. 10, 11, 12 and 13.



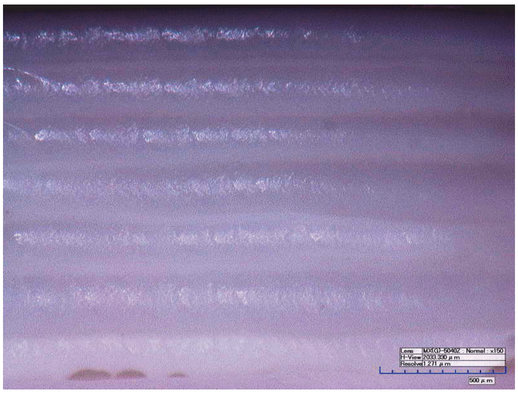
150×

Fig.10. ABS plastic, layer thickness 0,3 mm



150×

Fig.11. PLA plastic, layer thickness 0,3 mm



150×

Fig.12. PLA plastic, layer thickness 0,2mm

150×

Fig.13. PLA plastic, layer thickness 0,1 mm

4. EXPERIMENTAL RESULTS

4.1. Roughness measuring

The results of profile shape roughness measuring of PLA plastic are shown on Figs. 14 – 16.

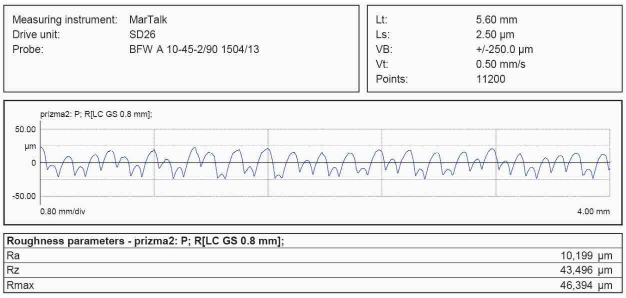


Fig.14. Profile shape, PLA plastic, layer thickness 0,1 mm

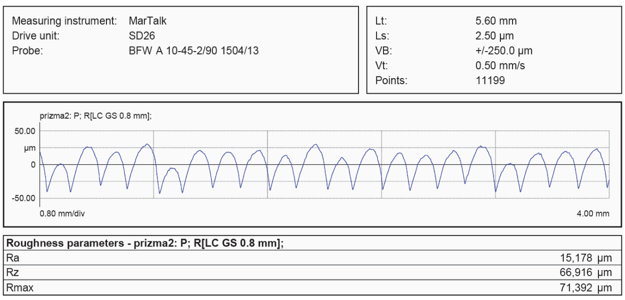


Fig.15. Profile shape, PLA plastic, layer thickness 0,2 mm

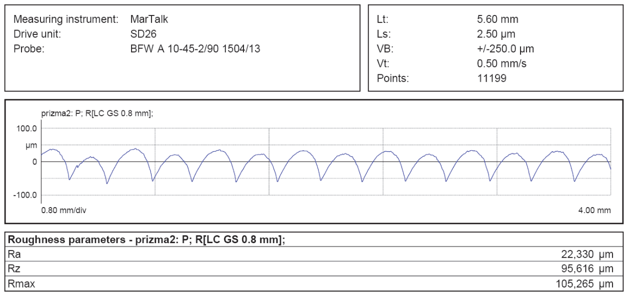


Fig.16. Profile shape, PLA plastic, layer thickness 0,3 mm

The roughness measuring along layers of PLA plastic are shown on Figs. 17 – 19, and in Table 3. The roughness of ABS plastic is shown on Fig. 20.

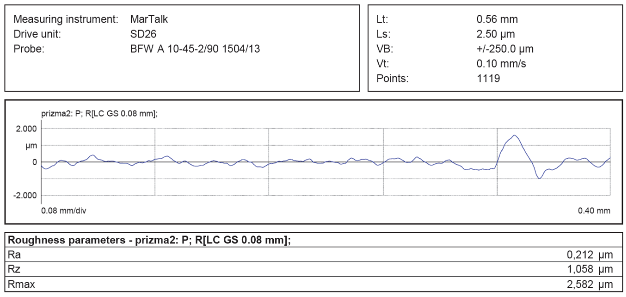


Fig.17. Along layer, PLA plastic, layer thickness 0,1 mm

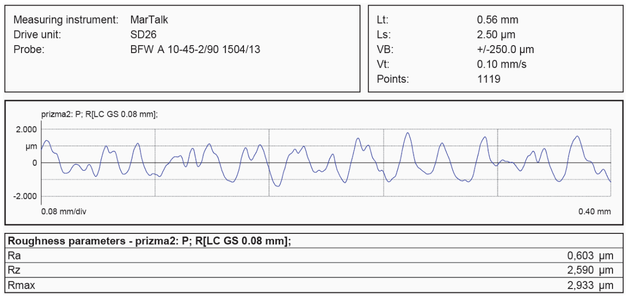


Fig.18. Along layer, PLA plastic, layer thickness 0,2 mm

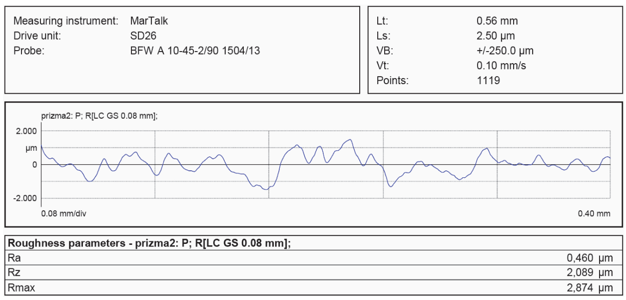


Fig.19. Along layer, PLA plastic, layer thickness 0,3 mm

Table 3. Roughness along layers of PLA plastic

Roughness	Layer thickness, mm		
	0,1	0,2	0,3
R_a µm	0,212	0,603	0,460
R_z µm	1,058	2,590	2,089
R_{max} µm	2,582	2,933	2,874

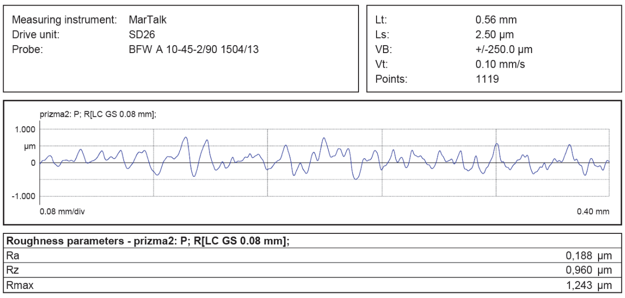


Fig.20. Along layer, ABS plastic, layer thickness 0,3 mm

The influence of material (PLA – ABS) on roughness in booth directions (along profile shape and along layers), can be seen by comparing measuring results of both materials with the same layer thickness, Fig. 21 and 22.

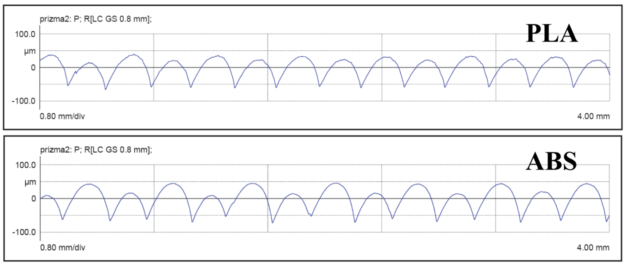


Fig.21. Roughness comparison along tooth shape of PLA and ABS plastic, layer thickness 0,3 mm

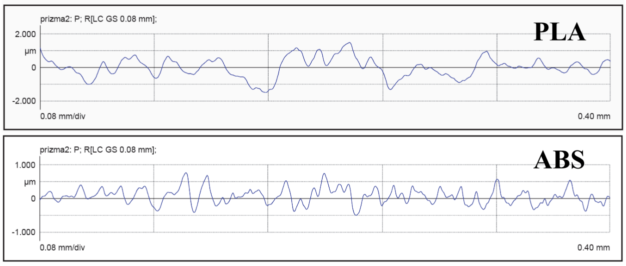


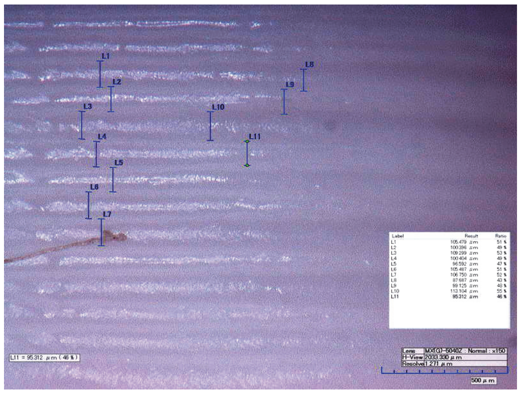
Fig.22. Roughness comparison along layers of PLA and ABS plastic, layer thickness 0,3 mm

4.2. Layer thickness measuring

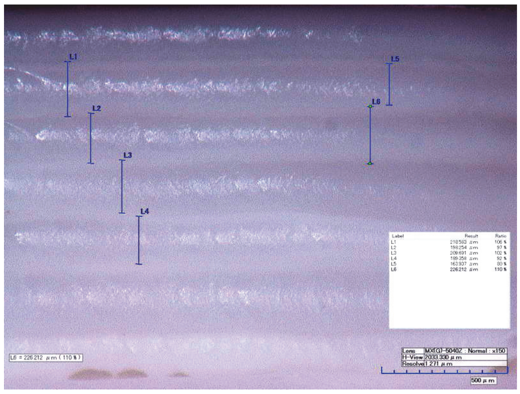
By using a 3D microscope under magnification of 150×, and its ability to measure very precisely a distances between predefined points (accuracy is 1/1000 of µm), it was possible to measure a printed layer thickness. The measurements were performed on layers made from both materials (ABS and PLA) with different printed thickness. The results are shown on Figs. 23 – 26, and Table 4.

Table 4. Average layer thickness for PLA and ABS plastic

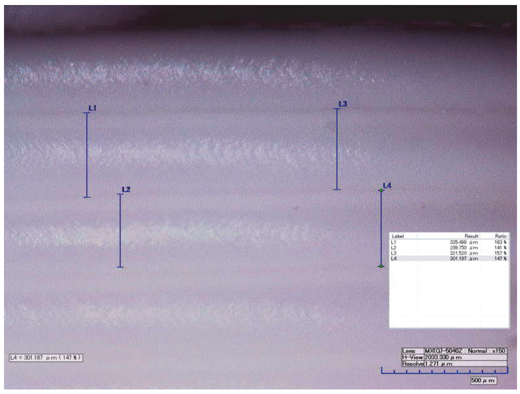
	Plastic material			
	PLA			ABS
	Defined printed layer thickness, mm			
	0,1	0,2	0,3	0,3
Average thickness, µm	101,876	201,005	311,926	303,945



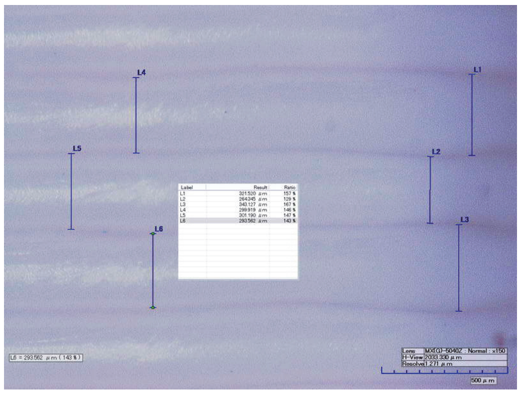
150×
Fig.23. PLA plastic, Layer thickness 0,1 mm



150×
Fig.24. PLA plastic, Layer thickness 0,2 mm



150×
Fig.25. PLA plastic, Layer thickness 0,3 mm



150×
Fig.26. ABS plastic, Layer thickness 0,3 mm

5. DISCUSION

Analyzing measured data of gear tooth's profile shape roughness, Fig. 21., it can be concluded that a surfaces made of PLA plastic are less „wavy" than of ABS plastic, i.e. a layers of PLA plastic are a little bit better distributed from layer to layer.

With reducing a printed layer thickness (0,3 0,2 to 0,1mm), a profile roughness between layers become increasingly irregular (Figs. 14 – 16).

Roughness along layers, according to measuring data (Table 5.), shows that arithmetical mean deviation (R_a) of the ABS sample is 40,87% less than the corresponding value of PLA sample. ABS sample maximal roughness (R_{max}) is more than 50% less than PLA sample.

Table 5. Roughness along layers of PLA and ABS plastic

	Material of printed layer (0,3 mm)	
Roughness	PLA	ABS
R_a μm	0,460	0,188
R_z μm	2,089	0,960
R_{max} μm	2,874	1,243

It can be observed that the measured values of average layer thickness deviate from defined printed layer thickness (Table 4.). Less deviation is on ABS sample.

6. CONCLUSION

From the aspect of surface quality and distribution of extruded layers, the samples made of ABS plastics are better. However, ABS plastics have lower mechanical and physical properties than PLA plastic (Table 6.), so it can be carefully used due to machine part function, i.e. external load, rotation speed etc.

Table 6. Some properties of ABS and PLA plastic

Plastic Material	Tensile strength [Mpa]	Elongation [%]	Flexural Modulus [GPa]	Density [g/cm^3]	Melting point [°C]	Biodegradable	Glass transition temperature [°C]
ABS	27	3,5-50	2,1-7,6	1,0-1,4	N/A	No	105
PLA	37	6	4	1,3	173	Yes	60

The research described in this paper, is an introduction to a larger experiment, in which the characteristics of the printed gears in exploitation (vibration, temperature etc.) will be compared with characteristics of appropriate steel gears. The goal is to see, if, and to what extent (what period of time) the printed gears can replace the steel ones.

7. ACKNOWLEDGMENTS

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