INNOVATION OF USING 3D PRINTING FOR TEXTILE FIBERS

Review scientific paper
DOI: 10.5937/CT_ITI24031D

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ABSTRACT: *Textile fibers are produced in a natural way, and more and more often we have the opportunity to see impossible textile structures that retain desirable properties, such as non-creasing, long-term coloring, temperature stability, resistance to insects and the like. For the expansion of the use of printed textiles, a well-organized system in which technology is connected with economy, ecology, resources, informatics and marketing will have a great merit. Many filament (material) input methodologies are similar, and the difference is in the materials used, as well as in the process of general application and combining and joining of materials, so that the product is used for a long time. Fashion trends are something that negatively affects products, but this is solved by recycling and refurbishing clothes or shoes. The key moment for the development of 3D printing in the textile industry will be widely available printing technology, broadband internet and broad social acceptance of innovative materials. This paper presents the technologies that use different filaments in the production of textile fibers, and then also final products that do not have to be only clothing, but also for the needs of construction, defense and agriculture. The reason that every industry is looking for the use of artificial material that has similar characteristics to natural ones, where some properties will be improved and competitive in the market.*

Keywords: *3D printing, textile fibers, innovations, technologies.*

INOVACIJE U KORIŠĆENJU 3D ŠTAMPE ZA TEKSTILNA VLAKNA

APSTRAKT: *Tekstilna vlakna se proizvode na prirodan način, a sve češće imamo priliku da vidimo nemoguće strukture tekstila koji zadržavaju poželjna svojstva, poput negužvanja, dugoročne obojenosti, postojanosti na temperature, otpornost na insekte i slično. Za širenje upotrebe štampanog tekstila veliku zaslugu će imati uređen sistem u kome je tehnologija povezana sa ekonomijom, ekologijom, resursima, informatikom i marketingom. Mnoge metodologije unosa filamenta (materijala) su slične, a razlika postoji u samim* *materijalima koji se koriste, kao i u procesu opšte primene i kombinovanja i spajanja materijala, tako da proizvod bude dugotrajno korišćen. Modni trendovi su nešto što negativno utiče na proizvode, ali je to rešeno reciklažom i doradom odeće ili obuće. Ključni moment za razvoj 3D štampe u tekstilstvu će biti širokodostupna tehnologija štampe, širokopojasni internet i širokodruštveno prihvatanje inovativnih materijala. U ovom radu se predstavljaju tehnologije koje koriste različite filamente u proizvodnji tekstilnih vlakana, a onda i konačnih proizvoda koji ne moraju biti samo odevni, već i za potrebe građevinarstva, odbramene svrhe i poljoprivrede. Razlog koji svaka industrija traži je korišćenje veštačkog materijala koji ima slične karakteristike kao prirodni, pri čemu će neka svojstva biti poboljšana i konkurentna na tržištu.*

Ključne reči: *3D štampa, tekstilna vlakna, inovacije, tehnologije.*

1.INTRODUCTION

Textile fibers are an important part of the product range of the textile industry. User needs in changing conditions require the textile industry to turn to innovation. With the help of innovative strategies, it is possible to eliminate the outdated technological processes of dyeing, washing, rinsing, and drying from the textile industry, and to bring speed and better quality of textiles through shortening. This can be achieved with the help of 3D printing of textile products.

With the modernization of equipment, the introduction of new technological solutions and innovations, production phases can be shortened and the processing process can be automated. With additional investments, production and distribution lines can be set up in the warehouse, with machines and tools that can change the functioning process. Computers and the development of the information society contributed significantly to all this, and microprocessors are installed in machines and optimization of drawings and transfer to fabrics is carried out. Research and development centers must encourage innovation, hire highly skilled engineers and technicians to research, connect with science centers for laboratory conditions, and test raw materials and molecules. With nanotechnologies in industries, noticeable results are achieved, because the technologies are integrated into a system that collects all the necessary information. Laser application of small furrows on the surface of the thread or microhermetization, the fabric can be printed in color and without dyes, so that the color changes depending on the change in external conditions.

Three-dimensional (3D) printing is seen as a process in which, during one stage, materials are deposited in layers according to a geometric configuration set through a digital record. The beginning of the prototype of the device was in the 80s of the last century, where UV rays were used to harden the polymer and obtain a structure that has three dimensions. The development of the 3D printer production methodology for the market was established by 3D Systems with the stereolithography patent. Clothing designers have used affordable printing technology to reduce the environmental impact of fast fashion and enable materials to be recycled to reduce production waste.

2. 3D PRINTING TECHNOLOGIES

Production using 3D printing enables the creation of shapes that are not available using ordinary technologies, and is characterized by uniqueness and the absence of molds. 3D printing is an additive manufacturing (AM) technology that produces objects by depositing materials in thin layers. The deposited material layers are interconnected in different ways depending on the 3D printing technology and the material used.

The impact of technology is great, especially in the textile and fashion industry, as new and personalized products are produced. These products can be used as technical textiles, protective clothing, for medical products, interior, clothing and affect the modernization of the process that requires production to be done without waste.

Using computer-aided design (CAD) to create three-dimensional objects in layers, 3D printing is created. From the very creation of graphic models of the objects to be printed, they are designed using software and the files are imported into the 3D printer. This printing of an individual object takes much longer than printing text on paper.

Refinement of textiles is always necessary for longer use, decoration and individualization, but the smart function of textiles is obtained by using smart fibers or through the printing process. The most commonly used printing techniques for printing smart textiles are screen printing and ink jet printing. In addition to them, the 3D printing technique is also used for printing on smart textiles [1].

2.1 Types of 3D printing in textiles

In textile and clothing design, 3D printing is used in three different forms, such as direct printing on textiles, printing rigid elements that can be folded into flexible structures similar to textiles, and printing elastic materials that resemble textiles. Each of these forms can be realized with different printing technologies [2]. In 3D printing on textiles, the material is applied directly to the textile substrate and the desired 3D objects, patterns or designs are created on its surface. For this purpose, fused deposition modeling (FDM) technology is commonly used. In addition, stereo-lithography (SLA) [3] and PolyJet technology can be used, where aesthetics, detail and surface treatment are most important [4].

Among the various 3D printing techniques, FDM is most often used, followed by SLA, then selective laser sintering (SLS) or melting (SLM).

1) **FDM (Fused Deposition Modeling)** technology is used in approximately 70% of 3D printers worldwide. The FDM method involves melting thermoplastic material using a temperature-controlled nozzle. The molten material is automatically pushed into the print head and comes out in a thin layer onto the printing table to form the model. The schematic diagram of the FDM 3D printer is shown in Figure 1.

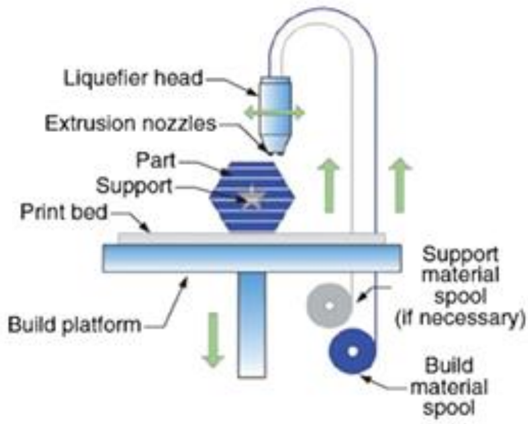

Figure 1: Schematic diagram of FDM 3D printing [5]

2) **SLA technology** is most often used in the photo-hardening process of liquid resin. Here, liquid resin is placed in a tank and a position-programmed laser scans the surface to begin photopolymerization. When the resin changes from a liquid to a solid state, chemical cross-linking occurs [6]. Schematic diagram of the SLA 3D printer shown in Figure 2.

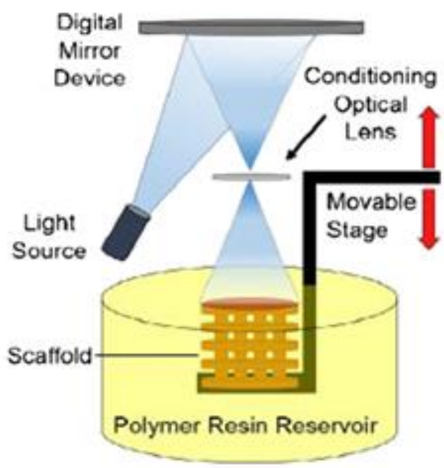

Figure 2: Schematic diagram of SLA 3D printing [5]

3) **SLS (Selective Laser Sintering)** is a selective laser sintering technology based on the hardening of resin materials in layers. This method uses Charles Hull's laser that patented stereolithography technology. A schematic view of SLS printing is shown in Figure 3, and this method is known as powder fusion [7].

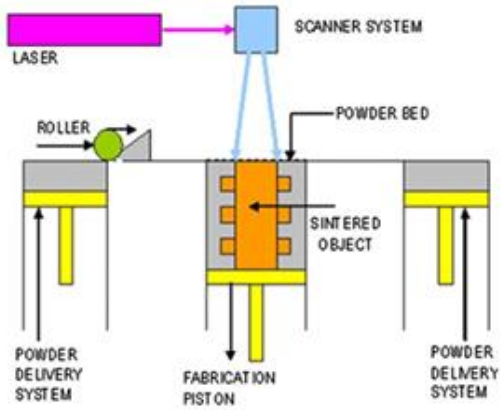

Figure 3: Schematic diagram of SLS 3D printing [5]

3. INNOVATIONS IN TECHNOLOGIES AND MATERIALS

Innovation always drives change, which means that the revolutionary development will be in 3D printing that encourages creativity and sustainability in the textile industry, which is at the top in terms of pollution compared to other industries.
New textile and additive manufacturing technology will affect textile production [2], so the printing of flexible structures will be based on:

- with rigid materials and that the structures are made to create some properties of the textile,
- another way is printing flexible materials,
- the third way is 3D printing on textiles.

The adhesion of 3D printed objects to textiles is affected by the preparation of the 3D model for printing, printer setup, placement of the fabric on the print table, and fabric construction parameters. Various polymers can be printed on textile surfaces in prepared forms to create multi-material objects that combine the advantages of technology and materials [8,9].

3.1 Clothing printing software

There are softwares that have 3D scanners for the body of the person who wants personalized clothes. Such scanners create a digital copy of the exterior of the human figure and then custom-made clothes are produced. With 3D human body scanning technology, there are no complaints about wrong measurements.
Computer-aided design (CAD) is a software tool that gives apparel designers a virtual representation of the garments they are designing. CAD software enables textile designers to utilize their creativity to the fullest when designing knits, printed and woven patterns. CAD can be used to design curves and figures in 2D and can be subsequently converted to 3D CAD for a better representation, as well as virtually prototype 2D designs through Browzwear’s 3D clothing design software, VStitcher. By utilizing VStitcher, textile

designers can design fabric while simultaneously having the capability to visualize the finished garment in real time, giving the designer more room to control and minimize any errors.
The 3D clothing design software gives designers the capacity to visualize completed garments virtually, which has streamlined and accelerated product development from concept all the way to creation (See Figure 4).

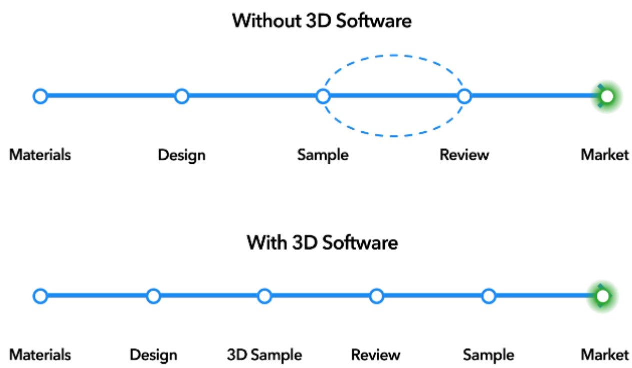

Figure 4: Shematic of proces without and with 3D Software (https://browzwear.com/products)

The removal of physical models for evaluation means that textile designers can create digital samples to alter and evaluate until prototyping. This procedure saves time and thus determines the best product that fits in terms of measurements, durability, and shape, and only then is it styled and placed on the market.

3.2 Innovations in polymer materials in 3D printing

The most important properties of multi-material objects made from 3D printed layers on textile substrates are good adhesion while maintaining the flexibility of the fabric. Adhesion of the polymer to the substrate is done with mechanical coupling, molecular bonding and thermodynamic adhesion [10].
In FDM, a 3D printer uses a process in which thermoplastic filaments are extruded and deposited in thin layers based on a previously designed 3D model [11]. During this process, the printer provides precise control over factors such as temperature and speed to regulate the flow of polymer material [12].
The most common polymer for 3D printing on textiles using FDM technology is polylactic acid (PLA-PolyLactic Acid). This biodegradable polymer is used on a textile substrate, because it has a low extrusion temperature [13]. After PLA, the most commonly used material is acrylonitrile butadiene styrene (ABS), followed by polycarbonate (PC), a mixture of PC and ABS, and others [14].
Thermoplastic polyurethane (TPU) has exceptional mechanical properties, such as tensile strength, hydrolytic stability, flexibility, durability and corrosion resistance, abrasion

resistance. The soft and hard segments in the polymer contribute to the unique properties and behavior of TPU [15]. In particular, it is expected that natural materials will be introduced into 3D printers and thus enable the biodegradability of materials and the use of natural pineapple, potato or kiwi skins.

3.3 Innovative technologies in 3D printing

The optimal technique for producing 3D printing polymers on textile fabrics may combine top-down printing, where the material would be placed only at the desired location with a low-viscosity printing material, i.e. resin or ink. This combination can be found in PolyJet Modeling (PJM) where liquid photopolymers are injected onto defined positions of the substrate and solidified there [16].
Poly-jet systems are better than SLA systems because the resins come in cartridge form and the devices are clean and quiet. With Polyjet technology, more than one material can be used simultaneously in production. Thus, it is possible for the material to be transparent and soft. A material that can be dissolved in liquid is used as an auxiliary material [17]. The schematic diagram of the polyjet 3D printer shown in Figure 5.

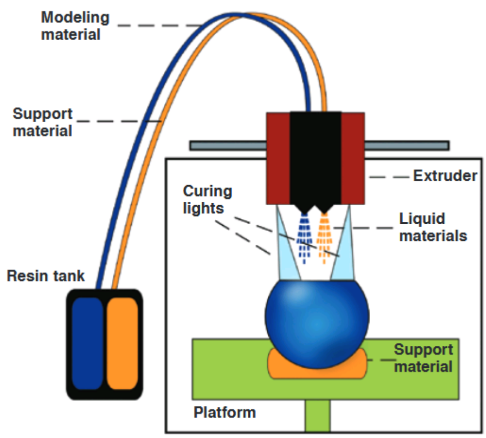

Figure 5: Schematic diagram of polyjet 3D printing [18]

A big advantage of using PJM technology for making composite models in combination with textiles is the possibility of using several different materials (hard and soft) as well as mixing them to make a new one.
Binder Jetting is a jet technology, known as 3D color printing. When the powder material is placed on the printing table, the 3D printer head passes over the powder and sprays the glue and paint. With the application of the next layer, the powder material is applied with a roller, and in this layer it is finished by re-spraying the glue and paint from the print head and it is repeated until the model is made in layers. Curing of the model is done in an oven, and after the production of the model is completed, the process is carried out with the help of a brush and water to remove the remaining dust. Schematic diagram of binder jetting 3D printer shown in Figure 6.

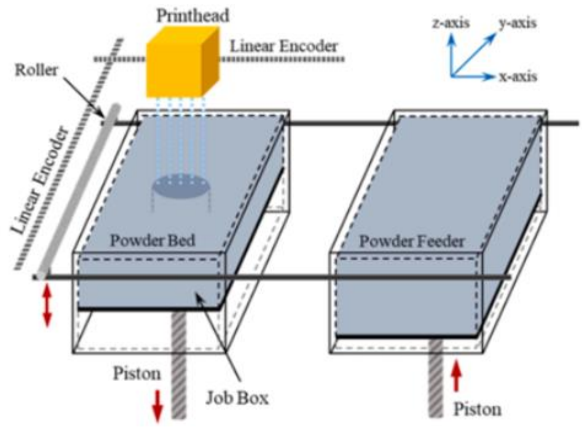

Figure 6: Schematic view of Binder jetting 3D printing [20]

Mold making, which takes time in the fashion industry, is being replaced by CAD software. With the help of CAD software, live model measurements can be transferred to a computer within minutes. With the help of this technology, the consumer becomes his own designer as well as a producer. One of the advantages of 3D printers is mass production and recycling, and the pollution that currently exists in factories is prevented.
Conventional fabrics have a thickness that is small compared to the width and length, and these are 2D fabrics. 3D fabrics have characteristic values in all three physical dimensions and can be created through yarn architecture or fabric architecture [19]. A split fabric is a 3D fabric consisting of two separate outer layers joined together but separated by spacer threads.

4. MATERIALS FOR 3D PRINTING IN TEXTILES

Input components are important because of the future structure of the subject. The properties of the materials to be entered must meet the requirements of being flexible, unbreakable, not colored when washed, not damaging the structure, healthy, compact, reusable and not polluting the environment.
The materials, or filaments, as fibers used in printing textile items depend on the printer and the project. In textiles, the object of manufacture may be fabric, footwear or a prototype garment, where heat resistance, impact resistance, ease of use, flexibility, visual appeal and similarity to the desired materials are considered.
The World Advanced Savings Project - WASP states that the most common filament for clothing is thermoplastic polyurethane (TPU). The reason for using TPU is that it has great durability and is resistant to wear and tear, due to the elasticity of the undercut rubber, and it can be an insulator and resistant to shocks.
Flexible filaments are easier to print and are important for 3D printing and the textile industry (Figure 7).

Figure 7: Flexible filaments and part of dresses

Flexible filaments are easier to print and are important for 3D printing and the textile industry. Combined with the holographic refraction pattern it transfers to the printed medium and enhances the style and appeal. Embossing of 3D printed components is done directly on the fabric and is integrated into the garment, so that sequins or various colors can be added at the same time on the material. Biodegradable polymers or two-color filaments of polylactic acid (PLA) are used to create 3D prints.

4.1 Innovative materials and printing technologies

Polyethylene terephthalate (PET) copolymer is a modified version of polyethylene with additional monomers or additives incorporated into the polymer chain. This modification introduces specific properties that make it suitable for use in 3D textile printing. A slightly higher temperature is required for 3D printing than PLA (240 °C) [13].

3D printing on textiles enables a variety of new aesthetic and functional properties because they have a visual identity that is more difficult to achieve with an analog way of working. Recently, the advanced technology of 4D printing (4DP), which combines functional materials and 3D printing, has been developed. By introducing time as the fourth dimension, the basis is created for the development of smart materials that have the properties of dynamism and adaptability of the structure based on external stimuli or environmental conditions. Compared to knitted textile backings, which are stretchy, flexible and more elastic, these offer greater stability and the possibility of using stronger yarns. This is suitable for achieving certain properties in the production of protective clothing, technical textiles and apparel textiles, making them an ideal textile substrate for many different 3D printing applications.

The improvement of adhesion is achieved by increasing the roughness and porosity of the textile material, thus increasing the thickness of the fabric, double weaving, lower thread density, etc. A very important part is pre- and post-treatment, which has a great influence on the adhesion of 3D printing to textiles. Apart from the composition and construction of the fabric, the distance between the print head (nozzles) and the fabric is increasingly important.

3. CONCLUSION

The fashion industry has to adapt to the new technological paradigm, because there is no more mass production and consumption. It is produced exclusively, on demand, with customizable products that are meant to last. It is certain that printed textiles will be a sustainable solution to reduce waste and encourage creativity. Printing a 3D object can be completed quickly and modified in a short time. All 3D files are stored in the cloud and printed alongside 3D models as CAD or STL files, so they are easily located and printed as needed. Parts can be created on a 3D printer that can be heat resistant or water repellent. With 3D textile printing, parts are produced as needed, so there is no waste, and due to the reduced use of fuel and some materials, there are no negative effects on the environment. In this way, the entire product is printed in one printer, which reduces the cost of transferring from one machine to another. Additionally, printer availability is greater as there are more local service providers to hire. In the medical sector, 3D printing can save many lives by printing human organs for emergency interventions. 3D printed clothing can be made from recycled and biodegradable materials, offering a sustainable solution. 3D printing has the advantage that it allows design variability, possibility of individualization, produces strong parts that are not heavy, short maturation period-life cycle, waste reduction, cost-effective, access from distance-online, ecologically and medically applicable. The disadvantages of 3D printing include limited materials, build size, and post-processing. The density of the fabric has the greatest influence on the adhesion force. With the new technology, which is recognized as 3D printing, designers can create unique pieces that were once unattainable, so that the clothes are exactly the order of the customer.

ACKNOWLEDGMENT
The research presented in this paper was carried out with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, as part of the funding of scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with number 451-03-65/2024-03 /200131.

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