Materials Science

AIMS Materials Science, 8(1): 18–28.
DOI: 10.3934/matersci.2021002
Received: 23 September 2020
Accepted: 22 January 2021
Published: 26 January 2021

http://www.aimspress.com/journal/Materials

Research article

Experimental characterization of mechanical properties and microstructure study of polycarbonate (PC) reinforced acrylonitrile-butadiene-styrene (ABS) composite with varying PC loadings

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Abstract: Fusion deposition modeling (FDM) is the most prevalent technique of additive manufacturing. This is for its practice in many applications. Polycarbonate (PC) reinforced acrylonitrile-butadiene-styrene (ABS) composite in 3D printing upsurges properties and crops better strength for components by 3D printing. A study on 3D printed (FDM) PC/ABS composite material was investigated in this paper. The influence of variations in material composition on mechanical properties such as hardness, flexural strength, and impact strength was studied. The proposed work aims at analyzing PC/ABS composite material by the FDM process in terms of mechanical performance, microstructural study, and their processibility. Specimens with three different compositions (10 wt%, 20 wt%, 30 wt%) polycarbonate (PC) reinforced in ABS were prepared. The best composition of polymer composite by FDM was proposed from their mechanical properties, and a microstructural study was done to trace the deviations in the impact strength of PC/ABS composite. The study evidences the compatibility of PC/ABS polymer composite. The hardness and strength of the composite are improved with a rise in polycarbonate (PC) content in the material. This exhibit excellent strength to the component at various compositions of polycarbonate reinforcement. Polymer composition contributes to producing intricate 3D printed components with various benefits and applicable for vast applications in many fields.

Keywords: 3D printing; polycarbonate; micro-structural study; fusion deposition modelling (FDM); additive manufacturing; acrylonitrile-butadiene-styrene

1. Introduction

Fusion deposition modeling is one of the techniques in additive manufacturing which is the fastest and efficient manufacturing process in industries [1]. Complex shapes with excellent flexibility and with less material wastage can be produced using this technique apart from conventional manufacturing process like machining and castings etc. FDM can be used in mass production as it reduces the time required to develop a product. Using of PC/ABS composite materials in developing various products in manufacturing is popular. Mechanical properties of a material increase with PC reinforcement into ABS material and produces higher strength in products manufactured by the 3D printing process [2].

Materials like acrylonitrile–butadiene–styrene (ABS), polylactic acid (PLA), polyamide (PA), and polycarbonate (PC) which are thermoplastic, and polymers like epoxy resins which are thermosetting polymer can be processed using the FDM technique in 3D printing [3]. ABS offers a good balance of impact, heat, chemical and abrasion resistance, dimensional stability, tensile strength, surface hardness, rigidity and electrical characteristics. ABS is considered a food grade thermoplastic assisted curing is required for the polymerization of reactive epoxy resins. Based on material selection, the usage of polymer materials in 3D printing found their applications in various fields like architecture, aerospace, medical, etc. Many of the 3D printed polymer components are used as prototypes than which are used as functional products. Since pure polymer components prepared by 3D printing are lack strength and functionality in various applications [4]. This restricts the usage of 3D printed pure polymers in wide industrial applications.

These problems are solved by using polymer composites in 3D printing. In the polymer, the matrix of the composite combines with reinforcement which gives a material with more useful structural and functional as well as better mechanical characteristics that cannot be attainable by constituent alone [5]. High mechanical performance and functionality can be attained by reinforcement of polymer matrix material. Traditional methods of manufacturing can create products with complex shapes and geometry through the removal of material. Composites produced their processing and performance using traditional methods is well understood and can be controlled, the ability to manage and control the complicated internal shapes is limited [6]. Any complex shaped composite structures can be fabricated using 3D printing with minimal wastage. Using composites in 3D printing shape and size of the component can be precisely controlled by using CAD techniques. Thus composites in 3D printing attain flexibility in process and performance components/products [8].

A schematic of the basic FDM process was shown in Figure 1. It has a Material spool that holds the filament of material, the filament will be fed into the extruder which moves the filament of material into the heating chamber [9]. In the heating chamber, the material softened and melted and will be deposited on the build platform passing through a nozzle. The nozzle of the printer can move in three axes, i.e., x, y, and z axes. Nozzle and build platform will have relative movements for the printing of various components. The build platform will have a heated bed that is maintained at a high temperature to remove the component easily from the platform after printing is completed.

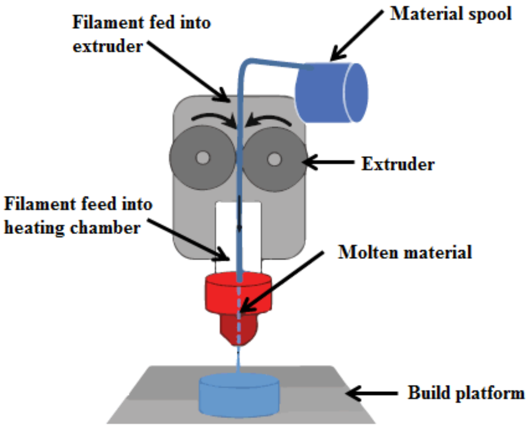

Figure 1. Schematic of the FDM process.

In 3D printing acrylonitrile–butadiene–styrene (ABS) is used widely which acts as a base matrix and polycarbonate was well known as reinforcement. ABS has low-temperature resistance which limits its usage. Polycarbonate (PC) is a polymer from a thermoplastic family that has better mechanical properties and good functionality [12]. Blends of Polycarbonate and acrylonitrile–butadiene–styrene were used in many applications due to their properties as composite material like high thermal resistance and impact behavior and good processibility [13]. The mechanical behavior of ABS was improved with polycarbonate reinforcement and capable of developing components with excellent mechanical properties. In this paper, fabrication and testing of PC/ABS composite polymers with various polycarbonate composition to obtain the best composition.

In this paper process of preparing polycarbonate reinforced ABS polymer composite was described. And also discussed the effect of varying PC content in ABS on mechanical characteristics and variations in mechanical properties was studied. Microstructural study of PC/ABS composite polymer material was included, Using SEM analysis to trace the fluctuations that happen in the structure of the material with varying PC content was conducted. Even 3D printing grasped the attention over many decades, many works are on pure polymer materials, Meger works were done on the development of processing techniques and printing of polymer composites. Therefore it would be relevant in the present work to analyze a 3D printed polymer composite with varying polycarbonate content.

2. Materials and methods

2.1. Fabrication process

Figure 2 shows the fabrication process of materials. PC and ABS composite materials need to follow various processes such as drying, kneading, water cooling, and piling in sequence. Through this process filaments of PC/ABS of various compositions of polycarbonate in ABS are made and are kept for the printing of specimens for testing. PC and ABS materials are dried for 8 h to remove moisture in the materials and the required compositions are fed to the extruder. The material was kept for an injection molding machine with an extruder. After the molten state was attained material was passed through the closed chamber injector and filaments of various compositions for 3D printing are prepared. Various process parameters of 3D printer are fixed to values such as Nozzle diameter as 0.5 mm, nozzle temperature was maintained at 240 deg cel, heating bed temperature was maintained at 80 deg cel, Each layer was printed with thickness of 0.3 mm and filling density was kept at 100%.

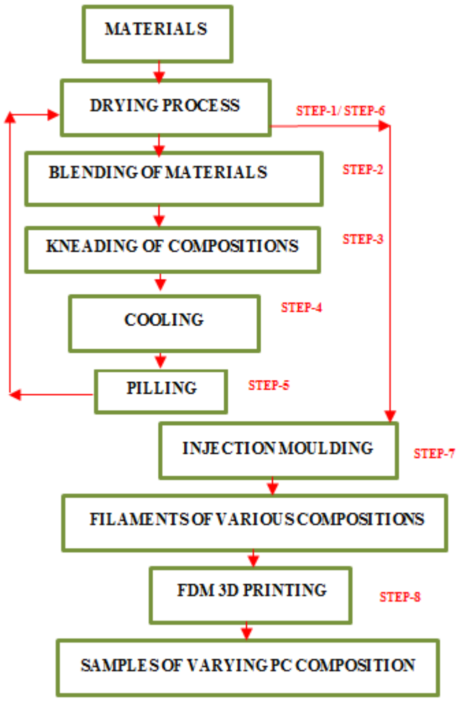

Figure 2. Material fabrication process flow chart.

Dog bone-shaped specimens of various compositions of polycarbonate were printed using the FDM process as per the ASTM D628 standard. Figure 3 shows the sketch of dog bone samples, specimens printed using the FDM process, and dimensions are tabulated and shown in Table 1.

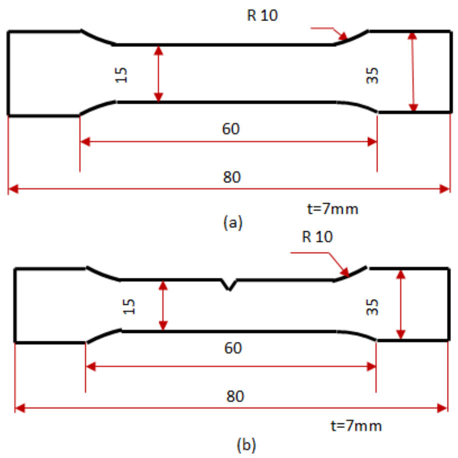

Figure 3. ASTM D628 dog bone sample.

Table 1. ASTM standard dog bone sample dimensions.

Sample	Shape	Length (mm)	Width (mm)	Thickness (mm)
1	Dog bone sample	80	35	7
2	Dog bone sample with the notch	80	35	7

2.2. Testing and analysis

Tests performed for attaining mechanical properties of 3D printed PC/ABS material with varying PC content was shown in Figure 4. Mechanical properties such as hardness, flexural, and impact strength of PC/ABS with varying polycarbonate were done using ASTM E-18 standards. As per ASTM D-790, a standard flexural test was performed to obtain flexural stress, strain, and modulus of PC/ABS composite with various polycarbonate content. Impact test was conducted to obtain impact strength as per the ASTM D-256 standard. The microstructural study was carried using SEM analysis as per the ASTM E-2809 standard to study the changes that occur with varying PC content in ABS material.

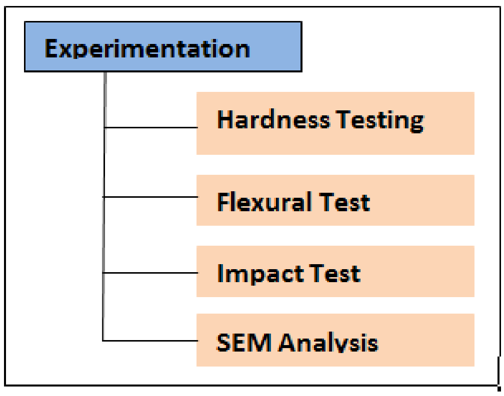

Figure 4. Test procedure.

3. Results and discussion

The hardness test results of PC/ABS composites by FDM process with varying PC polymer are plotted and were shown in Figure 5. Results show that the highest value of hardness was observed for the composite having 30 wt% of PC reinforcement compared to 20 wt% and 10 wt% of PC content in ABS material. The hardness of 20 wt% was observed to be less than the material with 10 wt% PC composition. This drop might be due to the ineffective binding of polymer material or due to voids in the structure of a material, hence to know the reason behind the drop of hardness SEM analysis was conducted.

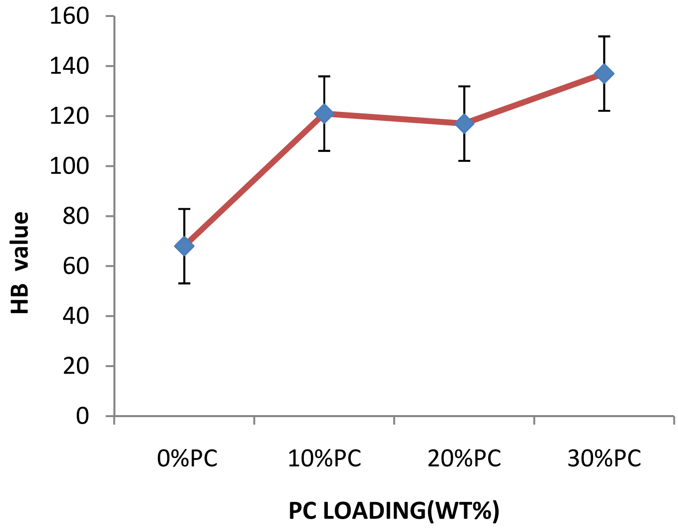

Figure 5. Effect on HB value for change in PC wt%.

A rise in flexural strength was observed with an increase in polycarbonate content in ABS. Flexural stress is high for the composite with 30 wt% of PC compared with the material which has less polycarbonate content and was plotted as shown in Figure 6. Concerning the plot is shown in Figure 7. Flexural strain was also observed to be high for the material with 30 wt% of polycarbonate. This shows the positive sign of overusing of polycarbonate in ABS polymer for increasing the characteristics and functionality. As was observed the flexural modulus was also observed to be high for the composite which has the highest content of polycarbonate which is shown in Figure 8. The rigidity is greatly increased by increasing the polycarbonate content in polymer material.

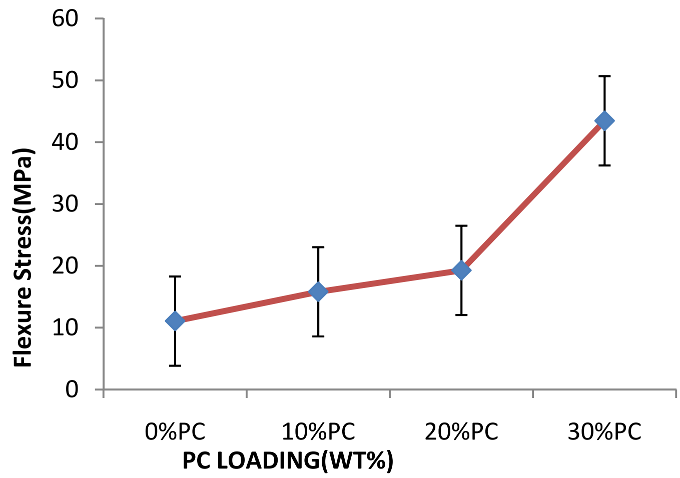

Figure 6. Effect on flexural stress for change in PC wt%.

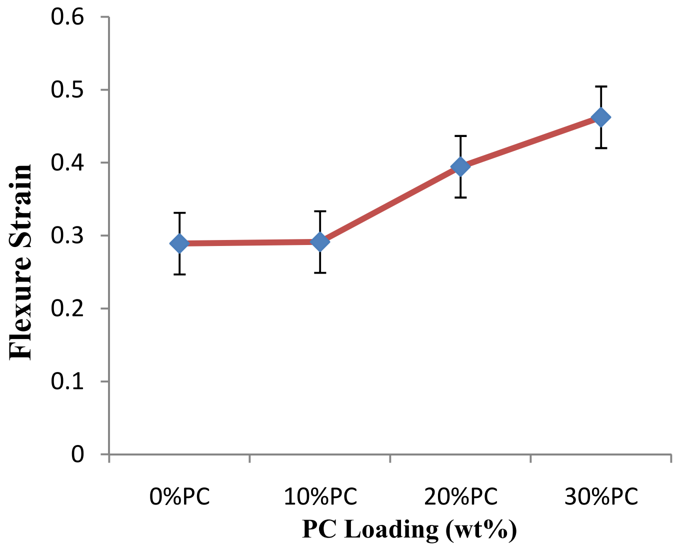

Figure 7. Effect on flexural strain for change in PC wt%.

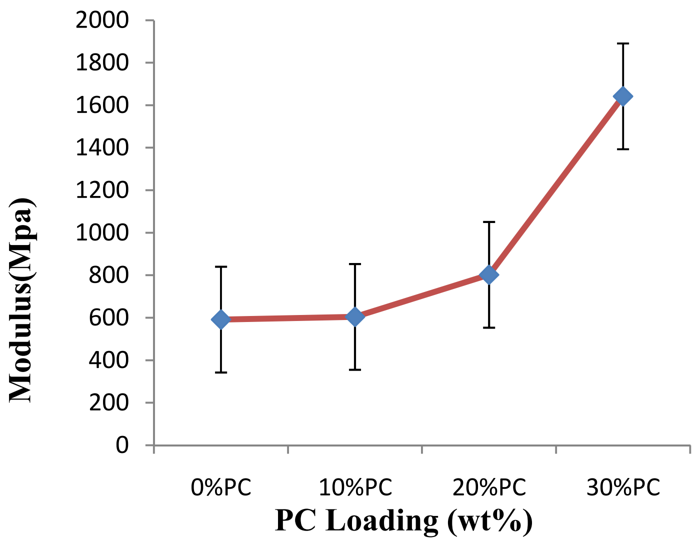

Figure 8. Effect on flexural modulus for change in PC wt%.

The results of the impact test show that initially impact strength was decreased with increase polycarbonate wt% in ABS material. This was observed up to certain compositions of PC. From Figure 9 it was observed that impact strength rises and it was raised till the 30 wt% of PC was attained. Even the highest impact strength was observed at the composition having 30 wt% of PC in ABS material, but PC content cannot be increased beyond 30 wt% since a further increase in PC content exhibits more properties of polycarbonate that limits the usage of the PC/ABS composites in some applications. The drop in impact strength might be due to the material intrinsic properties like the structure of molecules, distribution of molecules, cohesive forces in molecules, and morphology of structure. Also, the impact strength was affected by extrinsic properties such as temperature, speed of impact, the shape of the striker and weight of the sticker, the geometry of the specimen, and the size of the notch. SEM analysis was conducted for investigating the reasons for a drop in impact strength as the crystalline nature of material and voids will decrease the impact resistance of the material.

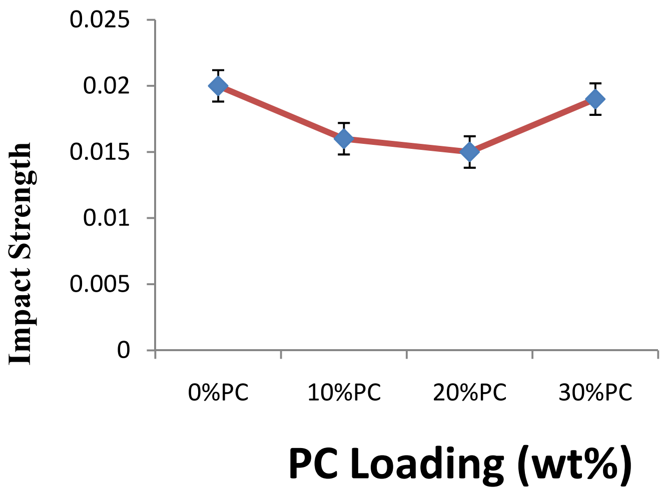

Figure 9. Effect on impact strength for change in PC wt%.

Table 2 shows the Void formations percentage with varying polycarbonate content. Figure 10 shows the microstructure of four specimens having different PC loadings. In pure ABS material void formation percentage was 0.22% and the dimension or size of voids is also comparatively very large in pure ABS material compared with the materials having varying PC content. In material with 10 wt% of PC 0.45% of a void, the formation was identified. And 0.93% void formation was observed with an increase in PC content to 20 wt%. The void formation was decreased to 0.76% with the increase in PC content to 30 wt% and this is the cause for a drop in impact strength. However, the percentage of void formation was decreased to 0.19%, hence the composite with 30 wt% of PC content leads to cause an increase in properties of the material.

Table 2. Void formation percentage table.

Specimen composition	No of voids (µm)	Voids formation (%)
Pure ABS	3	0.22
10 wt% PC loading	5	0.45
20 wt% PC loading	7	0.93
30 wt% PC loading	3	0.19

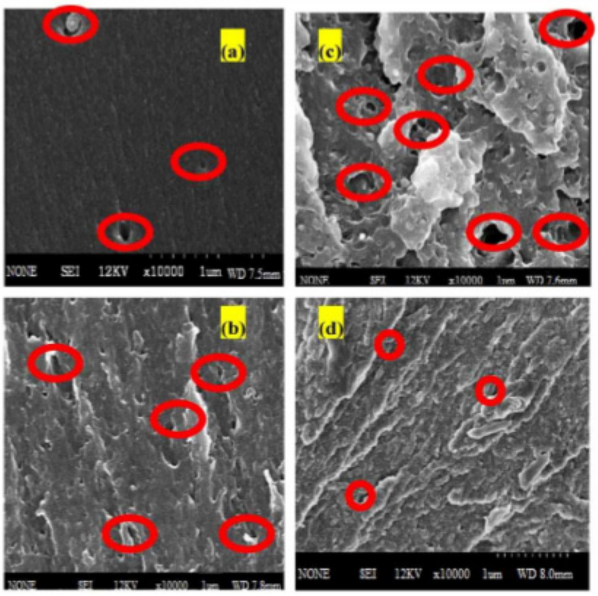

Figure 10. SEM analysis micro structure of 3D printed (a) pure ABS, (b) 10 wt% PC loading in ABS, (c) 20 wt% PC loading in ABS, and (d) 30 wt% PC loading in ABS.

4. Conclusions

Polycarbonate (PC) reinforced acrylonitrile–butadiene–styrene (ABS) with varying PC content was fabricated, and from the PC/ABS polymer composite specimens are prepared using the FDM technique. Results reveal that PC/ABS polymer composite exhibits good mechanical properties than the material with less content of PC and material with no polycarbonate content. The study conducted help in suggesting the best composition of PC/ABS polymer composite material. In this study, it was proved that with the increase in the content of polycarbonate in ABS material, mechanical properties of the composite were enhanced therefore the rigidity and strength of the material of the product were increased as per the requirement. variations in the strength of the material with varying PC weight percentage was justified by SEM analysis, using microstructure study of all specimens with different PC content. It is revealed that the 3D printing process with its controlled process and for its capabilities and use of PC as a reinforcement, increases the production of the best quality material in polymer composite family that can withstand heavy loads. Dynamic mechanical analysis and temperature effects of this PC/ABS material can be future scope to develop the best material composite.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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