EVALUATION OF MECHANICAL PROPERTIES OF MULTI-FIBER REINFORCED 3D PRINTED ABS COMPOSITES

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Abstract - *Reinforced composites having a huge impact on industrial application. With time revolution smart material and smart technologies come in front of the world and being important assets. The dual extruder FDM process is one of the revolutions in the field of additive manufacturing. Present dual extrusion process vastly used techniques for medical sector education. Printing of multi fiber-reinforced structural composite with different working process parameters defect-free is the most challenging sight. In this article with varying two reinforced composites and their structural composites specimens are being printed, tested, and evaluating analysis of it. To come up with behavioral measures of how dual extrusion is being stood with which are discussed here.*

Key Words: Fused Deposition Modelling, Fiber Reinforcement, Polymer Matrix Composites, Multi material printing, Mechanical Behaviour, Printing parameters, etc.

1. INTRODUCTION

Additive Manufacturing Technology has many applications for production of structures from computer aided models to high performance parts. Additive Manufacturing also referred as 3D printing, rapid prototyping(RP), or solid freeform(SFF), is a 'process of joining materials to make objects from 3D model data, usually layer by layer' [1], which was first described in 1986 by Charles Hull [2]. It differs from conventional manufacturing techniques such as machining and casting for its capability, to produce composite shapes with excellent design flexibility without any waste generation. It improves the time required to develop the product, thereby facilitating mass production[3]. Nowadays the usage of three dimensional printer has been raised with average cost ranging on market. For commercial usage three dimension printers have been increased in every sector on market, for example, aerospace, spare parts manufacturing, automobile, etc. In fact it is required skilled and expertise person to do both software and final printing work. In production industries three-dimension printers are most emerging product on market[4].

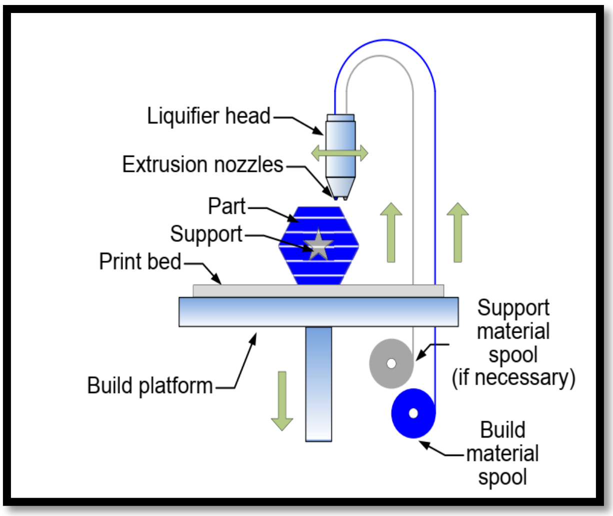

Fig -1: Fused Deposition Modeling[5]

Recent advances in the field of Additive Manufacturing (AM) have generated an increased interest in the context of Fiber Reinforced Polymers (FRP) part production [6]. The inclusion of reinforced fibers in printed parts has shown promising solutions to manufacture stronger FDM parts [7]. Different fibers have been used to improve mechanical properties of FDM parts [8,9]. Fiber reinforcement can significantly enhance the properties of resins/polymeric matrix materials. Although continuous fiber composites offer high mechanical performance, their processing is not commonplace. More commonly used for traditional low-cost composite part fabrication are the short fiber-reinforced polymers(SFRPs) with moderately improved mechanical properties[20]. This is largely owing to the possibility of AM to directly produce geometrically complex and functional parts with low lead times. Current applications combining AM with FRP include layup tooling [10] and structural lightweight AM elements with added functionalities. Lightweight, low price, and acceptable thermo mechanical properties make fiber reinforced 3D printed polymer composites great candidates to replace metals for a wide range of applications[11,12]. Nano materials, micro-particles, short and long fibers have been added to polymers to improve mechanical properties [10,13]. In the last few years, studying printing conditions and final properties of FDM parts reinforced by continuous fibers is under extensive investigation [14,15]. However, most of these investigations focus on experimental data analysis, there is no thorough study on the micro structural analysis of these components. Investigating the microstructure of these components is important to understand the failing mechanisms. This can serve as an insight to improve the design of parts for preventing failure and increasing performance[16].

From the development of 3D printing, we have come a long way with numerous development regarding printing speeds, accuracies, surface finish, costs, etc. in various 3D printing technologies. But for a long time now, in FDM printing only single material or a single color printing was an option. Recent developments have open doors for more research and development regarding the use of multiple material in a single print.[18].

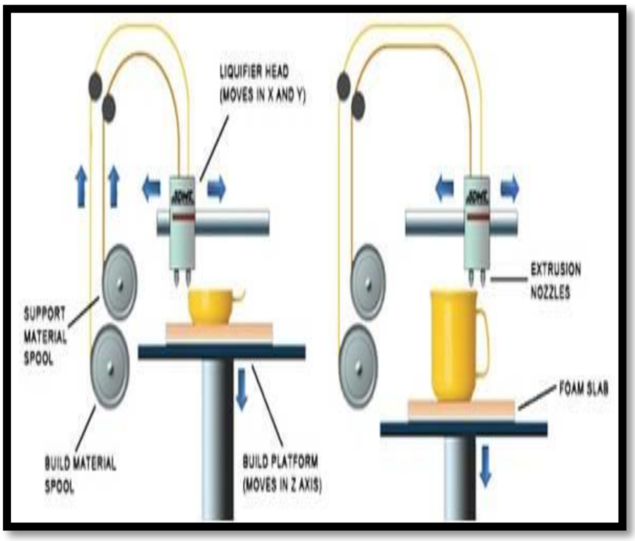

Fig -2: Dual Extruder FDM 3D Printer set up [4]

Moreover, the bead width, air gap, build temperature, color [27], raster width and layer thickness should be considered when executing a build via FDM[25].The raster orientation defines the tool path in the plane of deposited layers. The manufacturing parameters were limited to build direction and raster orientation and specimens were loaded quasi statically to failure. The report emphasizes a systematic naming convention for build directions ,and utilizes a scheme borrowed from traditional fiber-reinforced composites to discuss the raster orientations [26]. In order to print an object using the FDM technology there is a need to define a certain number of printing parameters. Since the quality of the final product is influenced by the majority of these parameters it is of relevance to know which, among them, are the most influential Mariya Fatima [20]. Zhang et al. [21] investigated the tensile and bending strength of fiber reinforced composites. The tensile properties of nylon and Kevlar reinforcement have been evaluated by Melenka et al., [23] by using a Marked forged Mark one printer. The properties of fiber reinforced 3D materials has enhanced properties on post treatment compare to raw material [22].Tensile test measures the strength and modulus parts under tension. Melenka et al. evaluated the tensile properties of continuous 3D printed parts and showed that an increase in fiber volumetric fraction increase the elastic modulus [21]. Dickson et al. studied tensile and flexural strength of 3D printed nylon matrix reinforced with CF, FG, and Kevlar [16,19]. The results showed an increase of tensile and flexural strength up to 6.3 and 5 times, respectively. Tekinalp et al. studied tensile properties and microstructure of CF reinforced ABS and compared the results with traditional molded composites. Their result showed that the tensile strength and modulus of 3D printed samples increased 115% and 700% respectively. Also 3D printed parts exhibited comparable tensile strength and modulus compared with compared with traditionally manufactured composites [20].

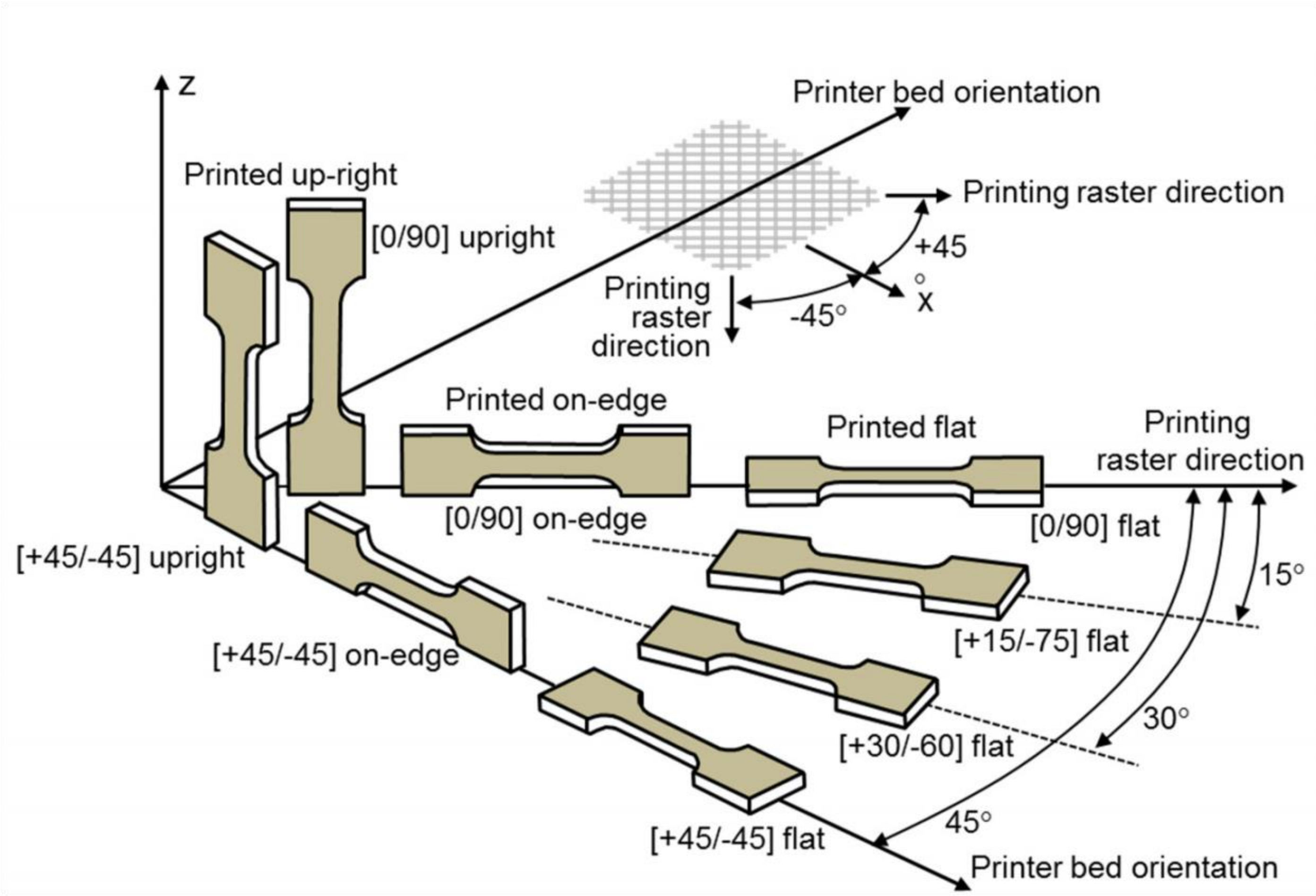

Fig -3: Build Raster orientation [29]

In this article authors first focus on to be printed Carbon fiber reinforced ABS and Glass fiber reinforced ABS with single extrusion and dual extrusion tensile specimens as per the standard of ASTM D638 Type-1[24]. Tensile test were conduct on UTM according to ASTM standards to obtain mechanical properties. Behavior of single and multi material printed specimens were observed after testing. After successfully completion of such investigation will provide brief knowledge regarding the results.

2. Material Selection and Methodology

2.1 Materials Section

Acrylonitrile Butadiene Styrene(ABS) as base polymer matrix and Carbon Fiber and Glass Fiber(10% content) as reinforcing filaments which were readily available and supplied by 3DXTech material filament manufacturing company USA. Both CF reinforced ABS and GF reinforced ABS filament had a 1.75mm diameter and printing with 0.40mm hardened steel nozzles. Simplify 3D software was used for slicing, print setting, for adjusting different process parameters, different wizard variation, putting necessary support, size settings, material optimization, fiber orientation, numbers of layers. The effect of these printing parameters was investigated on tensile strength, fatigue behavior and micro structural properties of fabricated parts[16]. Pratham 3.0 FDM 3D printer was used for printing of specimens. The printer has two extruder, it provides facility to print single as well as multi material printing layer by layer. Fig. 2 shows schematic representation of dual extrusion FDM printing process set up. The temperature for CF and GF reinforced composites for both extruder was set between 210°C - 240°C respectively. Printing speed was set at 55 mm/sec through out printing it can be vary as per required governing conditions. All specimens were printed following with below variation of parameters.

Table -1: Printing Parameters

Infill Percentage	100%
Infill Pattern	Rectilinear, Full Honeycomb
Layer Height	0.10mm, 0.20mm, 0.24mm, 0.30mm
Raster Angle	90°, 0° - 90°, 45° - 45°

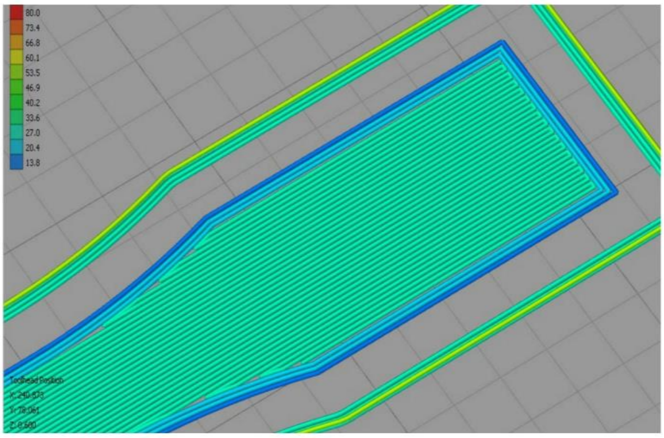

Fig -4: Dual Extrusion 1st Layer Printing

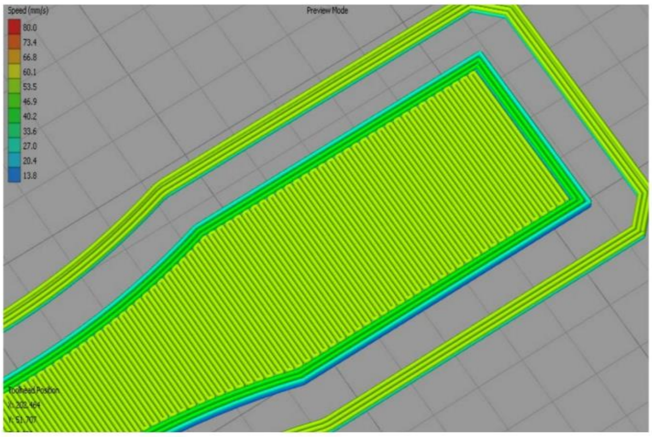

Fig -5: Dual Extrusion 2nd Layer Printing

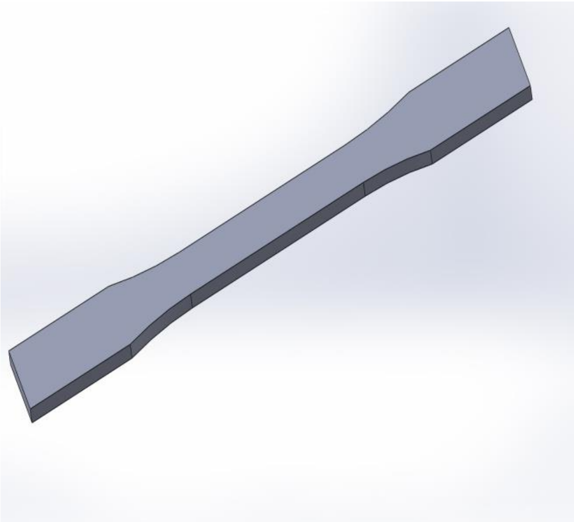

Fig -6: 3D Design of Tensile Specimen

Fig -7: Fabricated Single and Dual Extrusion Specimen

2.2 MEASUREMENT PROCEDURES

ASTM D638 standard [24] were followed for tensile test. All CFR, GFR and multi reinforced composite specimens of each sample were prepared by FDM for testing. Type-1 specimen dimensions in ASTM D638-10 standard were used for tensile testing of FDM fabricated parts. Fig. 5 shows experimental set up for tensile test. UTM specimen with H50KL capacity and with load cell availability of 0.1N- 5kN. Tensile Test employed two grips one fixed and another one is movable to hold the specimens. The relationships between force(N) and displacements(mm) were collected by computer with the help of a data acquisition software(Tinius Olsen Horization). From this fiber reinforced and multi fiber reinforced composites mechanical properties were obtained and analyzed further recommendation.

Fig -6: Set up for Tensile Test

Table -2: Testing Parameters

Testing Speed	5 mm/min
Sampling frequency	20 Hz

3. RESULTS AND DISCUSSION

Tensile Analysis

The different effect of infill pattern and layer height on mechanical properties was studied here. Also the study focus on variable material composition also point of concentration. The infill pattern orientation of fiber reinforced and multi fiber reinforced was grouped into two: Rectilinear and Honeycomb. In Rectilinear pattern, lines are added along the specimen perimeter. In Honeycomb pattern, fibers were laid in form of honeycomb. In both of case one individual angle and in other case angle can be changed for each layer.

With 3 different raster angle of 90°, 45°- 45° and 0°- 90° from that 90° tensile specimens with 4 different layer heights showed within in the range of 15-35 Mpa tensile strength with order of GF-ABS>Dual>CF-ABS. We can able to say that dual extrusion technique still in development phase their result may rectified with many more iterations. Same way for variable layer heights and composites at comparison results table for tensile test at 45°- 45° as shown in Table 3.

Table -3: Testing Parameters

Fiber	Infill	Raster Angle	Layer Height(mm)	Tensile Strength(Mpa)
CF-ABS	Rectilinear	45°- 45°	0.24	28.4
GF-ABS	Rectilinear	45°- 45°	0.24	38.2
Dual	Rectilinear	45°- 45°	0.10	30
CF-ABS	Honeycomb	45°- 45°	0.20	28.2
GF-ABS	Honeycomb	45°- 45°	0.10	27.8
Dual	Honeycomb	45°- 45°	0.20	25.9

From above observation rectilinear infill pattern showed us better results compared to honeycomb pattern at 45- 45 of raster angle. Here below Table 4 illustrated tensile testing results at 0°-90° raster angle in similar pattern of three different raster angle and material composition.

Table -4: Experimental Tensile Testing Comparison

Fiber	Infill	Raster Angle	Layer Height(mm)	Tensile Strength(Mpa)
CF-ABS	Rectilinear	0°- 90°	0.24	28.4
GF-ABS	Rectilinear	0°- 90°	0.24	40.7
Dual	Rectilinear	0°- 90°	0.10	36.5

Discussion

Normal trend behavior of the material in the range of CF-ABS < Dual < GF-ABS. So can come up with the point of discussion is that dual extrusion or say multi-fiber reinforcement helped in the enhancement of additively manufactured specimens. Now at the end, the last comparison table proved to us that 0-90 raster angle at rectilinear infill pattern showed us better results compared to other sets of parameters.

Another set of point of discussion is that at present dual extrusion FDM process is in the early stages of development. But noticeable criteria is lying between two actual individual composites. So by searching for its solutions and advancement we can able to achieve high strength results from dual or say multi-fiber reinforcement.

4. CONCLUSIONS

The research evaluates failure behavior by making the chain with a mechanical test as a bench point of mark. Therefore, mechanical tests are complementary in studying Single extrusion and multi extrusion parts results.

In this study, mechanical properties testing was upheld. Here in this study of the effect of different material composition and parameter variation mechanical properties investigation is complementary. The results give a promising sight of the design and application of multi-fiber-reinforced components in the industry. Our experimental data show that fiber added composites specifically GF reinforced ABS show that with different layer height and raster angle at rectilinear infill pattern exhibits superior mechanical properties compared to other parameters and composition.

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REFERENCES

[1] Standard A. F2792, Standard Terminology for Additive Manufacturing Technologies. West Conshohocken, Pa, USA: ASTM International; 2012.

[2] Hull, C.W., Apparatus for production of three-dimensional objects by stereolithography. 1986, Google Patents.

[3] M. Kumar, R. Ramakrishnan, and A. Omarbekova, "3D printed polycarbonate reinforced acrylonitrile butadiene styrene composites: Composition effects -

on mechanical properties, micro-structure and void formation study," Journal of Mechanical Science and Technology, vol. 33, no. 11, pp. 5219-5226, 2019.

[4] N. Parmar, V. Ranga, and B. Simhachalam Naidu, Syntactic interoperability in real-time systems, ROS 2, and adaptive AUTOSAR using data distribution services: An approach, vol. 89. 2020.

[5] F. Ning, W. Cong, J. Qiu, J. Wei, and S. Wang, \Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling," Composites Part B: Engineering, vol. 80, pp. 369-378, 2015.

[6] L. Love, V. Kunc, O. Rios, C.E. Duty, A.M. Elliot, B.K. Post,R.J. Smith, C.A. Blue, The importance of carbon fiber to polymer additive manufacturing, J. Mater. Res. 20 (2014) 1893-1898, https://doi.org/10.1557/jmr.2014.212.

[7] Brooks H, Molony S. Design and evaluation of additively manufactured parts with three dimensional continuous fbre reinforcement. Mater Des 2016;90:276–83.

[8] Caminero M, et al. Impact damage resistance of 3D printed continuous fbre reinforced thermoplastic composites using fused deposition modelling. Composite B Eng 2018;148:93–103.

[9] Goh G, et al. Characterization of mechanical properties and fracture mode of additively manufactured carbon fber and glass fber reinforced thermoplastics. Mater Des 2018;137:79–89.

[10] T. Schniepp, Design guide development for additive manufacturing (FDM) of composite tooling, SAMPE Conference Proceedings, Long Beach, CA, May 23-26, (2016) 2259-2269.

[11] Wang X, et al. 3D printing of polymer matrix composites: a review and prospective. Composite B Eng 2017;110:442–58.

[12] Dizon JRC, et al. Mechanical characterization of 3D-printed polymers. Additive Manufacturing; 2017.

[13] Fidan I, et al. The trends and challenges of fiber reinforced additive manufacturing. Int J Adv Manuf Technol 2019:1–18.

[14] Parandoush P, Lin D. A review on additive manufacturing of polymer-fibercomposites. Compos Struct 2017;182:36–53.

[15] Türk D-A, et al. Mechanical characterization of 3D printed polymers for fiber reinforced polymers processing. Mater Des 2017;118:256–65

[16] M. Mohammadizadeh, A. Imeri, I. Fidan, and M. Elkelany, \3D printed fiber reinforced polymer composites - Structural analysis,"Composites Part B: Engineering, vol. 175, no. July, p. 107112,2019.

[17] M. Mohammadizadeh, I. Fidan, M. Allen, and A. Imeri, "Creep behavior analysis of additively manufactured fiber-reinforced components," International Journal of Advanced Manufacturing Technology, vol. 99, no. 5-8, pp. 1225-1234, 2018.

[18] V. Daramwar and S. Kadam, \Design and Development of MultiMaterial Extrusion in Fdm 3D Printers," pp. 3634-3641, 2020.

[19] Dickson AN, et al. Fabrication of continuous carbon, glass and Kevlar fbrereinforced polymer composites using additive manufacturing. Additive Manufacturing 2017; 16:146–52

[20] Tekinalp HL, Kunc V, Velez-Garcia GM, Duty CE, Love LJ, Naskar AK, Blue CA, Ozcan S. Highly oriented carbon fiberepolymer composites via additive manufacturing. Compos Sci Technol 2014;105:144e50.

[21] G.W. Melenka, B.K.O. Cheung, J.S. Schofield, M.R. Dawson, J.P. Carey, Evaluation and prediction of the tensile properties of continuous fiber-reinforced 3D printed structures, Compos Struct. 153 (2016) 866–875.

[22] Zhong W, Li F, Zhang Z, Song L, Li Z. Short fiber reinforced composites for fused deposition modeling. Mater Sci Eng A 2001;301(2):125e30.

[23] K.K. Guduru, G. Srinivasu, Effect of post treatment on tensile properties of carbon reinforced PLA composite by 3D printing, Mat. Tod. Proc. (2020).

[24] ASTM D638-14, Standard Test Method for Tensile Properties of Plastics, ASTM, International, West Conshohocken, PA, 2014.

[25] A.W. Fatimatuzahraa, B. Farahaina, W.A.Y. Yusoff, The effect of employingdifferent raster orientations on the mechanical properties and microstructure of fused deposition modeling parts, IEEE (2011) 22–27.

[26] R.M. Jones, Mechanics of Composite Materials, second edition, Taylor and Francis, Philadelphia, 1999.

[27] S.H. Ahn, M. Montero, D. Odell, S. Roundy, P.K. Wright, Anisotropic material properties of fused deposition modeling ABS, Rapid Prototyping J. 8 (4) (2002)248–257

[28] J. C. Riddick, M. A. Haile, R. V. Wahlde, D. P. Cole, O. Bamiduro, and T. E. Johnson, \Fractographic analysis of tensile failure of acrylonitrile-butadiene-styrene fabricated by fused deposition modeling," Additive Manufacturing, vol. 11, pp. 49-59, 2016.

[29]Experimental characterization of them technical properties of 3D printed ABS and polycarbonate parts, "Conference Proceedings of the Society for Experimental Mechanics Series, vol.3, pp.89-105, 2017.