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ANALYSIS OF SMALL PLASTIC GEARS MANUFACTURED BY SLS PRINTING

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Abstract
Selective laser sintering (SLS) is an additive manufacturing method. During the production, the equipment sinters powdered material and binds this material together to create a solid structure. SLS 3D printers use a laser as the power and heat source. During the manufacturing process, the laser is aimed automatically at points in space defined by the 3D model. Since in the past we have worked on the manufacturing of small plastic gears by other additive techniques (FDM, stereolithography) and on the determination of their accuracy, in this article we determined the same characteristics for the SLS process.

Keywords: *gear, plastic, 3D printing, SLS*

1. Introduction

Selective laser sintering (SLS) is an additive manufacturing method. As a power and heat source, SLS printers use a laser. For SLS printing powdered polymer materials are used as the source material. The most commonly used powdered material is polyamide. During the manufacturing process the laser sinters powdered material, while it is aimed automatically at points in space defined by a 3D model. With this, it binds the material together to create a solid mechanical part. SLS, as well as the other 3D printing techniques is mainly used for rapid prototyping and for low-volume production of structures. However similar to the case of the other additive manufacturing techniques, more and more parts are manufactured with this method. (Formlabs, 2024)

SLS is considered to be one, if not the most accurate 3D printing method for plastic parts. As we studied the accuracy of other 3D printing methods (FDM, SLA) in our past research in the case of small plastic gears, in this article, we investigated the accuracy of small plastic gears manufactured with an SLS 3D printer. (Formlabs, 2024) (VDI 2736, 2014)

Small plastic gears are spur gears with an involute profile. They have a module that is not larger than 0.5 mm. They are made of plastic materials. (VDI, 1981) (VDI 2731, 2009) (JIS B 1759, 2019)

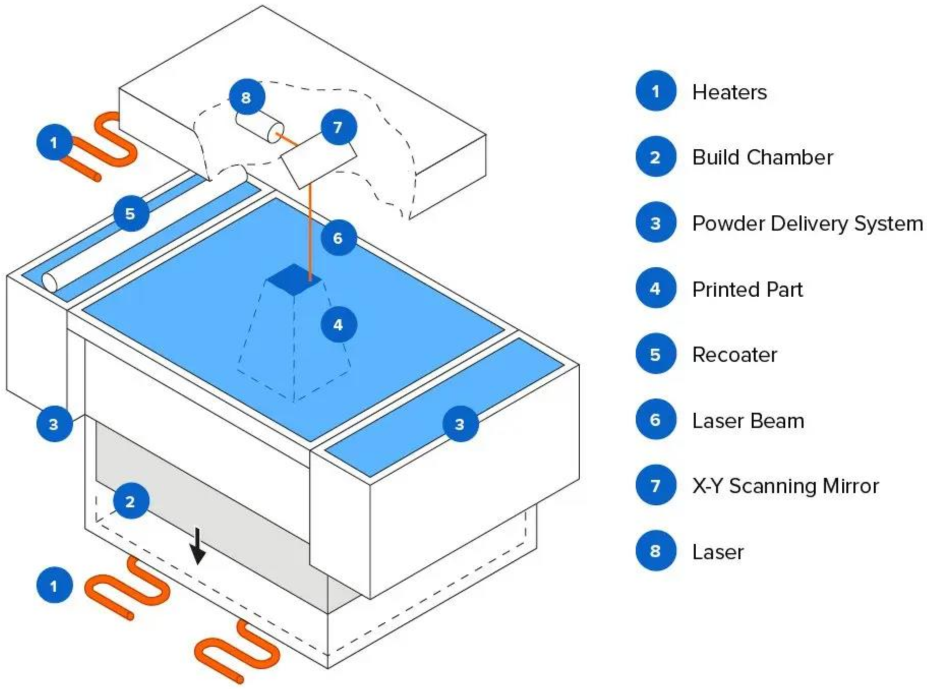

Figure 1. *The scematic of SLS printing*[1]

2. The geometry of the gears

For the tests, a module of m = 0.5 mm was chosen. Within this, two sets of gears with different numbers of teeth were generated using the KISSSoft software. The two types of gears had 30 and 50 teeth. The models of the gears were then converted into the right format and printed out with an SLS 3D printer. The initial geometry is shown in *Figures 2* and *3*, and the finished, printed gears are shown in *Figure 4*.

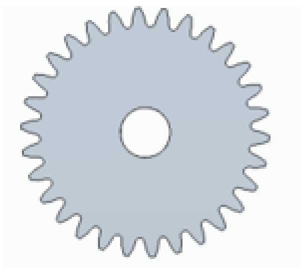

Figure 2. *The 3D model of the $m = 0.5$, $z = 30$ gear*

[1] https://formlabs.com/eu/blog/what-is-selective-laser-sintering/

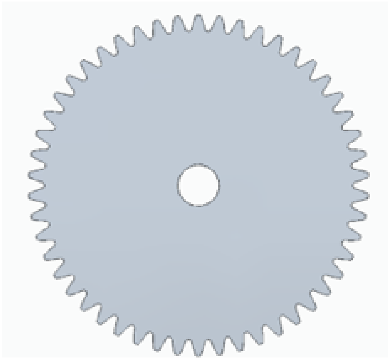

Figure 3. *The 3D model of the m = 0.5, z = 50 gear*

Figure 4. *The 3D printed gears*

3. The measurements

Two types of equipment were used for the tests. Firstly, an optical microscope and secondly a torque measuring device developed by us. With the microscope, we examined two parameters: First, the extent to which the shape of the teeth of the printed gear resembled the original geometry. Second, the tooth thickness measured on the pitch diameter. For the latter, we created a special measuring template made of plastic that had the pitch diameter of the gears, to make the measurements easier.

The torque measuring device was used to measure the recirculation torque. The recirculation torque is the torque required to drive the gearbox with the gears when there is no load on them. During the measurement, the torque measuring device is connected to the input shaft of the gearbox, so that the torque on the input side is measured. The device works on the principle of a differential. Its operation and structure will not be discussed in this article, as we have already done it in a previous work. (Marada et al., 2023)

3.1. The tooth shape

Microscopic images of the teeth of the printed gears are shown in *Figures 5* and *6*. The figures clearly show the grain structure caused by the powder base material. The graininess made it difficult to focus on the contour of the teeth in microscopic examinations, as it varied from layer to layer. However, it can still be seen that the teeth of the printed gears only partially similar to the initial geometry. Because of the grainy structure, there is no continuous, involute profile. Also, the top of the teeth has become rounded.

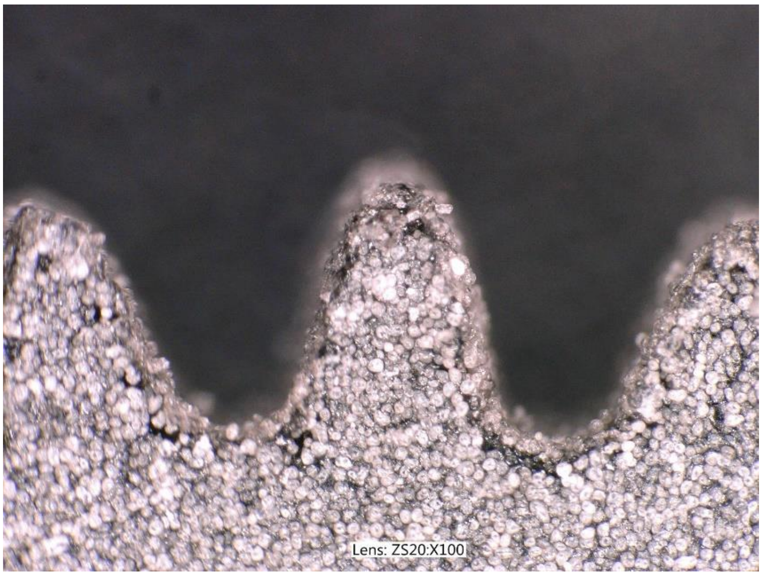

Figure 5. *The tooth shape for m = 0.5, z = 30*

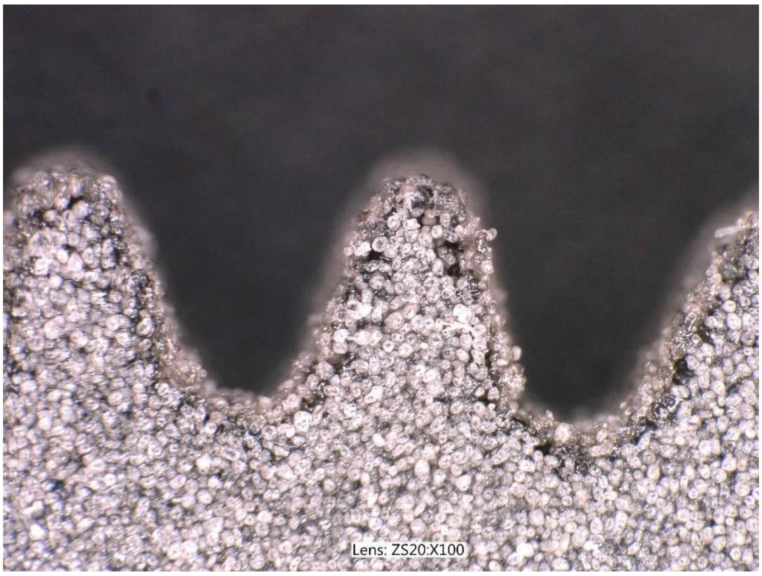

Figure 6. *The tooth shape for m = 0.5, z = 50*

3.2. The tooth thickness

The difficult-to-focus contours due to the grainy structure also made it more difficult to measure tooth thickness. However, it was still possible to measure this dimension on 50-50 teeth of a total of 8-8 gears. Before the microscopic measurements, this parameter was also measured on the 3D models of the initial geometry. For both gears it was 720 µm. The results from the 50 measurements per gear are summarised in *Table 1*. From the values in the table, it can be seen that the tooth thickness varied widely, and the average value was also quite different from the initial geometry. The distribution of the 50-50 value is shown in the graphs in *Figures 8* and *9*.

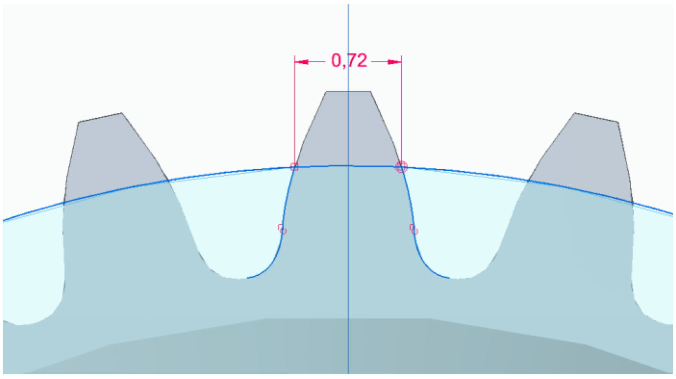

Figure 7. *The nominal value of the tooth thickness*

Table 1. *The results of the measurements*

Gear	Maximum value [µm]	Average value [µm]	Minimum value [µm]
m = 0.5, z = 30	826.74	748.734	670.39
m = 0.5, z = 50	869.3	771.9644	670.39

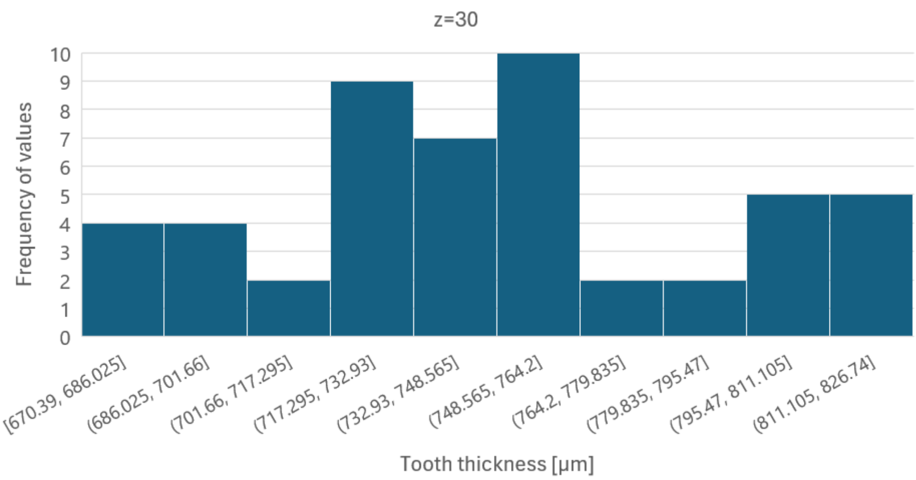

Figure 8. *Distribution of tooth thickness for m = 0.5, z = 30*

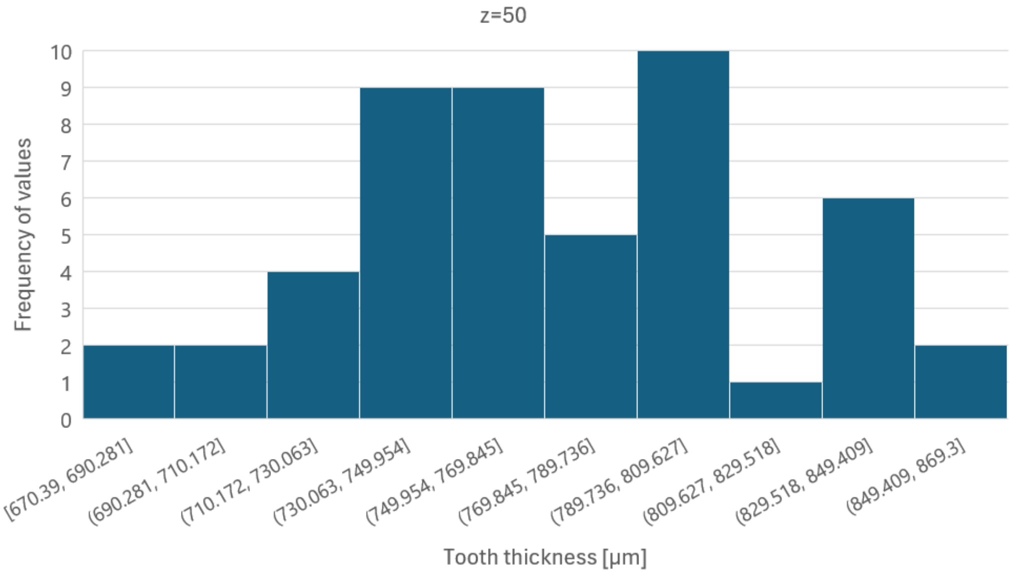

Figure 9. *Distribution of tooth thickness for m = 0.5, z = 50*

3.3. The recirculation torque

Measurements were taken on a single pair of gears with both gears having the same number of teeth. This way, 3-3 independent measurements were made for each number of teeth. The torque curves are shown in *Figures 10* and *11*. In addition, the maximum, average and minimum values of the measurements are summarised in *Table 2*.

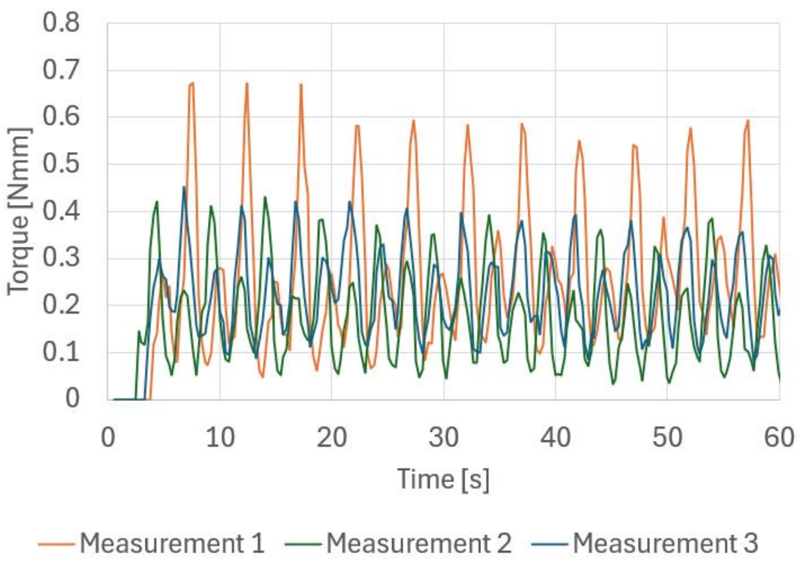

Figure 10. *The recirculation torque for m = 0.5, z = 30*

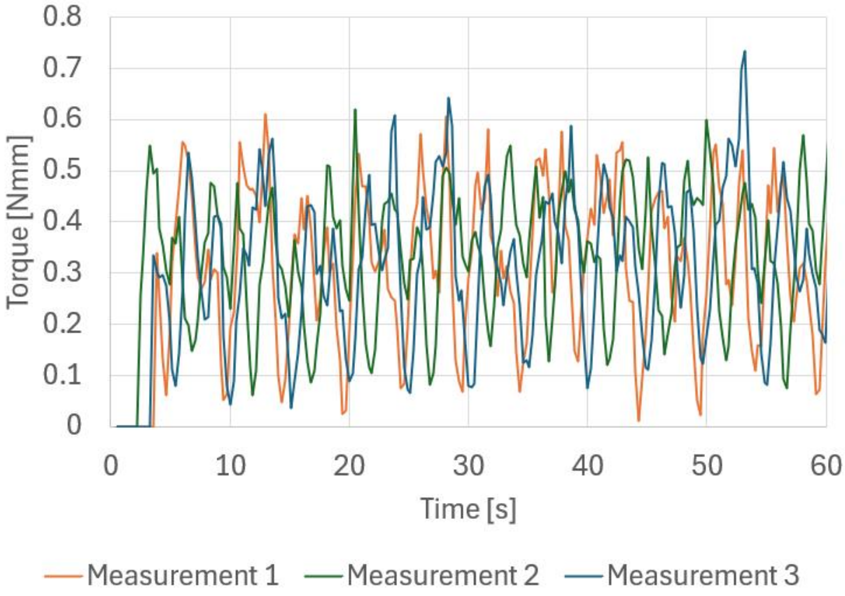

Figure 11. *The recirculation torque for m = 0.5, z = 50*

The torque curves and the values in the table show the same variance in values as the microscope measurements. For comparison, for a m = 0.5 z = 30 gear with a tooth thickness of 727 ±30 µm, the torque values range roughly between 0.13 and 0.0035 Nmm. In the case of m = 0.5 and z = 50, if the tooth thickness is 727 ±30 µm, the maximum value is 0.21 Nmm and the minimum value is 0.012 Nmm.

Table 2. *The results of the torque measurements*

Gear	Measurement	Maximum value [µm]	Average value [µm]	Minimum value [µm]
m = 0.5, z = 30	1.	0.673947	0.266728737	0.04635225
	2.	0.4311495	0.180159046	0.02869425
	3.	0.4517505	0.22912859	0.079461
m = 0.5, z = 50	1.	0.61189875	0.323227821	0.00981
	2.	0.6204825	0.339089494	0.06008625
	3.	0.73452375	0.32544675	0.0367875

4. Summary

In this paper, we investigated the accuracy of small plastic gears manufactured by SLS 3D printing. The characteristics of the SLS technology were briefly described at the beginning of this paper. Then, we used the KISSSoft software to generate the initial geometries of the gears, which were printed from plastic powder. For the tests we chose the m = 0,5 mm module and 30 and 50 number of teeth. The shape of the teeth of the printed gears was then compared with the initial geometry using microscopic examination. We then measured the tooth thickness on 50-50 teeth, also using an optical microscope. We found that the measured value of tooth thickness deviated from the nominal value over a wide range. Then, we used a special torque measuring device to measure the recirculation torque of each pair of gears, which showed similar inaccuracies. This suggests that SLS 3D printing in the form presented in this article is unsuitable to produce small plastic gears.

Acknowledgements

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