TENSILE PROPERTIES INVESTIGATIONS OF PURE, FIBER REINFORCED AND MULTI FIBER REINFORCED ABS COMPOSITE

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Abstract - *In the field of additive manufacturing technology there have been vast changes occurs as flow of research proceeds innovatively. As specially Fused Deposition 3d printing technology being characterized by its improved working methodologies. Fiber reinforced composites and smarts materials have add on phenomenon in the field of applications. Medical, Aeronotical, Automobiles and electrical field has vast grown up due to its application in small scale requirements and in development phase for large scale. In this research work analysis can be carried out with pure ABS and it's fiber reinforced composites to see how behavior changes take place. For that purpose different parameter variation are hook up to look up what mechanical properties behave after performing experimental tensile testing and comparison of that being discussed at end.*

Key Words: FDM, Fused filament fabrication, Multiple material reinforced composites, Dual Extrusion, Multi fiber reinforcement, printing parametric analysis, mechanical properties

1. INTRODUCTION

The competition in the world market for manufactured product has intensified tremendously in recent years. It has become important, if not vital for new product to reach the markets as early as possible, before the competitors. To bring the product to the market swiftly, many of the processes involved in the design, test, manufacture, and market of the product have been squeezed, both in terms of time and material resources; [1]. Generative production techniques have the advantage of manufacturing parts via an additive process without needing a forming tool. One of these additive manufacturing technologies is "Fused Deposition Modeling"[2]. Additive manufacturing (AM) is a design solution based upon computer-aided design (CAD) and computer-aided manufacturing(CAM) that enables the rapid production of three-dimensional (3D)solid prototypes from a computer file. AM, sometimes referred to as direct digital manufacturing (DDM), or generically as 3D printing, employs advanced technology to optimize development of complex parts and molds with unique surface topologies by reducing time and labour cost by eliminating the need for substantial, and costly, tooling. Commercially available AM techniques include direct metal laser sintering (DMLS), ultrasonic additive manufacturing (UAM), electron beam melting (EBM), and fused deposition modeling (FDM)[3]. The present study is an experimental investigation of the effect of selected manufacturing parameters on the mechanical proper-ties and ultimate failure of specimens fabricated by FDM, utilizing scanning electron microscope (SEM) images, referred to as fracto graphs. For the present study, FDM was chosen due to its rapid growth as a method-of-choice among a wide variety of users[4]. Developed by Stratasys Inc. in 1990, FDM accomplishes 3Dprinting by depositing thermoplastic material layer-by-layer. The modeling process is initiated by creating a graphical model using sophisticated 3D CAD software. The file containing the CAD model is then converted into 3D stereolithography (STL) format. The STL file data is used to tessellate the model of the part into cross-sectional facets upon which tool paths can be projected for forming eachlayer[5]. FDM processing is carried out by forcing a filament com-posed of thermoplastic material, referred to as feedstock, into a liquefier where it is softened to a molten state to be delivered through a nozzle under pressure for deposition onto a platform stage (Fig. 1). The material solidifies quickly due to cooling by the surrounding colder air. Subsequent layers are joined as molten material is deposited on solidified material to form layers and eventually build up a part. Several feedstock materials are widely used such as acrylonitrile–butadiene–styrene (ABS), FDM processing has also been adapted to produce composite materials, such as short-fiber reinforced polymers [6] and carbon-fiber reinforced ABS [7], glass-fiber reinforced ABS [8].

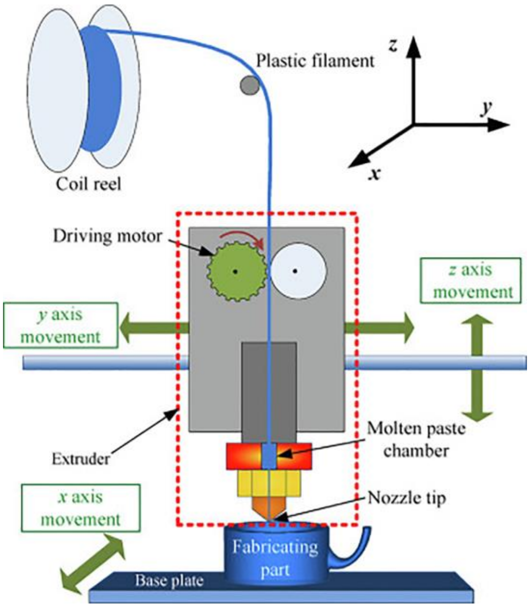

Fig -1: Diagrammatic representation of the working principle of FDM process as described by Jin et al.[9]

Dual extrusion

A single common extrusion channel (nozzle diameter 0.4 mm) was used for two material printing. This approach offers the advantage of obviating the calibration step necessary when two independent extruders and nozzles are used. This is not only time-efficient, but also allows for accurate automatic alignment of soft and hard structures as they are produced, hence, avoiding the need for manually combining the components post-printing. Two material 3D printing is becoming increasingly popular, inexpensive and accessible. In this paper, freely available printable files and dual extrusion fused deposition modeling were combined to create a number of functional anatomical models[13]. Dual extrusion is the process of 3D printing with multiple _laments. With two spools loaded, the printer alternates between them by printing one at a time. It's not actually faster at printing because its still using only one extruder at a time. Dual extrusion allows you to make more interesting, gravity-defying models with the help of support _laments. Dual extrusion also makes it much easier to create multi-colored prints. If these features are important to you, it's worth saving up for the added cost of a 3D printer with dual extrusion.

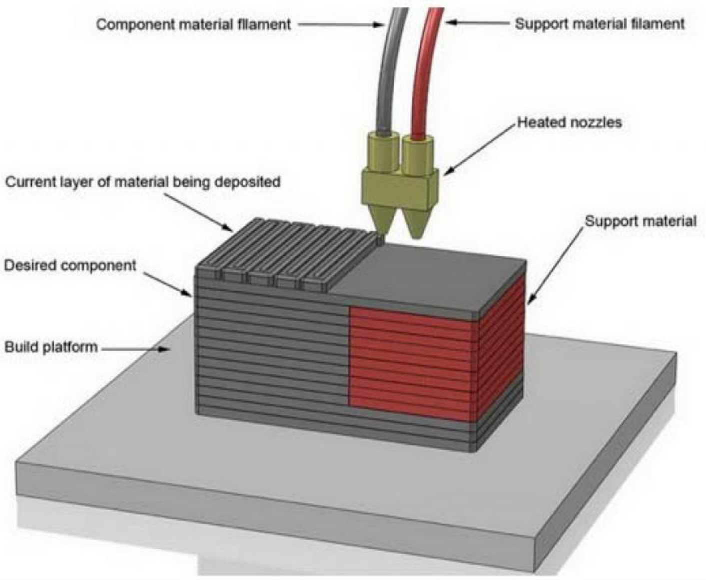

Fig -2: Multiple Extruder 3D Printer.[14]

Multi-fiber composite material[36]

Composite materials are defined as a combination of two or more synergic micro-constituents, which differ in physical form or chemical composition [14,15]. The structure of composite materials consists of two components, namely matrix and reinforcement, and the three dimensional region with specific characteristics between these two constituents is known as the inter phase region. The two-phased structure of composite materials, consisting of the reinforcement phase surrounded with the matrix phase, enables utilization of the superior characteristics of both materials [16,17]. The matrix of fiber-reinforced materials are chosen among different kind of resins (epoxy, phenolic, polyester, vinyl ester, etc.) while the reinforcement is selected among glass, carbon or aramid (kevlar). In general, reinforcements (fibers) act as the main load bearing element, whereas the matrix encloses the fibers and protects them in the desired direction. Matrices act as load transfer elements between the fibers and protect the structure against harsh environmental conditions such as high temperature and humidity [18].Carbon fiber reinforced composite materials, in which carbon fiber is used as the reinforcement element, can involve polymer matrix, metal matrix, ceramic matrix or carbon matrix. Carbon and glass fiber reinforced polymer composites have been commonly preferred in the space and aviation industry [19, 20]. Increasing number of aircraft components involve CFRP composite constituents due to their superior characteristics such as high strength and stiffness, low weight and high fatigue resistance [21-28].

The Acrylonitrile-Butadiene-Styrene polymers are mainly consisting of three monomer units: Acrylonitrile, Butadiene and Styrene. Plastic has got many versatile properties which include thermal resistance, light weight, easy formability, reflectivity etc. Regarding all these properties it has opened new way of use for material like ABS. This emphasizes the importance of studying the recycling of ABS as an aid to reducing economic, environmental and energy issues. Metallization is a process in which a non-conductive material such as plastic is made conductive by providing conductive layer on it. Additives play considerable role in determining final properties of every polymer material [29-30].An environment-friendly surface etching and activation technique for ABS material is a replacement for conventional chromic acid bath. By using this peel strength increases and adhesion strength reaches its maximum value [31].In this work we studied electro less metallization of part material (Acrylonitrile-Butadiene-Styrene copolymer) on fused deposition modeling machining. Variety of plastics such as Teflon, Polythene and ABS can be metalized using different metals like silver (Ag), gold (Au), copper (Cu) and nickel (Ni), etc. Generally in metallization plastic is made conductive by providing conductive layer on it. Once the ABS is coated with polypyrrole (PPy), Nickel electro-plating of ABS material can be achieved without chromium or palladium pretreatment.

Adding fibers into thermoplastic matrix has been demonstrated to effectively enhance the performance of composites. Researches on FDM-3D printing of fiber reinforced composites mainly concentrated on ABS other matrix polymer with better fluidity[32]. reported that the glass fibers (GF) can improve the tensile strength of 3D printed GF/ ABS at the expense of flexibility and ductility[33]. evaluated the tensile strength of FDM-3D printed carbon fiber (CF) reinforced ABS composites with fiber contents ranging from 10wt% to 40wt%.The results show that the tensile strength and Young's modulus grew with the increase of fiber content, although internal porosity of printed composites sample enlarged[34]. comprehensively evaluated the thermal, physicochemical as well as melting rheology properties of basalt fiber (KBF) reinforced PLA composite filaments, and studied the effects of fiber content and fiber length on the mechanical properties and micro morphology of 3D printed KBF/PLA composite parts[35].compared the effects of two reinforcements, carbon fiber and graphite, on the tensile strength and porosity of ABS composites fabricated by FDM process. Besides, investigations on the effects of different FDM process parameters: raster angle, infill speed, nozzle tempera- ture and layer thickness, on the mechanical properties of CF/ABS was firstly reported by [36][37].

The raster orientation defines the tool path in the plane of deposited layers (see Fig. 3). 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 [40]. The tensile test specimens were made using ABS-M30 filament according to ASTM D638-03, "Standard Test Method for Tensile Properties of Plastics." [41]. the results of the present study will be fundamental to the development of optimal designs of complex lightweight durable components where structural tailoring may offer an added benefit via weight reduction and structural efficiency.

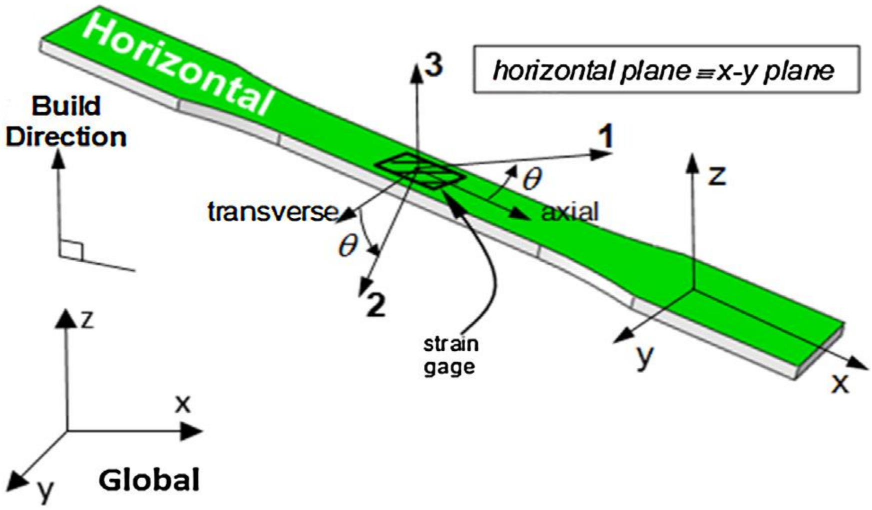

Fig -3: Dual Extruder Horizontal build orientation (For interpretation of the references to color in the text, the reader is referred to the web version of this article)[12]

2. MATERIAL AND METHODOLOY

Materials selection

Acrylonitrile Butadiene Styrene, often abbreviated as ABS, is an opaque engineering thermoplastic widely used in electronic housings, auto parts, consumer products, pipe fittings, logo toys, and many more. Durable and sturdy parts off practically every 3D printer on the market, easier to print than most industrial-grade materials, parts can be smoothed with acetone vapors were supplied by 3Dxtech company USA. Here in the present case, we have used reinforcement of Carbon fiber and Glass fiber with a context of 10-10% were also supplied by 3Dx tech material filament manufacturer. Both compositional filament readily available and has a filament diameter of 1.75mm. In both cases, the short chopped fiber blend used to frame requires composite. ABS+CF is a high-performance carbon fiber reinforced ABS filament ideal for anyone that desires a structural component with high modulus, excellent surface quality, dimensional stability, lightweight, and ease of printing. Made using 15% High-Modulus Carbon Fiber (not carbon powder or milled carbon fiber). Made in the USA using premium Sabic MG-94 ABS and high modulus carbon fiber. ABS+GF is glass fiber reinforced ABS. It is tough as nails, very stiff, and strong allowing users to create structural parts without the lifting or warping that can happen with unfilled ABS. We use premium ABS and a special glass fiber chosen to be compatible with ABS and the FDM/FFF 3D printing process.

Reinforced with Carbon fiber: With 5-25% of Fiber Content there increase in strength 24% more than the pure polymer ABS amount up to 42 Mpa. With more than 30% of fiber content we can achieved up to 115% more than the pure polymer and max tensile strength up to 70 Mpa[42].

Reinforced with Glass fiber: With 10-40% of Fiber Content it’s increase strength 140% than the pure polymer ABS. We gained Max Tensile Strength up to 58.6 Mpa.[42]

FDM 3D Printer:

Fig -4: Pratham 3.0 3D Printer

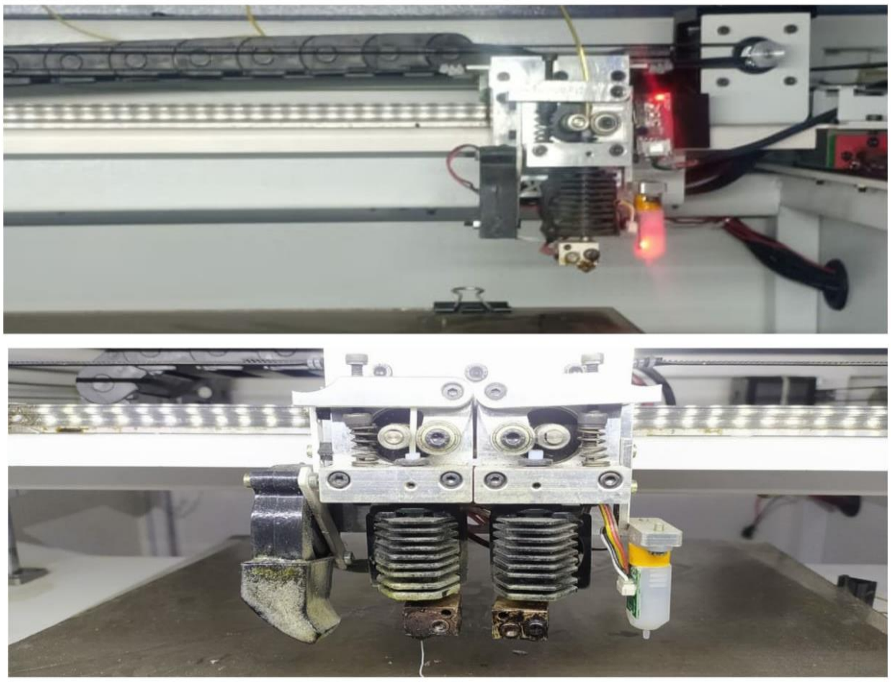

Fig -5: Single and Dual FDM 3D printing availability in one machine set up

Pratham 3.0 Indian manufactured 3D printer highly preferable for different variety of high strength material composites i.e. ABS, PLA and other composites with smooth, reliable and perfect finishing good products. It have building volume of 300mm × 300mm × 300mm with dimensional tolerance of ±0.1mm. Having printing speed in range of 40-120 mm/see. Nozzle size having of 0.4mm and different layer resolution of 0.08mm to 0.4 mm. Heat bed having higher temperature of 280°C, whereas extruder temperature having maximum value of 130°C.

Table -1: Printing Parameters

Infill Percentage	100%
Infill Pattern	Rectilinear
Layer Height	0.10mm, 0.20mm,0.16mm,0.24mm, 0.30mm
Raster angle	0°, 45°,67°, 90°, 0° - 90°, 45° - 45°

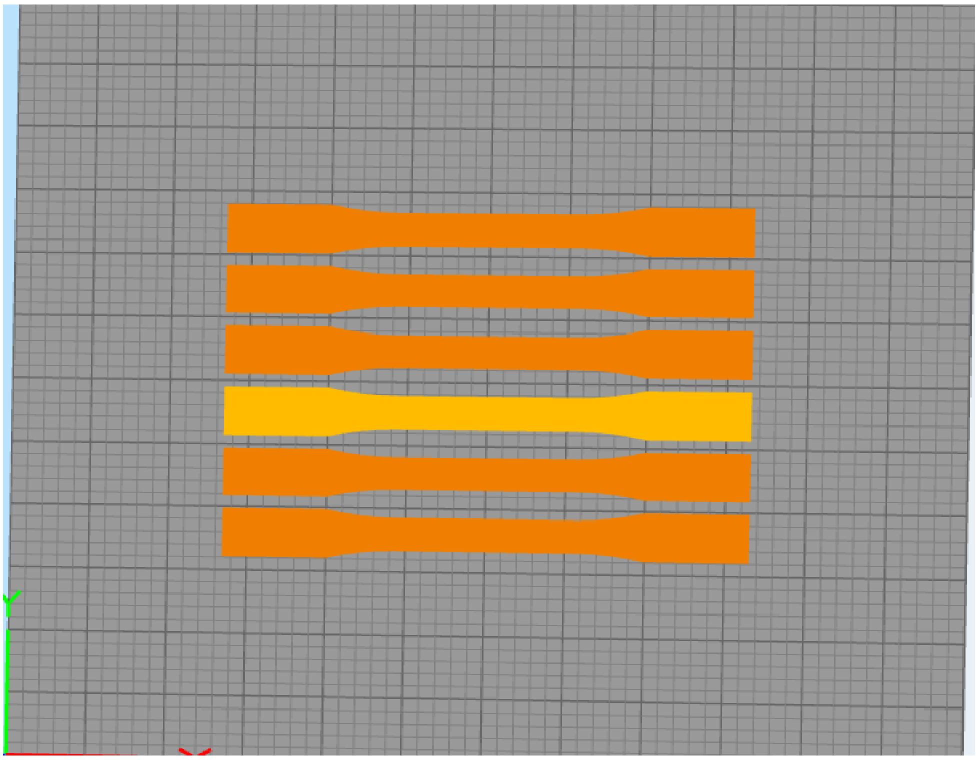

Fig -6: Specimens set up in printing software as per the required variation

Measurement procedures:

Here study focuses on single and dual 3D printed dogbone specimen Type-1 as per the standard of ASTM D638. Herewith individual to ABS material to solo reinforced specimen to multi reinforced specimens were printed as well as tested as per the mention variation in Table1. And to observe behavior in mechanical properties after testing.

Fig -7: Universal Testing Machine set up

Testing facility available at Charotar Universirty Changa, Nadiad at Mechanical Testing lab under skilled technical assistants. Tensile tests were performed utilizing a H50KL Universal testing machine with advance software attachment of Tinius Olsen. All specimens were held in place of both jaws, and testing can be carried at a crosshead speed of 5 mm/min as per the ASTM D638 standard. By obtaining raw data come with required Stress-Strain graph and combination comparison.

3. Results and Discussion

With single and dual extrusion settings in software were able to fabricate all specimens in pratham 3D printer as per given raster orientation and layer height variation. Afterwards performing testing performance of test samples are discussed in this section. Comparison can be mentioned here in 3 different way likewise first behavior of pure ABS, then afterwards took placed between pure and reinforcement composites and at the end with mutli-fiber-reinfoced specimens and other required discussion opted out.

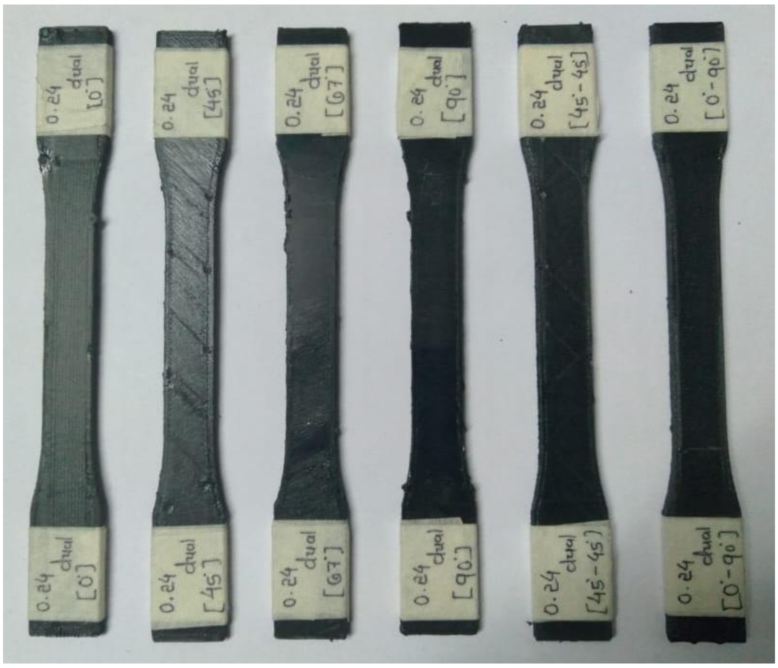

Fig -8: One set of dual FDM printed specimens at 0.24mm layer thickness at variable raster angle

Table -2: Behavior of pure ABS

Layer Height	Behaviour Pattern	Strength Range	Maximum Strength
0.10mm	0°> 45°-45°> 45°> 0°-90°> 67°> 90°	Up to 20 Mpa	18.7 Mpa
0.16mm	0°> 45°-45°> 45°> 0°-90°> 67°> 90°	Up to 25 Mpa	24.8 Mpa
0.20mm	0°> 45°-45°> 45°> 0°-90°> 67°> 90°	Up to 25 Mpa	23 Mpa
0.24mm	0°> 45°-45°> 45°> 0°-90°> 67°> 90°	Up to 30 Mpa	28 Mpa
0.30mm	45°-45°> 45°> 0°> 67°> 0°-90°> 90°	Up to 30 Mpa	27 Mpa

From above table we observed that 0° raster angle risen up with higher strength in printed parts as compare to other whereas 90° shows lower order strength. Also point to focus also the range of strength value which altered with increasing with increase of layer height. So both of these factor have to be considered in mind while design, printing as well as it's experimental analysis. In case of ABS 0.24 mm at 0° raster angle with 28 Mpa give higher value.

Table -3: Comparison of ABS with it's reinforcement composites

Layer Height	ABS	CF+ABS	GF+ABS
0.10mm	18.7 Mpa	33.3 Mpa	39 Mpa
0.16mm	24.8 Mpa	23.6 Mpa	43 Mpa
0.20mm	23 Mpa	26.7 Mpa	46.7 Mpa
0.24mm	28 Mpa	32.1 Mpa	41.1 Mpa
0.30mm	27 Mpa	28.9 Mpa	30.2 Mpa

With proper printing set up and with smooth flow of fabrication above table reflect that compare to pure material reinforced composites give almost double strength at only 10% of content mixture which high considerable point of present research. From above table we conveniently say that GF-reinforced ABS extract higher strength values compare to other two.

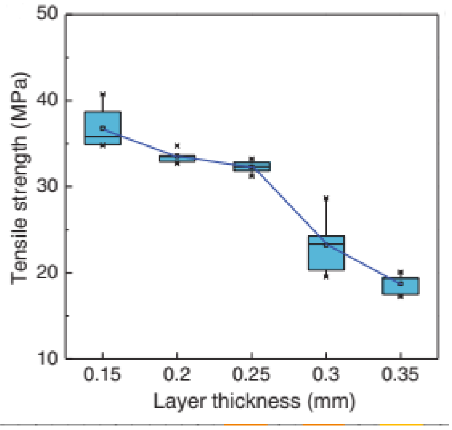

Fig -9: Effect of layer height on tensile properties[38]

Table -4: Comparison of Single and dual extrusion specimen strength

Layer Height	GF+ABS	Dual(CF-ABS + GF-ABS)
0.10mm	39 Mpa	38.5 Mpa
0.16mm	43 Mpa	43 Mpa
0.20mm	46.7 Mpa	32.8 Mpa
0.24mm	41.1 Mpa	38.7 Mpa
0.30mm	30.2 Mpa	23.9 Mpa

From above table focusable point of discussion is that dual FDM 3D printed parts almost give nearer to maximum of single FDM parts. So main effective and fruitful point of this research of dual or say multi fiber reinforcement give new innovation in the field of additive manufacturing. With still required improvement and advancement we can able to say that it can give better results than this. So in the field of composites dual extrusion is new tool to start up with small scale to step by step moving enhancement.

4. Conclusions

In this present research, the effects of printing process parameters on the tensile properties of FDM printed pure ABS, single reinforced ABS and multi(Dual) fiber reinforced ABS were investigated. In order to analyze the reasons of the experimental result whole comparison put up here.
The conclusions were drawn as follows:

(1) 0° raster angle exhibits larger tensile strength compare to other five with variable material composition.
(2) In the range of 0.16-0.25mm layer height shows higher amount of tensile strength with extra smooth surface behavior.
(3) Dual extrusion (multi fiber reinforcement composites) is also the interesting point of research that its result near or say near equal to single extrusion 3d printing. Why again and again put up this statement as the reason of dual extruder 3D printer still in development phase still improvement needed while machining still exhibits remarkable results.

Acknowledgements

The supports of Dr.Anish H. Gandhi, Prof.Vijay A. Radadiya is greatly appreciated. The authors also would like to extend the acknowledgements to 3Dx tech company for providing CF-ABS and GF-ABS for this work.

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