Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) 334-342
© Universiti Tun Hussein Onn Malaysia Publisher's Office

RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Fused Deposition Modeling(FDM) Custom Internal Filling Structural Mechanics Simulation

Sabri Japrin[1]**, Mustaffa Ibrahim**[1*]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Johor, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2021.02.02.038
Received 02 Aug. 2021; Accepted 27 Nov. 2021; Available online 25 December 2021

Abstract: FDM is a very complex method that relies on many factors which including the characteristics of the heat source scanning techniques, powder bed, and material properties makes several problems remain such as require too much printing time and material used. The objective of this study was to simulate and optimize internal structure infill so that the weight and printing duration of the 3D structure can be reduced and compare the mechanical performance between ABS filament and PLA filament using COMSOL Multiphysics. The carabiner infill structure used two different infill patterns and manipulating different densities of the same material using slicer software. At the end of the result, the printing time and filament used can be reduced by 17%. This shows that the custom infill is much more economical in terms of material cost compared to the solid infill. The study also finds that different material filaments produced different displacements. ABS filament produces longer displacement compared to PLA filament due to it is a bit flexible and therefore less brittle than PLA. Even though ABS material had higher displacement but in the real-life industry, PLA filament is easier to be printed because PLA nozzle temperatures are lower compared to ABS filament.

Keywords: FDM, Custom Infill, PLA, ABS, Simulation

1. Introduction

Additive manufacturing has grown into a favored industry that incorporates multiple materials and techniques and has gained prominence worldwide. Fused Deposition Modeling is a widely used AM process that is affordable with free control of process parameters. In this modern age, modeling and simulation will play a vital part which changes to conventional approaches to trial and error including for the design as well as the optimization of the components and materials. In additive manufacturing, existing modeling and simulation techniques used to simulate materials production are being expanded.

At various length scales, models are required to account for the structural specifics of this new class of materials and to explain the simple physical processes that are involved in these materials performance responses. The FDM process makes it possible to control the internal structure of the 3D printed object. Indeed, the slicer software proposes settings to control the fraction of material and the

*Corresponding author: mustaffa@uthm.edu.my

infill pattern geometry. Infill optimization is another way to reduce weight while maintaining good mechanical performance.

Additive technologies vary in many ways from traditional industrial technologies and have immense potential if applied purposely with regard to their unique characteristics [1]. Additive Manufacturing(AM) processes have the capacity to generate layer by layer 3D parts of relatively close measurements directly from 3D computer aided design data [2]. Some of the AM processes need no post-processing or limited post-processing, and in real-time implementations, the parts generated can be used directly. Several methods, such as selective laser sintering, selective laser melting and electron beam melting are used in additive manufacturing technology [3]

An additive manufacturing technology is also known as Fused Deposition Modeling (FDM) process. This procedure involves using a work head to melt a thermoplastic supplied in the form of a wire or filament and through a small nozzle to extrude the melted thermoplastic to deposit the material using machine control along a pre-planned route. For extrusion and deposition purposes, the majority of existing FDM machines use thermoplastic materials in a filament type which thermoplastics Acrylonitrile Butadiene styrene (ABS) and Polylactide (PLA) are primarily materials used in the process [4]. Due to the extreme variations in FDM technology, the strength of the components made using this technology must be tested which is the effect of two controllable variables such as the pattern and density of the infill was measured in this work [5]. Honeycomb structures are also used to provide the layer with physical stability and the object with mechanical integrity as an infill in additive manufacturing [6].

Different processes influence the characteristics of FDM-produced goods such as layer thickness, build orientation, raster distance and print speed parameters [7]. The mechanical qualities of 3D printed parts can be considerably influenced by the printing parameters [8]. Five process parameters which are an air gap, raster width, raster angle, contour number and contour width are considered in the investigation. Among the parameters considered, the influence of raster angle was the highest [9]. The printing method and physical features of the printed object are greatly influenced by the infill pattern and volume percentage [10]. In the case of flexural loading, the most cost efficient infill configuration was also the low density infill [11]. Other than that, using production-grade printers found that low density infill is more cost-effective than solid infill style [11].

The aim of this research was to simulate and optimize internal structure infill so that the weight and printing duration of the 3D structure can be reduced. Besides that, the purpose of this paper was to compare the mechanical performance between ABS filament and PLA filament and to analyze the simulation using CAMSOL Multiphysics in order to improve the efficiency in the additive manufacturing process.

The finding of this study will redound to the benefit of society especially in the manufacturing industry considering that simulation plays an important role in the industry today. The greater demand for simulation in additive manufacturing justifies the need to reduce weight and improve the mechanical performance of the 3D printed structure. Improved simulation capabilities can make it possible to address several important AM specific physics questions for the first time and it is crucial to enhance the quality which reduces the processing time and ultimately reduce the cost of an AM product. Thus, a simulation is needed in order to gain more understanding about additive manufacturing by using CAMSOL multiphysis software.

2. Methodology

In order to optimize the internal structure infill so the printing time and material used can be reduced, the custom infill been applied to the carabiner. COMSOL Multiphysis the used to analyze the von mises stress and deformation of the carabiner.

2.1 Custom Infill

The production and simulation of custom infill have gained more interest because AM enables certain components to be produced with different infill patterns and densities. By combining two or more different infill patterns or by manipulating different densities of the same material by additive manufacturing makes a custom infill product can be made. The infill density used is 25% and honeycomb pattern at low stress zone. The high stress zone then used 75% infill density and grid pattern.

2.2 Methods

The first process is to select the design and draw it in 3D model using Solidwork. The design selection is a very important part where the design must be able to fulfill the objective. The design must a model which can applied the force in order to measure the mechanical performance of the design by using COMSOL Multiphysics. The second process was to analyses the mechanical performance of the model by using COMSOL Multiphysics. The solid infill density is analyzing first in order to make the comparison with custom infill.

The third process was to modify the model using varies infill density. The infill density chosen was 25% and 75%. Infill pattern such as grid pattern and honeycomb shape is chosen as the best pattern to be used. Honeycomb shape are structures that have a honeycomb geometry to allow the amount of material used to be minimized to achieve minimal weight and minimal cost of the material. A structure shaped by a honeycomb offers a material with minimal density, compression properties and a relative high outline. The next process was to analyze the 3D model same as in the first process but with varies infill density to gain the result. The parameter such as the time needed to complete the model, mass of the model, Von Misses stress and displacement always checked after the data obtained. The overall flow process shown in Figure 1.

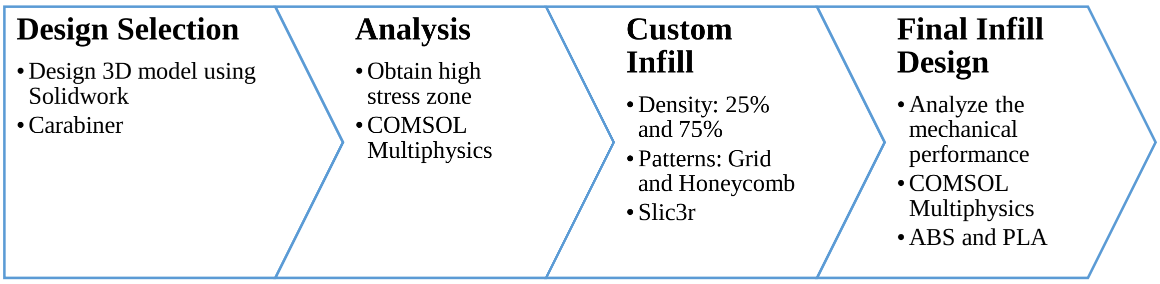

Figure 1: Process from Design Selection until Final Infill Design

2.3 Materials

The first filament material is Acrylonitrile Butadiene Styrene (ABS). ABS is indeed tough and has properties that are impact resistant. It is this power and moderate usability that makes it such a fantastic 3D printing option. It is very quick to extrude from the nozzles of the printer, making it a convenient material to deal with. Needless to mention, decent ventilation is invaluable. Combined, these items make ABS a material that is more favored by experts than by amateur consumers.

The second material is Polylactic Acid(PLA). PLA commonly used by amateurs. It is a special type of thermoplastic manufactured from organic ingredients, such as sugarcane and cornstarch. The key advantages of PLA are that it is cleaner and easier to use, and without caring about poisonous gases.

PLA creates 3D pieces that are more aesthetically appealing compared to ABS. This finish is due to its distinctive brilliance and smooth presentation.

Furthermore, this is due to it has a glass transition temperature that is low enough to achieve good bonding between layers of melt material that are successively coated and high enough to retain their form for printed parts at mild operating temperatures. In both disposable and packaging uses, PLA is already used and is currently under review. PLA also has a relatively low glass transition temperature. This leaves it fairly unsuitable for high temperature applications. In the summer, even things like a hot car can cause parts to soften and distort. Polylactic Acid is a bit more brittle than ABS for 3D prototyping, but it has some benefits as well.

3. Results and Discussion

The results and discussion section presents data and analysis of the study. This section can be organized based on the stated objectives, the chronological timeline, different case groupings, different experimental configurations, or any logical order as deemed appropriate.

3.1 Printing Time Results

The printing data is obtained from slicer software to make a comparison between solid infill and custom infill. Based on the previous research, it is found that honeycomb pattern produced high strength when used below 50% infill density. Then, grid pattern been used at high stress zone with 75% infill density. The custom infill using 25% and 75% density as shown in Figure 2.

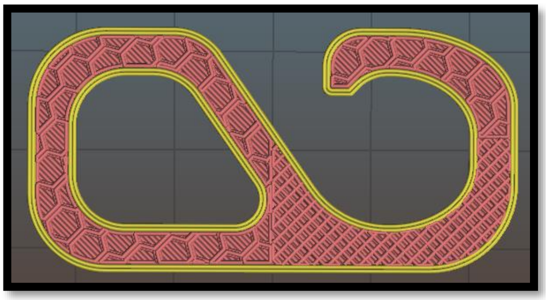

Figure 2: Carabiner with Custom Infill

The carabiner with custom infill then sliced using slicer software to find the printing time and material used. The printing time for custom infill is less than solid infill by 17% which use two different infill pattern and infill density. The filament used in custom infill use 0.3990 meters less by 17% compared to solid infill which is 0.4786 meter as shown in Table 1.

Table 1: Filament Used and Printing Time

Infill	Printing Time (min)	Filament Used (m)
Solid	41	0.4786
Custom	34	0.3990
Reduction	17	17

3.2 Von Mises Stress Results Using Custom Infill

The Von Mises Stress is the location where the infill structure to be adjusted to reduce the printing time and material used. The yellow indicated the maximum Von Mises Stress which is the location where the failure occurred. The blue colour indicated the lowest Von Mises Stress. The force used is maximum at 0.7kN which is the standard tensile test to be used when testing the open gate carabiner. The maximum Von Mises Stress for PLA filament is 1.18 GPa as shown in Figure 3.

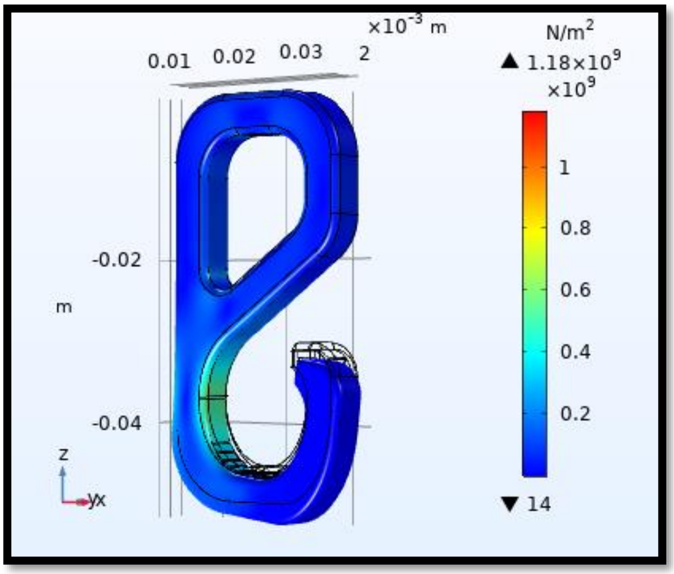

Figure 3: Von Mises Stress for PLA Filament

For ABS filament, the maximum von mises stress is 1.19GPa as shown in Figure 4. The stress is 0.17GPa when the 0.1kN force is applied then keeps increasing until the maximum force applied which is 0.7kN.

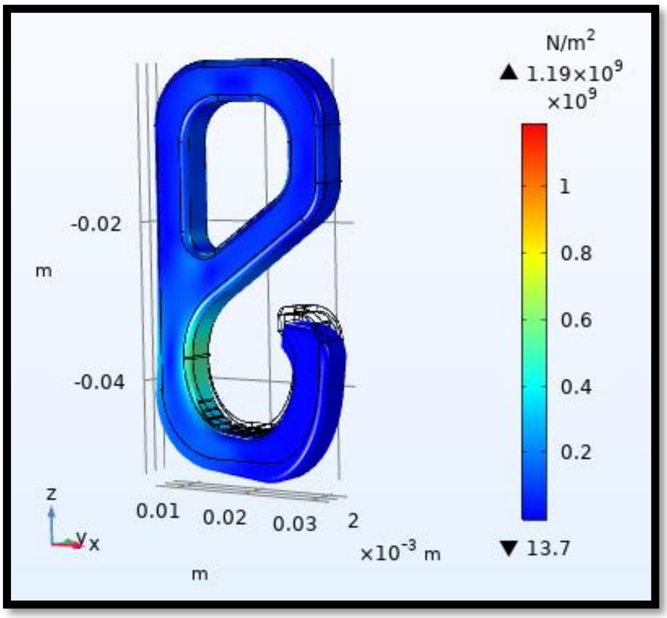

Figure 4: Von Mises Stress for ABS Filament

The force applied is from 0.1kN to 0.7kN as shown in Figure 5. The figure also showed a directly proportional graph which means that when the force is increased, the stress produced also increased. For example, when 0.1kN force is applied, the stress produced is 0.169GPa. Then applied force is increased to 0.2kN which makes the Von Mises Stress of the carabiner also increased to 0.338GPa. The Stress keeps increasing until the maximum 0.7kN force being applied which produces 1.18GPa stress to the carabiner.

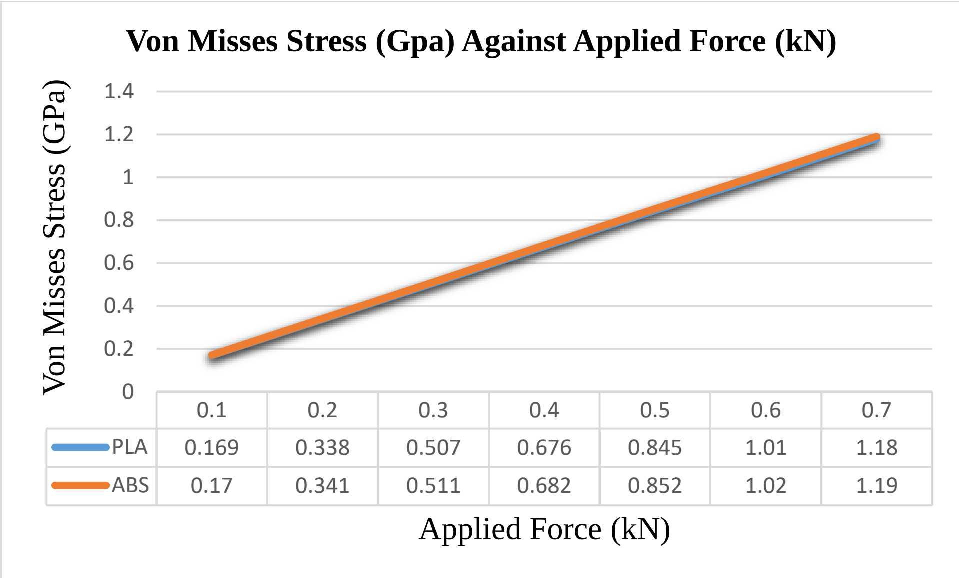

Figure 5: Graph Von Mises Stress against Applied Force for ABS and PLA Filament

3.4 Carabiner Displacement Results

After the force being applied to the carabiner, the displacement has been obtained. The displacement gradually increases as the force increased as shown in Figure 6 by using PLA filament. The figure shows that displacement is directly proportional to the is applied force. When 0.1 kN force applied to the carabiner hook, the displacement is 2.8684 mm by using PLA filament. The value then gradually increases as the force increased which is the maximum applied force is 0.7 kN produced 20.079 mm displacement.

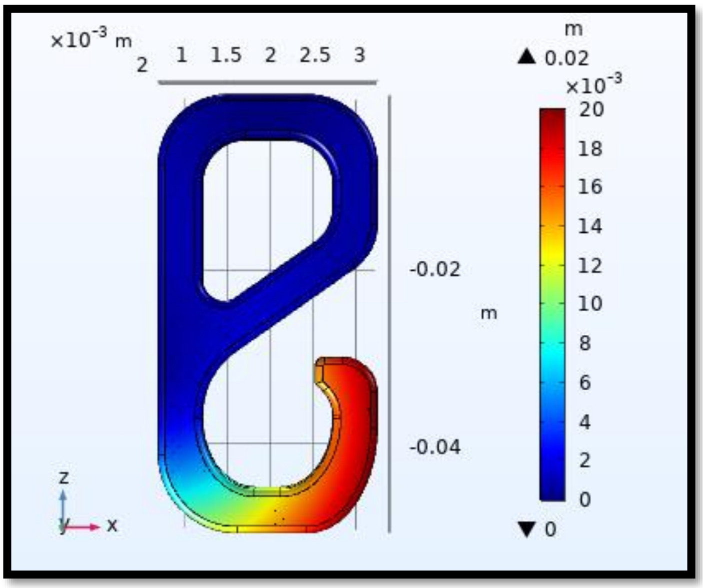

Figure 6: Carabiner Displacement Using PLA Filament

The displacement by using ABS filament is higher compare to PLA filament. The highest displacement is 35.554mm where the force applied is 0.7Kn as shown in Figure 7. The red colour indicated the highest displacement occurred.

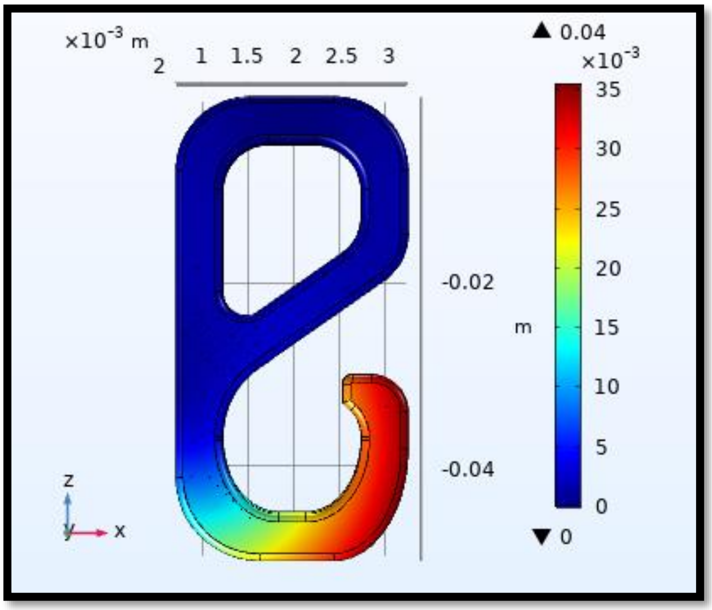

Figure 7: Carabiner Displacement Using ABS Filament

Based on Figure 8, it showed the comparison of carabiner displacement by using different filament material which is PLA and ABS. The red line represented the ABS filament while the blue line represented the PLA filament. The ABS filament produces higher displacement compare to PLA filament.

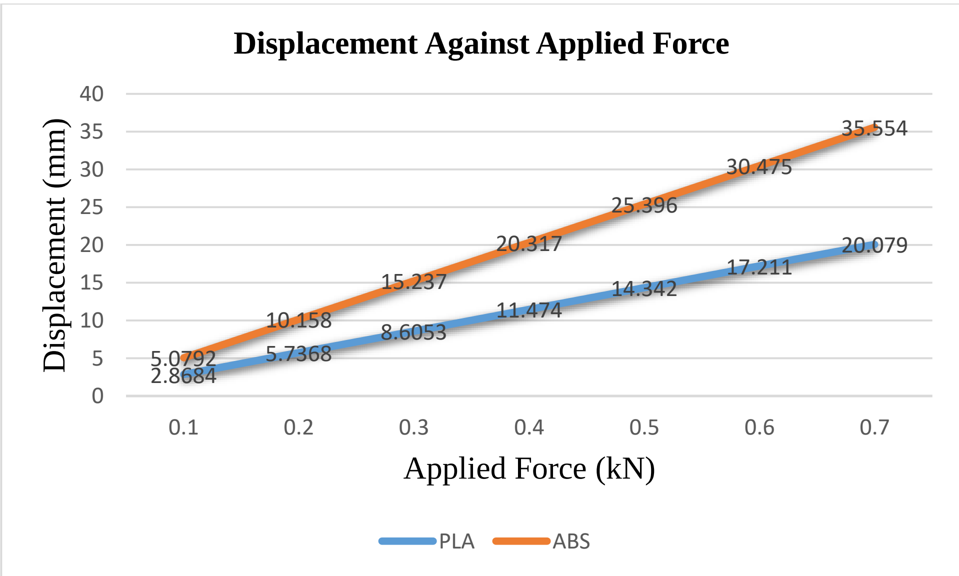

Figure 8: Graph Displacement Against Applied Force

4. Discussion

From printing time for both solid infill and custom infill, it can be seen that there is a reduction by 17% where the custom infill print faster than solid infill by 7 minutes. This is due to the custom infill use of 2 types of infill patterns which are applied in an effective way. The overall carabiner used honeycomb pattern with 25% infill density which provides greater overall strength in all directions with very little increase in print time. Then the zone with high stress zone been applied grid pattern which uses 75% infill density to make sure that the strength of the carabiner model is not affected. The solid infill used more filaments to be used when printing the model which is 0.4786-meter. The value is much higher by 17% compared to custom infill which only 0.399-meter filament. This shows that the custom infill is much more economical in terms of material cost compared to the solid infill.

The force has been applied from 0.1kN until 0.7kN because it is easy to monitor the displacement change of the carabiner. The filament material used is PLA and ABS in order to make a comparison of which is the better filament to be used. For von mises stress simulation, it shows that there is not much difference when using different material which is PLA and ABS. The graph for von mises stress against applied force show a directly proportional line which means that the stress increase as the force increases. The maximum von mises stress of the carabiner when 0.7kN load applied is 1.18GPa for PLA and 1.19GPa for ABS which only 0.01GPa difference.

The displacement for both ABS and PLA filament show directly proportional to the applied force which means the higher the applied force added, the longer the displacement of the carabiner. The maximum displacement for ABS filament is 35.554mm higher compared to PLA which is only 20.079mm. This is due to ABS material is a bit flexible and therefore less brittle than PLA. The PLA filament is a user-friendly thermoplastic with higher stiffness and strength compared to ABS which makes the model form PLA material is brittle and leading to parts with poor impact resistance and durability. The other reason which make the ABS filament had higher displacement compare to PLA filament are due to ABS is a bit more durable and has four times the higher impact resistance.

5. Conclusion

The study was about a simulation of custom internal filling structural based on FDM process. The printing time and material used able to be reduced by adjusting the infill pattern and infill density. The objective of this simulation was successfully achieved. The carabiner 3D model been successfully designed by using Solidworks following the stand for open gate carabiner. Optimising the infill design is important to meet the industry standard which produces a product high mechanical performance using low material usage. Using different filament materials produced almost similar results in von mises stress which is the maximum stress for PLA filament is 1.18GPa and 1.19GPa for ABS filament. There is a difference in displacement for using different filament materials. The ABS filament had higher durability and less brittle compared to PLA filament material. Even though ABS material had higher displacement, but it not user-friendly thermoplastic with higher stiffness and strength compared to PLA material. In real life industry, PLA filament is easier to be printed because PLA nozzle temperatures are lower compared to ABS filament. The PLA material also more recyclable and can be biodegraded which able to meet the element of sustainability. Furthermore, ABS and PLA are great materials but for different reasons.

Acknowledgement

The author would like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for it support in conducting the research.

References

[1] Gausemeier, Jürgen & Schmidt, Michael & Anderl, Reiner & Schmid, Hans-Joachim & Leyens, Christoph & Seliger, Günter & Winzer, Petra & Kohlhuber, Martina & Kage, Martin & Karg, Michael. (2017). Additive Manufacturing. Page 2

[2] Gokuldoss, P.K.; Kolla, S.; Eckert, J. Additive Manufacturing Processes: Selective Laser Melting, Electron Beam Melting and Binder Jetting—Selection Guidelines. Materials 2017, 10, 672, page 1

[3] Serin, G., KAHYA, M., Unver, H. O., Durlu, N., Eroğul, O., & Gulec, Y. (2016). A review of additive manufacturing technologies. In 17th Int. Conf. Mach. Des. Prod., Bursa, Turkey.

[4] Chennakesava, P., & Narayan, Y. S. (2014). Fused deposition modeling-insights. In International Conference on Advances in Design and Manufacturing (ICAD&M'14) (p. 1345).

[5] Ul Ahsan, A. M. M., and Khoda, B. (October 7, 2020). "Characterizing Novel Honeycomb Infill Pattern for Additive Manufacturing." ASME. J. Manuf. Sci. Eng. February 2021; 143(2): 021002.

[6] Dey, A., & Yodo, N. (2019). A systematic survey of FDM process parameter optimization and their influence on part characteristics. Journal of Manufacturing and Materials Processing, 3(3), 64.

[7] Onwubolu, G.C.; Rayegani, F. Characterization and optimization of mechanical properties of ABS partsmanufactured by the fused deposition modelling process. Int. J. Manuf. Eng. 2014, 1–13

[8] Chamil Abeykoon, Pimpisut Sri-Amphorn, Anura Fernando, 2020, “Optimization of fused deposition modeling parameters for improved PLA and ABS 3D printed structures”, International Journal of Lightweight Materials and Manufacture, page 284-297.

[9] Aboma Wagari Gebisa, Hirpa G. Lemu, 2019, “Influence of 3D Printing FDM Process Parameters on Tensile Property of ULTEM 9085”, Procedia Manufacturing, page 331-338.

[10] Wang, W., Wang, T. Y., Yang, Z., Liu, L., Tong, X., Tong, W., ... & Liu, X. (2013). Cost-effective printing of 3D objects with skin-frame structures. ACM Transactions on Graphics (TOG), 32(6), 1-10.

[11] Dr. h.c. Svante Littmarck, “Modeling Stresses and Strains in COMSOL Multiphysics,” 2018. https://www.comsol.com/video/modeling-stresses-strains-comsol-multiphysics.html (accessed Dec. 07, 2020)