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FDM technology printing methods

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Abstract

3D printing technologies were developed almost 30 years ago and one of their main features is that instead of removing 3D printing adds material layer by layer and the elements are created directly from CAD models. This type of technology offers an advantageous ability to produce components that are complex in shape and material, which cannot by produce by the traditional methods. Intensive research has led to significant advances in technology in recent years in the development and commercialization of new innovative 3D printing processes by modeling molten deposition (FDM), including composite printing. This paper outlines the main methods for creating polymer composite structures using FDM technology. Thanks to the constantly increasing quality of the final product produce by the am machine, there is a much greater connection and appearance between it and the prototype. Many components are already manufactured directly in these machines, so it is not correct to label them as prototypes.

Keywords: 3D printing; Additive technologies; FDM; SLA; SLS; Composite materials

1. Introduction

Technologies of additive production, which were commercialized at the end of 80`s and allow fast production of model or design based on 3D model, which was created in CAD system or from 3D scanned data obtained using spatial digitalization. This technology uses component production using layers. Compared to conventional production technologies is production significantly reduced. For use all the benefits are important to proper integration of the whole course of development of product and proper incorporation of technologies into development cycle. Their advantage is use of a wide range of serial components and production of individual components too. Basic principle AV technology is model created in 3D CAD program where it can be made directly without prior planning of the whole process. The whole process requires detailed and exact description of product, its geometry, used material and tools. Products are made by adding materials in horizontal layers. Each layer is thin cross section of the component derived from CAD data (AM). In its beginnings additive production was used at production plastic prototypes and many processes (SLA, SLS, FDM) have been developed to produced components from various plastics. After intensive development and research, this technology has become more and more popular and with the development of additive production, materials focused in this area were also developed at the same time. Today, this technology can produce complex components in the shape of network or almost in such a form from materials that can be used directly as functional parts, including metals, ceramics and composites [1] [2].

1.1. The pros and cons of FDM

The main advantages of this process are that several starting materials can be used (thermoplastics) if a suitable printhead is available. FDM parts are very rigid and therefore can act as operating parts, lasers are not needed, so its

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safe and economical. It is a clean process that does not require cracking/liquid starting materials and the equipment can be easily stored in the office. As far as the support material is concerned, it is easier to separate, and no subsequent chemical treatment is needed. In this case, machines and materials are cheaper, which leads to a more cost-effective process and is considered to be the simplest of all AM processes.

1.1.1. Disadvantages of this technology are

Graded layers

These are visible scratches of the deposited material due to a certain distance between the edges of the following layers. This effect can be minimized by pressing the bottom layers as well as reducing the diameter of the extruder (which expands the process and increases the cost).

1.1.2. Overhang and bridging

Leakage

This type of problem occurs if during the movement of the extruder between two points some fiber escapes due to gravity

1.1.3. Deformation

Structural inhomogeneity

Is associated by layer-by-layer deposition on the surface, according to temperature differences or porosity. It is about unevenness, discontinuity, ripple, particle size of the structure or insufficient density of the object. Print damage [3] [4] [5] [6] [7] [8].

2. Material and methods

2.1. FDM printing methods

Based on a review of several publications, it is proposed to divide the FDM printing methods according to the type of extruder.

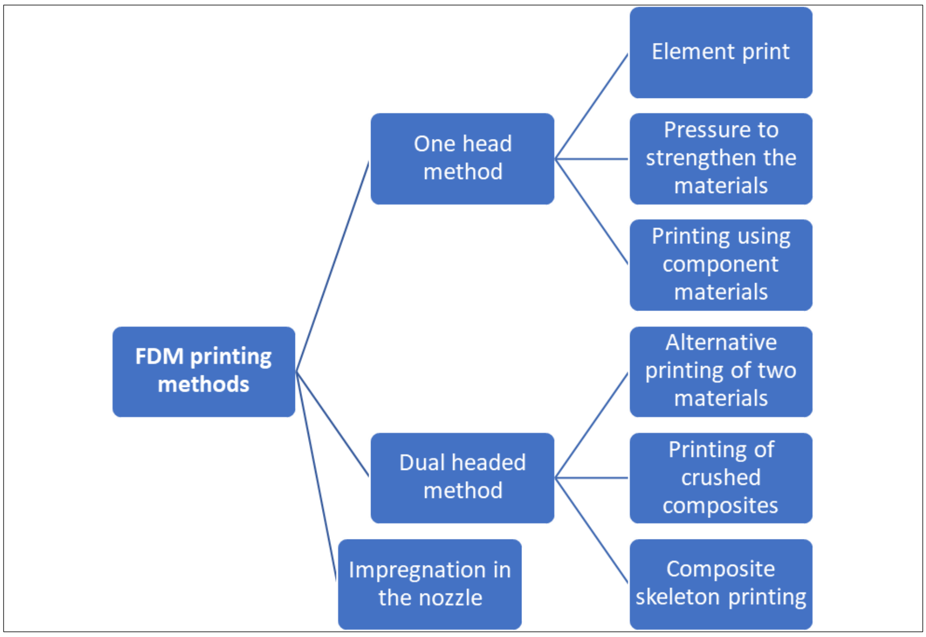

Figure 1 FDM printing methods

2.2. Production and composite structure

- one head on the reinforcing material (figure 1)
- printing of two materials (figure 2)
- impregnation in the nozzle (figure 3)

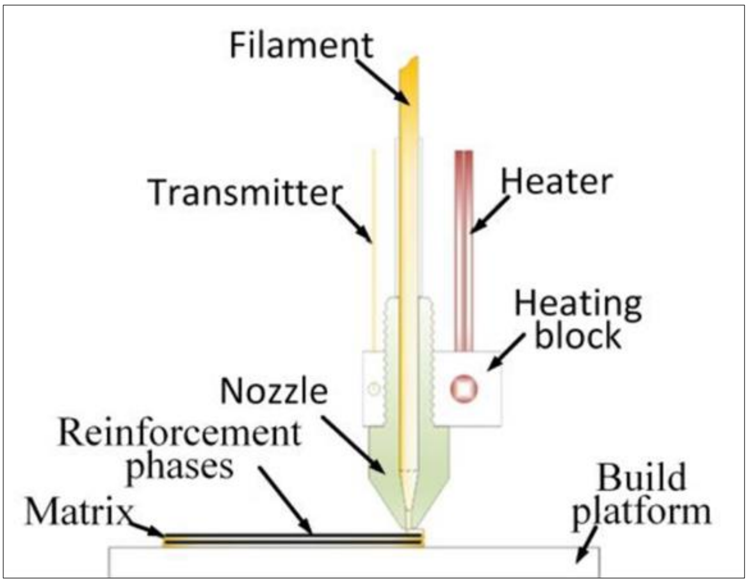

Figure 2 Printing with one head on the reinforcing material [6]

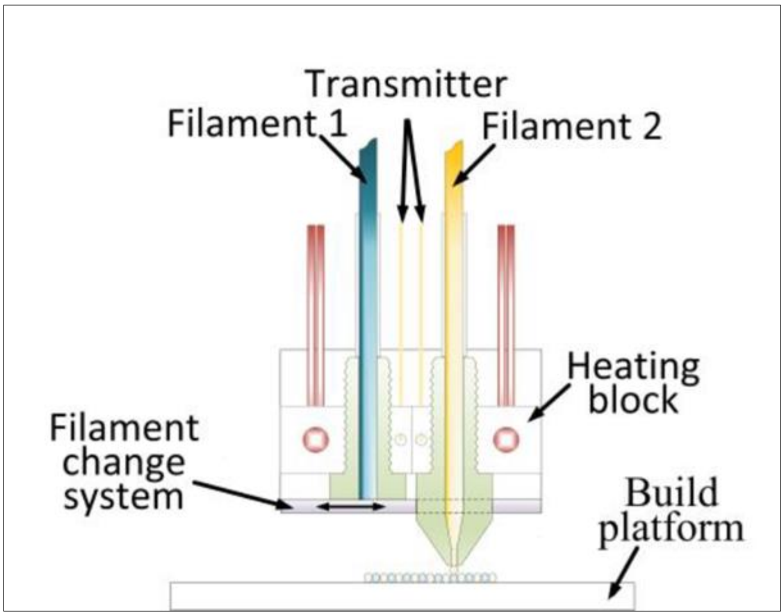

Figure 2 Printing of two materials [6]

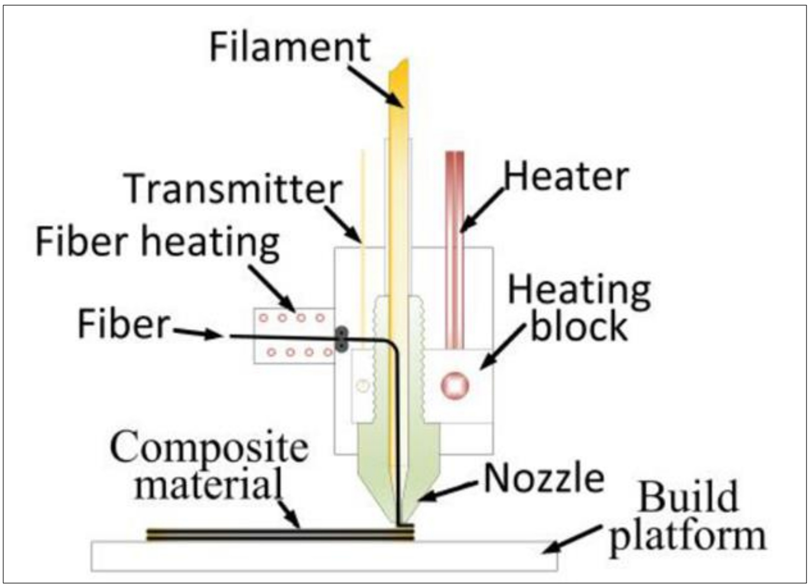

Figure 3 Impregnation in the nozzle [6]

2.3. Creating multi-material structures by printing on an element

It is an interesting method of creating multi-material structures which is based on pressing a layer of polymeric materials on the surface of a ceramic, metal, wood, or polymeric materials. The structural elements obtained may be composed of several materials in which the built-in element occupies the largest part.

The biggest disadvantage of this method is the need to divide the model into parts separated by parallel plane that identify the subsequent stages of printing. In addition, it is necessary to know how to control the print head and stop now when it is necessary to place other elements. The technological problem of this method is the restoration of printing without disrupting the continuity of the material [6] [7].

2.4. Creating a composite structure by printing one nozzle on the material outlet

Production of a composite structure using one head by printing on reinforcing material is a method that is similar to the creation of multi-materials structures. Composite materials are obtained by a multi-stage process in which the number of stages depends on the number of reinforcement layers in the finished element. Each stage of printing is designed by the specification of the dividing plate what allows to stop printing and save the reinforcement phase of the printout. The layered composites produced in this way can be reinforced with an endless fiber, fabric, or mat [6].

Disadvantages of this type of printing include limitations associated with the process and the thickness of the individual layers of reinforcement material in the composite. If the reinforcing fiber bundle is too coarse, the reinforcing phase may deform due to the fibers sticking to the stream and the material may shift. The reinforcement layer commonly found in literature has a thickness of about 0.5 mm [3] [4] [5].

2.5. Forming a composite structure using a single nozzle with specific fiber

This type of technology uses a different fiber than traditional 3D printing technology. The fiber contains besides polymeric material also an additive such as micro-rubber beads, glass or carbon fiber particles, wood flour, etc.

The biggest limitation of this method is the availability of material for printing. Prepared fiber can be purchased but currently the market offers a limited number of such products. Composite fiber could also be produced as a result of extruding a monofilament of a defined diameter, but it is a process that requires special equipment and know-how. For example, for obtain the desired fiber diameter (1.75 mm or 3 mm) the fiber should be extruded at a specific speed. The higher the speed is the smaller id the fiber diameter. The particles are also limited by the size and volume fraction of the reinforcement in the filament. In case of excessive particle size or volume, the flow of the 3D printer nozzle can be blocked, which will result in poor printing [5] [6] [7] [9] [10] [11].

2.6. Creating a composite structure by alternative printing from two materials

A diagram showing production of a composite structure by alternative printing using two materials is shown in pic. 2. The process of selective printing with two materials is an advanced method of 3D printing, which is appearing more and more often. Consists of a head which consists of two nozzles, or a newer solution is one nozzle with a fiber exchange system. The method consists in alternately applying different types of materials in one printing process.

The main advantage of this method is the ability to control the properties of the finishing object during the design because we can design and then produce any composite structure (pic. 4). The biggest limitations of this production method result from two-material printing imperfections, such as contamination due to the inability to pass from one fiber to another, fragment to fragment, as well as the problems with configuration of G-code and the requirement to use materials with similar thermal properties. These problems solve the constant introductions of new fiber exchange systems and software update by printer production [6].

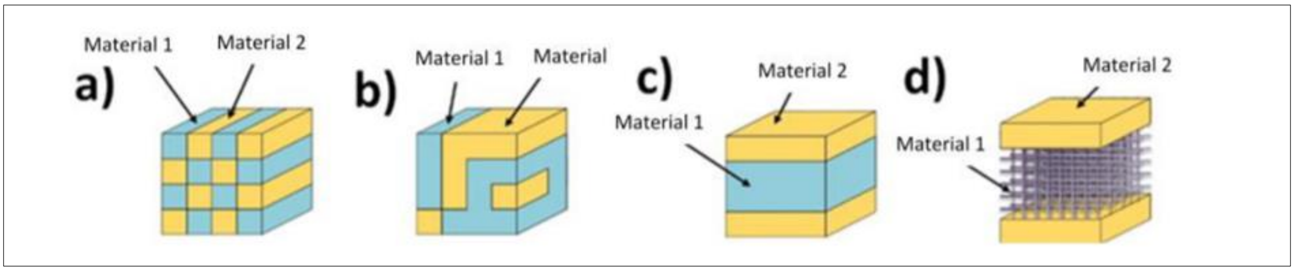

Figure 4 Example of printing structures made of double composite material: a-b) varied distribution of materials c) sandwich structured composite - layered, d) sandwich structured composite - skeleton [6]

2.7. Forming a layered composite structure using two materials

The formation of a layered composite structure belongs to the form of printing from two materials. A significant difference between these methods is the method of applying the material, which in this case is layered, first material number 1, then material number 2, again number 1 and so the process is repeated until the product is finished. The schematic structure obtained by this method is shown in pic. 4c [5] [6].

2.8. Creating a skeletal composite structure by using two materials

Skeletal composite printing technology is similar to layered composite printing, with the biggest difference being that one of the materials is not solid but has a skeletal structure (pic. 4d). To produce such structures, we can use filler reduction algorithms known from prototype printing technology, which have helped save time and material in the printing process.

The most common skeletal structure includes hexagonal cells, square cells, honeycomb cells, and can be individually designed, given that the FDM method has limitations on overhangs known as bridges [5] [6].

2.9. Forming a layered composite structure by using a special nozzle which allows the introduction of a continuous fiber

Picture 3 schematically shows the production of continuous composite by nozzle impregnation. The fiber, which is the matrix material, and the continuously reinforced fibers are supplied to the muzzle separately. To increase the impregnation of the fiber with the thermoplastic material before its insertion, the reinforcement is heated in the nozzle. The fibers are automatically delivered to the head through the movement of the fiber. The fiber is plasticized inside the printer head and connected to the reinforcing phase. The following printing processes are similar to a traditional 3D printer [5, 6, 12-15].

3. Conclusion

3D printing allows the production of individual pieces of complex parts based on the CAD model without the use of expensive tools or molds. The result of the development of this technology are prints in various areas of life. Of the several 3D printing technologies the one based on FDM technology is especially widespread. It is a simple technology that has unlimited possibilities. Other benefits include printer prices, improved software, expanded range of materials used, including composites and mechanical properties of 3D prints.

Literature on this topic contains several publications dealing with 3D printing of composite materials. In this case it is possible to use different types of reinforcement, such as carbon structures, reinforcement plates and short fibers, as well as carbon, polymers, and glass.

However, most research concerns the preparation and printing of fiber composites. These composites usually show worse mechanical properties compared to composites produced by conventional methods, because composites reinforced with short fibers or particles are mechanically worse than those reinforced with endless fibers. As a result, the use of endless fibers for 3D printing is an interesting solution. 3D printed composites are designed to produce elements with high electrical conductivity, low coefficient of thermal expansion and high thermal conductivity. Despite the increased interest in the printing of composite materials and many publications on the development of this technology, there are still number of problems that requires further analysis. Necessary technical problems that need to be solved are associated with intermittent printing of fiber changes. In this case, it is also necessary to look for new material connections and adapt them for printing, provided that such solutions are cost-effective and environmentally acceptable. This requirement can be met by one polymer composites in which the matrices and reinforcements are made of the same or similar material, while the components may be different in molecular weight, density, or degree of branching.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors have declared no conflict of interests.

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