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Mechanical Characterization of PC-ABS Reinforced with CNT Nanocomposites developed by Fused Deposition Modelling

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Abstract. Fused Deposition Modeling (FDM), a category of Additive Manufacturing (AM) is a versatile form of manufacturing technology that enables the development of the part layer by layer, of any complex geometry. The development and utilization of polymer nanocomposites for has seen a wide range of implementation. The development of polymer nanocomposite by fused deposition technology and evaluation of its mechanical propertieshave been carried out in this study. Polycarbonate (PC) and Acrylonotrile Butadiene Styrene (ABS) are compounded together with carbon nanotubes. Different proportion of Carbon Nano Tubes (CNT) was added as reinforcement at to PC-ABS matrix. Two variations of samples were developed with incremental addition of CNT to PC-ABS. Ultimate tensile strength and impact strength were analyzed for the developed nano composite FDM parts. It was observed that, with the addition of CNT the ultimate tensile strength of the parts increased significantly. Similar trend was seen for impact strength as well.

Keywords: Polycarbonate, Acrylonotrile Butadiene Styrene, Fused Deposition Modelling, Carbon Nano Tubes

1. Introduction

The ease of development of parts has taken a new dimension through the process of Additive Manufacturing (AM). Shapes of any complex geometry that could be developed in CAD model can be easily printed through the process of AM. Among the 7 classifications of AM as stated by ISO/ASTM52900-15, Fused Deposition Modeling (FDM) has taken a wide spectrum of utilization in global scenario. Thermoplastic polymer or its composites is utilized as a raw material in the form of filament to feed into the nozzle that moves in X-Y direction. This is heated above the glass transition temperature and is extruded through nozzle and laid on the bed with specified thickness [1]. The domain of additive manufacturing is seeing huge competence with its applicability in medical, electronic industry, automobile and aerospace [2,3]. The utilization of FDM for development of defined parts has huge opportunity. However, the materials available for the development of such parts are still in the stage of infancy. Polymer nanocomposites are the materials that can be used to bridge this gap and enhance the mechanical, thermal and electrical properties of the parts developed through FDM. All these developments can be achieved with reduced cost and in sustainable manner in comparison to conventional system. The process parameters of FDM also play an important role in determining the mechanical properties. Keshavamurthy et. al., [4] have stated the effect of layer thickness, orientation angle and fill angle on certain defined parameters. It was found that each of these parameters have different effect on tensile properties, surface roughness and dimensional accuracy. Apart from these numerous factors like size of particles, distribution, printing temperature

and speed, bed temperature and nozzle temperature has to be optimized for better results [5].Many researchers have tried to develop new materials by adding various reinforcements in the form of metal particles, fibers, oxides of metal and many more [6].Vijay et. al., [7] have successfully developed a filament by reinforcing graphene at 0.2, 0.4, 0.6 and 0.8wt% in PC-AS matrix. The studies were conducted to analyze the dispersion properties of the graphene in the matrix. Through the microstructure studies the dispersion was considered to be homogenous. The enhancement in density of the polymer nanocomposites was also seen with increment of graphene.
ABS as a matrix was reinforced with continuous Kevlar fibers, to understand the variation of tensile properties with variation of filler material by volume fraction from 4.04%, 8.08% and 10.1%. The ultimate tensile strength, strain and Young's modulus increased with increase in the volume filler content. [8].Dul et. al., have claimed the first time development of ABS- reinforced graphene platelets polymer nanocomposite at a reinforcing weight of 4%. The developed specimens were tested for building the parts with different orientation. It was observed that the storage modulus and elastic modulus increased with any kind of orientation. Thermal stability of the nanocomposites increased along with addition of graphene platelets and reduction in stress and strain at break was seen [9]. Fudaet. al,. have manufactured ABS nanocomposites by reinforcing carbon fibers of two different lengths. The study was focused on maintaining the optimal parameters for FDM machine, hence, the layer thickness was chosen to be 0.2mm with nozzle temperature of 230^0C and printing velocity of 1.5m/min. The orientation was maintained to be 45^0 and 135^0 respectively. The mechanical properties showed improvements with addition of reinforcement [10]. In the present investigation,Polycarbonate and Acrylonotrile Butadiene Styrene are blend in the ratio of 70:30 with addition of Multiwall Carbon Nanotubes at 0.15wt% and 0.3wt% . Mechanical behavior of the FDM parts with varying reinforcing content is discussed.

2. Methodology and Materials

2.1 Raw Materials and processing
Polycarbonate (PC) is tough material, which exhibits the property of high toughness and resistance. It acts brittle during certain strain conditions. To balance this, a small quantity of ABS is added to PC which improves the mechanical and thermal stability; it also improves the physical properties. PC-ABS is very high impact and adaptable thermoplastic material which can be easily extruded in the form of filament for development of model by FDM. PC and ABS in the form of pellets were mixed in the ratio 70:30[11]. The PC and ABS polymers were obtained in the form of pellets. Research grade MWCNT of average diameter 10-15nm having surface area of approximately $400m^2/g$ were procured from M/s Adnano Pvt Ltd, India.SEM of MWCNT along with EDAX are shown in figure1 (a) and (b) respectively. These pellets were dried in an oven at 120^0C for 4 hours for removal of moisture content, then the dried pellets were added to the compounding machine along with measured quantity of MWCNT and mixed properly at varying temperatures and are pulled out in the form of wire, which later is cut in form of pellets. These compounded pellets are again dried in an oven and then fed to the extruder machine. Lab grade compounding machine and single screw double rod extruder was used for extrusion of filament of 1.75mm diameter from GLS Polymers, Bangalore.

2.2 Tensile and Impact Test
ASTM 638 standard procedure was adopted to carry out tensile test and ASTM D 256 was followed for measuring the impact behavior of the developed parts at National Analytical Laboratories and Research Centre, Bangalore. Make of FIE with a capacity of 0-60 tons machine was used for tensile test.

2.3 FDM
Praman FDM printers from Global 3D labs with Prusa i3 technology was used for development of 3D parts. The machine was $300mm^3$ enclosed chambers. Optimal layer thickness of 0.2mm, with nozzle temperature of 240^0C, 1.2m/min printing speed and 45^0 orientations with 90% infill density were the

parameters chosen for manufacturing of FDM parts. Figure 2a shows the photograph of tensile test specimen built by FDM process. Figure 2b shows the SEM of PC-ABS FDM part reinforced with MWCNT.

3. Results and Discussions

The graph shown in figure 3 indicates the increase of the Ultimate Tensile Strength (UTS) with addition of CNT from 0.15wt% to 0.3wt%. The increase in tensile strength was 18.5% for PC-ABS+0.15wt% CNT when compared to virgin PC-ABS. 19% increase was noted for PC-ABS+0.3wt% CNT when compared with PC-ABS+0.15wt% CNT. Hence, the addition of CNT will lead to the increase of UTS of the PC-ABS, which again depends on various process parameters of 3D printing. The SEM images of the tensile samples after load application at the break point is shown in figure 5.The impact strength were also studied for the developed specimens which indicated the enhancement of impact resistance with increase in CNT addition. Figure 4 shows the improvement in impact strength with addition of CNT. The addition of CNT leads to increase in breaking resistance due to the enhancement of impact strength by combining PC and ABS. the improvement in both tensile and impact strength is attributed to homogenous dispersion of CNT in PC-ABS matrix. The strengthened bond formation between the filler and matrix and ability to form long chains without any agglomeration has lead to enhancement of mechanical properties. Reduction of pores with increased CNT content is yet another factor that determines the strong bond between the phases.

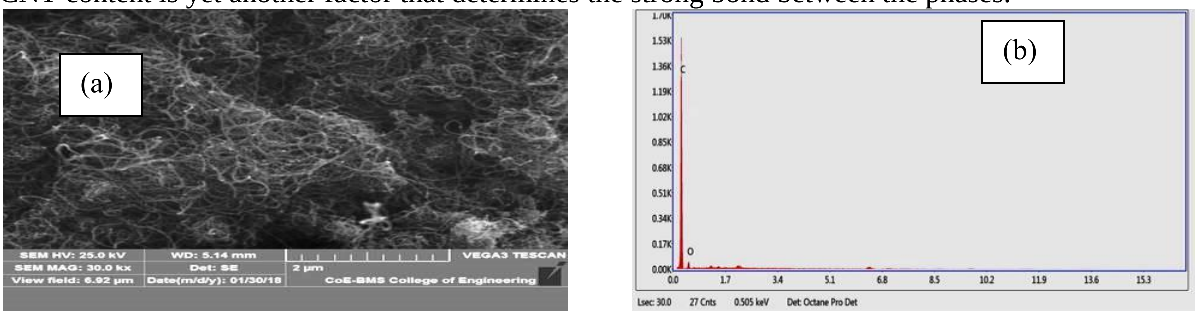

Figure 1. (a) SEM and (b) EDAX of Multiwalled carbon nanotubes

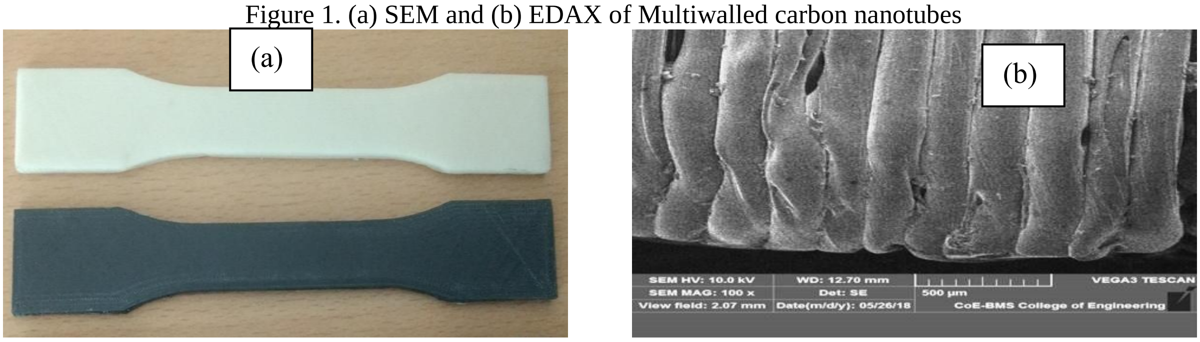

Figure 2. (a) Photograph of Tensile Test Specimen (b) SEM of printed layers

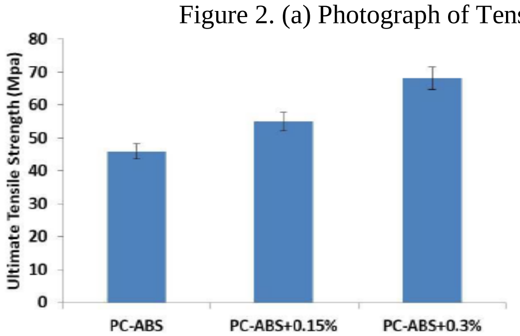

Figure 3. Variation of Ultimate Tensile Strength for increased composition of CNT

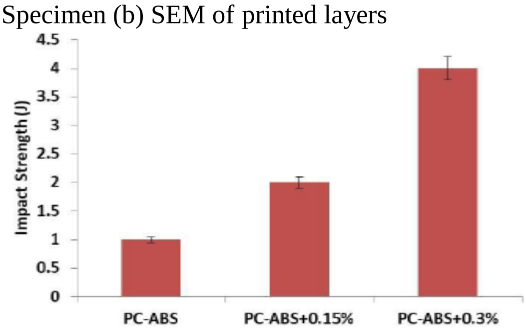

Figure 4. Graph representing the impact strength of the developed specimens

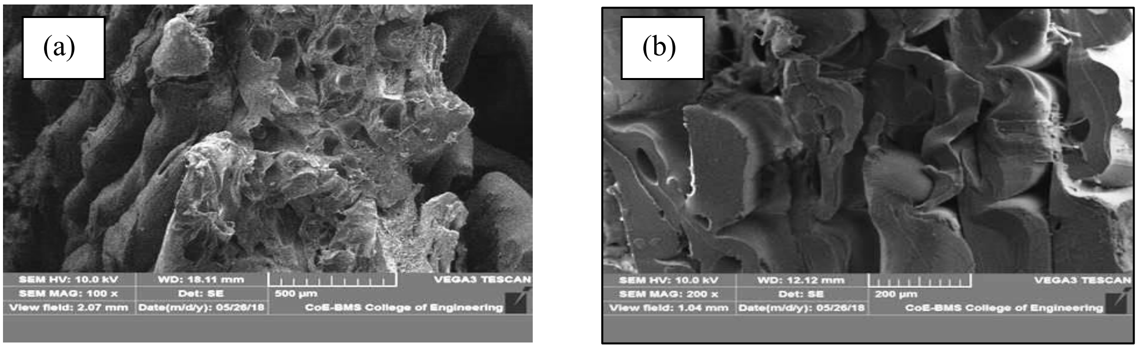

Figure 5. SEM of tensile specimens after application of load for (a) PC-ABS (b) PC-ABS+0.3wt% CNT

Conclusion

PC-ABS polymer reinforced with Multiwall CNT was successfully extruded into filaments for FDM applications. FDM part built by MWCNT reinforced PC-ABS nanocomposites exhibited increment in ultimate tensile strength and impact compared to unreinforced PC-ABS matrix.

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