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RESEARCH ARTICLE

Single bead property of short fiber carbon reinforced ABS composites produced with large scale additive manufacturing (LSAM)

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Abstract

This study presents an analysis of the mechanical behavior of different amounts of carbon fiber additive ABS composites produced by the large-scale additive manufacturing (LSAM) method. Additive manufacturing is distinguished from other manufacturing methods such as casting, molding, machining or etc. by its ability to obtain complex parts by this manufacturing method. Even it is desired to make rapid prototyping, due to the manufacturing time related to material deposition rate; it is not suitable for mass production. Also, the mechanical strength of produced parts is not adequate in terms of strength for the end-user. So, engineers made great efforts to overcome this problem, in particular, increasing the strength of produced parts with additive manufacturing technology. Adding some strengthen additives (carbon, fiberglass, etc.) into the material, therefore, significant having high strength materials would have been manufactured by this method. In order to validate enhanced material in terms of tensile and compression strength, flexural bending capacity, and non-supported bridging distance ability, many studies were carried out by researchers, however, these studies were generally carried out for small volume printers. Namely, there is a gap that must be filled in huge volume printing systems (LSAM) in view of these studies. Here, flexural capacity was investigated in a large-scale additive manufacturing system. Flexural tests were conducted following the ASTM standard of D790. In this study, In order to evaluate the flexural bending capacity of a single layer, four specimens are produced from the direct extrusion system of LSAM.

1. Introduction

Large scale additive manufacturing (LSAM) has become popular in recent years due to the advantages of rapid prototyping in the huge volume of parts and availability in different characteristics of raw material [1]. The working principle of the LSAM system is similar to fused deposition modeling (FDM) printers. Namely, both technologies extrude hot thermoplastic material along specific tool paths to generate three-dimensional shapes [2]. Traditional commercial printer types, fused deposition machines (FDM), are also very popular in the rapid prototyping of the small parts. However, these printers have some limitations in terms of printing time, printing capacity, and cost [2]. In addition to this, used raw material flexibilities in terms of mechanical characteristics are too narrow that it limits the part quality for end-users [3]. Thus, LSAM is needed in production with the additive manufacturing method [4]. In this area, researchers carried out many studies in order to prove the capability of LSAM in terms of material mechanical properties [5].

The fiber reinforcement can significantly improve the properties of polymeric matrix materials [6]. Although continuous fiber composites provide high mechanical performance, their processing is not ordinary. So, short fiber-reinforced polymers with moderately improved mechanical properties are more commonly used for low-cost composite parts [7]. Tekinalp et al. compared carbon fiber reinforced ABS composites fabricated by both compress molding and FDM [8]. Shofner et al. developed a Nano-fiber reinforced ABS matrix composites using FDM [9]. Roschli et al. [10] are studied in big area additive manufacturing systems improving inter-laminar strength and process control and they carried out the effects of carbon fiber additive ABS to the tensile strength.

In this study, in order to see the effects of carbon fiber additive to the mechanical behavior of ABS composites flexural tests were conducted. In a single layer, four specimens are produced by using the direct extrusion LSAM system. Each specimen has a different amount of carbon fiber. Three-point bending tests were carried out on the specimens according to the ASTM standard of D790. The experimental methodology and results are discussed in the manuscript.

2. Materials and methods

2.1 Material

An Acrylonitrile Butadiene Styrene (ABS) thermoplastic polymer, with the properties shown in Table 1 was used in the experimental study. The granules were dried at 80°C for 4 hours before using. The material was deposited at 240°C onto a heated building plate at 80°C.

2.2 Printing System

A direct extrusion system shown in Figure 1 is designed, manufactured and it was replaced with the spindle of the 3-axes CNC unit available in the department. The maximum displacements in X, Y, and Z directions are 1800, 2500, and 400 mm, respectively. The extruder is a single screw extruder and it is driven by a variable speed motor. The ABS granules are

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feeding through the extruder by an automatic feeder. The feed rate of granules and the speed of the screw can be controlled to melt and deposit molten polymer at a rate consistent with the movement of the axes (building speed) and desired bead profile. The barrel has band heaters and a control unit to keep the chamber and nozzle temperatures in the required ranges. In the experimental study, four types of specimens having an 8 mm diameter and 100 mm length were printed from each material composition. Three specimens were printed from each type for repeating the mechanical tests.

Table 1. The mechanical properties of ABS [11]

Properties	Unit	Value
Density	kg/m3	1060
Thermal Conductivity	K (W/mK)	0.177
Specific Heat	C (J/KgK)	2080
Emissivity	ε	0.87
Glass Transition Temperature	Tg (°C)	105

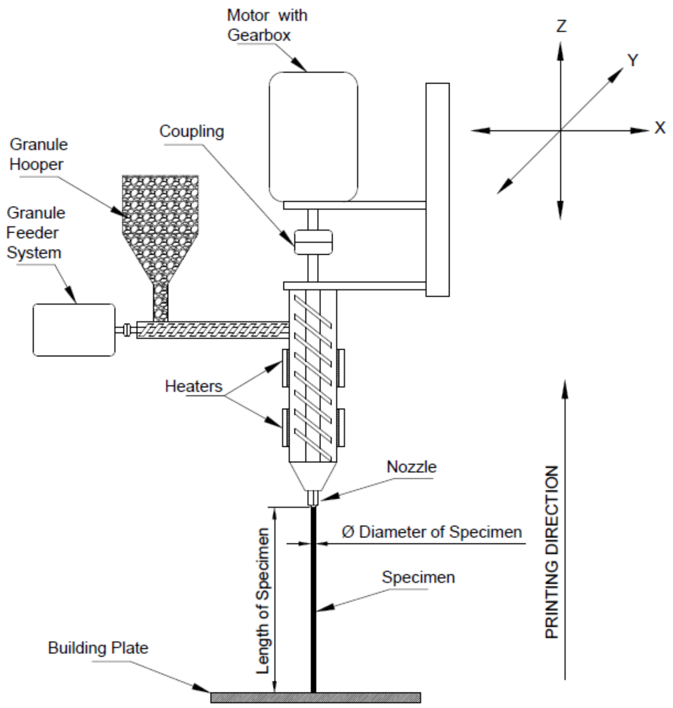


Figure 1. Schematic view of the direct extrusion system

Flexural tests were conducted according to the ASTM D790 standard and the specimens are prepared in accordance with the procedure of the standard [12] . The specimens were divided into four groups according to their carbon fiber additives; 0%, 5%, 10%, and 15% carbon fiber by weight. The carbon fiber was 7 µm in diameter and 1±0.3 mm in length.

Table 2. Deposition parameters

Feature	Unit	Value
Printing Temperature	°C	240
Deposition rate	kg/hr	0.2
Z Axis Feed rate	mm/min	180

The specimens are printed in a direct extrusion printing system. In order to provide straightness and circularity of the specimen, each layer was printed in a vertical direction. Namely, the printing operation is started from building plated and, while extrudes is moving in Z+ direction in a constant feed rate, extrusion is started. Also, during the printing, each layer is cooled in order to prevent some geometrical deformations. The printing parameters are listed in Table 2.

2.3 Experimental Study

Flexural bending tests were conducted in a Universal testing machine (SCHIMATZU AGS-X 30KN) having three-point test fixtures such as specimen support and loading nose. A 3-point flexural bending test scheme is given in detail in Figure 2. Testing parameters were conducted according to ASTM D790 Standards. All of these parameters are defined software that controls the testing machine. Thus, the test machine gives the test results simultaneously.

Flexural strength Fs is calculated by software from peak load in the flexural test. Also, the formulation was given in below in order to calculate the flexural capacity (see Eq 1).

$$F_s = \frac{PL}{\pi R^3} \quad \text{(Eq. 1)}$$

here, Fs is flexural capacity, P is peak load, L is span length of supports R is the radius of specimen. Span length was set according to ASTM D790 Standard and, support span-to-radius is set in ratio of 16:1.

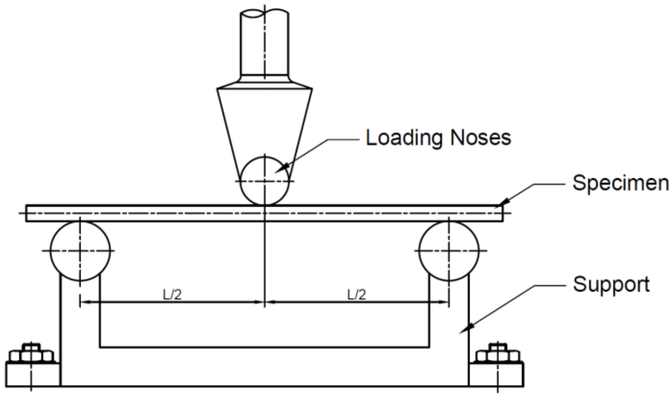
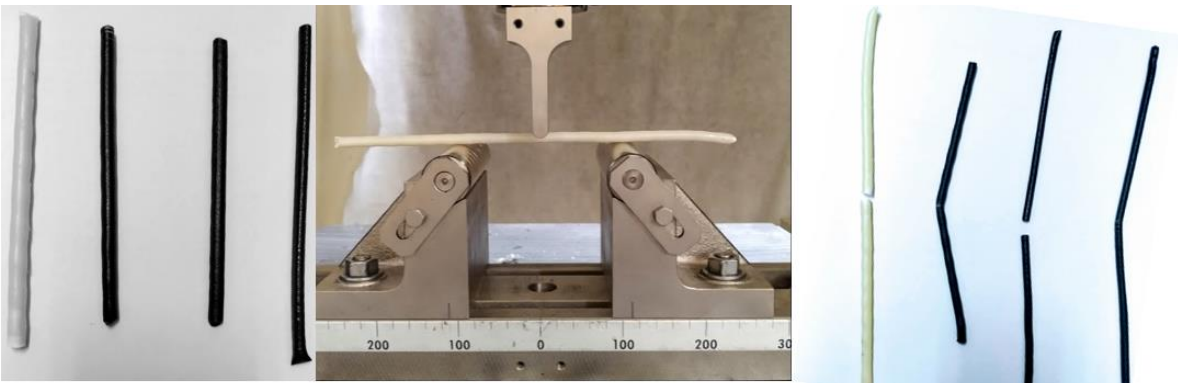


Figure 2. 3-Point bending test scheme

3. Results and discussion

In this section, the experimental results carried out from a single layer bead which is conducted with a 3-point flexural test were given. First of all, the specimens, were before testing, testing in-situ and after tests, were given in Figure 3. Also, a load-displacement table is given in order to evaluate the results clearly. In Figure 4, the flexural bending capacity of each featured specimen was plotted in terms of stress and strain. In this figure, the changes in the strains were as expected, i.e. the ductility reduces with the amount of carbon fiber addition. The maximum strain is measured as 12% for the pure ABS (no carbon fiber). However, the bending capacities are changing with the various amounts of carbon fiber. The maximum loads predicted for all specimens are given in Table 3. The maximum flexural strength is 95.3 MPa for pure ABS, 116 MPa for 5%, 91.6 MPa for 10% and 72.9 MPa for 15% carbon fiber added specimens. However, the maximum flexural strength has been achieved for ABS 5% CF. The reason could be due to the lower porosity. Namely, more amount of CF may cause more porosity in the interior of the bead. So 10% CF additive ABS and 15% CF additive ABS material contains more amount porosity. This can be the main reason to cause lower flexural strength.



a b c

Figure 3. Test images; a) during testing, b) before bending test, c) after bending test

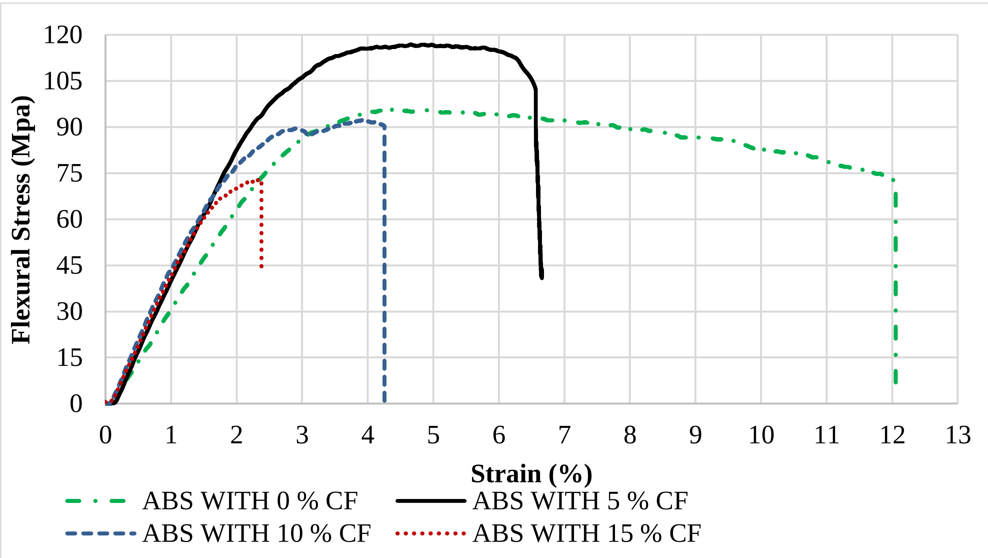
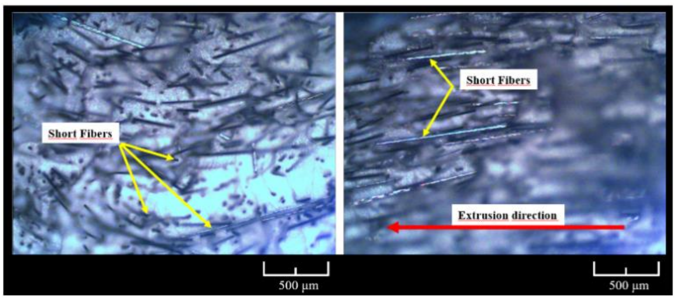


Figure 4. 3-point bending test results; flexural stress – strain diagram

Table 3. Load – Displacement table

Specimen	Load (N)	Displacement (mm)
ABS with 0% Carbon fiber	93	16.95
ABS with 5% Carbon fiber	103	11.9
ABS with 10% Carbon fiber	81	10.05
ABS with 15% Carbon fiber	64	6.06



(a) (b)

Figure 5. The microscopic views of the 15% carbon fiber reinforced ABS bead in a) the cross-sectional direction and b) are the longitudinal (extrusion) direction

Also, in order to observe the carbon fibers orientation in the extruded bead, the specimen was examined under a microscope. Specimens were investigated in its longitudinal direction (direction of extrusion) and transverse direction (cross-section).

In Figure 5, the microscopic views of the 15% carbon fiber reinforced ABS bead in (a) the cross-sectional direction and (b) are the longitudinal direction. It can be seen from the figure that, the carbon fibers are oriented in the extrusion direction. The orientation of the short-fibers has significant effects on the mechanical properties [13]. More parallel oriented short fibers along the extrusion direction provides more flexural strength. However, a number of fibers may have been rotated due to forcing the flow through the nozzle inlet and shear rate (See Figure 5a).

4. Conclusions

In this study, in order to see the effects of carbon fiber additive to the mechanical behavior of ABS composites flexural tests were conducted. In a single layer, four specimens are produced by using the direct extrusion LSAM system. Each specimen has a different amount of carbon fiber. Three-point bending tests were carried out on the specimens according to the ASTM standard of D790. The followings may be concluded from the results of the study:

- The carbon fibers in the ABS matrix are properly oriented in the direction of extrusion during LSAM process.
- The ductility of the extruded bead reduces with the increasing amount of carbon fiber addition. Pure ABS has the maximum ductility.

- The maximum flexural stress is obtained for 5% carbon fiber reinforced specimen among all specimens having various amounts (0%-15%) of carbon fibers.
- The reduction of flexural stress for further addition of carbon fibers (>%5) may come from the porosity formation, this is going to be inspected as the study is progressed.

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Author contributions
Omer Eyercioglu: Supervision, Writing - review & editing, Validation
Engin Tek: Conceptualization, Methodology, Resources, Writing - original draft, Validation, Visualization
Mehmet Aladag: Conceptualization, Methodology, Resources, Writing - original draft, Validation, Visualization

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