Mechanical Properties of Graphite Filled ABS Parts Developed by Fused Deposition Modelling

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Abstract. The current work focuses on synthesis of graphite filled ABS plastic filament suitable for Fused Deposition Modelling applications. The Effect of graphite reinforcement on mechanical properties of Acrylonitrile Butadiene Styrene (ABS) parts developed by FDM process have been studied. Twin screw extrusion technique was adopted for synthesis of filament required for FDM process. Pure ABS and graphite filled FDM parts have been subjected to microstructure and tensile studies. Microstructure studies confirms that graphite filled filaments are free from micro porosity. Tensile test shows that graphite filled ABS parts have exhibited significant enhancement in ultimate tensile strength when compared pure ABS parts.

1. Introduction

Fused Deposition Modeling (FDM) is based on the principle of Additive Manufacturing (AM) that builds the plastic components in layer by layer process. It is a process in which a plastic filament or metal wire is unwound from a coil and supplies material to produce a solid part. Thus, FDM is also known as a solid-based AM technology. In the recent years extensive research is being carried out to enhance the applications of parts built by fused deposition modeling. FDM process involves extrusion of plastic filament wire which will be used as feed stock material [1]. FDM process possesses low production cost with excellent dimensional accuracy compared to other manufacturing techniques.

Plastic parts built by fused deposition modeling process are used for prototyping as well as functional parts applications in the field of Electronics, architecture, fashion industry, automotive, aerospace etc. [2]. Thermoplastics such as Polycarbonate, Acrylonitrile-Butadiene-Styrene, Polylactide, nylon are the commonly employed feed stock material (filament wire) for FDM applications owing to their low melting temperature. Generally, plastic filament used in the FDM process will be melt into semi solid state at the nozzle of the printers to print the components in the form of layer by layer one above the other [3]. Anoop Sood [4] etl have studied the compressive strength by investigating experimentally and by developing empirical model of FDM technique. Five important input process parameters were varied to see their effects on test specimen compressive strength which is a response characteristic.

They have developed a statistical equation to predict results and optimum parameters were achieved. QPSO and ANN was used to predict the values and was compared with the equation developed.
Galntucci et al. [5] have analyzed dimensional accuracy for an open source 3D printer based on FDM technique by evaluating and comparing on benchmarks using industrial 3D printer and a homemade 3D printer. They have achieved optimum values of dimensional accuracy using DOE and homemade 3D printer came out as better, quick, simple parts and with less cost. Also, homemade 3D printers are affordable easily. Vijay et al. [6] studied parametric optimization for fused deposition modeling process. Layer thickness, ultimate tensile strength, surface roughness, dimensional accuracy and manufacturing time were considered as response parameters. Using Taguchi’s orthogonal array effect of each parameter is tested and verified. Pranjal Jain [7] et al. have reported on the feasibility of manufacturing using FDM process. In process prototype was built for casting a product which was used for sand casting from available software. Disc was produced using both FDM process and sand casting. Results were obtained in the form of opinion from foundry people. They have concluded from that FDM process has helped them to a greater extent especially for complex parts. Prashant [8] et al. have tested based on advance material for powder based RPT, based on powder materials for RP SLS, here powder is fused compacted or sintered under heat and thermal applications. On the other hand, the limited information is available as regards effect of filler materials on Mechanical behaviour of FDM parts.

In the light of the above, Present investigation is focused on synthesis of ABS parts with graphite fillers using fused deposition modelling technology. Percentage of graphite powder was varied from 0 to 5wt% in steps of 2.5wt% (i.e., 0%, 2.5% and 5%). Twin screw extrusion was employed to synthesis the filament required for FDM process having diameter of 1.75mm. Developed FDM parts were tested for its mechanical strength as per ASTM standards.

2. Materials and Process Details

2.1. Materials

2.1.1. ABS (Acrylonitrile butadiene styrene)

![Figure 1. Photograph of ABS Pellets](image)

Acrylonitrile butadiene styrene (ABS) was used as matrix material and is a common thermoplastic polymer. ABS plastics were procured in the form of pellets as shown in Fig 1. ABS plastic was used as filament material; ABS plastic was preferred as matrix material owing to its wide applications in the industrial sector.

2.1.2. Filler material: Graphite powder
Fine graphite powder having particles size in the range of 5 to 40 microns was used as filler in the ABS plastic. 99% pure graphite is used in this study.

Figure 2 shows SEM of graphite powder used in the study. From SEM, it is observed that particles are irregular in nature and particle sizes are in range of 5-50 microns. Further, EDAX analysis carried out on graphite powder clearly confirms purity of graphite. Figure 3 shows EDAX pattern of as received graphite particles. Further, Elemental Analysis carried out on graphite reconfirms the purity of graphite.

2.2. Blending and Extrusion

Plastic compounding machine was used to blend ABS pallets and graphite material in proposed composition and pellets were obtained as per required size suitable for twins screw extrusion process. Temperature and speed were optimized with help of experimental trials to achieve homogeneous dispersion of graphite in ABS. Graphite filled ABS pallets were subjected to twin screw extrusion process to obtain FDM filament having diameter 1.75mm. Extrusion temperature and extrusion speed were optimized with experimental trials to achieve uniform dimensions and better surface finish suitable for FDM applications. Filaments required for FDM were synthesized for all the compositions. Figure 4 shows photograph of graphite filled ABS filament after twin screw extrusion.
2.3. Fused Deposition Modeling

Fused deposition modelling parts were developed for all three compositions such as pure ABS, 2.5wt% graphite filled ABS and 5wt% graphite filled ABS filaments. Parts were built according to ASTM D638 standards for conducting tensile test for both pure ABS and graphite filled ABS parts. FDM temperature of 245°C was adopted which was slightly higher compare to pure ABS in order to ensure complete melting of filament during FDM process and the other parameters were maintained constant throughout and are reported in Table 2. Figure.5 shows photograph of Make-In 3D printer used in this study.

![Make-In 3D printer](image)

**Figure 5.** Photograph of Make-In 3D printer

**Table 2.** Process parameters

| Orientation       | X,Y,Z directions |
|-------------------|------------------|
| Layer height      | 0.2mm            |
| Shell thickness   | 0.9mm            |
| Fill Density      | 60%              |
| Speed             | 25mm/s           |
| Nozzle            | 0.3mm            |
| Bed temperature   | 90°C             |

2.4. Tests & Measurements

Parts built by FDM process for various composition have been subjected to tensile test. Tensile test specimens were built as per ASTM-D638-10 standards. Dog bone shaped specimens with dimensions 165mm length, 20mm width and 4mm thickness was built as shown in Figure. 6 was used for tensile test. An average of 3 specimens were considered as tensile strength of each composition.
3. Results and Discussion

3.1. Microstructure of filament

Figure 7 and Figure 8 shows SEM of pure ABS and 5wt% graphite filled ABS filaments obtained from twin screw extrusion process. From the figures below, it is noticed that filaments reinforced with graphite powder shows a very minimum defects which clearly demonstrate good wettability of graphite particles in ABS plastic. Further, it is also noticed that there is no sign of de-bonding and agglomeration of graphite filler in ABS filament, which makes filament suitable for fused deposition modelling applications.
3.2. Ultimate Tensile Strength

Fig.10. shows variation of ultimate tensile strength of pure ABS and graphite filled ABS parts developed by FDM process. It is observed from the results that there is a considerable enhancement in the ultimate tensile strength of the ABS plastic with addition of graphite powder. It is also noticed that with increase in the percentage of the graphite, the amount of load required for fracture has increased. The values of ultimate tensile strength increases as observed in the Table:2. An improvement of 4.95% and 13.30% is observed with addition of 2.5wt% of graphite and 5wt% graphite in ABS plastic respectively.

![Tensile test](image)

**Figure.9. Variation of Ultimate Tensile Strength with weight percentage of graphite**

| Parameters      | Initial area mm² | Ultimate Tensile Load, KN | Ultimate Tensile Strength, Mpa |
|-----------------|------------------|----------------------------|--------------------------------|
| 0wt% C+ABS      | 61.47            | 1.90                       | 30.90                          |
| 2.5wt% C+ABS    | 60.74            | 1.97                       | 32.43                          |
| 5wt% C+ABS      | 61.97            | 2.17                       | 35.01                          |

3.3. SEM of fractured tensile specimens

From the analysis of scanning electron micrographs. It is noticed that filaments reinforced with graphite powder are defect free in the form of porosity which may attributed to good wettability of graphite powder in ABS plastic as discussed earlier. FDM parts of all three compositions appears to be fused completely and bonded to each layer without showing any defects. This clearly shows addition of graphite filler in ABS plastic acts as load bearing elements contributed to enhanced tensile strength.
4. Conclusions

- Graphite filled ABS filaments have been successfully synthesized by twin screw extrusion process.
- A maximum of 13% enhancement in ultimate tensile strength is achieved with 5wt% graphite filled ABS parts.

5. References

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