Computer simulation of the strength of joints made by 3D printing

Juraj Beniak, Peter Križan, Miloš Matúš
Slovak University of Technology in Bratislava,
Faculty of Mechanical Engineering
Nam. Slobody 17, 812 31 Bratislava,
Slovak Republic
e-mail address: juraj.beniak@stuba.sk

***Abstract*—Presented paper deals with realized computer strength simulation of prepared samples for tensile strength testing. There is used FEM analyse for calculation of maximum stress within testing part. Simulation is made with using of material model suitable for 3D printed parts. The purpose is to compare the different types of joints that can be used to join parts made by 3D printing, if it is necessary to join them into larger units.**

Keywords—3D printing; additive manufacturing, FEM analysis, strength

I. INTRODUCTION

Additive manufacturing methods has progressed in the past few years, to meet the demands of producing complex structures with the extreme quality output. The factors that have driven this technology are rapid prototyping, the potential to print complex and larger structures, defects in printing and strengthening the mechanical properties of the part [1]. FDM technology the commonly used technology in additive manufacturing family [2-5]. The whole additive manufacturing methods has been classified into 7 categories as stated by International Organization for Standardization (ISO)/ American Society for Testing and Materials ISO /ASTM 52900:2015 (ASTM F2792) and few technologies are mentioned below to corresponding methods [6]

1. Binder jetting:
    • Three-dimensional printing (3DP)
2. Directed energy deposition
    • Laser metal deposition (LMD)
3. Material extrusion
    • Fused Deposition Modelling (FDM)
4. Material jetting
    • Multi jet modelling (MJM)
5. Powder bed fusion
    • Selective laser sintering (SLS)
    • Selective laser melting (SLM)
    • Electron beam melting (EBM)
6. Sheet lamination
    • Laminated object manufacturing (LOM)
7. Vat photopolymerization
    • Stereolithography

This paper deal with FDM technology which is is the most widespread in the world and many parts for rapid prototyping and also for final use parts are produced by this technology.

Fused filament fabrication (FFF), also known as fused deposition modeling (FDM), is a 3D printing process that uses an unceasing filament of a thermoplastic material [7]. Filament is nursed from a large coil through heated printer extruder head, and is placed on the mounting work. The print head is stimulated by computer control to describe the printed shape. Generally, the head passages in two dimensions to bond one horizontal plane, or layer, at a time; the work or the print head is then enthused vertically by a slight amount to begin a new layer [8-10]. The speed of the extruder head can be adjusted to stop and start deposition and produce an interrupted plane without lacing or drooling between sections.

In FDM, to make a geometry, at first everything must work in a harmonized way to get the job done. A special software is used to figure the communication among various mechanical systems [11-13]. This software elects and controls various parameters such as nozzle temperature, bed temperature, layer thickness, direction and movements of both printing head and platform to produce accurate model. [14] In Fused deposition modelling, the thermoplastic filament is heated to its melting temperature at the nozzle with the help of a heated coil surrounding the nozzle to transform the material to a suitable molten state. This liquid material streams out of the nozzle succeeding the layers of the geometry to print it [15-16].

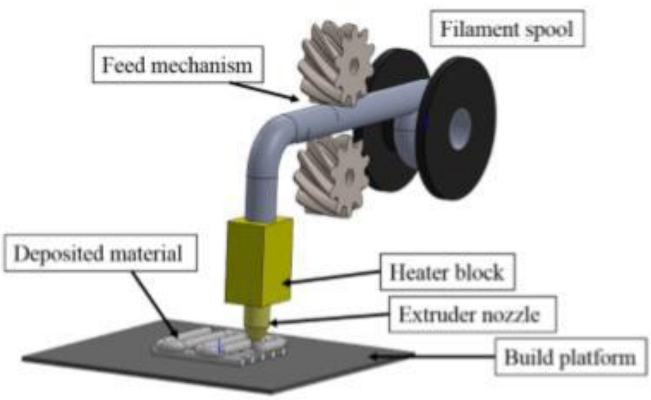

Fig. 1. *Schematic principle of FDM technolohy* [17]

The extrusion material thickness is obtained by the layer thickness for printing. As each layer is done, the extruder head moves up to print the successive layers. The adhesion of layers is defined by the layer thickness. Once the molten material leaves the nozzle it solidifies. If it is not appropriately solidified it generates warping which is a huge apprehension for FDM thermoplastics which lessens its mechanical strength [1]. Cost effective, diversity of materials, less time taking and user-friendliness are the key benefits to FDM technology. Disadvantage is that it often results in ribbing, warping and poor mechanical strengths.

II. Materials and Methods

FDM printers are cheaper and more consumer-reliable production technique than other technologies, because of the easiness of the mechanical construction of FDM machines, and also the lesser need in finishing than powder or resin practices. Bigger models can also be produced as per wish of consumers. Although these add some weightage to FDM, it has some disadvantages on the other hand. SLS and Binder jetting technologies can achieve a higher resolution of 10µm while FDM can only achieve 100µm or above it. So, factors such as surface quality, accuracy have a huge impact on producing a part.

Considering the criticality such as in printing the parts using FDM this paper deals with selection of joints that can be suitably manufactured by FDM 3d printers. Some of the joints that have been used classically for mechanical works i.e. basic mechanical joints have been taken it considerations.

- Annular snap fit joints
- Dovetail joints
- Pen cap fit joints
- Screw fit joints
- Buckle joints

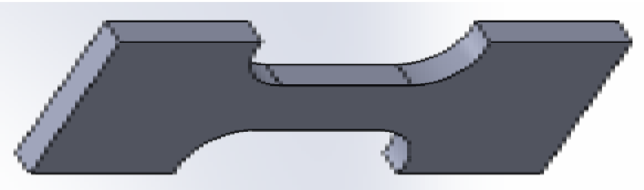

Fig. 2. *Shape of tested specimen – not divided*

Annular Joint

Designing parts with snap fits can bar time and money in manufacturing by plummeting material costs and part quantities and also improving assembling effortlessness. Classical thermoplastic materials are better suited because of their good suppleness and skill to be simple and economically molded into compound geometries. Hence, it is better to have a considerable idea of snap fit design and its design interaction with FDM printer and its properties. With this design intent right parts can be manufactured at ease. Snap fits are ideal for FDM printers, especially for prototyping.

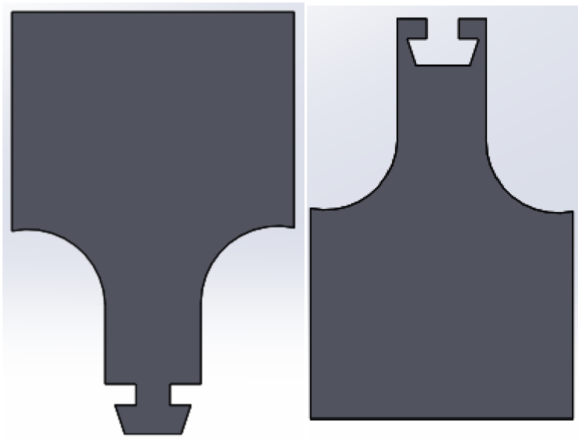

Fig. 3. *Anular Joint*

Pen cap fit

Pen cap fit are normally used for all kinds of stationary products like pens, sketches extra. Sometimes these types of joints are also used in the piping fields for crating a removable joint. These joints hold each other by an interference fit, where the mating parts width might be slightly higher than the other mating part. The friction between them also helps in the fitment of this joint. Chamfers and fillets are used at the edges of the fitments in order to ease the action of joining and to reduce the damage of the part, which thereby increases the quality of the part. These joints are well suited for a FDM printing because it is well suited for materials like PLA and ABS.

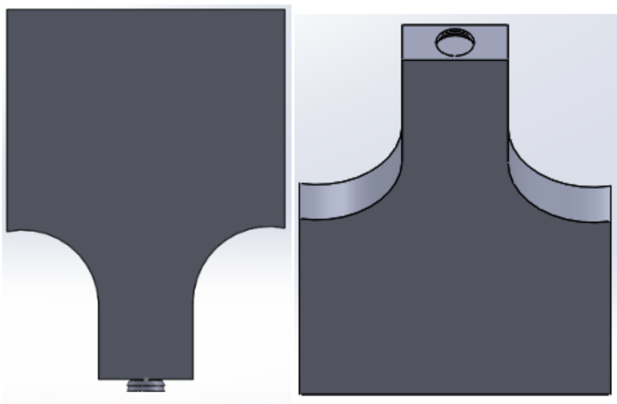

Fig. 4. *Pen Joint*

Buckle Joints

Buckle joints are type of snap fit joint. These types of joints are commonly seen this mostly every daily used product like bags, purse, etc. These joints can be made only into separable joints based on the construction of its design. They add an ease of application to its working. The strength of the printed part has to be ensured as the fitment area of this joint will be exposed to consecutive stress and strain while in application. This joint also uses the concept of interference for fitment and hence the friction acts on the walls of the fitment area during the load application.

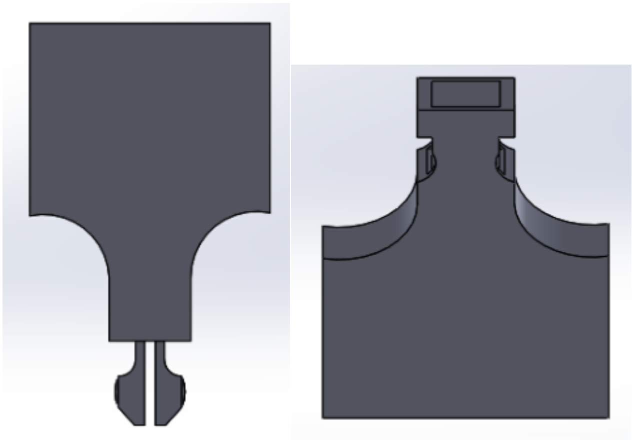

Fig. 5. *Buckle Joint*

Dovetail Joint

Conventionally dovetail joints only yield the making of two - dimensional frames that are then joined in three dimensions, approximately in a very similar piped or triangulated form within the whole part. The friction between the joint's members held it together, without the help of other adhesive elements, enabling the assembling of joints without designated tools. Dovetail joints or tenon and mortise, have been used since ages for construction and architectures, all around the world. Advancements in the manufacturing technology have made the cost as low as possible for mass production. [18]

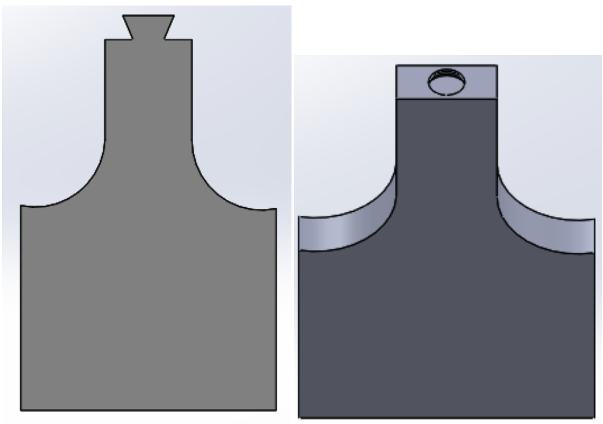

Fig. 6. *Dovetail Joint*

Screw joints

Injection molded screw should be robust to attain the anticipated holding forces and but not very thick to dodge the part flaws like descends or cavities in the plastic. Threading into plastic with metal screws can affect in a diverse failure. Hence, precise hole size and wall thickness are most important as failures may rise on both sides of the sizing. If the hole has oversized, the joint will flop due to the missing of thread engagement that will be stripped out completely as the screw is made to fit.

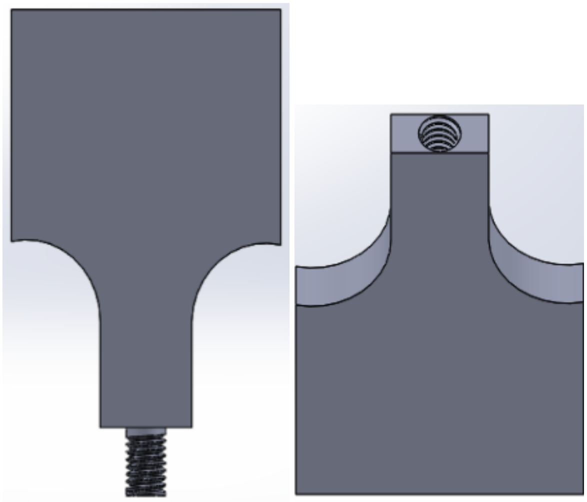

Fig. 7. *Screw fit Joint*

The minimum sized screw may actually rip off because of the torsion required for inset or the screw engagement or thread fitment. Undersize holes will incline to break the threads or the part will break because of radial and/or hoop stresses, if the large screw size is large.

These above mentioned joints types are used for further simulation. This simulation is made by SolidWorks Simulation module. Applied force is F = 2000 N. Material of samples is ABS (Acrylonitrile butadiene styrene). Loading is in the same way as within the tensile strength testing.

III. Results

Each of mentioned type of join, including the regular solid part without any joint, are simulated and the resulted maximum values are examined (Table I)

TABLE I. Stress values from analysis

Joint tipe	Stress (MPa)
(1) Regular	31,2

(2) Annular	14,8
(3) Pen	6,2
(4) Buckle	4,1
(5) Dovetail	12,1
(6) Screw fit	17,9

On the Figure 8 is illustration of result from simulation which is made on Regular solid part. Critical areas are colored in red color. Blue color is the place where the part is fixed, so there is no stress caused by applied force.

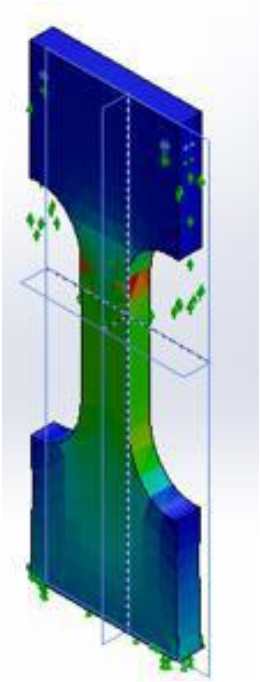

Fig. 8. *Ilustration of Stress Analysis result*

Measured values, which are presented in Table 1, could be presented also in graphical form, what give us better overview (Figure 9.).

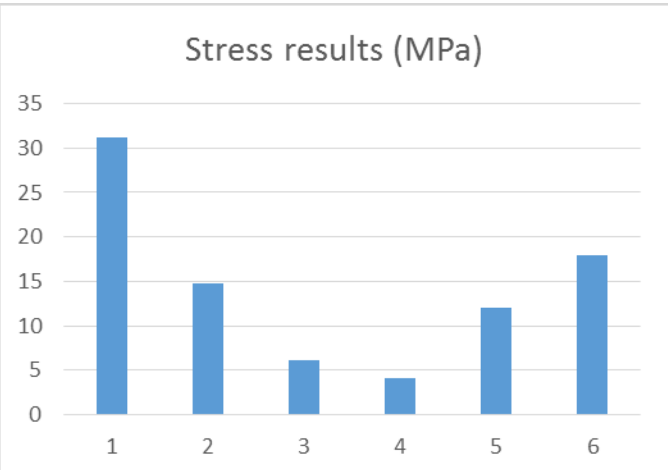

Fig. 9. *Comparison of Stress Analysis Resulst*

We can clearly see, that the best result is given by joint number 6 (Screw fit) with value 17,9 MPa. The regular sample is not taken into consideration. This value is just for comparison.

Second best result is given by Joint No. 2 (Annular) with value 14,8 MPa.

On the third place is joint No. 5 (Dovetail) with value of 12.1 MPa.

On the fourth place is joint No. 3 (Pen) with 6,2 MPa calculated stress value.

Last place become to the Buckle joint (No. 4) with value 4,1 MPa.

IV. Conclusion

From the presented data, which are displayer above, can be state that the best strength can be obtained by using of screw fir joint. This is because that the screw type have the biggest connection surface, which is distributed to the separate threads. The loaded force is equally spread.

The same reasoning can be applied also for others shapes of joints but with worse result.

Obtained simulation results have been confirmed also by real testing on tensile strength machine with the same order of joints.

Results are important when it is necessary to connect more parts together with shaped joint without gluing or others solid connection.

Acknowledgment

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