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RESEARCH ARTICLE

Effect of carbon fiber additive on tensile properties of large scale additive manufactured (LSAM) ABS single wall parts

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Abstract

Additive Manufacturing (AM) is one of the most studied technologies to produce different parts today. Large-scale additive manufacturing (LSAM) is used to produce complex parts without further technological processes and for the production of large-sized polymer parts. In order for the parts produced from polymer materials to show better mechanical properties, a range of different materials is required. In this study, the tensile properties of 3D-printed ABS single-wall parts using LSAM were investigated experimentally. The effect of carbon fiber (0, 5%, and 10%) additive on the main mechanical properties of ABS was investigated. The tests were carried out according to ASTM D638 standards as the spatial printing direction (0º and 90º). According to the results of the tensile test, ABS material reinforced with 5% carbon fiber showed higher load resistance than other mixture ratios. In all groups, it was observed that the samples with a horizontal (0º) orientation compared to the printing direction showed better performance.

1. Introduction

The technology of printing objects layer by layer through additive manufacturing (AM) has increased tremendously in recent decades [1,2]. Combining computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies, 3D printing technology produces parts without requiring any traditional cutting techniques, and the raw material waste that occurs in this process is very low. Considering these advantages, AM technology is always used to produce complex structures and thin-walled structures [3,4]. Nowadays, 3D printing technology is widely applied in manufacturing, civil engineering, automotive engineering, biomedical engineering, food, and clothing [5,6].

Fused Deposition Modeling (FDM) is one of the most popular AM technologies in the production of polymer and composite components. FDM requires a 3D model in stereolithography (STL) format to print a part [7]. After the model is created, it is made into layers with slicing software. During the printing process, the raw material filament is injected into a pre-heated nozzle, making it semi-liquid, and laid out layer by layer along a predetermined path, creating the final part. Although FDM has advantages over traditional methods, it has some limitations. These are limited printing areas, printing speeds, and raw material limitations. Large-scale additive manufacturing (LSAM) fills the gap created by these disadvantages [8].

Compared to traditional FDM printers, LSAM provides a wide range of usage opportunities in terms of printing speed, printing area, and raw material. LSAM uses a direct extruder system and uses granules as raw materials, thus offering a wide variety of raw materials [9]. LSAM can achieve print speeds of up to 50 kg/h. Thus, it is capable of printing large-scale parts quickly and easily [10].

A shortcoming of the LSAM wide range of materials is that for a new material class, the mechanical properties are still unclear. Therefore, real LSAM 3D printing structures cannot be accurately modeled and analyzed, and the use of new materials is difficult. Due to this lack of information, studies on the material have increased recently [11,12].

In research conducted in this context, Lee et al. [13] investigated the effects of several process variables on the compressive strength of 3D printed components, including raster direction, air spacing, bead size, color, and the thermal condition of the model. Their findings demonstrated that these components' compressive characteristics are anisotropic. In a different work, Weng et al. [14] found that adding organically modified montmorillonite to ABS nanocomposites improved both tensile strength and flexural resilience when the materials were 3D printed. In their analysis of the mechanical properties of FDM-produced ABS materials, Rodriguez et al. [15] found that the strength decreased between 22% and 57% while switching from ABS monofilament to FDM ABS components. Roschli et al. examined large-area additive manufacturing systems, focusing on enhancing inter-laminar strength and process regulation. They also investigated the impact of adding carbon fiber to ABS on its tensile strength [9].

The materials used in production with additive manufacturing are relatively limited. In order to improve the physical and mechanical properties of materials, composite additive manufacturing parts have been produced by using different materials in different compositions and it is aimed to improve the mechanical and physical properties. Kartal et al. [16] have investigated the Salvadora Persica (Miswak) additives effect on reinforced polylactic acid (PLA) matrix composites' mechanical performance. This study investigates the use of natural fibers as reinforcement for composites that are 3D

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printed, providing information about substitute materials that may be contrasted with other additives. Moreover, the effect of production parameters on the mechanical properties of the final product in the additive manufacturing process has been found to be undeniably important. Another study by Kartal et al. [17] showed how crucial manufacturing parameters are to achieving the required mechanical properties in 3D-printed parts. This study also provided valuable insights into how nozzle diameter affects tensile strength and could offer a comparative viewpoint on how various manufacturing parameters impact the characteristics of materials. In addition, Kaptan et al. [18] are examined how various fill rates affect the mechanical characteristics of PLA samples made with 3D printers, this research provides a wider framework for comprehending how different printing parameters affect the final result by examining fill rate, another important component of 3D printing, and its effect on mechanical properties.

In this study, the mechanical properties of a new material mixture for use in LSAM were examined. A single-skinned wall was produced by adding different amounts of carbon fiber to the ABS material (0%, 5%, and 10%). It was produced by cutting samples horizontally and vertically according to the printing direction in accordance with ASTM 650 standards from the single-walled wall. In the samples taken, it was seen that 5% carbon fiber-reinforced ABS material was the most usable. Compared to the printing direction, horizontal (0°) samples gave better results.

2. Materials and methods

2.1 Materials

A thermoplastic polymer called ABS (Acrylonitrile Butadiene Styrene) was employed in the experimental work, and Table 1 lists the ABS's characteristics. The ABS granules were dried at 80 °C for four hours before to use. On a heated construction plate that is heated to 80 °C, the melted material is deposited at 240 °C.

In this work, an ABS polymer-based multilayer wall was created using varied quantities of carbon fiber additive, and form variations of these samples were noted with carbon fiber additive ratio. The carbon fiber was 7 µm in diameter and 1±0.3 mm in length.

Table 1. The mechanical properties of ABS.

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
Thermal Contraction Coefficient	$°C^{-1}$	0.0001

2.2 Printing System

LSAM is a printer that uses the direct extrusion system. Figure 1. The direct extrusion system has been replaced by a 3D CNC spindle. The technical specifications of the LSAM are given in Table 1. The single-screw extruder is powered by a motor with a variable speed. An automated feeder feeds ABS granules through the extruder. To melt and deposit molten polymer at a rate commensurate with the movement of the axis (building speed) and desired bead profile, the rate of granule feed and the speed of the screw may be regulated. To maintain the chamber and nozzle temperatures within the specified limits, the barrel is equipped with band heaters and a control device.

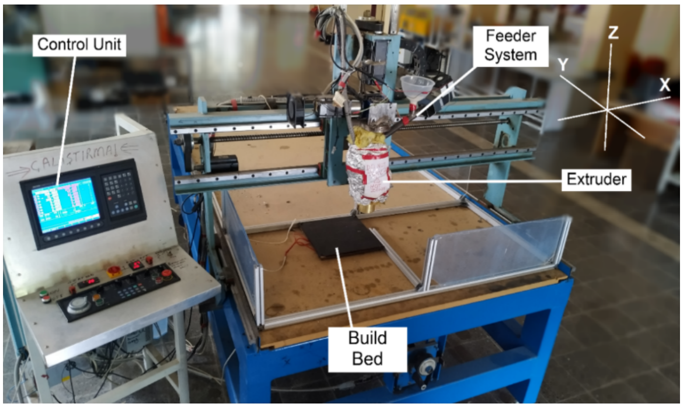

Figure 1. View of Large Scale Additive Manufacturing System.

Table 2. Parameters of LSAM

Parameter	Unit	Value
X-Axis	mm	1800
Y-Axis	mm	2500
Z-Axis	mm	400
Nozzle Diameter	mm	6
Deposition Temperature	oC	240
Layer Height	mm	6
Printing Speed	mm/min	400

2.3 Experimental Study

In the experimental investigation, single-walled structures were produced in LSAM utilizing ABS thermoplastic material, augmented with incremental concentrations of carbon fiber additives by weight (0%, 5%, and 10%). To ensure these structures adhered to the specified dimensional parameters, a milling procedure was executed via a CNC milling machine in figure 2. Regarding the tensile testing, specimens were prepared in accordance with the ASTM D638 standards. They were produced using a router, oriented both in a parallel (0 degrees) and perpendicular (90 degrees) manner relative to the printing direction, as delineated in Figure 3.

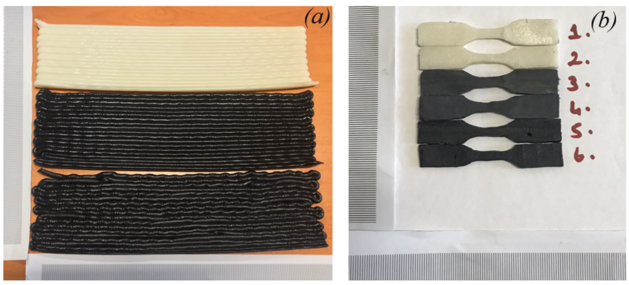

Figure 2. The tensile test samples a) before and b) after the CNC milling machine process

The SCHIMATZU AGS-X 30KN apparatus was employed for the tensile testing. Prior to the test, the setup was configured in compliance with ASTM D638 standards. The specimen's dimensions are given in Figure 3. In the course of the experimental investigation, five samples from each group were prepared and subjected to testing. Following the tensile test, distinct load and displacement graphs were generated for each sample using auxiliary software provided by the device.

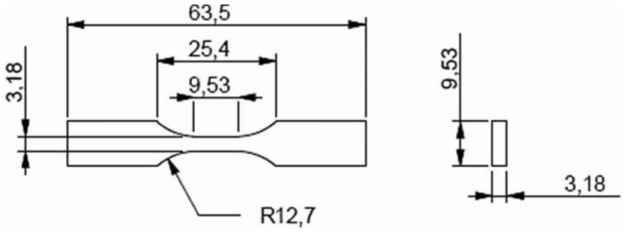

Figure 3. Dimension of tensile specimens

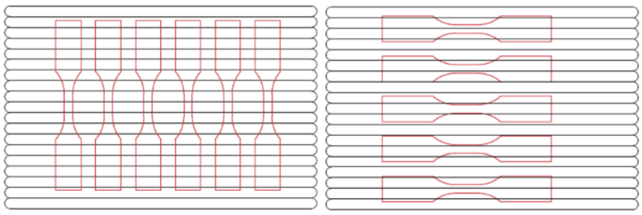
Figure 4. Orientation of tensile specimens

3. Results and discussion

In this section, tensile test results of samples produced from single-walls are given. First of all, the image of a sample during the test is given in Figure 5. Experimental results are given in two graphs for the printing direction horizontally (0º) and vertically (90°).

In the first graph, stress and strain results are given from samples prepared horizontally (0) to the printing direction. As seen in Figure 6, ABS reinforced with 5% carbon fiber gave the highest load resistance. Pure ABS material showed ductile behavior by providing the highest elongation. 10% carbon Fiber reinforced ABS has been found to be brittle and has less load resistance than others.

In the second graph, the experimental results of samples prepared perpendicular to the printing direction are given. Figure 7. Similar result curves were observed as in the previous graph. However, there is not as much difference between ABS reinforced with 5% carbon fiber and pure ABS material as in other graphics.


Figure 5. During tensile test

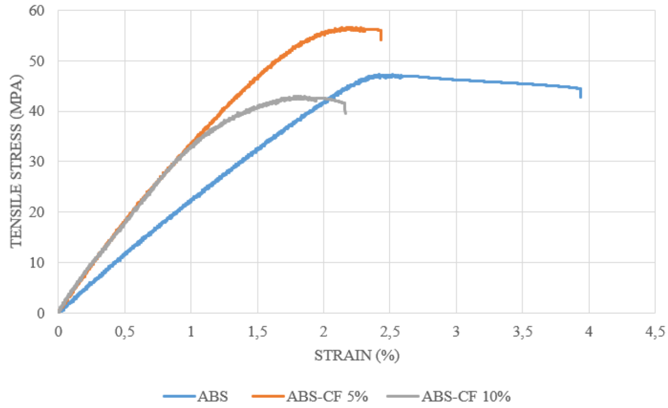

Figure 6. Tensile test result; horizontal (0º) in the printing direction

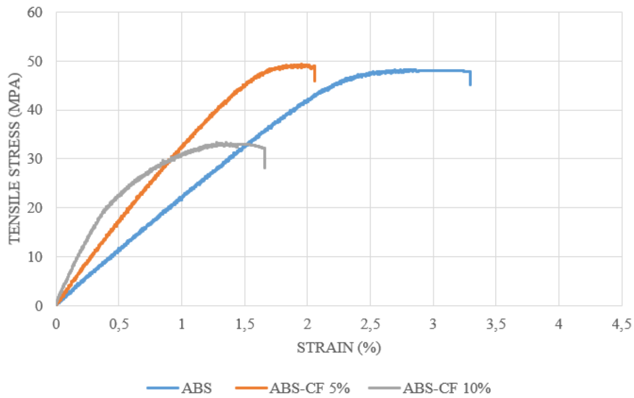

Figure 7. Tensile test result; horizontal (90º) in the printing direction

4. Conclusions

In this study, tensile tests were carried out to see the effects of carbon fiber additives on the mechanical behavior of ABS composites. Using the direct extrusion LSAM system, 5 samples were produced for each sample group from a single wall. Each sample group has a different amount of carbon fiber. The samples were subjected to tensile testing according to the ASTM D638 standard. It is possible to draw the following conclusions from the results of the research:

- With the addition of increasing amounts of carbon fiber, the ductility of the extruded cord decreases. Pure ABS has maximum ductility.
- Among all samples containing various amounts (0%–10%) of carbon fiber, the maximum tensile stress was obtained for the 5% carbon fiber-reinforced sample.
- Samples that were horizontal (0º) in the printing direction gave better results than samples that were vertical (90º) in the printing direction. Anisotropy is a common problem in additive manufacturing due to bonding characteristics of the layers.

Author contributions

Omer Eyercioglu: Supervision, review & editing.

Engin Tek: Preparing samples, Testing, Writing - original draft

Mehmet Ali Akeloglu: Preparing samples, Testing, Writing - original draft

Mehmet Aladag: Writing - original draft

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