Saimaa University of Applied Sciences
Technology Lappeenranta
Mechanical Engineering and Production Technology

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3D printing: technology and processing

Thesis 2016

Abstract

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3D printing: technology and processing, 41 pages
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The objective of the research was to improve the process of 3D printing on the laboratory machine. In the study processes of designing, printing and post-printing treatment were improved. The study was commissioned by Mikko Ruotsalainen, head of the laboratory.

The data was collected during the test work. All the basic information about 3D printing was taken from the Internet or library.

As the results of the project higher model accuracy, solutions for post-printing treatment, printing of the standard parts and guidelines for the designing 3D printed objects were achieved. The results can be applied in the future printing processes on SUAS 3D printer.

Keywords: 3D printing, 3D printing technology

Contents

List of abbreviations

ABS - Acrylonitrile butadiene styrene, common type of thermoplastics. (Wikipedia 2016)

PLA – Polylactic acid, biodegradable type of thermoplastics. (Wikipedia 2016)

PVA – Polyvinyl alcohol, water-soluble synthetic polymer. (Wikipedia 2016)

Base material – permanent material, which creates the body of printed object.

Support material – temporary material, which creates support structures for the not solidified base material.

Introduction into printing technology

1.1 Definition

3D printing (also called additive manufacturing) is a manufacturing technology, which is based on imposing of the material layers to create the 3D objects. According to the Encyclopedia Britannica, the process is analogous to the fusing of ink or toner onto paper in a printer (hence the term printing) but is actually the solidifying or binding of a liquid or powder at each spot in the horizontal cross section where solid material is desired. (3D printing 2016)

1.1.1 Fused deposition modeling

Formation of the object is made by adding micro drops of melted thermoplastics with formation of consecutive layers, which solidifies after extrusion. Typical materials of this technology are ABS, PLA, PVA, nylon and composites.

This technology is commonly used in the prototyping and rapid production. It gives possibility to create a normally operated prototype with smaller amount of time and cost.

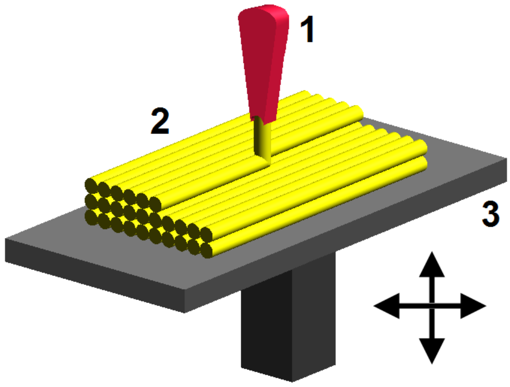

Figure 1. Fused deposition modeling. Source: Wikipedia. (https://en.wikipedia.org/wiki/Fused_deposition_modeling)

The principle of 3D printer operating is the following: the sequence starts from adding of the support material to the work plate. This procedure is needed to reduce the affect of the work plate roughness and for purpose of safe removing of the part from plate. Then, the printer starts to print the base and support material at the same time, according to the layout of the contour. After finishing the contour, the printer starts to build a new contour and the process continues till the end of the printing. On figure 1 the method of adding a new material layer of the part can be observed.

1.1.2 Study equipment

Saimaa UAS laboratory is using Stratasys Dimension Elite 3D printer, which is using fused technology. This machine is printing parts with ABS support material and soluble support material technology. The standard layer thicknesses are 0.178 and 0.254 mm. Dimension Elite can create models with dimensions up to 203 x 203 x 305 mm.

Power requirements for the machine are 110–120 VAC, 60 Hz, minimum 15A dedicated circuit; or 220–240 VAC50/60 Hz, minimum 7A dedicated circuit.

2 Printer accuracy test

2.1 Hypothesis

A higher layer thickness affects the 3D printed model’s accuracy and creates a bigger error in all dimensions, compared to the previous test, held by Michel Bosch. This test will create data, which will be needed for selecting the optimal dimensions of 3D printed objects with smaller error.

2.2 Test methodology

For approving the hypothesis, nine flat squares with the thicknesses of 0.2 to 1.0 mm were created. The measures of the squares were 30x30xThickness. 3D models were created at Solidworks CAD system and sent to the printer in STL format.

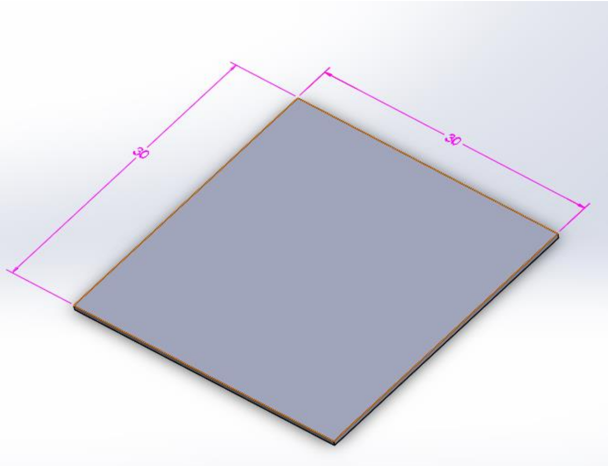

Figure 2. Testpiece in Solidworks CAD program

The test was held with the layer thicknesses of 0.254 and 0.178. The printing time was approximately 1 hour and 10 minutes for both layer thicknesses.

2.3 Results

The average error of the printer can be obtained from the following formula:

$$\Delta b = [\sum(b - bt)]/n \qquad (1)$$

Formula 1: printer error formula

Where:

Δb – average printer error, mm

b – test piece thickness, mm

bt – theoretical thickness of test piece, mm

n – number of measurements

During the testing the following data was obtained:

For 0.178 mm layer thickness

Model thickness	Measured 1	# layers 1	Theoretical thickness 1	Measured 2	# layers 2	Theoretical thickness 2
0.10	- - - - - - - - - - - - - - - - - - Did not print (error in Catalyst) - - - - - - - - - - - - - - - - - -					
0.20	0.42	2	0.356	0.42	2	0.356
0.30	0.42	2	0.356	0.42	2	0.356
0.40	0.60	3	0.534	0.59	3	0.534
0.50	0.58	3	0.534	0.59	3	0.534
0.60	0.74	4	0.712	0.75	4	0.712
0.70	0.74	4	0.712	0.75	4	0.712
0.80	0.95	5	0.890	0.95	5	0.890
0.90	1.10	6	1.068	1.13	6	1.068
1.00	1.10	6	1.068	1.13	6	1.068

Figure 3. Obtained results

Figure 4 shows the calculations of the printing error in every test piece.

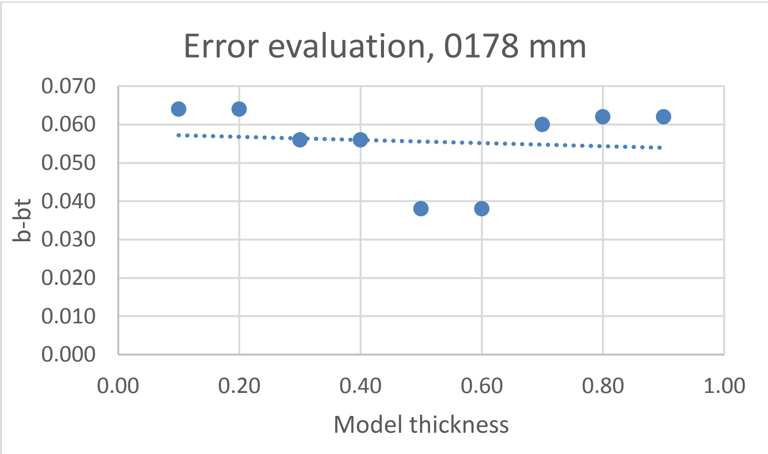

Figure 4. Error of the laboratory printer at the layer thickess of 0.178 mm

By the behaviour of the trendline, we can assume, that on this layer thickness the printer error is slightly reduced by increasing the model thickness. In practice, using of the average printer error shows perfect results.

According to formula 1, the average error of the printer with the layer thickness of 0.178 mm equals to +0.056 mm. This value is essential and will be needed in the subsequent works of the thesis.

For the 0.254 mm layer thickness:

Model thickness	Measured 1	# layers 1	Theoretical thickness 1	Measured 2	# layers 2	Theoretical thickness 2
0.10	- - - - - - - - - - - - - - - - - Did not print (error in Catalyst) - - - - - - - - - - - - - - - - - - -					
0.20	0.62	3	0.254	0.64	3	0.254
0.30	0.63	3	0.508	0.63	3	0.508
0.40	0.64	3	0.508	0.63	3	0.508
0.50	1.03	4	0.508	1.04	4	0.508
0.60	1.04	4	0.762	1.04	4	0.762
0.70	1.05	4	0.762	1.04	4	0.762
0.80	1.04	4	1.016	1.05	4	1.016
0.90	1.04	4	1.016	1.04	4	1.016
1.00	1.05	4	1.016	1.04	4	1.016

Figure 5. Obtained results for the layer thickness of 0.254 mm

Figure 6 shows the error for every test piece. Behaviour of the trendline gives us information, that printing errors have a tendency to decrease.

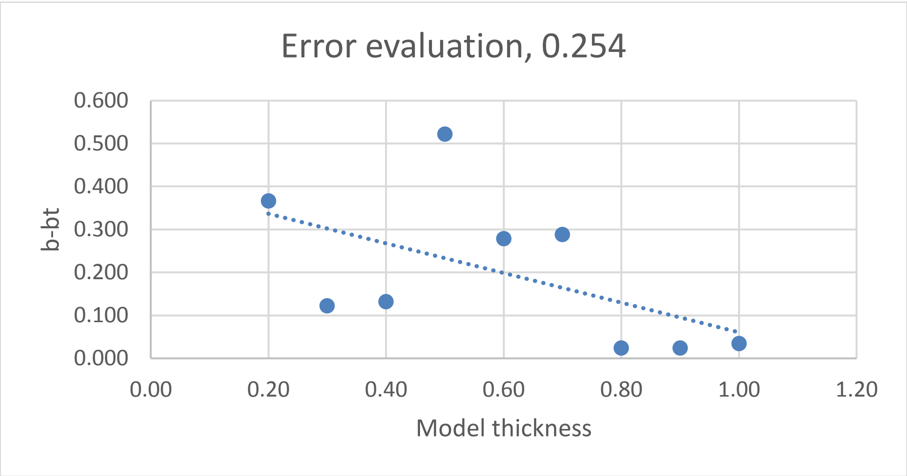

Figure 6. Error of the laboratory printer at the layer thickness of 0.254 mm

In the result of the calculations by formula 1, the average error of the printer equals to +0.199 mm. According to that information, it is reasonable to print objects with accuracy more than 1 mm.

3 Effect of 3D printing direction and internal structure on part accuracy

3.1 Hypothesis

The direction of the 3D printed layers and the internal structure of the model affect the accuracy of the model. Sparse models have lower accuracy compared to the solid ones.

3.2 Test methodology

To perform the test cylindrical test pieces with the diameter of 50 mm were created. There were four types of 3D models created: sparse, sparse with vertical positioning, solid and hollow.

Figure 7. Test pieces

After printing, all the models were checked on the SUAS coordinate measuring machine.

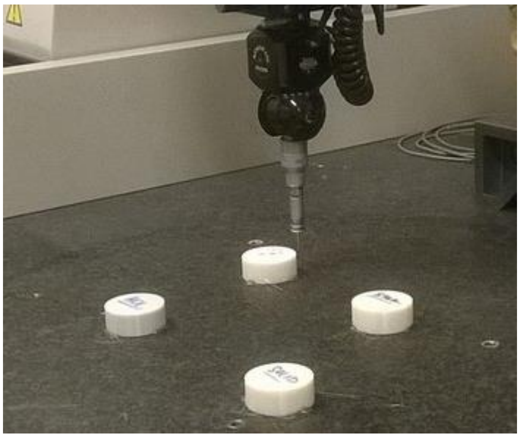

Figure 8. Test pieces measuring process

3.3 Results

The following results were obtained after measuring. Test pieces are sorted by the circularity value decreasing.

3.3.1 Sparse model

Sparse model is the 3D printed objects' internal structure, when the model is hollow inside and has a support system (trusses).

Sparse model showed the best result of circularity from all test pieces. The part was printed as shown in Figure 9.

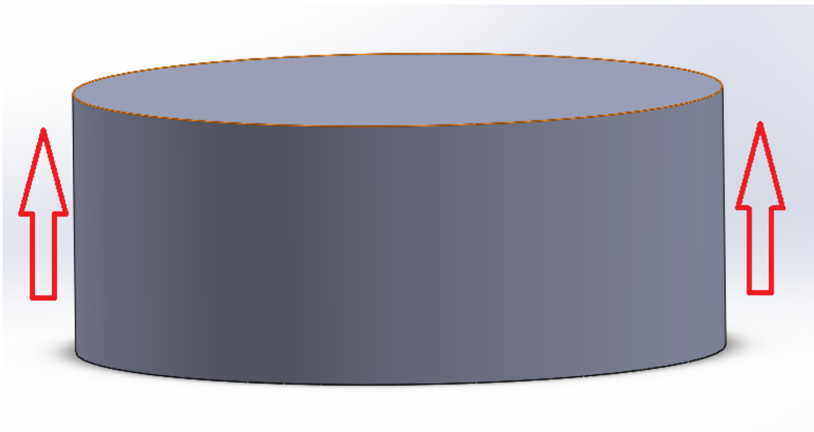

Figure 9. Printing direction of sparse, hollow and solid part

Tolerance zone	0.100	Upper tol. Lower tol.	0.062 -0.038
X	122.541	No. of pts.	50
Y	266.702	Min./Max. Pnt.	30 / 42
Z	-44.024	Std. dev. * 4	0.134
Actual Radius	25.050	Circularity	0.133
Min. dist.	-0.054	Max. dist.	0.079
X	-21.983	X	10.630
Y	11.896	Y	22.769
Radius	24.996	Radius	25.128
Phi	151.579	Phi	64.973

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Figure 10. Mitutoyo sparse model test result table

In this part the circularity value of 0.133 and the actual radius of 25,050 mm were obtained.

Sparse model showed the best results because of the base material internal support system (which created automatically). As the result, first of all, supports help to keep the previous layer solid and reduce the effect of the gravity to not solidified material layers.

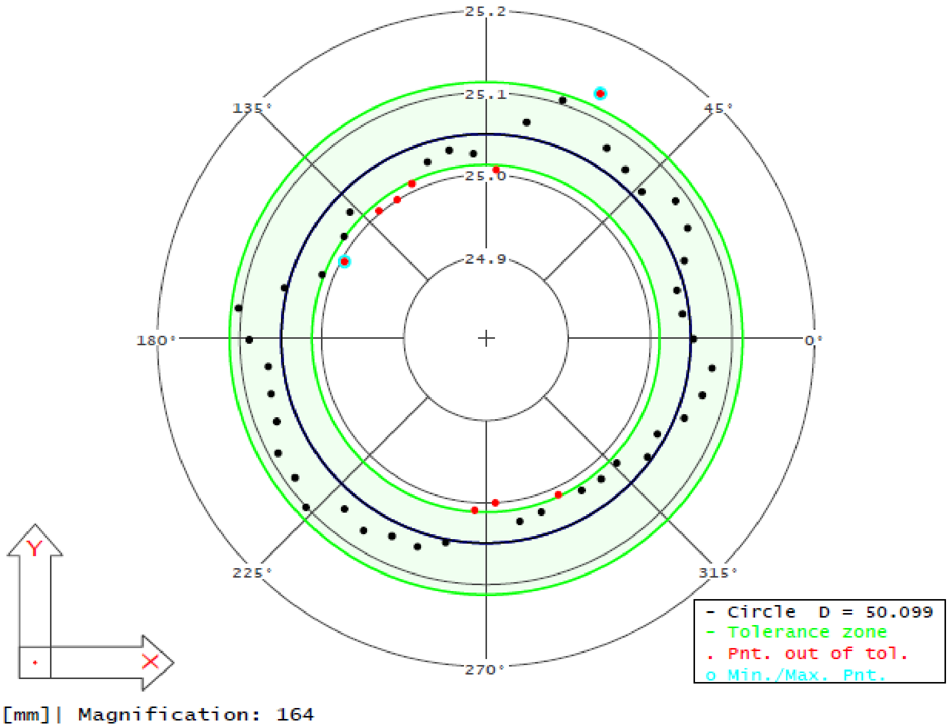

Figure 11. Sparse part measurement result

Figure 11 shows the results of measurements. The green circuit shows the tolerance zone of the part. In measurements for all parts 0.100 mm tolerace was used. Black points show the measurement results in the tolerance zone, when red ones show the exceeding of the results out of tolerance area.

This graph shows, that the test piece is slightly compressed from the sides.

3.3.2 Solid

The solid part shows a smaller circularity value of 0.140. This part is also compressed from the sides and has distortions, which go over the tolerance limit at segments 135°-225° and 0°-90°.

At 136° degree region the highest position was observed. That situation was caused by the layer offset. A possible reason for the offset is the roughness at the working plates.

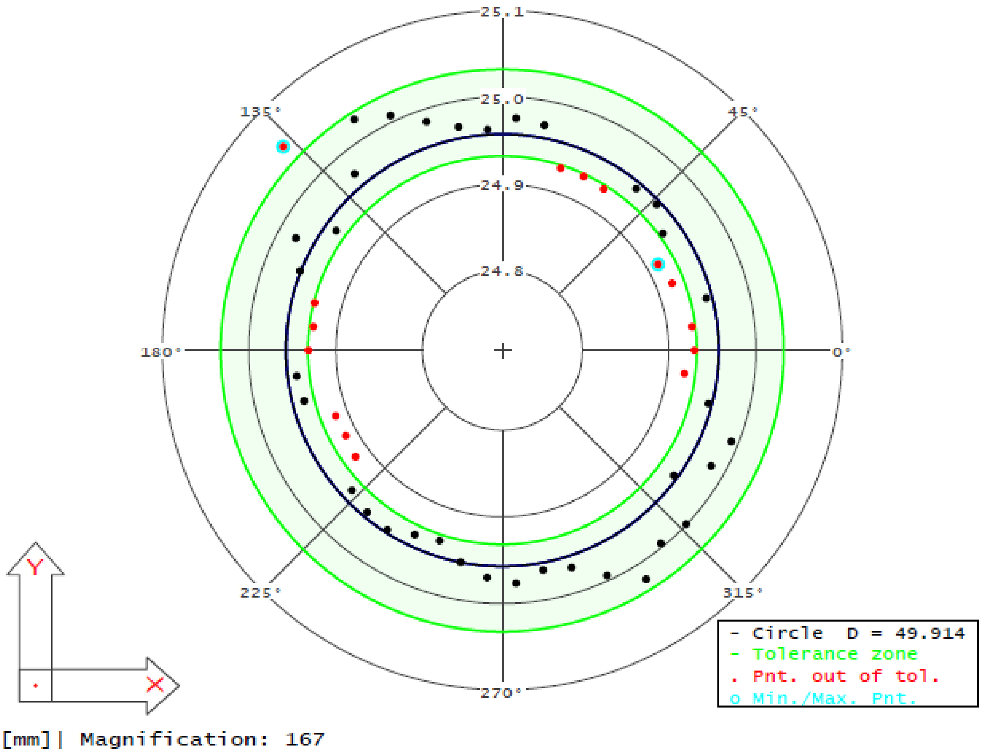

Figure 12. Solid part measurement result

As shown in the Figure 12, the actual radius of the solid model is slightly less than 3D model's. In overall, the solid part has less circularity number and it is has roughly the same dimension accuracy as sparse model.

Tolerance zone	0.100	Upper tol. Lower tol.	0.075 -0.025
X	199.621	No. of pts.	50
Y	115.289	Min./Max. Pnt.	47 / 32
Z	-44.024	Std. dev. * 4	0.128
Actual Radius	24.957	Circularity	0.140
Min. dist.	-0.045	Max. dist.	0.095
X	21.822	X	-18.357
Y	12.016	Y	17.048
Radius	24.912	Radius	25.052
Phi	28.839	Phi	137.118

Figure 13. Mitutoyo solid model test result table

3.3.3 Hollow

The hollow model showed the best actual diameter result of 49.999 mm. The hollow part showed less circularity than the solid and sparse model. Distortions of the part were caused by the formation of the support material. The support material is applied first and then the base material is applied. That is why, at the printing process the error of the support material and the error of the base material are summarized.

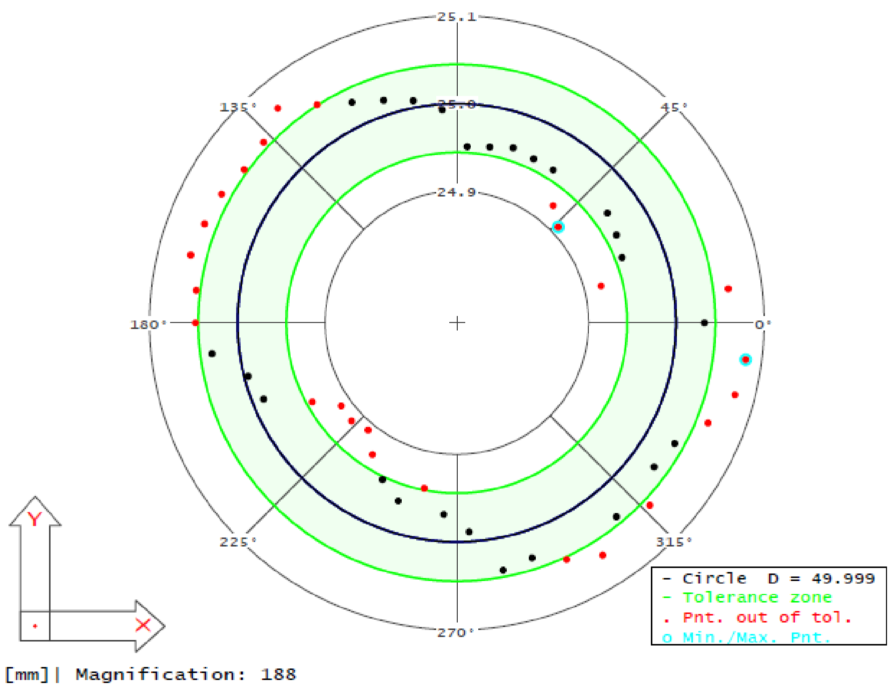

Figure 14. Hollow part result

This model is compressed higher than the previous ones. Distortions below the tolerance zone are situated at the section 180°-270° and on the opposite side 0°-90°. Distortions above the tolerance zone iare situated at the sections 90°-180° and 270°-0°.

Tolerance zone	0.100	Upper tol. Lower tol.	0.045 -0.055
X	-8.942	No. of pts.	50
Y	106.569	Min./Max. Pnt.	45 / 2
Z	-44.024	Std. dev. * 4	0.220
Actual Radius	24.999	Circularity	0.173
Min. dist.	-0.092	Max. dist.	0.081
X	18.116	X	24.876
Y	17.094	Y	-3.200
Radius	24.908	Radius	25.081
Phi	43.337	Phi	352.670

Figure 15. Mitutoyo hollow model test results table

3.3.4 Sparse vertical

For checking the affect of the positioning of the internal model structure with the highest circularity value was chosen. The model has the same dimensions as a normal sparse model.

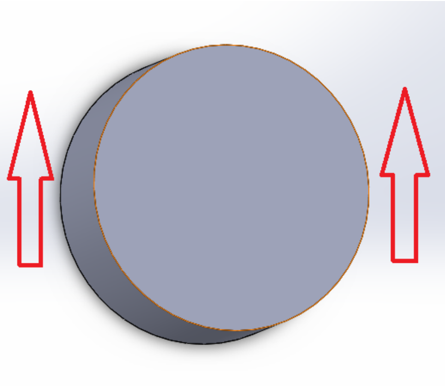

Figure 16. Sparse vertical model printing direction

As it was predicted, the model has the worst circularity number.This part also has distortions from the sides, but in this situation they are higher. Distortions were caused by the affect of gravity to the support system, which designed to counter-act to the normal force (in the case of vertical part it withstands shear force).

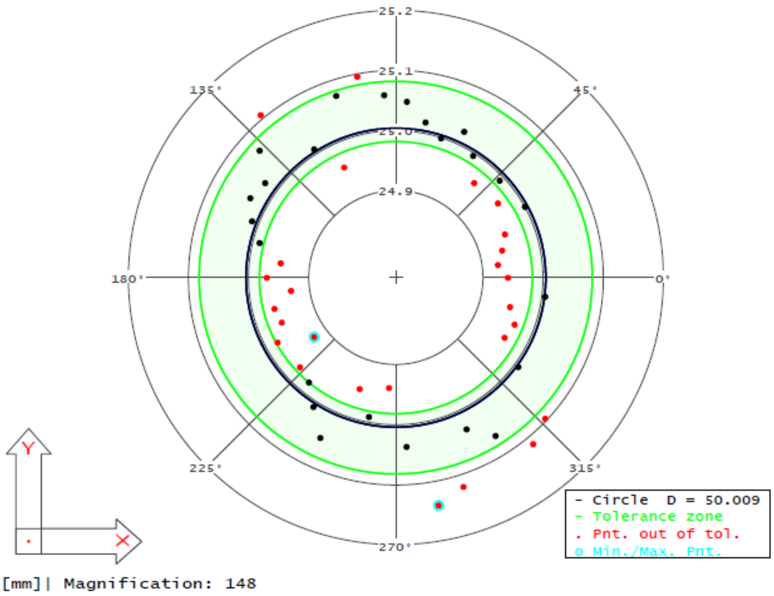

Figure 17. Sparse part measurement result

Distortion in the sparse vertical model has the same behaviour as in the hollow model, but it has more points, which exceed the tolerance limit.

Tolerance zone	0.100	Upper tol. Lower tol.	0.077 -0.023
X	-43.511	No. of pts.	50
Y	262.399	Min./Max. Pnt.	21 / 12
Z	-44.024	Std. dev. * 4	0.229
Actual Radius	25.004	Circularity	0.218
Min. dist.	-0.081	Max. dist.	0.136
X	-20.133	X	4.631
Y	-14.690	Y	-24.710
Radius	24.923	Radius	25.141
Phi	216.117	Phi	280.614

Figure 18. Mitutoyo sparse vertical result table

3.3.5 Conclusion

The test work shows, that basically there is no difference in the printing method according to the dimension requirements. That can clearly be seen at the table .

	Sparse	Solid	Hollow	Sparse vertical
Diameter, mm	50,099	49,914	49,999	50,009
Circularity	0,133	0,140	0,173	0,218

Table 1. Comparision according to the circularity and actual diameter values

For the applications, which require good part circularity or shape accuracy it is favourable to choose the sparse and solid models. For the cases which require the dimensioning accuracy it is reasonable to choose the hollow or sparse with vertical positioning.

4 Support material in hollow, enclosed objects

4.1 Hypothesis

Support material in hollow, enclosed objects is removed by dipping inside the tank with sodium hydroxide (NaOH). During the time, alkali leak through the objects walls which are made of base material (ABS).

4.2 Test methodology

For checking the hypothesis, 11 test pieces were created. All models have 3 basic types of shapes: cube, sphere and parallelepiped.

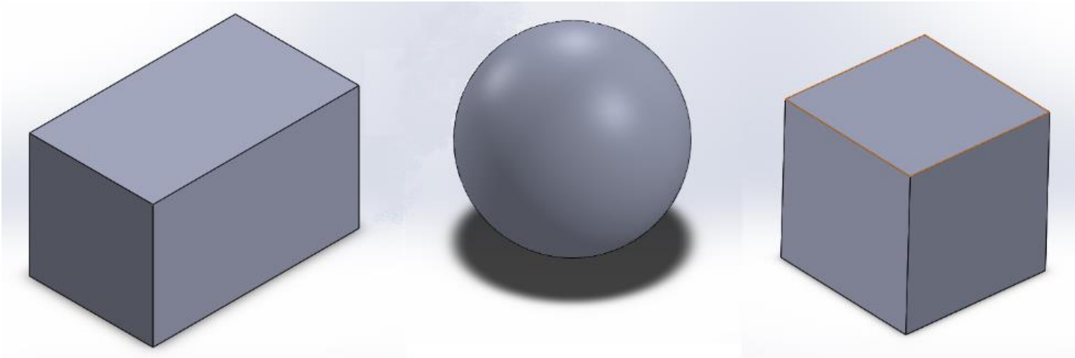

Figure 19. 3D models of parallelepiped, sphere and cube

Models had the following dimensions:

Cubes – 30 mm height, wall thickness from 1 to 3 mm + 1 model with 1 mm hole (3 mm wall thickness)

Spheres – 30 mm diameter, wall thickness from 1 to 3 mm + 1 model with 1 mm hole (3 mm wall thickness)

Parallelepiped – 50x30x30, wall thickness from 1 to 3 mm

All the test pieces were placed into tank with NaOH (temperature 70 °C) for 16 hours. After NaOH treatment, the specimens were sawed.

4.3 Results

This test showed, that in most of the models the support material was not destroyed during the treatment.

Different shapes and wall thicknesses do not affect the leaking of alkali through the model.

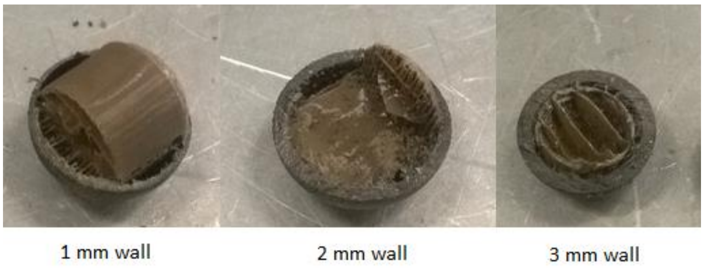

Figure 20. Spheroidal test pieces with support material after treatment

Some specimens' support material was damaged during sawing, it can be clearly observed in figure 21 on the model with 1 mm wall thickness.

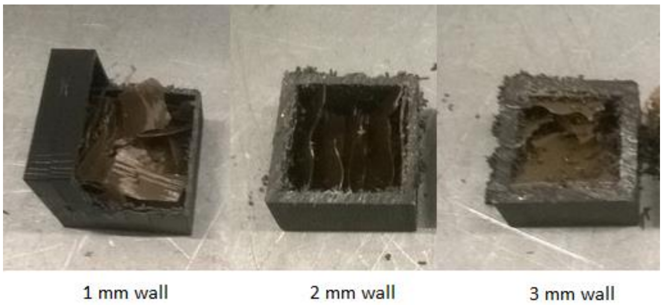

Figure 21. Cubic test pieces with support material after treatment

Damage, which was generated during sawing, did not affect the observation accuracy, because in figure 20, specimen with 1 mm wall thickness survived more than others and does not have any evidence of melting.

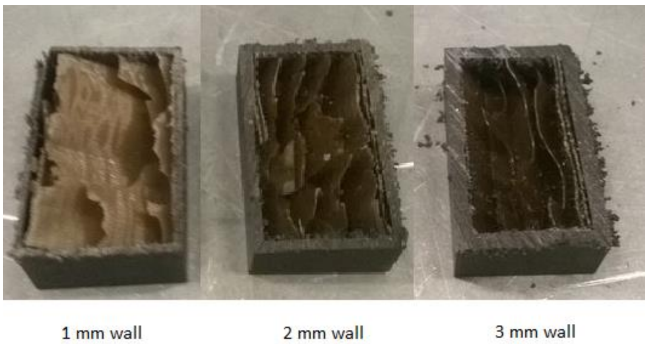

Figure 22. Parallelepidic test pieces with support material after treatment

4.4 Possible solutions of the problem

Depending on the application of the model, the following solutions are appropriate:

4.4.1 Creating hole in the model

As it was already mentioned, the test sample included cubic and spheroidal models of 3 mm wall thickness with hole Ø1 mm.

It showed better results, but support material was not fully removed from the model. Increasing of the diameter and correction of the position in the tank (hole side should be upwards for the air removing purpose) will help to remove all the support material. This solution is the most cost effective and requires small changing in the model.

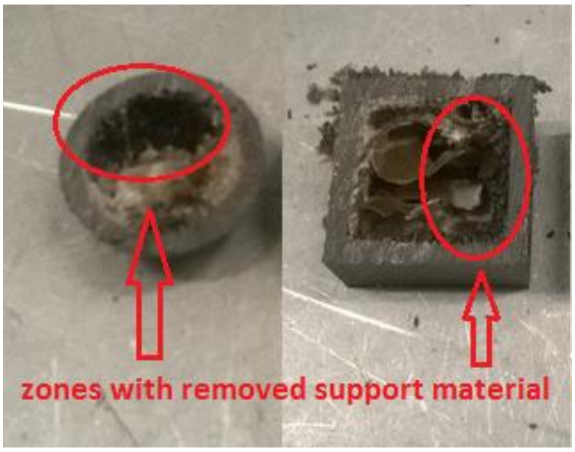

Figure 23. Test pieces with Ø 1mm hole

4.4.2 Increasing of the pressure in the NaOH tank

This method requires purchasing/development of the heating tank, which can produce high pressure. Disadvantages of this method are high cost and possible failure of the model inside the tank, after melting of some amount of support material. This method requires further investigation.

5 Mechanical fits

5.1 Work objective

The main goal of this work is to define the optimal parameters for printing parts, which needed mechanical fits.

5.2 Methodology

For defining the appropriate settings of the details two sets of shafts and holes were made. Two types of the mechanical fits were used: loose running fit and free running fit.

Dimensions are in millimeters.

Basic Size		Loose Running			Free Running			Close Running			Sliding			Locational Clearance		
		Hole H11	Shaft c11	Fit	Hole H9	Shaft d9	Fit	Hole H8	f7	Fit	Hole H7	Shaft g6	Fit	Hole H7	Shaft h6	Fit
1	Max	1.060	0.940	0.180	1.025	0.980	0.070	1.014	0.994	0.030	1.010	0.998	0.018	1.010	1.000	0.016
	Min	1.060	0.880	0.060	1.000	0.955	0.020	1.000	0.984	0.006	1.000	0.992	0.002	1.000	0.994	0.000
1.2	Max	1.260	1.140	0.180	1.225	1.180	0.070	1.214	1.194	0.030	1.210	1.198	0.018	1.210	1.200	0.016
	Min	1.200	1.080	0.060	1.200	1.155	0.020	1.200	1.184	0.036	1.200	1.192	0.002	1.200	1.194	0.000
1.6	Max	1.660	1.540	0.180	1.625	1.580	0.070	1.614	1.594	0.030	1.610	1.598	0.018	1.610	1.600	0.016
	Min	1.600	1.480	0.060	1.600	1.555	0.020	1.600	1.584	0.006	1.600	1.592	0.002	1.600	1.594	0.000
2	Max	2.060	1.940	0.180	2.025	1.980	0.070	2.014	1.994	0.030	2.010	1.998	0.018	2.010	2.000	0.016
	Min	2.000	1.880	0.060	2.000	1.955	0.020	2.000	1.984	0.006	2.000	1.992	0.002	2.000	1.994	0.000
2.5	Max	2.560	2.440	0.180	2.525	2.480	0.070	2.514	2.494	0.030	2.510	2.498	0.018	2.510	2.500	0.016
	Min	2.500	2.380	0.060	2.500	2.455	0.020	2.500	2.484	0.006	2.500	2.492	0.002	2.500	2.494	0.000
3	Max	3.060	2.940	0.180	3.025	2.980	0.070	3.014	2.994	0.030	3.010	2.998	0.018	3.010	3.000	0.016
	Min	3.000	2.880	0.060	3.000	2.955	0.020	3.000	2.984	0.006	3.000	2.992	0.002	3.000	2.994	0.000
4	Max	4.075	3.930	0.220	4.030	3.970	0.090	4.018	3.990	0.040	4.012	3.996	0.024	4.012	4.000	0.020
	Min	4.000	3.855	0.070	4.000	3.940	0.030	4.000	3.978	0.010	4.000	3.988	0.004	4.000	3.992	0.000
5	Max	5.075	4.930	0.220	5.030	4.970	0.090	5.018	4.990	0.040	5.012	4.996	0.024	5.012	5.000	0.020
	Min	5.000	4.855	0.070	5.000	4.940	0.030	5.000	4.978	0.010	5.000	4.988	0.004	5.000	4.992	0.000
6	Max	6.075	5.930	0.220	6.030	5.970	0.090	6.018	5.990	0.040	6.012	5.996	0.024	6.012	6.000	0.020
	Min	6.000	5.855	0.070	6.000	5.940	0.030	6.000	5.978	0.010	6.000	5.988	0.004	6.000	5.992	0.000
8	Max	8.090	7.920	0.260	8.036	7.960	0.112	8.022	7.987	0.050	8.015	7.995	0.029	8.015	8.000	0.024
	Min	8.000	7.830	0.080	8.000	7.924	0.040	8.000	7.972	0.013	8.000	7.986	0.005	8.000	7.991	0.000
10	Max	10.090	9.920	0.260	10.036	9.960	0.112	10.022	9.987	0.050	10.015	9.995	0.029	10.015	10.000	0.024
	Min	10.000	9.830	0.080	10.000	9.924	0.040	10.000	9.972	0.013	10.000	9.986	0.005	10.000	9.991	0.000
12	Max	12.110	11.905	0.315	12.043	11.950	0.136	12.027	11.984	0.061	12.018	11.994	0.035	12.018	12.000	0.029
	Min	12.000	11.795	0.095	12.000	11.907	0.050	12.000	11.966	0.016	12.000	11.983	0.006	12.000	11.989	0.000

Figure 24. Table of mechanical fits. Source: Slide Plyaer (http://slideplayer.com/slide/4644856/)

The test used the minimum values of the holes and shafts, detailed dimensions shown in Figure 24. For the best accuracy of the printed details, the method was used, which reduces the printing error and was described in part 2. The layer thickness of 0.178 was used in this test. According to chapter 4, best solution to achieve good circularity is to print part in horizontal direction.

After calculating, the following shaft and hole dimensions were prepared for printing:

Fit type	Hole, mm	Shaft, mm	Tolerance, mm
Loose running	9.942	9.772	0,17
Free running	9.942	9.866	0,076

Table 2. 3D models' dimensions

5.3 Results

After the measurement of printed test pieces the following results were obtained:

Fit type	Hole, mm	Shaft, mm	Tolerance, mm
Loose running	9,99	9,7	0,29
Free running	9,85	9,8	0,050

Table 3. Test piece dimensions

Figure 25. Loose and free running fit test pieces

All the test pieces have the difference in the tolerance due to the Solidworks settings. All the values were rounded into two significant numbers. In the subsequent works, Solidworks should have settings for three significant numbers.

6 Enclosure of the foreign components into part

6.1 Work objective

The goal of this work is to define the optimal and safe for the printer procedure to include foreign objects into printed parts. The second objective is to define the method of removing the support material.

6.2 Methodology

Inserting of the foreign component inside a 3D printed model requires high tolerance and dimensioning accuracy. All the dimensions were corrected according to formula 1.

To insert the foreign component, e.g. ISO nut M12, the 3D model shown at Figure 26 was created.

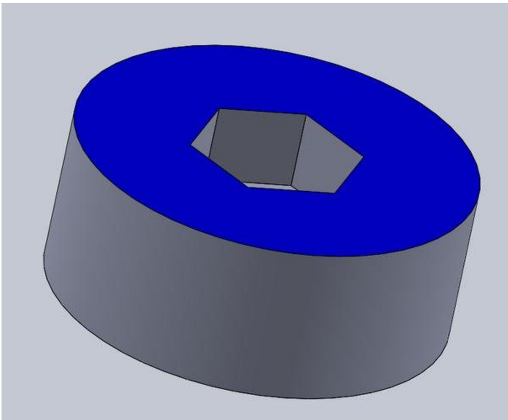

Figure 26. 3D model section view

For the safety purpose, the 3D model has the tolerance of 2 mm to prevent the damage of the printer due to the colission. All the dimensions are shown in Figures 27 and 28.

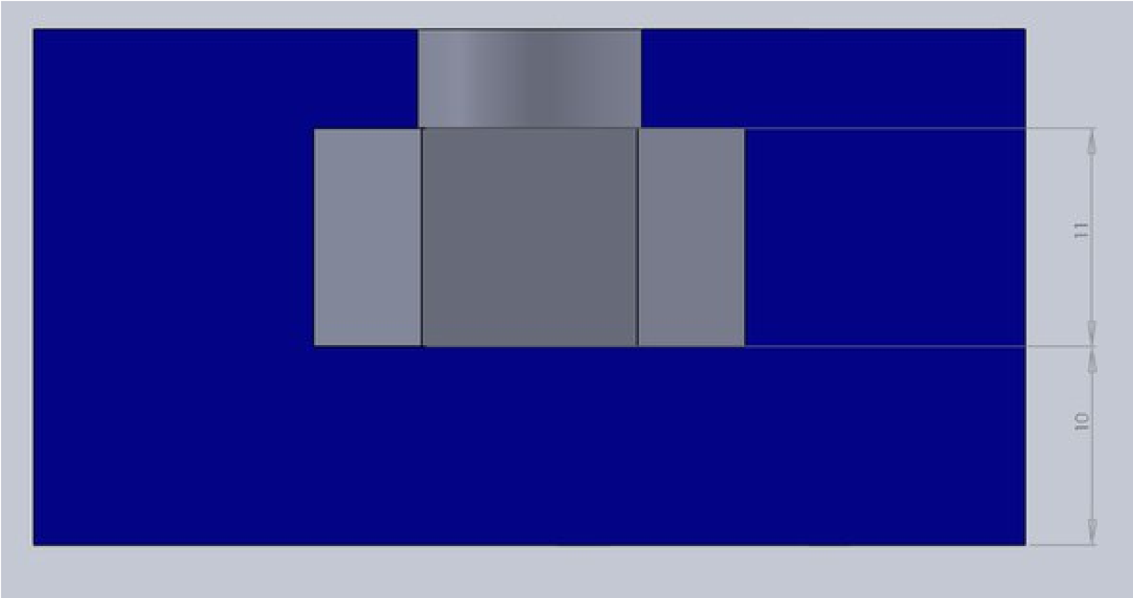

Figure 27. front plane dimensions of the hole for the M12 nut

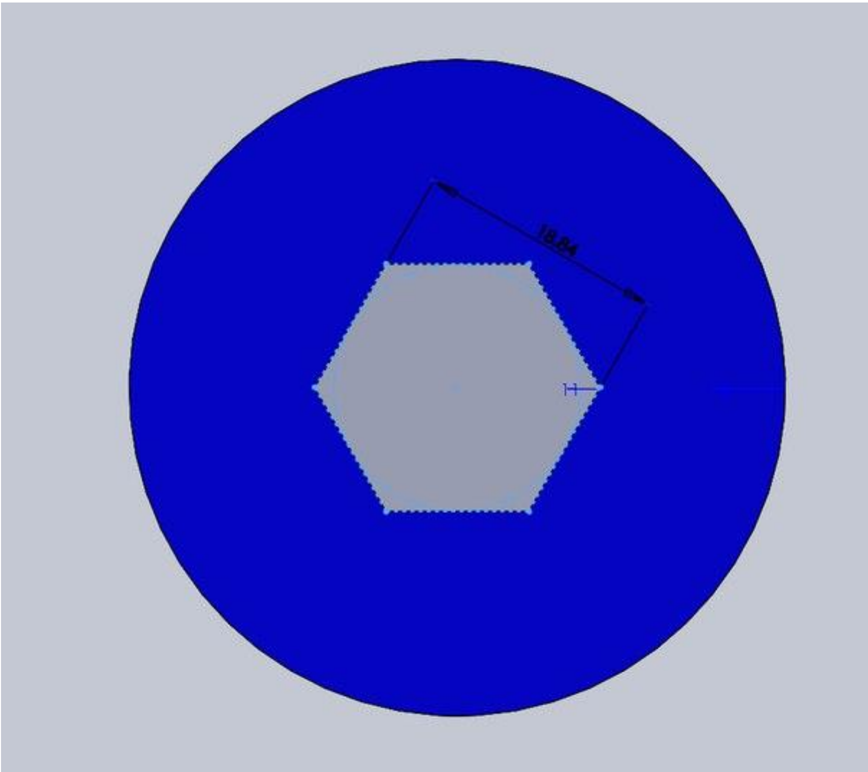

Figure 28. Front plane dimensions for M12 nut

The printing process was stopped at the end of the hole at 21 mm height. It is essential not to remove the model from the working table, because it will affect the printing process. The support material was easily removed by the forceps due to its sparse structure. The test was performed twice with the sparse and solid base material internal structure.

6.3 Results

Nuts are perfectly fitted inside the models without any damage to the model. However, there are two issues, which affect the printing of the objects with enclosure of the foreign objects.

The first issue is the roughness of the inserted part. The test shows, that the support and base material have a tendency not to stick to the metal materials. This situation creates a problem with distortion of the first layer at the nut. The 3D printer fixes distortion after few layers, but they are affect the impact strength of the printed model.

Figure 29. Completed and sawed model

For the case of working with metal materials there is the requirement for the surface roughness. This problem can be fixed with application of the rough material at the top of the nut, e.g. paper, or by increasing of the surface roughness.

The second issue is concerning the model internal structure. The solid part shows good strength. It has lower sensitivity to the model stop and distortions. On the other hand, the sparse model can not withstand the load, has low impact strength due to distortions on the nut subsequent layer (was broken after falling on the ground).

For the purpose of the reliability and part lifetime it is reasonable to choose the solid internal structure.

7 3D printed threads

7.1 Work objective

The goal of the work is to create a working ISO bolt and nut with M10 thread by using the 3D printer. The second objective is to check if the printed nut/bolt fit into a real nut/bolt.

7.2 Methodology

For the test ISO M10 hexagon cap bolt and corresponding nut were chosen. Smaller standard components can not be replicated, because the thickness of the printed thread will be smaller than the layer thickness. Smaller size standard components require to create custom threads. Due to the fact, that Solidworks do not create any operating standard parts, all the threads were made manually.

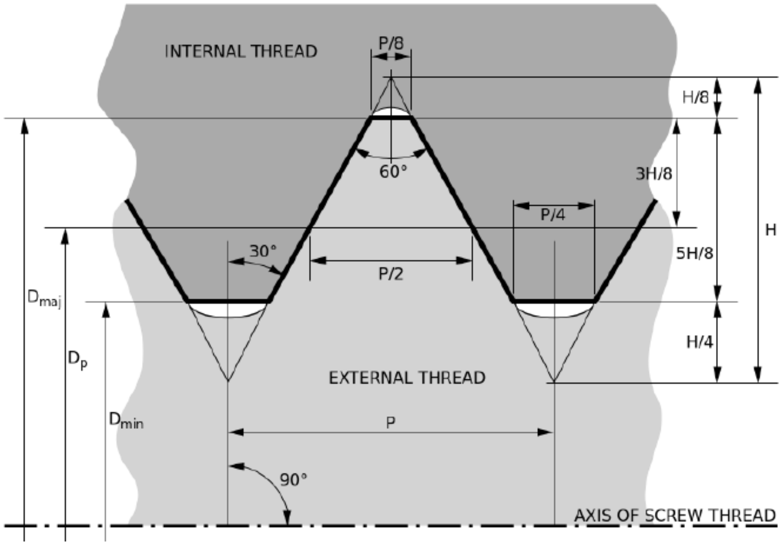

Figure 30. ISO thread dimensioning. Source: Wikipedia (https://en.wikipedia.org/wiki/ISO_metric_screw_thread)

Nominal Size	Thread Pitch	Major (D_{maj})	Minor (D_{min}) Max - min
M8	1,25	8,000	6,912 - 6,647
M10	1,5	10,000	8,676 - 8,376
M12	1,75	12,000	10,441 - 10,106

Figure 31. ISO thread dimensions. Source: RoyMech (http://www.roymech.co.uk/Useful_Tables/Screws/Hex_Screws.htm)

All the dimensions were corrected by formula 1 and rounded by four significant numbers. The result is shown in figures 32 and 33.

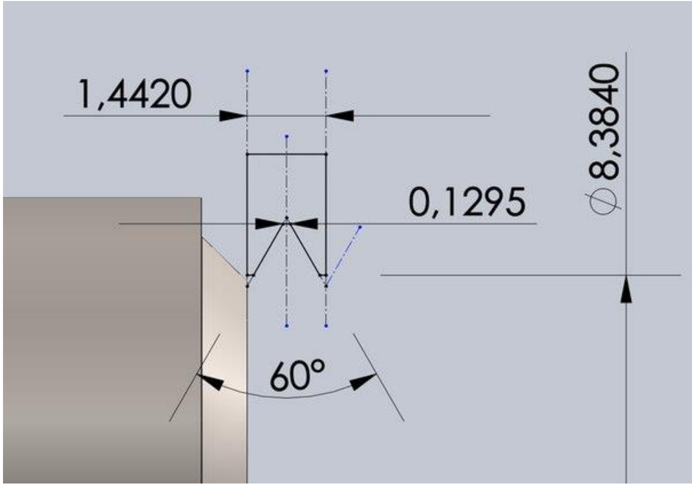

Figure 32. Bolt thread size

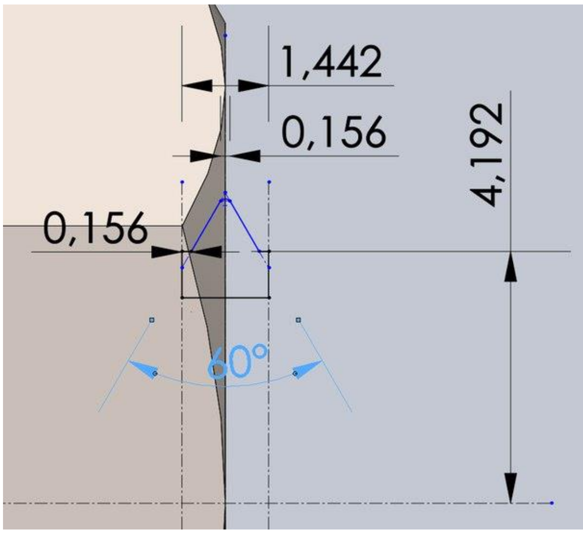

Figure 33. Nut thread profile

The bolt and nut were sent to the printer. The part was printed by using ABS plastics. The printing time was about 3 hours. After finishing of the printing, the parts were placed into the tank with NaOH for removing the support material.

7.3 Results

The results of the printing are shown in Figure 34. The test bolt and nut are fitted to each other, but it requires force to fully tighten them. This situation happened due to the distortions, which were caused by the support material. Distortions can be clearly observed on the end of the each contour. Distortions can not be prevented, because the thread has the requirement of 60° angle, when formation of the support material starts after exceeding 45° angle. Otherwise, the thread is working correctly and is very solid.

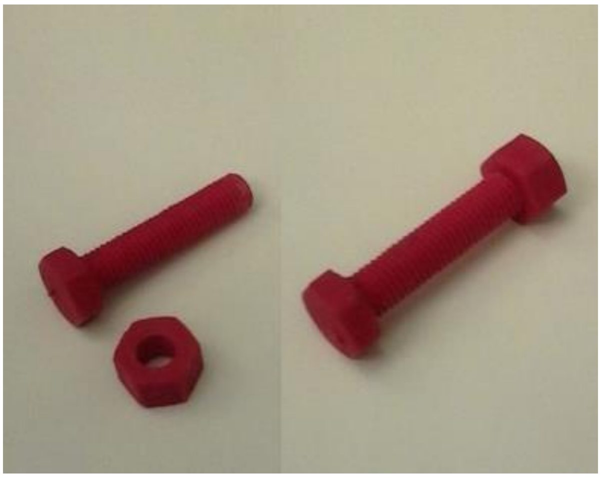

Figure 34. Test result

8 Internal supports for thin walled objects

8.1 Work objective

The objective of the work is to define the optimal design of the internal support system, which is reliable and easy to replicate.

8.2 Methodology

To define the best support design, cube was taken. The cube has the side of 100 mm and 3 mm wall thickness. There are three types of support systems in this work: hollow, X-shaped truss and X-shaped trusses at the two planes.

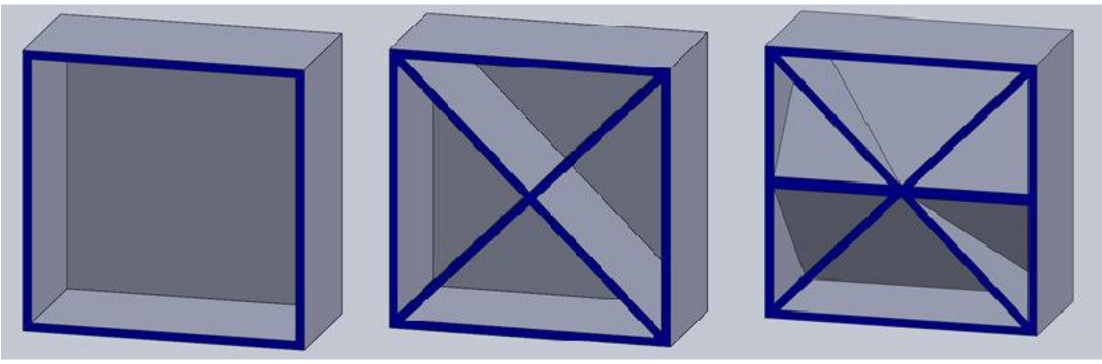

Figure 35. Test models' support systems

In the Solidworks Ad-Inn for the models was specified ABS material. The fixture was made on the opposite side of the model for the purpose of creating a compressive force of 800 N. The mesh type had high accuracy.

8.3 Results

8.3.1 Hollow model

Figure 36 shows the behaviour of the part under the compressive load. The red zone on Figure 36 takes the highest stress of 1,555*10^7. This stress is half of the ABS tensile strength.

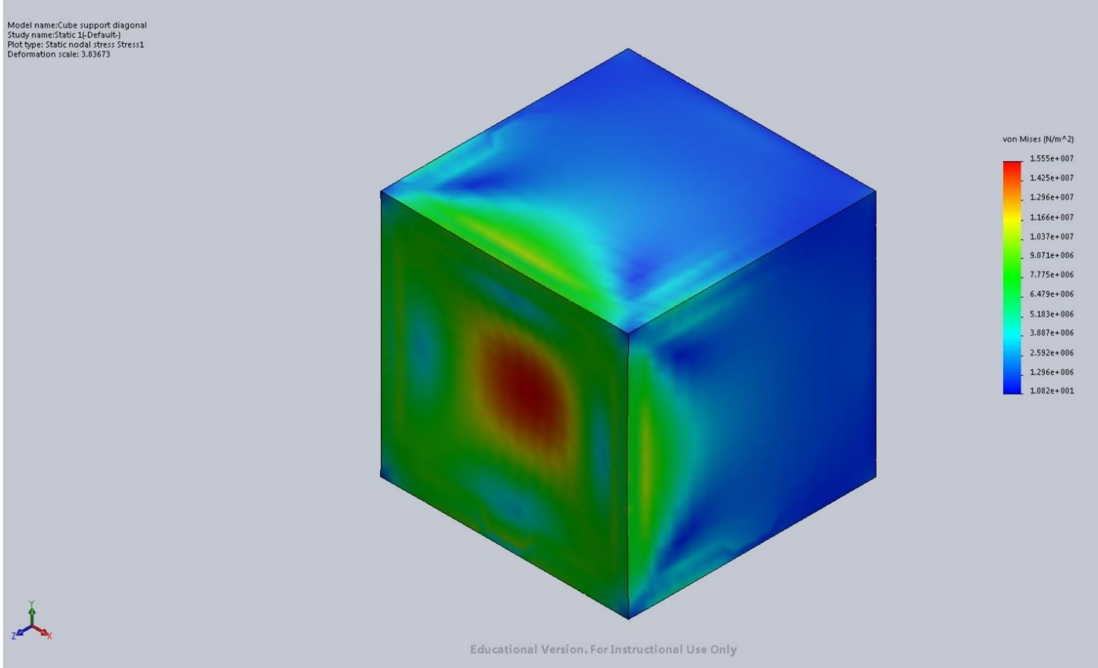

Figure 2 Hollow part von Mises stress, N/m^2

Figure 37 shows the displacement in millimeters. After application of the force, the model has a displacement of 2,8 mm in the red zone. On other zones values of the displacement are in normal condition.

It means, that the model has failed after application of the force and have low strength in the red zone.

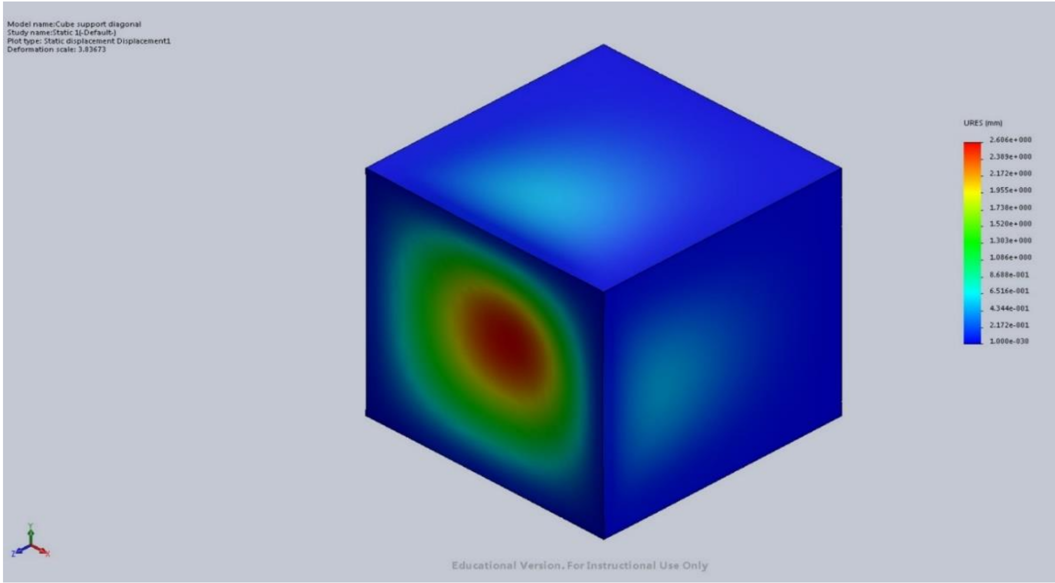

Figure 37. Hollow model displacement, mm

8.3.2 X-shaped truss model

The internal truss has the thickness equal to the wall thickness of the model. By adding a X-shaped truss the maximal stress was reduced about 5,3 times and has the value of 2,95*10^6 N/m^2.

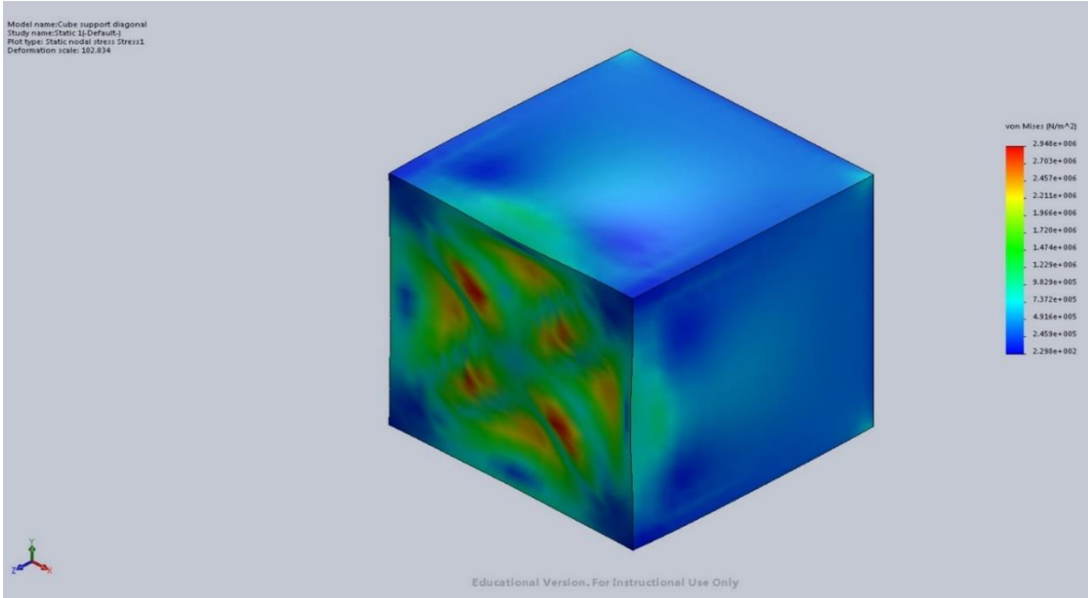

Figure 38. X-shaped truss model von Mises stress, N/m^2

Displacements also reduced and have value 0.00086518 mm.

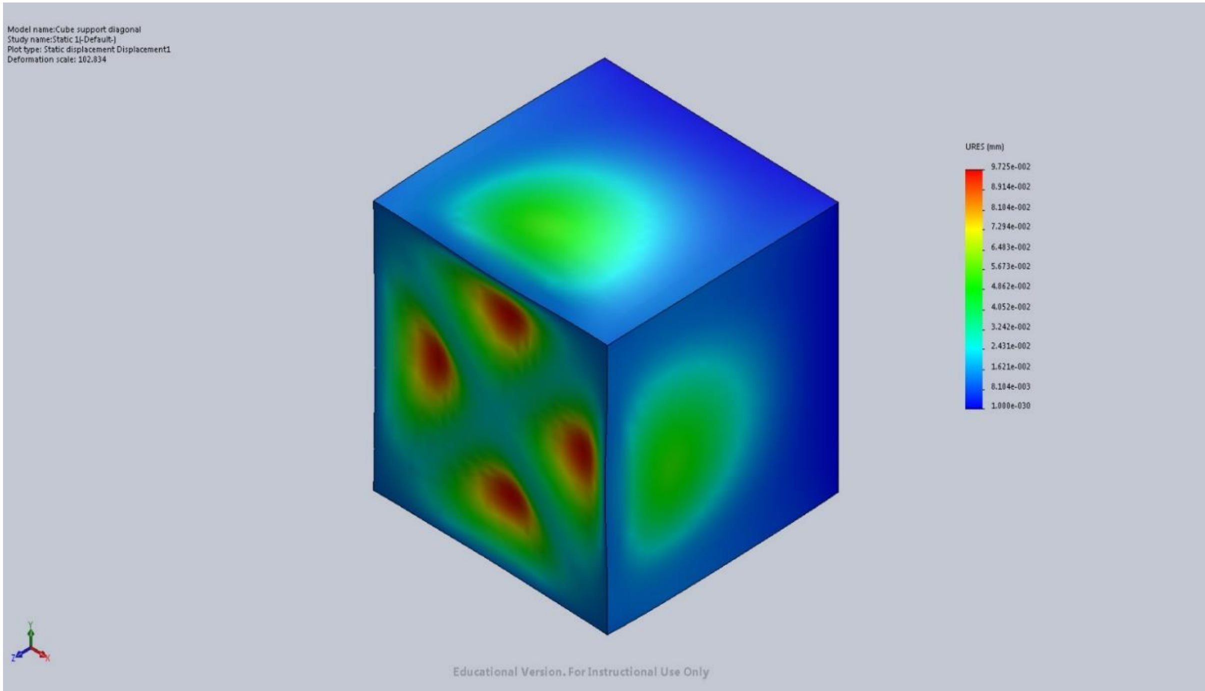

Figure 39. X-shaped truss model displacement, mm

8.3.3 X-shaped truss at the two planes

The X-shaped truss at the two planes helps to reduce the stress in the model, but it has a bigger value of displacement between the sections of the truss.

Von Mises stress at the model with trusses at two planes is 2,53668*10^6 N/m^2.

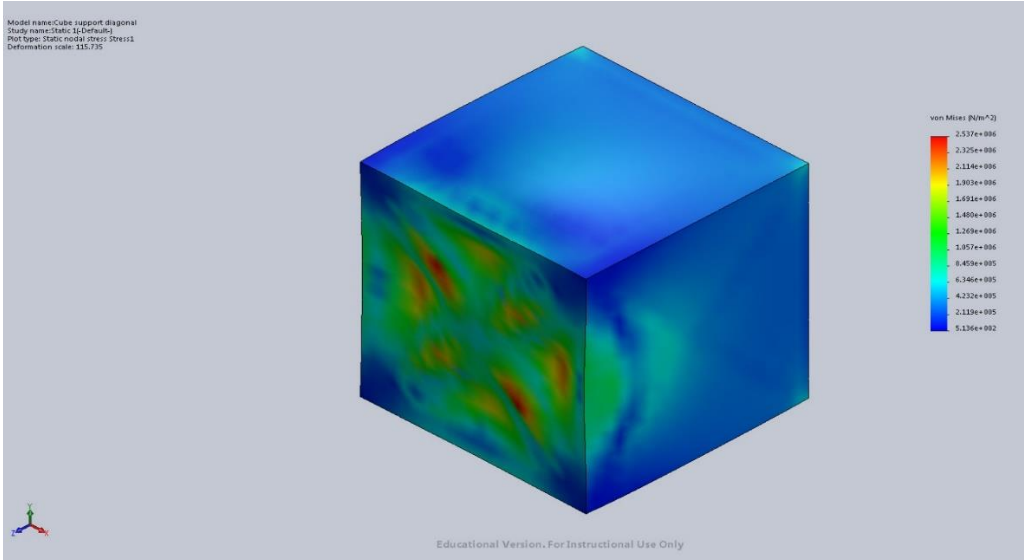

Figure 40. Two plane X-shaped truss model von Mises stress, N/m^2

Displacement in the model is higher - 0.0864048 mm, but in practice, that kind of displacement will not cause the failure.

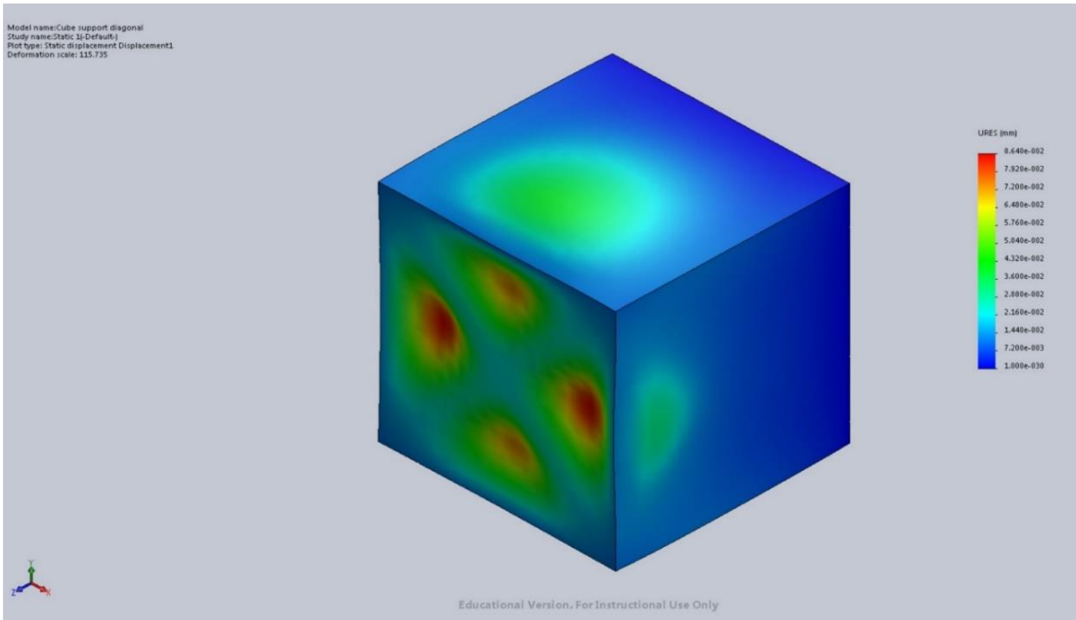

Figure 41. Two plane X-shaped truss model's displacement, mm

8.3.4 Conclusion

Both of the parts are easy to replicate and they have good strength. It is important, that the model with one plane X-shaped truss will not withstand the shear load.

For the loading at different planes it is reasonable to use a two plane X-shaped truss internal support system.

9 Summary

This thesis has high practical value for the further development and improvements of the 3D printing in the SUAS. All the results will help to create more accurate and complex models to the customers of the university.

That is why, the most important part of the thesis is the work, which tests the accuracy of 3D printer. Most of experiments needed high accuracy to create parts with small tolerances to achieve preferable parameters. The average error of the printer, which was calculated in chapter 2, helped to achieve satisfactory results, but further study is still needed.

10 List of figures

1 List of tables

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