# INVESTIGATION ON MECHANICAL PROPERTIES OF DUAL MATERIAL POLYMER FABRICATED BY ADDITIVE MANUFACTURING

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***Abstract—****One of the additive manufacturing (AM) techniques called Fused Deposition Modeling(FDM) is used for layer by layer fabrication of plastic parts offering advantages of building ability to build parts with geometric and material complexities, accuracy, flexible material change. AM finds numerous applications in aerospace, automotive, biomedical, energy and other fields. But single material parts fabricated by FDM have poor mechanical properties. One of proposed solution is making composite polymer. So this study investigates effectiveness of dual material printed part by evaluating its mechanical properties like tensile strength, breaking load and s/w ratio with reference to input parameters such as raster angle, material proportion and nozzle temperature. Dual material parts shows positive response in terms of tensile strength and breaking load with reference to pure ABS parts and shows better s/w ratio than both single material printed parts.*

***Keywords— Additive Manufacturing; FDM;Temperature; Raster Angle;Tensile Strength;S/w***

## 1. INTRODUCTION

### *1.1 Background*

In recent time, the upgrading and replacement of old products with new one is becoming rapid. Existing product is superseded by new enhanced function and more innovative products. The competition is increased for newly manufactured products to approach the market before any competitors has done in companies having to launch their new products in the shortest possible time interval. In this case process like machining, casting etc. incapable to meet market requirement due to long production time and inherent material wastage due to subtractive process. In order to cooperate with the demand in this fast growing process of product change, new technologies have to be developed. Time for the design, manufacture, test, and market phases must be shortened. AM is expected for solution of this problem.

### *1.2 Additive manufacturing*

Additive manufacturing (AM) or rapid prototyping, as name suggests, fabricates parts by adding layer by layer of material under computer control. In this process first computer aided design (CAD) is made and then transferred into stereo lithography (STL) format that is readable by AM machines. Thermoplastic material such as Acrylonitrile butadiene styrene (ABS), Polylactic Acid (PLA), polyamide (PA), and polycarbonate (PC) and thermosetting polymer material like epoxy resins can be processed by AM.

### *1.3 Fused decomposition modeling*

FDM, one of the AM technologies, is the most commonly used techniques for composite 3d printing. It builds parts in consecutive layers by heating thermoplastic material filaments to a glass transient state and extruding through a nozzle as per 3D CAD models which are in STL format as shown in below Figure 1. The filaments are usually of circular cross section with specific diameters as per FDM system. The most widely used diameters are 1.75 mm or 3.0 mm.

Due to the features of FDM process, many advantages arise, such as the production of complex parts or products without making moulds or complex process, the possibilities of production of internal features, which is not possible in traditional manufacturing methods. FDM gives features of producing assembly in a one parts or easily assembles complex parts [1]. More advantage of FDM can be gain by reducing the lead time and there is no need of storage and less need of transportation, especially in applications where high customization is required. One common drawback of FDM is that the composite materials must be in the form of filament for extrusion process through nozzle. It is hard to homogeneous reinforcements and removal of the void formed during the manufacturing of composite filaments. There is also limitation in availability of thermoplastic material which is suitable for FDM.

## 2. LITERATURE REVIEW

[1]M. Nikzad et al. (2011) studied effect of polymer composite fabricated by FDM by homogeneous distribution of metal powder with ABS matrix material and tested two parameters, Thermal conductivity and stress-strain behavior. According to result stiffness can be improved by composite thus higher moulding pressure can be withstand. Thermal conductivity and dynamic mechanical properties improved.

According to [2]J. Martinez et al. (2013) FEM programs required to analyze behavior and main manufacturing properties; in order to get previously mentioned parts. For

this purpose Deformation applied to laminated and solid samples and Von Mises stress is calculated in abaqus software.
From the investigation of built orientation effect it is observed by [3]Sandip raut et al. (2014) that in z-axis orientation least tensile strength and maximum tensile strength at 0 degree orientation and at 0 degree built up orientation has good flexural strength and medium cost for testing of ABS-p400 part tested on Instron 1195.
[4] Seyeon Hwang (2014) studied Thermo mechanical properties of metal polymer composites in FDM. According to result With increment in temperature flow rate increase and viscosity decreases. Tensile stress decrease with increment in fill density.At 60% fill density Ductility is highest.
[5]Ning et al. (2016) investigated effects of process parameters for CFRP composites using FDM. By studying results it is clear that Infill speed 25 mm/min gives best result for tensile strength, All the tensile properties at start increased and then decreased with an influence point at the nozzle temperature of 220 °C, where well-bonded inter-layers and rasters could be obtained. Tensile strength, Young's modulus, and yield strength had the largest mean values when layer thickness was 0.15 mm. However, toughness and ductility had the largest mean values at layer thickness of 0.25 mm.
[6]Delin Jiang et al. (2017) studied anisotropic properties of CFFP composites produced by FDM. In this experiments matrix material were ABS, PLA and PETG and carbon fibre as reinforcement. According to its research findings:

1. CFF ABS gives higher modulus when compared to the unfilled samples, CFF ABS indicates lower ductility than the unfilled ABS coupons.
2. CFF PLA has least ductile material in all the test materials in this study, tensile strength and tensile modulus is increased by 14.0% and 162.9%, respectively, for CFF PLA.
3. The tensile strength and tensile modulus is increased by 48.2% and 313.2%, at 0 degree for CFF PETG.

According to [7]air wolf 3d site following Is a list of compatible HD2x material combinations and the uses that would be associated with the combination.

- PVA can be used as support material with PLA due to high water solubility of PVA but there is difficulty in clean printing with PVA.
- In ABS and PET dual material printing ABS is used as support material with PET. ABS is soluble in Acetone solvent.
- HIPS can be used as soluble support with ABS. It dissolves in Limonene. This combination allows the creation of more intricate parts and lesser effort require for cleanup and setting.
- PC-ABS and HIPS: It gives higher temperature tolerance. Currently due to high temp temperature for HIPS cause nozzle jamming.

## 3. PROJECT METHODOLOGY

Various data and information gathered from Literature review becomes input for the startup of work regarding to project. This information is utilized and idea of composite/dual material is generated with different parameter.

### *3.1 Rapid Prototyping Technology selection*

There are various additive manufacturing technology available for processing project work of dual material, but the most suitable and widely used in literature technology is FDM (Fused Deposition Modeling) is selected for required objective. For this technology 3D desktop printer named "Pratham" of make3d.in is used.

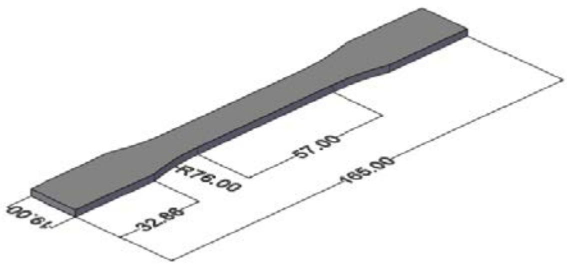



Figure 3.1 ASTM D638 design

TABLE 3.1 FDM PARAMETERS

| Parameter | Value |
|---|---|
| Infill speed | 60 mm/s |
| Layer thickness | .35 mm |
| Infill pattern | rectilinear |
| Infill density | 100% |
| Bed temperature | 80°C |
| Nozzle diameter | 0.4 mm |

After completion of design of experiment through Multi-Level Full Factorial design and getting 18 number of experiment combination from according to input parameters, experimentations were conducted on FDM printer and specimens were fabricated according to design of experiment as shown in figure 3.8.

Figure 3.2 ASTM D638 specimens

*3.2 Testing of specimen:*

After completing the formation or production of 3d printed component for knowing targeted mechanical properties of that parts testing is required.

After fabrication of ASTM D638 specimens according to design of experiment testing of those specimens were done on UTM machine for knowing the response parameter according to combination of input parameters. Specimens after testing are shown in figure 3.9.

| PLA(Poly Lactic Acid) PROPERTIES | VALUES |
|---|---|
| Breaking Load | 1960 N |
| Max Extension(Strain) | 6.1 Mm |
| TENSILE STRENGTH In Mpa | 43 Mpa |
| Density | 1.25 Gram/Cm^3 |
| Young's Modulus | 3.5 Gpa |
| Poisson's Ratio | 0.33 |
| Glass Transition Temperature | 60 C |
| Melting Temperature | 160 C |
| Standard Printing Condition | 200 – 230 C |
| Bed Temperature | 60-80 C |

FIGURE 3.3 ASTM D638 specimens after testing

TABLE 3.3 ABS PROPERTIES

| Abs Properties | Values |
|---|---|
| Breaking Load | 1480 N |
| Max Extension(Strain) | 3.6 Mm |
| TENSILE STRENGTH In Mpa | 35.577 Mpa |
| Density | 1.07 Gram/Cm^3 |
| Young's Modulus | 2.2 Gpa |
| Glass Transition Temperature | 105 C |
| Melting Temperature | 200-238 C |
| Standard Printing Condition | 200– 240 C |
| Bed Temperature | 60-80 C |

From the testing of specimens mechanical properties of pure PLA, pure ABS and dual material parts are acquired as shown in above tables and further discussion is carried out in result and discussion section

## 4. RESULTS AND DISCUSSION

After obtaining the design of experiment data through multi-level full factorial design total 18 numbers of experiments were performed on PRATHAM 2.0 FDM. Mainly three response parameters are obtained through testing on UTM and that data were fed to MINITAB software.

After applying ANOVA, % Contribution of each process parameters is obtained for Tensile strength is discussed next.

ABS content is the most significant factor (64.49197% ) affecting the tensile strength.

Whereas RASTER ANGLE (1.112511%), RASTER ANGLE*ABS CONTENT (4.955817%) and is the least significant factor as its P-value is greater than 0.05.

After applying ANOVA, % Contribution of each process parameters is obtained for breaking load is discussed next.

ABS CONTENT is the most significant factor (64.51331% Contribution) affecting the breaking load.

Whereas RASTER ANGLE (1.104839%), RASTER ANGLE*ABS CONTENT (4.938816%) and is the least significant factor as its P-value is greater than 0.05.

After applying ANOVA, % Contribution of each process parameters is obtained for s/w ratio.

ABS CONTENT is the most significant factor (31.73164% Contribution) affecting the S/W ratio.

Whereas RASTER ANGLE (2.347273%), RASTER ANGLE*ABS CONTENT (9.58957 %) and is the least significant factor as its P-value is greater than 0.05.

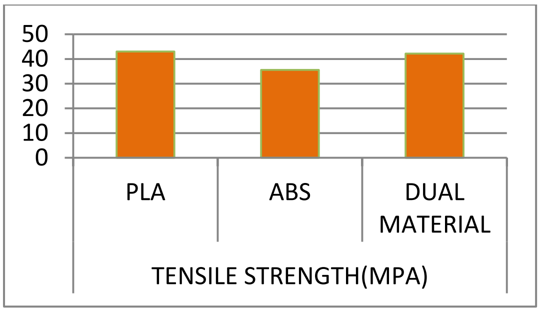
To compare mechanical properties of Dual material specimens with normal single material specimen, ABS and PLA components are fabricated and tested for same properties as dual material components. The results are as below Table:

TABLE 4.1 COMPARISONS OF PROPERTIES

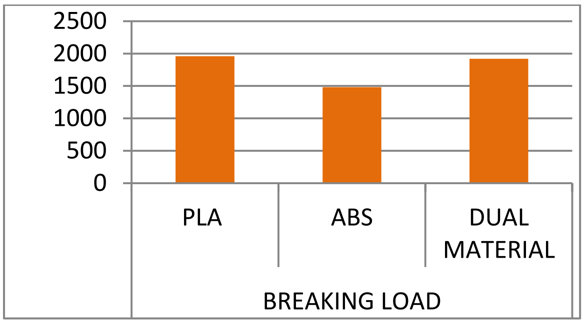
| Property | PLA specimen | ABS specimen | Dual material | Positive Change |
|---|---|---|---|---|
| Tensile strength(MPa) | 43 | 35.577 | 42.198 | 6.621 |
| Breaking load(N) | 1960 | 1480 | 1920 | 440 |
| S/W ratio(kNm/kg) | 34.4 | 33.25 | 35.8217 | 1.42,2.57 |
| Stiffness(N/mm | 784 | 462.5 | 772.727 | 310.227 |
| % elongation | 10.70 | 6.316 | 8.947 | 2.631 |

From the comparison of individual properties of pure PLA and ABS material specimens with DUAL material specimen it is clear that dual material specimen shows the positive results in all mechanical properties aspect.

Figure (c) indicates that value of S/W ratio for Dual material specimen is higher than both of that pure PLA and ABS specimens.
Figure (d) and figure (e) indicate same result for stiffness and %elongation respectively and result is that Dual material has higher values of both properties than ABS and lower than PLA.

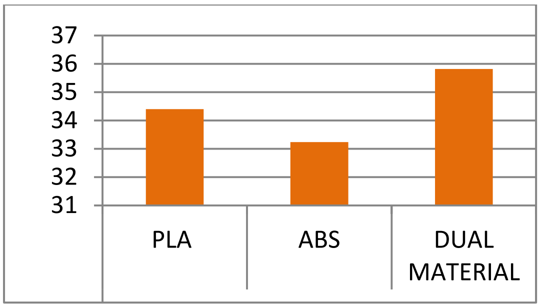



(a)

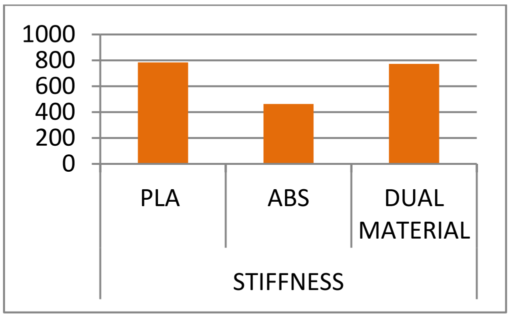



(b)

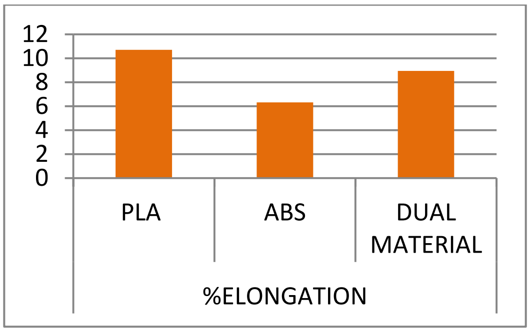
As shown in below figure (a) Dual material specimen got higher tensile strength than ABS and lower than PLA. Same results with different numbers is found for Breaking load as shown in figure (b).




(c)




(d)




(e)

Figure 4.1 Comparison of response parameters

## 5. CONCLUSIONS AND FUTURE WORK

### *5.1 CONCLUSION*

Additive Manufacturing (AM) has a range of potential thus it is catching rapid attention of researchers. There is vast variety of work done on composite filaments in AM. This work represents important conclusion derived from the investigation of Dual Material composites polymer fabricated by FDM.

FDM printer used in this work was capable of printing Dual material products. Considering the fact that ABS and PLA are the widely used filaments, successfully experiments were conducted to compare mechanical properties regarding input parameters such as temperature, ABS contents and raster angle and following conclusions are derived.

- The most significant parameter affecting tensile strength, S/W ratio and breaking load is ABS content and the least significant parameter is Raster angle.
- 2 layer ABS content and 45 degree raster angle give the highest value of output parameter.
- Values of tensile strength and breaking load for dual material component lie between the respective values of ABS and PLA but value of S/W ratio for dual material is higher than that of ABS and PLA value.

Based on such a consideration, mechanical properties of FDM parts can be enhanced with Dual material composite products.

### *5.2 FUTURE WORK*

1. Different dual material combination or multi material concept can be investigated.
2. Other mechanical properties regarded 3D printed parts can be analyzed regarding other input parameters of FDM process.
3. As S/W ratio shows positive and better response than both of single material, it can be studied deeper.
4. Adhesion properties of different types of dual materials with its properties can be analyzed in FEA software.

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