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Exploring the Potential of 3D Printed Molds for Rapid and Affordable Prototyping of Carbon Fiber Composites

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Abstract

This research paper aims to investigate the feasibility and effectiveness of using 3D printed molds for producing carbon fiber composites in an inexpensive prototyping process. The study delves into the manufacturing process of 3D printed molds and their compatibility with carbon fiber composites. In this paper our team conducted tensile testing on the specimen and further x-ray diffraction was done to study the matrix composition and at last to study the feasibility of the process our team designed custom molds for application based parts.

Keywords: additive manufacturing, epoxy resin, chopped carbon fiber, molds, composites

1. Introduction

Many industries, including the aerospace, automotive, railway, naval, sports industry, medical, and civil construction industries routinely employ carbon fiber-reinforced polymers (CFRPs) since they frequently provide higher advantages than the majority of other commonly used materials [1,2]. In additive manufacturing (AM) techniques, the usage of polymers is quite common and has applications in a wide range of fields [3]. According to the ISO/ASTM 52900:2015 standard, fused deposition modeling (FDM) or fused filament fabrication (FFF) is a material extrusion technique [4]. Recently, the technology around FDM/FFF has advanced quite quickly due to the low manufacturing costs and capacity to include a high level of automation [5-8]. With the help of this technique, complicated parts can be made from a variety of thermoplastic filaments, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polycarbonates, nylons, etc., at a relatively cheap cost of manufacturing. However, FDM is too intrusive for many people. For example, the mechanical properties of thermoplastics parts are significantly worse than a more conventional manufacturing process like injection molding [9].

PLA is preferred over other materials in the context of Fused Deposition Modeling (FDM) owing to its low cost, strong three-dimensional (3D) printability, and natural biodegradability. In addition, the PLA has a lower thermal stress and this diminishes warping during the FDM process. [10]. The enhancement of mechanical properties and surface finish of a product produced through FDM printing can be achieved through the utilization of post-processing methodologies and modifications in the printing parameters. In the research conducted by Porter et al., an examination was carried out to determine the optimal infill percentage for PLA beams in order to enhance specific flexural rigidity, revealing that the optimum infill percentage is situated within the range of 10% to 20% [11].

In the realm of composite material (CM) production, there exists a diverse array of manufacturing methodologies and processes that are currently within reach. The utilization of molds, generated through various techniques and technologies, is a common practice for manufacturing components with intricate geometries. Conventionally, molds are crafted through the computer numerical control (CNC) milling of a solid block of raw material or diverse types of epoxy resins. This particular technological approach demands a substantial investment of labor and time, often accompanied by significant expenses. The adoption of CM presents an alternative route for mold creation; in this scenario, a prototype model is essential, generated through a technique tailored to the specific composite material intended for mold fabrication. In this procedure, FRP layers are applied to the component model, the manufactured part is polymerized after which the mold is removed from the master model. Despite being time-consuming, this technique has a pretty high level of accuracy.

Rapid tooling (RT) [8,10,12,13] is a 3D printing process that was developed for short manufacturing runs. Depending on the material used, the technique can be used to create soft or hard tooling. Through the use of a master 3D printed model or directly through AM, RT is able to make tooling and molds. Thus, using additive manufacturing (AM) enables the direct and quick production of hard tooling, jigs, and molds from a variety of durable materials of the designer's choosing (metals, resins). This study [14] showed that 3D printed molds can be used in dental applications by 3D printing compression molds using PLA and ABS filaments, which were subsequently polished to create customized tooth fillings.

Forging [15, 16] , injection molding[17], and CFRP[18] parts are just a few of the processes that have increased interest in the measurement of tools and molds by optical 3D scanning. Traditional molds, such as metal or epoxy resin blocks or composite molds, are frequently very durable but only economically viable when used in conjunction with mass production. Molds that can be created rapidly and for a reasonable price are becoming more and more necessary for the production of small quantities or customized items. An approach that will considerably cut manufacturing time and costs to make molds for CM is 3D printing using FDM/FFF processes and low-cost filaments, like PLA or ABS.

1.1 Literature review

bera et al [1] discuss the unconventional method to manufacture a complex carbon fiber reinforced part using a fused depositional modeled die .In their research they discuss the advantages of carbon fiber reinforced polymer and their application in various industries . [1] Has taken the sports industry as their application. Since there are many categories of additive manufacturing they have chosen fused deposition modeling with an astm standard since out of all the categories fused deposition modeling has the lowest production cost and has high degree of automation. [1] Has also discussed about the capability of FDM to manufacture low cost part as compared to conventional manufacturing method. Although FDM is cost effective, it also has a lot of limitations when compared to traditional methods of manufacturing. To manufacture the molds [1] has chosen Poly lactic acid as the material as compared to acrylonitrile butadiene styrene and have subsequently discussed the application of PLA and ABS. [1] has defined rapid tooling. [1] Concludes that 3d printed molds can be effective approach for limited production runs of composite parts. [2] Stated that additive manufacturing with chemical smoothening of molds can give a smooth external surface finish to the component to be made. [2] Compared the advantages of FDM molds as compared to fiberglass molds. [2] Gave an explanation on chemical smoothening by isopropyl alcohol. [2] Fabricated Fuel Tap Protection for Husqvarna Motorbike with carbon fiber sheets. [2]

Sliced the component in cure and chose the optimized orientation of the component. The orientation with minimum surface defects on the curvature and minimum staircase effect on the surface was chosen. Settings of cura were optimized so that there was minimum material wastage. Dimensional Verification of a 3D-Printed Mold was done with an Optical 3D Scanner. [2] Used vacuum lamination process to fabricate the component.

1.2 Literature gap

In this research paper our team has used the FDM process for manufacturing molds. PLA was chosen to manufacture the molds since it is more economic as compared to other materials. Our team used chopped carbon fiber to fabricate the specimen. Compression molding was done.

2. Materials and Methods:

2.1 *Design of Connecting*

Materials:

Chopped Carbon fiber (Plain weave)
Epoxy resin (Clear)
Hardener (Non-toxic)
3D printer filament (PLA)]

Methods:

CAD design and 3D printing of molds: The CAD model of the required part was designed using computer-aided design software. The mold design was then converted to an STL file and 3D printed using a fused deposition modeling (FDM) 3D printer. The printing material used was polylactic acid (PLA) filament.

Mold preparation: Once the mold was printed, it was cleaned and coated with a release agent to prevent the carbon fiber composite from sticking to the mold during the curing process.

Composite layup: The carbon fiber fabric was trimmed to the specified measurements and positioned onto the mold. Subsequently, epoxy resin was blended with hardener in accordance with the guidelines provided by the manufacturer, and then administered onto the fabric using either a brush or roller.

Curing: The carbon fiber composite underwent the curing process within a regulated setting at ambient temperature for duration of 24 hours.

Mold removal: Following the completion of the curing process, the mold was cautiously extracted from the component made of carbon fiber composite.

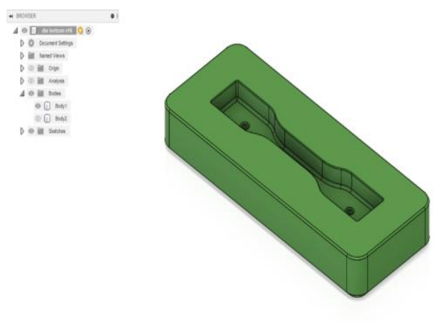

Fig. 1. (a) Male Die CAD design; (b) Female Die CAD design

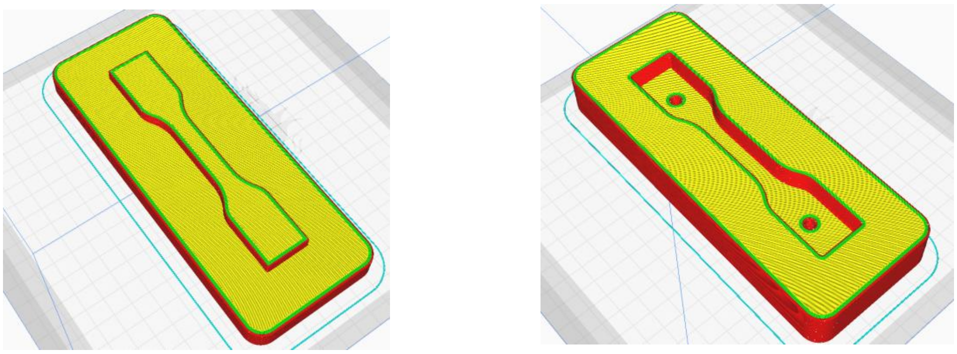

Fig. 2 (a) Male Die ; (b) Female Die

Table 1. 3D printing process parameters

Parameter	Value and Unit
Nozzle diameter	0.4 mm
Layer height	0.2 mm
Wall thickness	0.8 mm
No. of walls	4
Infill density	45 %
Nozzle temperature	205 ℃

Table 1. Chopped carbon fiber properties

Property	Value and Unit
Fiber length	12 mm
Density	1.81 g/cm3
Carbon content	95%
Tensile strength	3800 Mpa
Elastic modulus	242 Gpa

Table 2. Epoxy resin properties

Property	Value and Unit
Mixing ratio	3:1
Curing time	24 hrs
Tensile strength	78 MPa
Ultimate strength	68 MPa
Tensile modulus	3250 MPa
Flexural strength	90 MPa
Flexural modulus	3700 MPa
Shear strength	58 MPa

Conclusion

Thus this study presents the investigation of 3D printed molds for fabricating carbon fiber composites as a cheap prototype alternative with applicable feasibility and effectiveness. These 3D-printed molds were then fabricated and investigated for their composite properties in the research analysis. The results showed that 3D-printed molds are able to produce carbon fiber composites, which have similar properties as those manufactured using conventional methods.
Further, the non-contact 3D scanning technology facilitated an accurate and dependable operational one for quality control, where the derived information generated necessary tweaks to improve final product quality. The cost-effective and suitable alternative of 3D printed molds was demonstrated by cost-time efficiency analysis compared to traditional methods. In general, this study establishes 3D printed molds for CFRP production as an applicable and encouraging route to low-cost

prototyping in the composites industry with potential for improvements to increase manufacturing efficiency and part performance.

Molds manufactured via FDM with thermoplastic polymers exhibit notably reduced expenses and quicker production times, approximately 37.5% and 30% lower, respectively, in comparison to aluminum molds milled using CNC techniques. At first, a high-viscosity epoxy resin designated for casting purposes was utilized, yielding test specimens with slightly inferior strength. Transitioning to a lower-viscosity epoxy resin tailored for carbon fiber composites resulted in enhanced strength.

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