International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Material Properties of Additive Manufactured Composite Materials

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Abstract: ***Additive manufacturing (AM) also known as 3D printing has tremendous advancements in recent days with a vast number of applications in industrial, automotive, architecture, consumer projects, fashion, toys, food, art, etc. Composite materials are widely used in structures with weight as a critical factor especially in aerospace industry. Recently, additive manufacturing technology has gained lot of importance in making composite materials. The properties of composite materials depend upon the properties of constituent's matrix and fiber. There is lot of research on effect of fiber orientation on mechanical properties of composite materials made using conventional manufacturing methods. It will be interesting and relevant to study the relationship between the fiber orientation and fiber volume with mechanical properties of additively manufactured composite materials. In this work Pin-On-Disk tests were conducted to ascertain the coefficient of friction, frictional force and rate of wear of the materials. Tensile tests were conducted to determine the mechanical properties of 3D printed polymer composites.***

Keywords: additive manufacturing, composite material, 3d printing, Pin-On-Disk, Tensile tests

1. Introduction

3D printing has vast potential to become one of the future technologies. The most basic, differentiating principle behind 3D printing is that it is an additive manufacturing process. And this is indeed the key because 3D printing is a radically different manufacturing method based on advanced technology that builds up parts, additively, in layers at the sub mm scale. This is fundamentally different from any other existing traditional manufacturing techniques.

It is one of the best replacements for the traditional manufacturing. Understanding the advantages of 3D printing allows the designers to make better decision when selecting a manufacturing techniques that results in delivery of optimal product. All the traditional techniques require the subtraction of material from a large block, both to fabricate the end product itself andto produce tool for casting or moulding processes. This implies the use of a combination of different machines and processes (e. g., forging, milling, bending, stamping, cutting, welding, gluing and assembly), thus imposing several limitations in terms of cost, time and material waste [3]. On the contrary, 3D printing allowsthe direct production of objects by means of a single layer by layer deposition process, reduces costs, waste and duration of the whole manufacturing cycle [4]. Due to these advantages, AM has been utilized more specifically in aerospace and motorsports [2] domain. Revenues from the production of end use parts, as a proportion of total AM production, have risen from under 4% in 2003 to 34.7% in 2013 [1].

3D Printing

Additive Manufacturing (AM), also referred to as 3D printing, is a manufacturing process that produces three dimensional (3D) parts from computer-aided design (CAD) software. From the CAD software, a file is generated in Standard Tessellation Language (STL), which is then imported into software called a Slicer, which slices, or discretizes the model into layers and generates the instructions used by the 3D printer. These instructions, sometimes called G-code, are loaded onto the 3D printer to fabricate the desired part. FDM (Fused Deposition Modeling) is one of the category of 3D printing. Many materials can be used for FDM printing like Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Polyethylene Terepthalate Glycol-Modified (PETG), Polyamide (Nylon), Polyether Ether Ketone (PEEK), Polyethylenimine (PEI), Polycarbonate (PC), Polyphenylsulfone (PPSF/PPSU), ASA, ULTEM. In this work the main focus will be on Onyx, Glass fiber, High Strength High Temperature Glass Fiber, Carbon fiber, Kevler.

Materials for 3D Printing

Onyx (Nylon with chopped Carbon Fiber)

Nylon mixed with chopped carbon fiber offers a high-strength thermoplastic with excellent heat resistance, surface finish, and chemical resistance. Onyx serves as a thermoplastic matrix. It can be printed alone or reinforced with one of our continuous fibers to give strength comparable to aluminium. Use Onyx filament for anything from tooling and fixtures to end-use parts

Glass Fiber

The glass fiber composites strength/weight ratios are higher than those of most other materials and their impact resistance is phenomenal. Further they possess good electrical properties, resistance to moisture and outdoor weathering and resistance to heat and chemicals. These properties are coupled with ease of fabrication.

High Strength High Temperature Glass Fiber

High Strength High Temperature (HSHT) Fiberglass exhibits Aluminium strength and high heat tolerance. Five times as strong and seven times as stiff as Onyx, it's best used for parts loaded in high operating temperatures.

Kevlar

Kevlaris a heat-resistant and strong synthetic fiber, related to other aramids such as Nomex and Technora. This high-strength material was first commercially used in the early 1970s as a replacement for steel in racing tires. Kevlar has many applications, ranging from bicycle tires and racing sails to bulletproof vests, because of its high tensile strength-to-weight ratio; by this measure it is five times stronger than steel. It is also used to make modern marching drumheads that withstand high impact. When used as a woven material, it is suitable for mooring lines and other underwater applications.

Carbon Fiber

Carbon fibers (alternatively CF, graphite fiber or graphite fibre) are fibers about 5–10 micrometres in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports.

Markforged Mark Two 3D Printer

The Mark Two combines Markforged's unique continuous carbon fiber reinforcement with workhorse reliability for the strongest, most versatile parts. It is the only printer in the industry that enables to go from CAD to strong parts in less time. The Markforged Mark Two has the capability of printing parts reinforced with short and continuous carbon fibers. The Mark Two allows for concentric placement of fibers as well as isotropic placement of fibers. Both Concentric and Isotropic Fiber fill patterns can be used simultaneously or independent of each other, yielding much more flexibility for the designed.

Even though Markforged has released Mechanical Properties of parts printed with onyx, carbon fiber, glass fiber, kevler, HSHT using Markforged Mark Two printer [5], very few studies have been done extensively to examine these mechanical properties in detail. Also less information is available on how physical part parameters such as placement of carbon fibers affect mechanical properties.

2. Experimental Procedure

The specimen analyzed in this study were modeled with SolidWorks Computer Aided Design (CAD) software (SolidWorks 2016). The geometry of the specimen was defined as perASTM D3039. The Test machine and Specimen dimensions are shown in Figure1. The modeled specimen was exported from SolidWorks as a Standard Tessellation Language (STL) file and imported into the appropriate slicer. Two printers were used to print the specimen.

The 3D printed part was fabricated using Nylon, Continuous carbon, Glass and Kevlar fiber. The part fabricated by carbon fiber yielded the largest increase in mechanical strength. A maximum efficiency in tensile strength was observed in glass specimen as fiber content approached 18%, with higher fiber contents (up to 33%), yielding only minor increases in strength. [6]

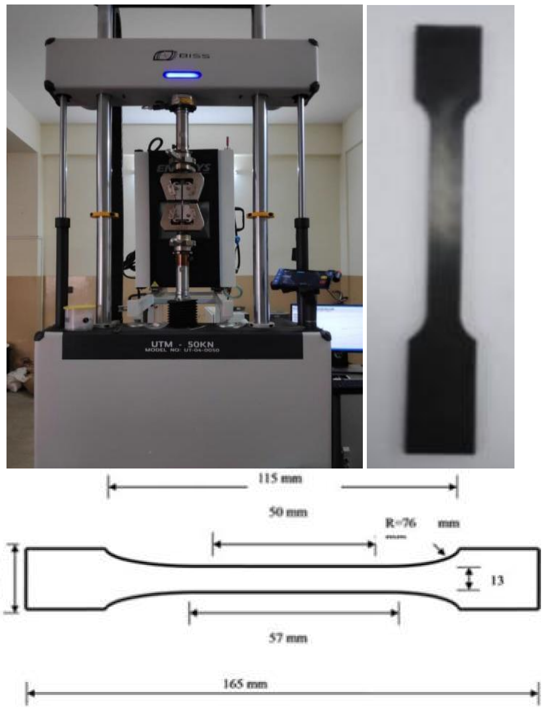

Figure 1: Universal testing machine and 3D printed tensile test specimen

Specimens are placed in the grips of a Universal Test Machine at a specified grip separation and pulled until failure. For ASTM D3039 the test speed can be determined by the material specification or time to failure (1 to 10 minutes). A typical test speed for standard test specimens is 2 mm/min (0.078 in/min). An extensometer or strain gauge is used to determine elongation and tensile modulus. Depending upon the reinforcement and type, testing in more than one orientation may be necessary.

State-of-the-art equipment including Align-pro for reduced bending. A thermal chamber is installed on a Universal Test Machine. The chamber is designed to allow the test mounts from the base and crosshead of the Universal Tester to pass through the top and bottom of the chamber. Standard test fixtures are installed inside the chamber, and testing is conducted inside the controlled thermal environment at ambient temperature. The chamber has internal electric heaters for elevated temperatures and uses external carbon dioxide gas or liquid nitrogen as a coolant for reduced temperatures.

Table 1: Tensile Stress test Results

Properties	Onyx	Onyx + Glass Fiber	Onyx + HSHT Glass Fiber	Onyx + Carbon fiber	Onyx + Kevlar)
Peak stress (MPa)	7.87	45.72	46.87	54.16	39.44
Peak load (kN)	0.479	2.78	2.85	3.293	2.398
Yield Strain (%)	7.06%	1.61%	1.54%	1.44	1.568
Yield Load (kN)	0.4	1.174	1.171	2.333	1.574
Modulus (GPa)	0.052	1.328	1.406	3.16	1.847
Upper Yield Point (MPa)	6.584	19.313	19.257	38.38	25.891
Lower Yield Point (MPa)	7.212	37.461	39.634	2.831	5.082
Limit of Proportionality (MPa)	5.91	15.005	14.937	31.025	23.922
Elongation at Break (Using Strain) (%)	17.59%	5.80%	5.66%	2.681	2.948
Reduction in Area at break (User Input) (%)	100%	100%	100%	100	100
Strain % at Max. Load	16.005	5.755	5.633	2.658	2.918

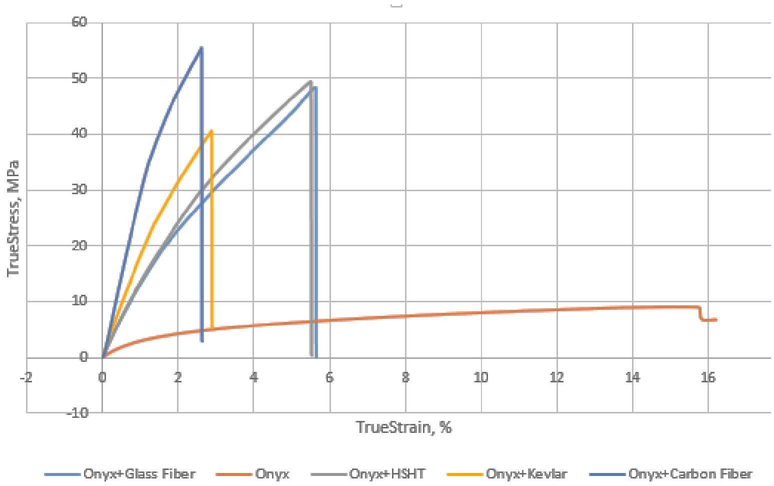

Figure 2: Stress strain diagram of different composite material

Wear Test

The specimen designed in SolidWorks and its imported to the Eiger Cloud based Software. Specimen used for conducting wear test is the pin as shown in the fig

Pin-On-Disk wear testing is a method of characterizing the coefficient of friction, frictional force and rate of wear between two materials. A Pin-On-Disk tribometer consists of a stationary pin that is normally loaded against a rotating disc. The pin-on-disk measurement is usually done as per ASTM G99-05 (2010) Standard Test Method for Wear Testing with a Pin-On-Disk Apparatus.

Calculating Operational Time:

Given,

Distance (d): 4000m

Velocity (V): 2*m/s*

Velocity (V): = Distance (d) /Time (t) (1)

$t = d/V$

t = 4000/2

t = 2000sec or 33.33min

Operational time = 33.33min

Calculating operational Speed:

Diameter of (D): 120mm

Velocity (V): 2m/s

$V = \pi DN/60$ (2)

$N = 60V/\pi D$

$N = 60 \times 2/\pi \times 120 \times 10-3$

N = 318.30 rpm

Operational Speed = 318.30 rpm

Table 2: Wear test Results

Specimen	Sliding distance (m)	Velocity (m/s)	Time (min)	Initial mass (gms)	Final mass (gms)	Wear (micrometre)	Weight loss (gms)
Onyx	4000	2	33.19	1.08	1.071	213	0.009
Onyx + Carbon Fiber	4000	2	33.19	1.56	1.557	140	0.003
Onyx + Kevlar	4000	2	33.19	1.44	1.435	168	0.005
Onyx+ Glass Fiber	4000	2	33.19	1.565	1.563	93	0.002
Onyx+ HSHT Glass Fiber	4000	2	33.19	1.478	1.477	86	0.001

3. Conclusion

Markforged Mark Two 3D printer is used to print the polymer composite parts. The materials used are nylon with chopped carbon fiber (Matrix Material), Glass fiber, Kevler, Carbon Fiber and High Strength High Temperature Glass fiber (Reinforcement Materials).

The polymer matrix composite specimens were printed using 3D printer for conducting the wear and tensile tests. As a result of wear test conducted on Pin-On-Disk, maximum wear rate were observed for Onyx specimen printed with the axis of the pin oriented in horizontal direction and minimum wear rate were observed for Onyx with HSHT glass fiber reinforced specimen.

The tensile test was conducted on BISS UTM with ASTM D3039standard specimen (dumbbell), As a result of the test maximum peak load and peak stress (refer with: fig.2) is observed in Onyx + Carbon Fiber and minimum peak load and peak stress was observed in Onyx.

Scope of future work can be to additive manufacture any end use components with required tensile strength and wear resistance. The component can be then subjected to experimental and analytical study to know its performance.

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