Acta Mechanica Slovaca **27 (2): 48 - 52,** June **2023**
https://doi.org/10.21496/ams.2023.020

Acta Mechanica Slovaca
ISSN 1335-2393
www.actamechanica.sk

Static Compressive Stress Tests of the 3D Grid Model in the Solid Edge Program

Ján Kopec [1,*], Peter Trebuňa [1], Miriam Pekarčíková [1], Matúš Matiscsák [1]

[1] Department of industrial and digital engineering, Technical University of Košice, Park Komenského 9, 04001 Košice

Abstract: The company turned to us with a request for 3D printing of the grid, which is part of the cooling device. 3D printing became an attractive option for the company because creating a model would require making a mold and the company was looking for a financially viable option for production. 3D printing is a cheap option from a financial point of view since it is not necessary to have a mold, it is enough to redraw the model in the 3D form in the Solid Edge program. Another advantage is the price of the material and its properties, which we describe in more detail in this article. The only problem was the printing, more precisely the dimensions of the grid model. After consultation with the company, we agreed that the grid will be made of 3 parts, which will be complicated using a welding machine. Furthermore, the company demanded that the printout be sufficiently flexible and strong because it was inserted into the cooling device at an angle due to the limitation of the dimensions of the device's insertion space. Therefore, we also created a static test for the company in the SolidWorks program to verify the properties in a simulated environment. The results of the study are presented in the article.

Keywords: FDM, PLA, Solid Edge, static simulation

1. Introduction

FEA, which stands for Finite Element Analysis, is a method used by more and more engineers and addresses many engineering disciplines such as machine construction and strength analyses. In the field of mechanical engineering, FEA is used precisely to solve structural and thermal problems. Thanks to the versatility of FEA, this analysis is part of several modeling software, including Solid Edge. The ultimate objective of using FEA as a design tool is to change the design process from repetitive cycles of "design, prototype, test" into a streamlined process where prototypes are not used as design tools and are only needed for final design validation. With the use of FEA, design iterations are moved from the physical space of prototyping and testing into the virtual space of computer simulations [1].

The FEA methodology consists of 3 steps:
- *building a mathematical model,*
- *construction of the finite element model by discretization of the mathematical model,*

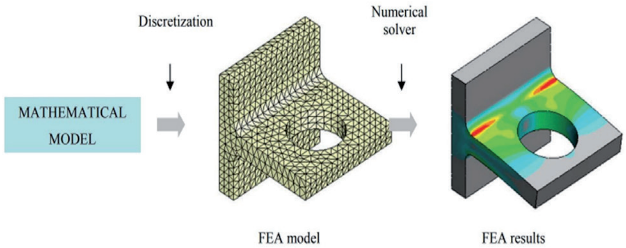


Figure 1: Building the finite element model [1].

*** Corresponding author:** Ján Kopec, ***E-mail address:*** *jan.kopec@tuke.sk*

- *finite element model solution,*
- *analysis of results (Fig.1).*

2. Experimental conditions of 3D printing

We chose the FDM (Fused Deposition Modeling) method for the print because this 3D printing technology is the most widespread in our workplace.

The extruded material in this type of 3D printing is in the form of a thermoplastic polymer, the so-called filament. Using the extruder, the filament is fed toward the heated nozzle where it is melted (Fig.2). Subsequently, the molten string is applied to the working surface of the printer through the nozzle along a predetermined path. On the surface, the string solidifies and cools, and the desired object is created by successive layering [2].

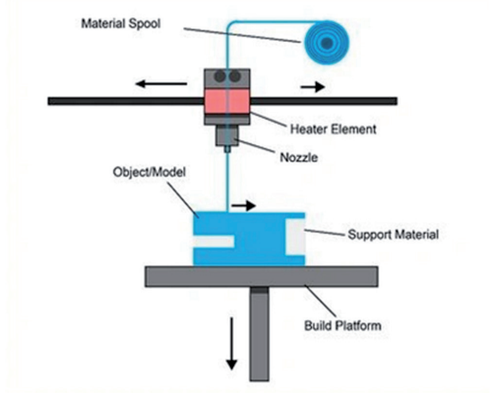


Figure 2: The process of creating 3D models using FDM technology [3].

We chose the TRILAB Deltiq 2 plus (Fig.3) as the printer. We chose the TRILAB Deltiq 2 plus printer because of the silent operation of the printer, as it is a type of delta printer. They are characterized by their accuracy and a significantly larger space for printing in the Z axis, in contrast to classic printers with a moving surface, where the printing surface moves exclusively in the Z axis. The disadvantage of this printer is the size of the printing area in the Y and X axes and the sensitivity of the Z axis calibration. This printer requires frequent maintenance and calibration. Mostly it is a manual calibration, because the printer performs the calibration itself before the printing process, but the accuracy is far from satisfactory. We chose this printer because, according to the needs of the company and the technical drawing of the printed grid, it is a large model with dimensions of up to 547 mm. The printer can print a model with a height of up to 500 mm (Z axis) and a width of up to 250 mm (X, and Y axes) [4].

Figure 3: TRILAB Deltiq 2 plus [5].

Due to the dimensional limitations of the printer, it was necessary to divide the model into 3 parts, which were welded after printing. It was not even possible to think about the orientation of the print in the KISSlicer program in portrait, because the grid is too thin and would come off the printer's base. Another problem with vertical orientation would be the need to create support between each gap, and this would waste a lot of material, which in the final form would represent unusable waste.

The material for the model was PLA (Extruded Polylactic Acid), which has the properties that the company required. This material is one of the most used and is characterized by the high quality of printed models, and an excellent lamination of the printed object.

In terms of recycling, PLA is made of natural material and is easily biodegradable, e.g., composting. This feature allows it to have safe contact with food. PLA can handle printing even at higher speeds while maintaining a perfect surface without defects. The choice of PLA material was due to its properties exactly for the elastic load of the print. It is among the easily biodegradable materials used in 3D printing, so it is also a friendly material from an ecological point of view. The material does not emit a chemical odour when heated to 210°C, unlike ABS material. The material properties of PLA directly from the manufacturer (Filamentum) are processed in Table 1. The manufacturer Fillamentum states that the PLA material is suitable for prototypes, the material does not smell and its use in electronic devices is allowed, and the material is styrene-free [6].

Table 1: Material properties of PLA [6].

Physical properties	*Typical Value*	*Test Method*	*Test Condition*
Material density	1.24 g/cm^3	ASTM D792	
Melt flow index	6g/10min	ASTM D1238	210°C, 2.16kg
Diameter tolerance	+/- 0.05 mm		
Mechanical properties	Typical Value	Test Method	Test Condition
Tensile strength	60 MPa	ASTM D882	at yield
	53 MPa	ASTM D882	at break
Elongation at break	6%	ASTM D882	
Tensile modulus	3 600 MPa	ASTM D882	
Flexural strength	83 MPa	ASTM D790	
Flexural modulus	3 800 MPa	ASTM D790	

3. 3D model processing

We chose Solid Edge as a 3D modeling program. Thanks to the technical drawing, it was only necessary to create a 3D model, without further measurements and calculations. Subsequently, the model is converted to the appropriate format (STL), for the program designed to set the printing parameters.

As stated by the printer manufacturer TRILAB, the best and freely available program for setting parameters is KISSlicer. The software is easy to use, and the setting is available in three levels, according to the user's experience.

To increase strength, we chose 100% infill without support. With this type of filling, although more material is consumed, the printing time will be significantly longer than with a normal filling of 16.7%, but the printout will be stronger. At the same time, from the point of view of accuracy, it is a more acceptable solution, because the thickness of the walls is too small, and the printer cannot create an accurate perimeter at small thicknesses and infill less than 50%.

According to the manufacturer's recommendations, a print head temperature of 210°C was used and the printing pad was heated to 55°C. The filament manufacturer also recommends the use of liquid adhesives to ensure better adhesion of the print string to the printer's substrate. The print speed should not exceed 100mm/s, so we chose 80mm/s.

After setting the print parameters, the program also provides a visual representation of the transitions of the print head, in case of collision paths or problematic filling.

4. Simulation of static tests

After the grid has been printed and welded into its final form, the static tests that the company requested from us follow. The tests took place in the form of simulation in the Solid Edge environment. After uploading the model, it was necessary to define the test parameters for the program. The program in the material library did not have properties assigned to PLA, so it was necessary to upload them manually. In the definitions of the properties, we used the PLA properties listed in Table 2.

Table 2: PLA properties defined [7,8].

Density	1.27 g/cm^3
Coef. of Thermal Exp.	101÷120 µm/m°C
Thermal Conductivity	0.13 kW/m°C
Specific Heat	1200 J/kg.K
Modulus of Elasticity	3 600 MPa
Poisson´s Ratio	0.3
Yield Stress	60 MPa
Elongation %	6

After defining the properties of the program, it is possible to assign the material to the model. The definition of force is another parameter for a static test. Since the company will bend the grid only by hand and not with the help of equipment, the force was set at 0.006 kPa. It is also because of the thickness of the wall when it is not necessary to develop more force. Another factor is the determination of boundary conditions. It is necessary to configure the program for places that are static. The last element that needs to be defined is the Mesh. Mesh represents the division of basic parameters into a set grid, which creates a network of finite elements. The start of the calculation is activated using the Run This Study option [9].

Displaying the simulation according to the specified parameters, or field of reduced voltages in Figure 4.

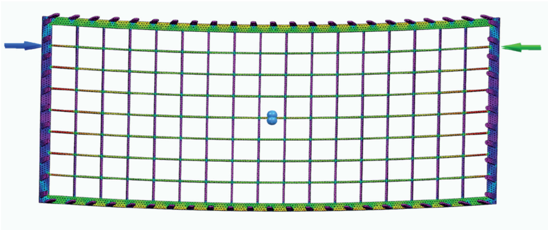


Figure 4: Field of reduced voltages.

3. Results

As can already be seen from Figure 3, the grid bent due to pressure, and the places with the greatest probability of failure were distinguished by colour. This is shown in more detail in Figure 5. The greatest probability of failure is near the application of pressure on the grid, in the walls of the grid and the ribs themselves at a constant level, except for the central area of the grid, where the stress is again increased because this area is more stressed than the others grid membranes.

In the post-simulation program, it is possible to modify the properties of the material, the grid, if necessary, creates smaller objects for a better representation of stresses, and anchor points.

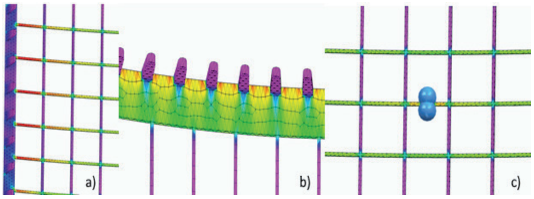
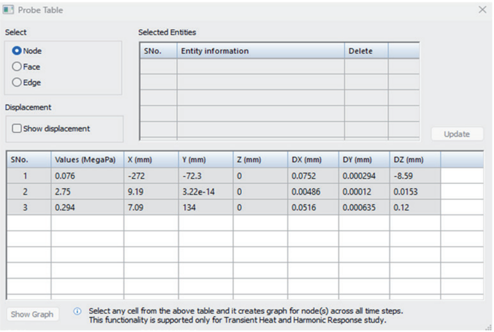


Figure 5: a) tension in the pressure area, b) deformation in the extreme region of the grid, c) area of probable violation in the centre of the grid.

The Solid Edge program also offers the possibility of creating a report on loaded areas. It is enough to mark them in the Probe option and the results will be recorded in the table (Fig. 6). The first place written in the table is the pressure area. A value of 2 indicates the action of stresses in the central area, where the stress is greatest. A value of 3 indicates the side edge that is affected. The other columns indicate the deformation in the X, Y and Z axes.



SNo.	Values (MegaPa)	X (mm)	Y (mm)	Z (mm)	DX (mm)	DY (mm)	DZ (mm)
1	0.076	-272	-72.3	0	0.0752	0.000294	-8.59
2	2.75	9.19	3.22e-14	0	0.00486	0.00012	0.0153
3	0.294	7.09	134	0	0.0516	0.000635	0.12

Figure 6: Tabular stress processing in the Solid Edge program.

Other results of the static test in the Solid Edge program include the maximum distortion criterion (von Mises yield criterion). The result is the equivalent tensile stress σ_V, which is used to determine the overload of materials under multiaxial loading conditions using the results of simple uniaxial tensile tests. In ordinary expression, calculations would be required to determine this value. The static load simulation performs the calculations automatically and no additional data from the user is required.

The voltage results are processed in Table 3.

Table 3: Stress results.

Result component: Von Miss				
Extend	Value	X	Y	Z
Minimum	1.62 e-08 MPa	265.621 mm	133.000 mm	-22.121 mm
Maximum	0.00671 MPa	-259.600 mm	-1.000 mm	0
Result Component: Factor of safety				
Extend	Value	X	Y	Z
Minimum	8.95 e+03	-259.600 mm	-1.000 mm	0
Maximum	3.65 e+09	265.621 mm	133. 000 mm	-22.121 mm
Result component: Total Summation				
Fx	Fy	Fz		
3.61 e-08 mN	1.2 e-07 mN	-9.46 e-08 mN		

4. Conclusions

The simulation process was created in the Solid Edge program, which is user-friendly and easy to operate. The result of this stress simulation is the optimal value, and the grid is most likely to resist bending. As we already described in the article, the grid was not printed in one piece but was completed by welding. Therefore, it is necessary to consider the stresses at the weld locations, which are not included in the simulations. On the other hand, the weld is made of additional material, so it is a solid place, and it is very unlikely that the grid will break in the weld area. At the indicated pressures, the simulation did not exceed the yield point of the PLA material.

The grid has already been sent to the company that put it in the machine. The network installation process took place without any violations and therefore the simulation produced correct results. Welding 3D objects also has its limitations. In this case, it was necessary to combine several parts into a whole. The 3D printing of one part of the grid created a rounding on the end parts and not a flat surface. This is because the grid was only 2 mm thick, and the print head could not create a straight edge with such a small perimeter. The resulting roundings lacked material for welding, which made the welding process even more difficult. Plastic welding is a process in which harmful substances and a strong odour are released into the air. Missing material could affect the overall strength of the grid. However, it does not significantly affect the functionality of the grid.

A classic voltage test would not be possible without a test device that must be placed in the laboratory, the test must be performed at specified temperatures and under predetermined laboratory conditions. This would make the test financially unsatisfactory. The simulation of stresses in Solid Edge only needed access to the software and sufficiently powerful hardware, because a large amount of data is processed in the calculation of the simulation. In the end, the simulation does not take much time and is more friendly for this type of test than a classic stress test.

Another goal of this article is to create comparisons of several materials and their static tests in the Solid Edge program. Another direction will be a study dealing with changes in perimeters to edges and roundings of models during 3D printing, elimination of shortcomings in the program and modification of the code for 3D printing, and last but not least, the influence of material thickness on unwanted changes in perimeters.

Acknowledgments

This article was created by the implementation of the grant projects: APVV-17-0258 Digital engineering elements application in innovation and optimization of production flows, APVV-19-0418 Intelligent solutions to enhance business innovation capability in the process of transforming them into smart businesses. VEGA 1/0438/20 Interaction of digital technologies to support software and hardware communication of the advanced production system platform. KEGA 020TUKE-4/2023 Systematic development of the competence profile of students of industrial and digital engineering in the process of higher education. VEGA 1/0508/22 „Innovative and digital technologies in manufacturing and logistics processes and system".

References and Notes

1. Kurowski, P.M., SDC Publications, USA, 2018, Engineering Analysis with SOLIDWORKS Simulation 2018, ISBN-13: 978-1-63057-153-5.
2. Gavin, T., Asadi, AA, 2015. 3D Make & Print. IMAGINE PUBLISHING, 2nd volume, 148 pages. ISBN: 978 1 78546 202 3.
3. 3D PARTS UNLIMITED, FDM FUSED DEPOSITION MODELING, from https://www.3dpartsunlimited.com/blog-post/fdm-fused-deposition-modeling/.
4. TRILAB, Trilab Deltiq 2 plus, from https://trilab3d.com/.
5. TRILAB, TRILAB DELTIQ 2 PLUS, from https://trilab3d.com/cs/3d-tiskarna-deltiq-2/.
6. Fillamentum. PLA Extrafill, from https://fillamentum.com/collections/pla-extrafill-filament/.
7. Roffelsen 3D, Material Data Sheet PLA, from https://roffelsen3d.com/wp-content/uploads/2023/02/Roffelsen3D_FFF_PLA_Material-Data-Sheet_v5.pdf?fbclid=IwAR1-_iaik2J3wcD9DGzPiwqMVX-5xT15sLfwvNXFcvQ5h4tmak1hyayfSp4.
8. MatWeb, Overview of materials for Polylactic Acid (PLA) Biopolymer, from https://www.matweb.com/search/DataSheet.aspx?MatGUID=ab96a4c0655c4018a8785ac4031b9278.
9. Bocko, J., Delyová, I., Huňady, R., Lengvarský, P., Edícia vedeckej a odbornej literatúry, Košice, 2018. SIMULÁCIA V PROGRAME SOLIDWORKS, ISBN: 978-80-553-2772-3.