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Mechanical Behavior of CNT reinforced PETG based Nanocomposite developed by Fused Filament Fabrication

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Abstract

With any complicated geometry, the fabrication of parts layer by layer can be achieved with FFF (Fused Filament Fabrication), which is a type of AM (Additive Manufacturing). A wide range of applications have been seen in polymer nano composites' development and utilization. This study evaluated the mechanical properties of a polymer nanocomposite prepared using fused deposition technology. The PETG compound is combined with carbon nanotubes. For the PETG (polyethelyne terephthalate glycol) matrix as a reinforcement the CNT (Carbon Nano Tubes) have been added at different proportions. CNT had been incrementally added to PETG to produce the samples of two variations. The nano composite FFF parts which is developed have been examinedfor impact strength and ultimate tensile strength. The developed parts' ultimate tensile strength hadbeen substantially increased when CNT was added to them. As with impact strength, a similar trend had been noticed. The fractured surfaces have been analyzed by scanning electron microscopy and strengthening mechanisms have been discussed.

Keywords: PETG, Fused Filament fabrication, Carbon Nano Tubes, tensile strength, impactstrength.

1. Introduction

As an emerging technology, 3D printing, or additive manufacturing (AM), is becoming increasingly popular with both industrialists and researchers. For developing functional models or prototypes, FDM, a market leader in the field of additive manufacturing, uses polymer, such as filament, as the raw material. FDM is capable of creating any complex model. 3D printing begins with the creation of a CAD model (any form will do), which's then converted into a file .stl, which's then sliced and then fetched to the printer as an input. In terms of design properties and printing speed, AM opens a wide range of possibilities [1]. Light weight, manufacturing stability, process ability, low cost etc, are the few properties that has made vast use of plastics in sectors such as medical, automobiles, electronics, aviation, dentistry. Plastics have been used in FDM due to theseadvantages. PLA, ABS, Nylon, PEEK are few of the common polymers used in FDM [2]. AM hasbeen developed for a wide range of applications, such as electronics, medical, automotive, aviationas well as aerospace, biotechnology, electronics, engineered composites and energy storage [3].

The use of these polymers alone remains a challenge in achieving the desired properties. So as a result, it is crucial to enhance the properties of fabricated parts, which can be achieved by the fillermaterial inclusion. For increases in specified properties, various combinations of filler materials have been examined by researchers. In order to investigate the variation in tensile properties of ABS reinforced with Kevlar, different filler fractions of 4.04%, 8.08%, and 10.1% were used to fill the ABS matrix. With an increase in volume filler content, the strain, tensile strength, strain, and Young's modulus all increased [4]. Vijay T et.al, have successfully developed graphene reinforced PC-ABS composite. The fabricated specimens were analyzed for thermal studies which provided improvised results in aspects of glass transition temperature and material loss with increased temperature. The filaments were fabricated with maximum addition of 0.8wt% of graphene [5]. In addition to their remarkable material properties, CNTs have excellent tensile properties such as greater ability to conduct heat, modulus and tensile strength [6]. Besides facilitating mechanical reinforcement by interfacial stress transfer, CNTs induce the formation ofhighly ordered interphase polymer layers [7]. Fuda et. al. has used the carbon fibers of two differentlengths to reinforce as well as to produce ABS nanocomposites. The studies had been concentratedto keep the FDM machine's optimal parameters, therefore the printing speed of 1.5m/min, temperature of 230^0 C and to the 0.2mm the layer thickness was set. As a result, the orientations remain at 450^0 and 135^0, respectively. As reinforcement was added to the structure, mechanical properties exhibited an improvement. Using the various 3D printing materials, there have been numerous researches were carried out. The author similar to the same study examined the load bearing capacity using various thermoplastic materials when subjected to cyclic loads. The materials of Nylon and PLA can withstand low folding cycles, while up to 800 cycles with the folding angular displacement of 1800 the PETG can withstand [9]. Leonardo Santana et al., A number of

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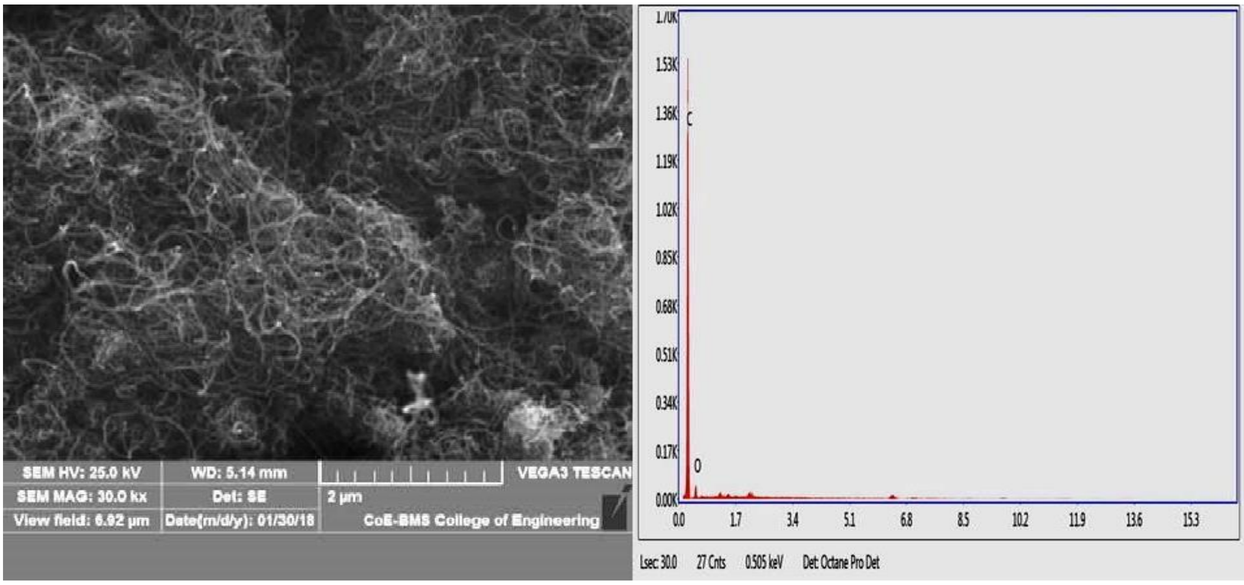
PETG and PLA specimens were designed with Taguchi experimental design in the experiment. In this study, process parameters such as filament diameter, fluidity, deposit rate are examined and observed to have an effect on the properties of printed specimens [10]. One study compares different printing parameters for PETG material specimens that are 3D printed. An ANOVA analysis is performed for the optimization of factor representations and statistical expressions are derived for predicting the printed specimens' tensile strength. PETG specimens have been reported to have a greater impact on strength by the factors such as infill density and feed rate [11].

In this present investigation Carbon Nanotubes is added as a filler material to PETG in 0, 1.5 and3wt% proportion. The developed polymer composite is tested for microstructure studies and mechanical properties.

2. Materials and Methods

2.1 Raw Materials and processing

PET stands for Polyethylene Terephthalate and G stands for glycol. The plastic resin of polyester-based PETG which is utilized for some thermoforming applications and also to prepare the food, beverage and other liquid containers. The plastic resin PETG may be sheet extruded because it is a clear amorphous thermoplastic. PETG was in the form of granules. In the pellets form, the fabricated parts are obtained which is prepared by the polymers. PETG pellets are separately purchased from M/s polyshakti Polymers, Bangalore. Firstly, for the removal of moisture, these pellets are pre dried for about 3 to 4 hours at 120^{0}C in an oven. They are then added along with the measured amount of CNT to the compounding machine & blended them together at different temperatures and in the wire form these are subsequently pulled out and later it's been cut in the pellets form. The SEM and EDAX of CNT is shown in Figure 1. In addition to being heated in an oven, the compounded pellets are fed into the extruder machine. To extrude filament sized 1.75mm, an extruder of single screw double rod had been used from GLS Polymers, Bangalore, and also used lab grade compounding machine from GLS polymers. Figure 2 shows the photographs of the filaments prepared in this investigation.



(a) (b)

Figure 1: (a) SEM of CNT (b) EDAX of CNT

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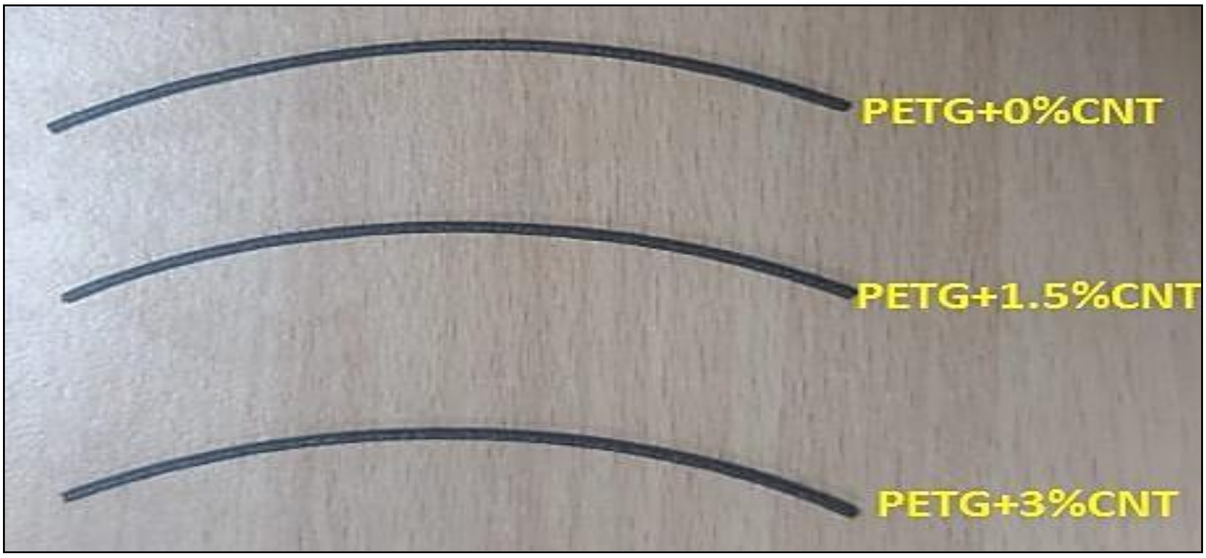

Figure 2: Photograph of FDM filaments reinforced with different percentages of CNT

2.3 Fused Deposition Modeling (FDM)

3D parts were developed using Praman 3D printers with Prusa i3 technology from Global 3D Labs. The machine had enclosed chambers of 300mm3. In order to manufacture the FDM parts some of the parameters were chosen such as 1.2m/min print speed, 0.2mm layer thickness, 240^0 C nozzle temperature, and 90% infill density based on 45^0 orientations. For fabrication the FDM printer is utilized which is illustrated in Fig 3.

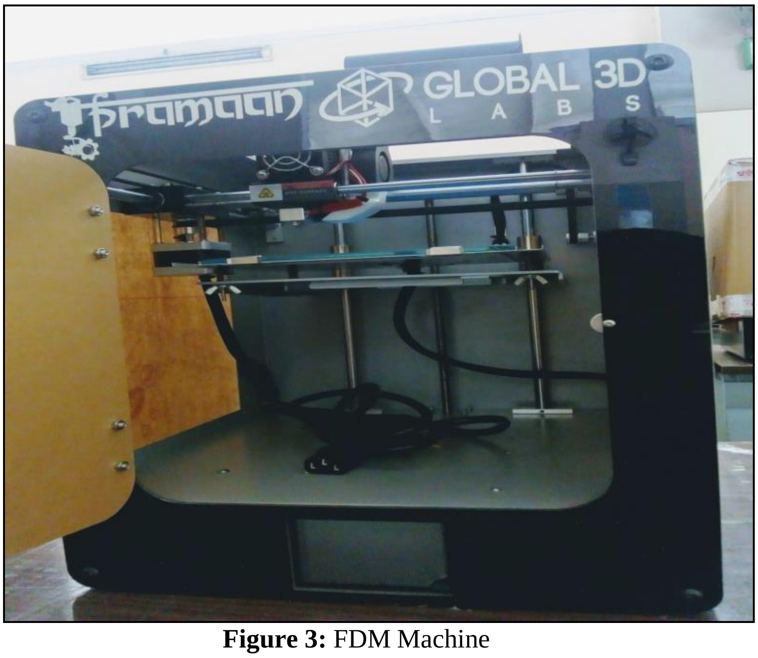

Figure 3: FDM Machine

2.2 Tensile and Impact Test

In National Analytical Laboratories and Research Centre, Bengaluru, the tensile test procedures according to ASTM 638 were followed, and measurements of the developed parts' impact behaviorwere performed according to ASTM D 256. Tensile tests were conducted on a machine by the manufacturer FIE with 0-60 tons capacity.Figure.4a and b shows the photographs of nano composite specimens prepared for tensile test and impact test. For each composition, three specimens were fabricated for tall the mechanical tests. An average of all three specimens were accounted for calculating the tensile properties and impact test. The fractured surfaces of the tensile specimens were analyzed through scanning electron microscope to determine the failure mechanisms.

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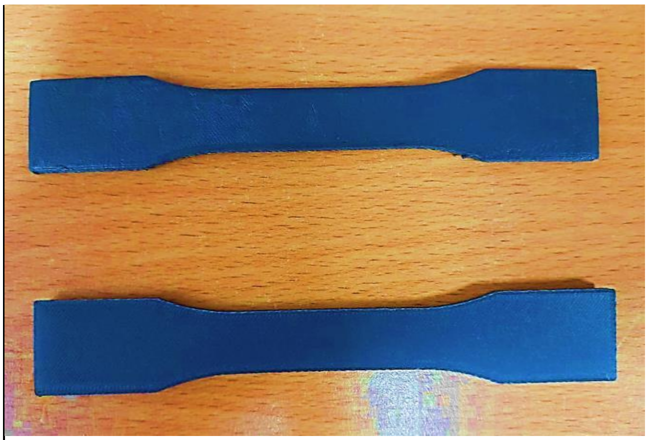

Fig.4a Photograph of Tensile test specimenfabricated as per ASTM D638 standard

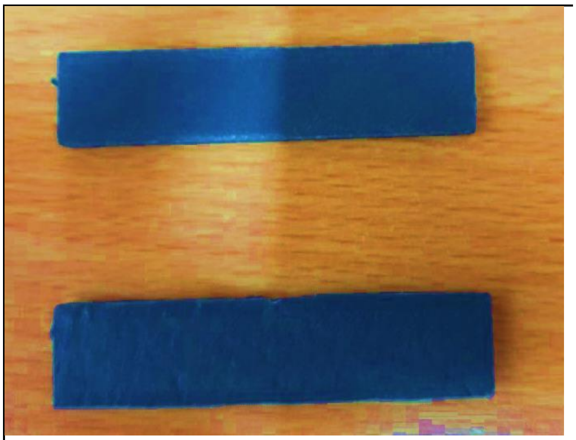

Fig.4b Photograph of Impact test specimen fabricated as per ASTM D256 standard

3 Results and Discussion

In figure 5, the CNT content increases from 1.5wt% to 3wt%, resulting in an increase in Ultimate Tensile Strength (UTS). In comparison with virgin PETG, CNT of 1.5wt% plus PETG showed an18.5% of enhancement in tensile strength. Comparatively to PETG+1.5wt% CNT, PETG+3wt% CNT produced a 21 percent increase had been noticed. By adding CNT to PETG, the UTS will beincreased, but this will be dependent on the 3D printing process parameters.

Figure 6 shows the tensile samples' SEM images after the load was applied at the break point. Similarly, the impact resistance was observed to be enhanced with an increase in CNT addition inthe developed specimens.

Zare et al. [12] has established that the polymer nanocomposites' mechanical properties can be enhanced by the effective stress transmission between the reinforcement and matrix, and it may beachieved by obtaining suitable adhesion. The resulting behavior is because of the interaction of PETG and CNT finely as well as in the interphase. CNT has been shown to increase yield strength with increasing additions. In comparison with pure PETG, PETG + 1.5 wt % CNT results in a 26.2% improvement in yield strength. CNT additions to PETG matrix, however, have reduced percentage elongation. There was relatively brittle behavior in all the composites with CNT-filled.Figure 7 and 8 shows yield strength and elongation respectively. Inclusion of CNT improves the impact strength which is shown in Figure 9. Due to an increase in impact strength, the CNT

inclusion results in the enhancement of the breaking resistance. In PETG matrix the dispersion of CNT results in both improvements in impact strength and tensile strength. Enhanced mechanical properties are attributed to stronger bonding between matrix and filler and also because of capability of the long chain formation with no agglomeration. Another factor contributing to the strong bond between phases is pores reduction associated with an increased CNT content.

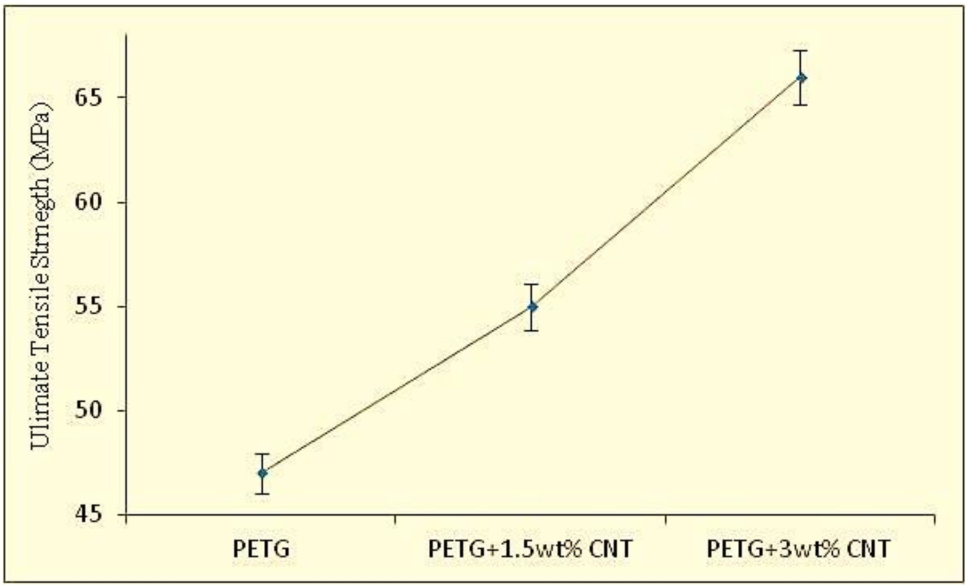

Figure 5: Tensile strength of PETG along with reinforced CNT

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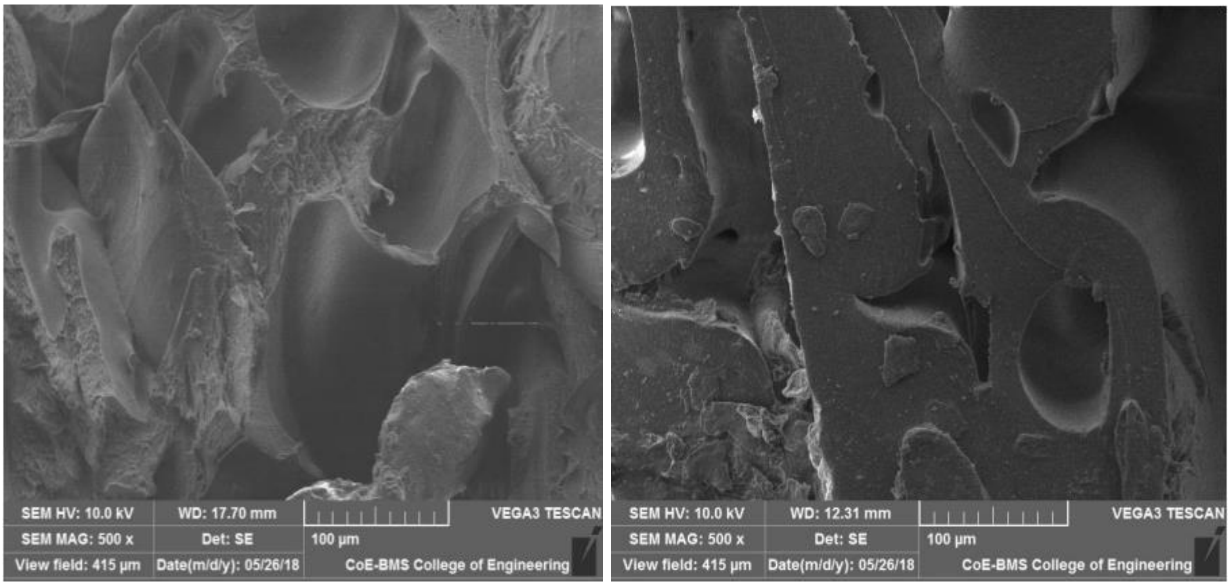

(a) (b)

Figure 6: SEM of tensile fractured specimens of (a) PETg and (b) PETG + 3wt% CNT

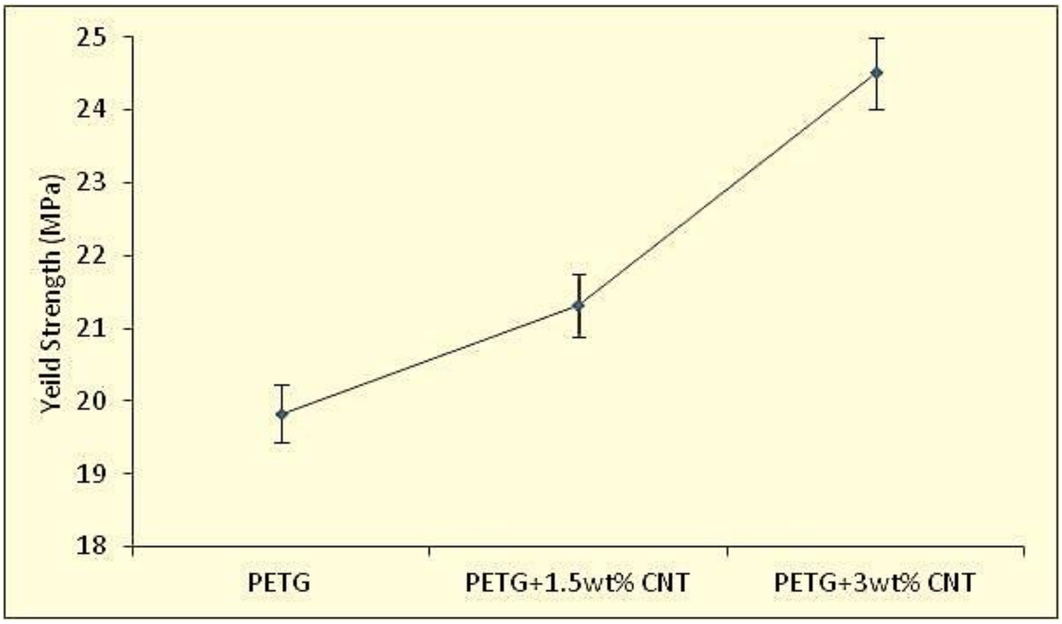

Figure 7: Yield Strength of PETG and PETG reinforced with CNT

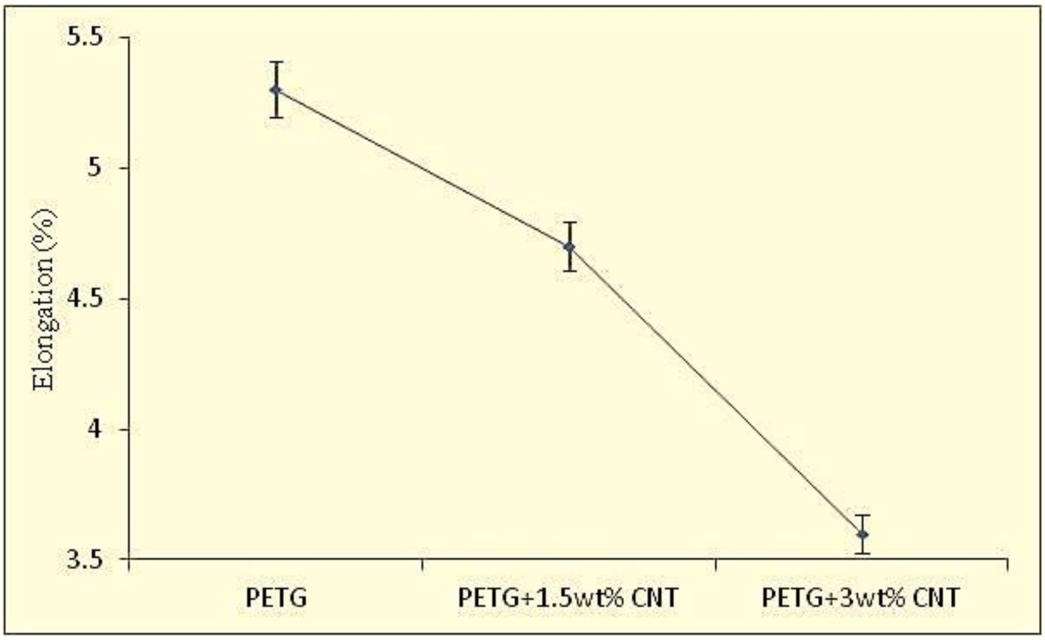

Figure 8: Elongation variation of PETG and PETG reinforced with CNT

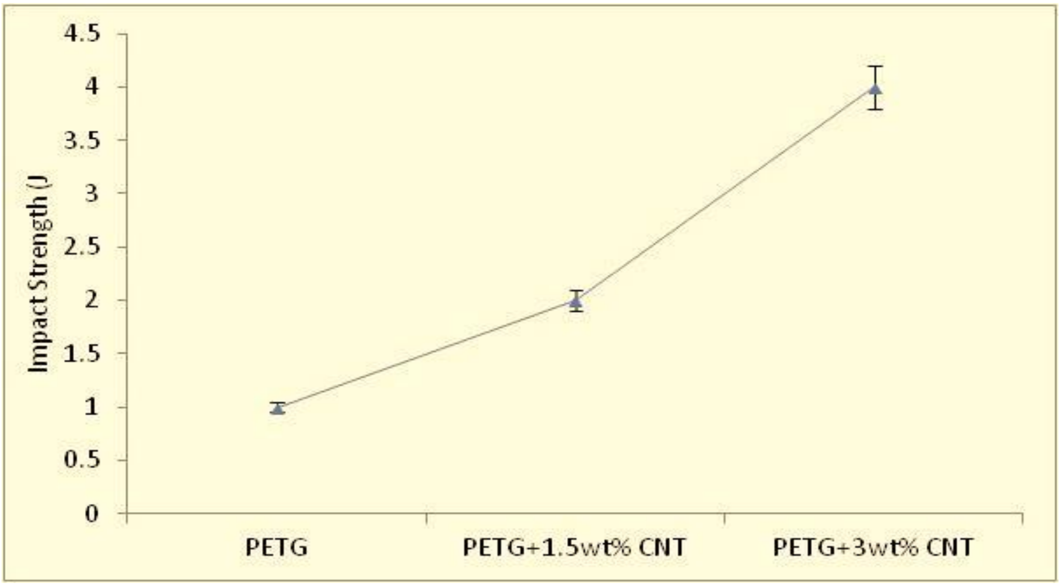

Figure 9: Impact strength of PETG and PETG reinforced with CNT

4.0 Conclusions

Investigations on 3D printed PETG/CNT nanocomposite described in this study reveal remarkable improvement in mechanical properties indicating its industrial significance. A considerable gap still exists in the knowledge relating to how CNTs are introduced as part of nanocomposites which is prepared by 3DP technique, despite the 3DP technique rapid evolution toward numerous applications, starting from simpler devices to high-tech structures for everyday use. The deposition into the filaments of PETG reinforced with CNT for the FDM applications had been successful. In comparison to unreinforced PETG, the increased tensile strength and impact strength have exhibited by the FDM parts made from PETG nanocomposites reinforced with maximum of 3wt%CNT.

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