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Investigation of a new approach for additively manufactured continuous fiber-reinforced polymers

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Abstract

First additive manufacturing processes (AM) for the production of fiber reinforced plastics (FRP) have been developed, which use Fused Layer Modelling (FLM) processes by implementing the fibers into the matrix material prior to extruding or within the nozzle. A method for implementing the fibers outside of the printing nozzle and outside of the thermoplastic filaments directly into the part while it is being manufactured has not yet been analyzed properly. This study shows the gain in tensile strength and Young's modulus for different implementation methods of glass and carbon fibers on the building platform.

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1. Introduction

A relatively new field of additive manufacturing technologies (AMT) is the production of fiber reinforced polymers (FRP). Some processes use stereolithography (SLA) [1, 2] for additively manufacturing FRPs, but most use fused layer Modeling (FLM) sometimes also named fused deposition modeling (FDM) or fused filament fabrication (FFF) [3–8]. Thanks to companies like Arevo Labs, everybody with a cheap FLM printer can print FRP parts due to their short fiber reinforced polymer filaments [9].

The mechanical properties of FRPs, especially tensile strength and Young's modulus, increase with the length of the fibers [10]. So in order to additively manufacture parts for high performance use, continuous fiber-reinforcements need to be used.

2. Additive manufacturing of continuous fiber reinforced polymers

As shown previously, fiber reinforcements are most often used in FLM processes. FLM processes usually use one or

more nozzles to locally extrude molten thermoplastic in order to additively manufacture a part [11]. Since the extrusion process itself generates a 2-dimensional string of thermoplastic, the fiber rovings can be implemented very easily by placing them directly into the extruded material.

In general, there are three different ways to implement continuous fibers into a printjob in FLM processes [4]:

- The fibers can be placed into the printing filaments prior to the nozzle, which usually implies the need for a prepreg material.
- In addition, the fibers can be implemented into the matrix material inside the nozzle. This way, a wide selection of fiber-matrix-combinations can be achieved.
- The third method for implementing the continuous fibers into the matrix material is after the matrix material passed the nozzle while the part is being manufactured.

Fig. 1 shows the aforementioned points from left to right. Grey areas are the nozzles, green strings are the extruded thermoplastic and the black strings are fibers.

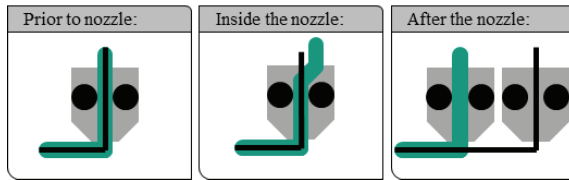


Fig. 1: Methods of fiber implementation based on [12]

Implementing the fibers prior to the nozzle is done by Markforged for use in their MarkOne, MarkTwo and MarkX printers, the only commercially available printers which can manufacture continuous FRP [6]. Research to a similar process is being done in Dresden [8].

Research about the implementation of continuous fibers inside the nozzle is being done by [4, 5, 7]. General disadvantages of this implementation method are the more difficult process control due to the fiber infiltration parallel to printing and the handling of the fibers [4].

Implementing the fibers after the nozzle directly into the printjob is done by Mori et al. with carbon fibers and acrylonitrile butadiene styrene (ABS). Their research shows, that the carbon fibers were entirely pulled out of a ruptured tensile test specimen and the fibers affected the resulting tensile strength only a little. With an additional thermal bonding the test specimen reached about double of the tensile strength of unreinforced specimens [5]. The shown results should be perceived with care. Since the tensile strength without fibers was only at 11MPa, about a quarter of common values of ABS, the quality of the FLM process in this case is more than questionable.

When the 3D-printer has only one nozzle, both methods of fiber implementation “prior to nozzle” and “inside the nozzle” result in the whole print job being made out of FRP. This may be useful in some cases, but the more efficient and economical way of fiber implementation is by placing the fibers only where they are absolutely needed. Only method 3 “after the nozzle” allows the local addition of fibers, so it gets addressed by the research shown in this manuscript.

3. Experimental Design

To integrate continuous fibers in the additive manufacturing process following method 3 “after the nozzle”, three different approaches are being developed and evaluated:

- Concept 1: Direct overprinting of the fiber rovings
- Concept 2: Insertion of the fiber rovings through a hypodermic needle
- Concept 3: Using a solvent

Following fibers are chosen to manufacture the test specimens:

- Carbon fibers: Torayca T300 1K
- Glass fibers: 3B Advantex SE 1200 300 tex

As matrix material the ABS Cytolac CTR52 is being chosen. Five Tensile test specimens similar to specimens of DIN EN ISO 527 are printed for each concept and each fiber type using the additive manufacturing system Arburg freeformer. Every test specimen is printed with a layer thickness of 0.265mm and consists of 14 layers. The infill parameters are chosen in a way that the specimens have a theoretical porosity of 0%. The fibers are being inserted according to each approach between layers seven and eight in order to produce a symmetric specimen with reduced warping.

3.1. Experimental setup

Since the fiber rovings are placed between the seventh and eighth layer of each specimen, the printing model needs to be divided into a bottom half and a top half. The bottom half has to be taken out of the 3D-printer’s building chamber to integrate the fibers. When it is put back into the printing chamber, the correct positioning and fixing is necessary. Therefore, the standard ISO 527 test specimens have to be edited by adding six small wings on the specimen’s side, on which small struts are placed to hold the specimens in place, also see Fig. 2.

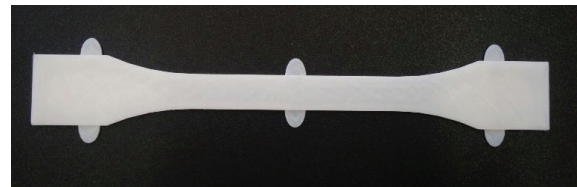


Fig. 2: Bottom half of test specimen

The positioning is ensured by putting the bottom half between six pins. The procedure for 3D-printing a FRP specimen is as follows:

- Print bottom half
- Insert fiber rovings, see chapters 3.2 to 3.4
- Position bottom half on the building platform
- Fix bottom half with small struts
- Heat building chamber to 80°C
- Print top half

Fig. 3 shows the positioned and fixed specimen including the fibers on top of the building platform.



Fig. 3: Building platform with specimen

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