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ALGILAMA VE ELEKTRİK BAĞLANTISI İÇİN TEKSTİL ÜZERİNE ESNEK İLETKEN POLİMERLERİN 3D BASKISI

3D PRINTING OF FLEXIBLE CONDUCTIVE POLYMERS ON TEXTILES FOR SENSING AND ELECTRICAL CONNECTION

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3D PRINTING OF FLEXIBLE CONDUCTIVE POLYMERS ON TEXTILES FOR SENSING AND ELECTRICAL CONNECTION

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ABSTRACT: Additive manufacturing (AM) is a 3D printing technology that works by deposition of a material, layer by layer, creating 3D objects. The growth of these technologies has been exponential and the application of AM in the textile industry has also been a subject of increased interest in the past few years. The applications are not only for decorative purposes, but also for biomedical and other uses in e-textiles. However, a crucial point for making such assembly is the adhesion between the material and the textile substrate, as well as the premise of meeting demanding wash resistance requirements. This work aims to investigate the possibility of creating sensors by combining textiles with conductive polymeric filaments used in 3D printing. Merging the flexibility of use, mechanical properties and electrical conductivity of the polymeric filaments with the comfort and physical properties of the textiles can be a promising approach to create novel sensing structures. In this document, we give an overview of the recent state of the art of experimental research on adhesion in textile and polymer composites as well as an optimization of the printing parameters with a conductive filament, PI-ETPU. Some results from the printed samples in terms of print quality and electrical resistance are presented. Combining both topics, further work will include printing with conductive filament on textile substrates to study the possibly of creating sensing and electrical connections.

Keywords: *Additive manufacturing, e-textiles, adhesion, sensors, conductive.*

ALGILAMA VE ELEKTRİK BAĞLANTISI İÇİN TEKSTİL ÜZERİNE ESNEK İLETKEN POLİMERLERİN 3D BASKISI

ÖZ: Eklemeli üretim (EÜ), bir malzemenin katman katman birleştirilmesiyle 3 boyutlu (3B) nesnelerin oluşturulmasını sağlayan bir 3B baskı teknolojisidir. Bu teknolojilerin ilerlemesi katlanarak artmıştır ve özellikle son yıllarda EÜ'nün tekstil endüstrisinde uygulanması da artan bir ilgi konusu haline gelmiştir. Uygulamalar sadece dekoratif amaçlı değil, aynı zamanda biyomedikal ve e-tekstil ürünlerinde de gerçekleştirilmektedir. Bununla birlikte, malzeme ile tekstil yüzeyi arasındaki yapışmanın yanı sıra eklemeli üretim için önemli noktalardan biri de zorlu yıkama direnci gereksinimlerini karşılama konusudur. Bu kapsamda gerçekleştirilen bu çalışmada, tekstil yüzeylerinin 3B baskıda kullanılan iletken polimerik filamentlerle birleştirilmesiyle sensör oluşturma olasılığının araştırılması amaçlanmıştır. Polimerik filamentlerin kullanım esnekliğini, mekanik özelliklerini ve elektriksel iletkenliğini tekstil malzemelerinin konforu ve fiziksel özellikleriyle birleştirmek, yeni algılama yapıları oluşturmak önemlidir. Bu çalışmada, öncelikle tekstil yüzeyleri ile polimerlerin birleştirilmeleri üzerine yapılan deneysel araştırmaların yanı sıra iletken bir filament olan PI-ETPU için baskı parametrelerinin optimizasyonu hakkında bir genel bakış sunulmuştur. Çalışmada daha sonra, gerçekleştirilen 3B baskı ile üretilen numunelerin baskı kaliteleri ve elektriksel direnç değerleri ile ilgili bazı sonuçlar verilmiştir. Her iki konuyu birleştirecek şekilde ileriki çalışmalar, algılama ve elektrik bağlantıları oluşturma olasılığını incelemek üzere farklı tekstil yüzeyleri üzerine farklı iletken filamentler ile baskı çalışmalarının gerçekleştirilmesi üzerine olacaktır.

Anahtar Kelimeler: *Eklemeli üretim, e-tekstiller, birleştirme, sensörler, iletkenlik.*

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1. INTRODUCTION

Additive manufacturing (AM), also known as three-dimensional printing (3DP), enables creating a 3D object, layer by layer, by the deposition of a material. Contrary to traditional fabrication methods, it allows the building of more complex shapes [1,2]. Research in this area first began in the 1980s with a focus on small products [3,4]. As additive materials improve in performance and efficiency, they are being used for production of all kinds of products [5]. AM allows successfully obtaining the desired product by saving the resources, costs and time as well as by reducing the waste [2,3,6]. Therefore, AM is being used in many different applications, including automotive [7], aerospace [8], architecture [9,10], medical [6,11], food processing [12,13] and fashion and textiles [14-17].

The selection of materials to be used in additive manufacturing directly affects the characteristics of the object to be printed, namely durability, mechanical properties and applications. The materials used in AM can be classified as solid/powder and liquid, based on the physical state [3,5]. A wide range of materials are used such as metals, ceramics, polymers and their combinations in the form of composites, hydrogels, waxes, sand and resins [3,5,11,18]. The most commonly used material among these is polymers, the material chosen for this study. Fused deposition modelling (FDM), one of the extrusion-based 3DP technologies, and SLA are the most widespread processes, using polymers as material [17]. In FDM, a thermoplastic material filament is fed and molten into a heated nozzle and is deposited on a - often heatable - printing bed, layer-by-layer [1,19]. By printing one layer each time, a 3D object is constructed. The main advantage of FDM is its low cost, which makes it reachable for small companies and researchers.

The use of AM in the textile industry creates a future-oriented production opportunity for fashion products as well as for e-textiles. In usual manufacturing methods of smart textiles, the conductive materials are integrated into textiles using standard textile technologies such as sewing, coating, embroidering, weaving, knitting, among others. [20]. In this regard, 3DP is emerging as an easy and low-cost alternative method for combining textiles with conductive polymeric filaments to create textile sensors. In last few decades, there are several attempts on building smart textiles by 3DP such as shape memory textiles [21], textile-integrated RFID tags [22], textiles for energy harvesting [23,24], force sensors [25,26], strain sensors [27-29], tactile sensors [30], and EMG electrodes [31].

This study aims to investigate the possibility of creating sensors and connections using 3DP by combining textiles with conductive polymeric filaments. In such bi-material systems, the adhesion between the materials becomes the main challenge [32]. The parameters considered essential to ensure good adhesion between materials can be classified into three main groups: printing parameters, printing polymers and properties of the textile substrate. Adjusting the printing parameters such as z-distance (vertical positioning of the extrusion head relative to the textile), printing temperatures, speed and orientation can induce a greater bonding of the polymer with the textile substrate [15,33,34]. Eutionnat-Diffo et al. examined the effect of the printing table temperature, the fabric orientation and the textile substrate's properties (PET fabric) on the tensile strength of the virgin or conductive PLA printed material. An increase in the printing table temperature caused an increase in the crystallization rate of conductive and non-conductive polylactic acid (PLA) filaments, therefore the tensile strength of the printed material decreased. Moreover, printing in the cross-direction obtained better stress at break [35]. The properties of the printing polymers are also important in obtaining good adhesion. Brinks et al. evaluated the bonding of six different polymers and found the polyurethane polymer variants more suitable for printing on polyester/cotton fabrics [36]. Korger et al. investigated the different flexible thermoplastic elastomers adhesions to textile substrates made of cotton, polyester or aramid. They obtained good adhesion and washing fastness in the materials printed using thermoplastic polyurethane [6]. Also, the type of textile material and structures, such as the pore size and the surface roughness of the materials' surface influences adhesion [15,37,38]. In addition, the surface properties of the textile material are important parameters that affect adherence. It is recommended to apply pre-treatments and post-heat treatments to the substrates to provide better adhesion. Increasing the hydrophilicity of the substrate can result in an increase in bond strength [19, 32].

While previous experiments always concentrated on creating textile-based structures [39] and 3D print forms directly on textile fabrics [15], the present work examines the possibility of using a conductive polymeric filament to create sensing and electrical connections on textile substrate.

2. MATERIALS AND METHODS

For 3D printing, the FDM printer Lulzbot Taz PRO (0,4mm diameter nozzle) by Lulzbot was used. To investigate applications of conductive materials, the printer was fed with a PI-ETPU filament by Palmiga. PI-ETPU is a conductive 3D printing filament made of a rubber-like TPU (thermoplastic polyurethane) compound material with a carbon black filler, which has a hardness of 95A, volume resistivity of <800ohm·cm and a 250% elongation at break.

First, it was tested some adjustments on the printing parameters, given that this kind of material is tricky to use regarding adhesion, extruder clogging and evenness. Squares of 20mm x 20mm area with a thickness of 2mm were printed. Z offset was calibrated to be approximately 1.2 mm above the printing bed, the printing bed temperature was set to 50ºC, and a blue paper tape was used on the bed. Considering print quality, initial tests were carried out with varying print speed, layer height, and nozzle temperature.

Concerning the electrical resistance, a specific specimen was designed and printed. Figure 1 shows the CAD drawing of the specimen design and the overall dimensions. The thickness of the specimen is 2 mm. Onshape was used for 3D design, which was exported as a STL file and imported into the Cura software for slicing.

Electrical resistance was first measured using a multimeter. Two copper plates were clamped on the larger part of the sample, and crocodiles were attached to the plates, as shown in Figure 2a. As the measurements revealed quite unstable, a new setup using a voltage source, a voltmeter and an ammeter was used next (Figure 2b). 20 V were applied to the samples and the current was measured. In this way, stable measurements could be taken.

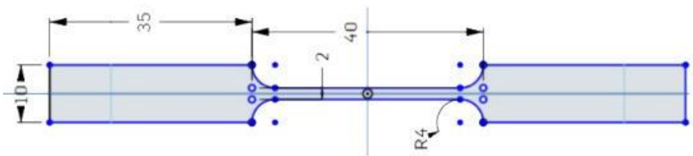
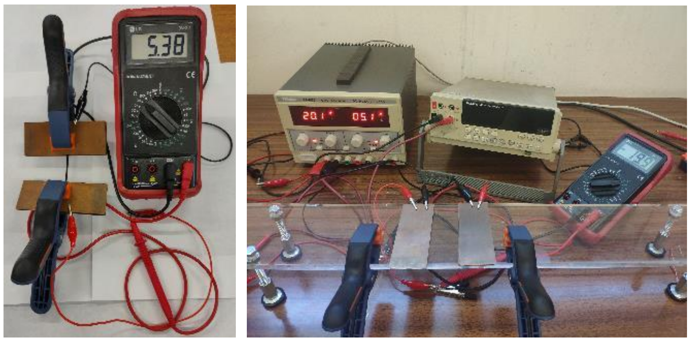


Figure 1. CAD drawing of the specimen

3. RESULTS AND DISCUSSION

3.1. Print quality

Table 1 lists the operation printing parameters used to investigate the influence of speed variations on print quality. Results are shown in Table 2. All prints showed promising outcomes, adhesion to the printing table and between layers. However, with a slightly higher speed, V3 (35 mm/s), the results were better, with greater uniformity.



(a) (b)

Figure 2. Setup for measurement of electrical resistance

In a second test series, the effect of layer thickness on print quality was studied. Table 3 shows the print settings. In this case, it is possible to observe the dependence of the print quality on this parameter. As shown in Table 4, for low layer thickness (<0,3mm) the filament exits the print nozzle intermittently, decreasing the connection to the printing table and, consequently, decreasing the quality of the final sample.

Table 1. Print speed dependence on the print quality

	Print Speed (mm/s)	Print Temperature (ºC)	Layer Thickness (mm)
V1	25		
V2	30	220	0,3
V3	35		

Table 2. Print speed influence on the print quality

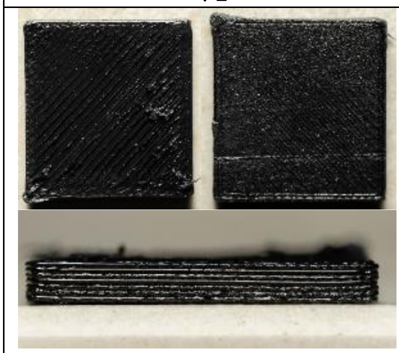
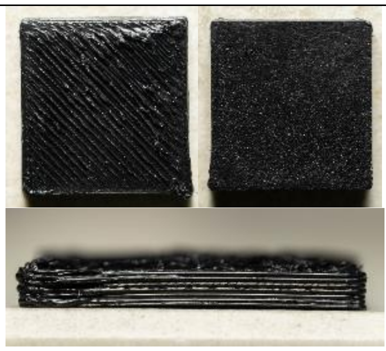
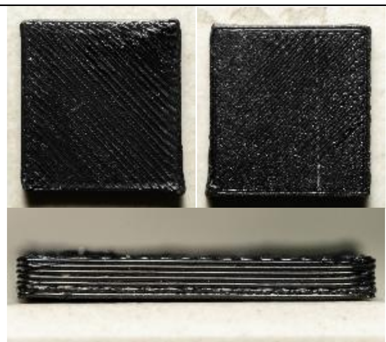
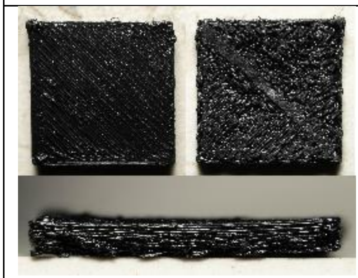
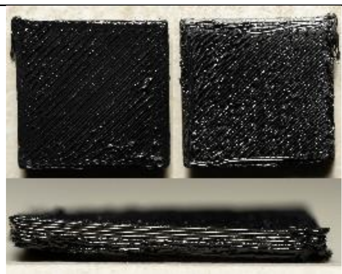
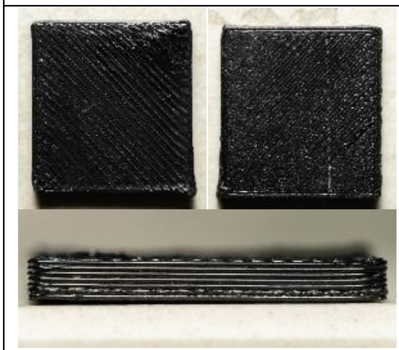
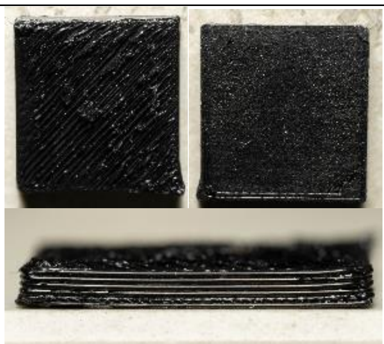
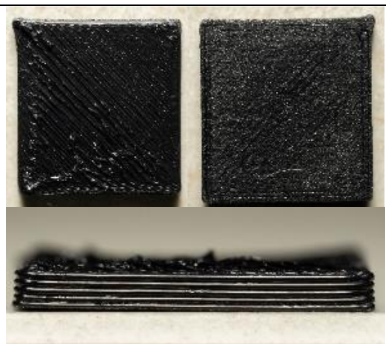
V1	V2	V3
		

Table 3. Layer thickness dependence on the print quality

	Layer thickness (mm)	Print Temperature (ºC)	Print Speed (mm/s)
L1	0,15		
L2	0,20		
L3	0,25	220ºC	35mm/s
L4	0,30		
L5	0,35		
L6	0,40		

Table 4. Layer thickness dependence on the print quality - results

L1	L2	L3
		
L4	**L5**	**L6**
		

Another critical parameter that must be considered is the printing temperature of the nozzle. The influence of increased temperatures is shown in Table 6. Here, when the temperature is too high, stringing can occur, and layer adhesion can be poor when it is too low, so it is very important to study these differences. As we can see through the pictures, above 230ºC (T5), the print quality drops significantly. Moreover, a sizzling sound could be heard, meaning the temperature was too high. Below 230ºC the performance was better and the sample T3, at 220ºC, was the one that obtained the best results.

3.2. Electrical resistance

Table 7 shows the parameters used to print the samples shown in Figure 1 and the resulting measured resistance. The presented resistance is the average between 3 measurements.

Having a first look at the results, the printing parameters substantially influence the resistance. Printing with higher layer thickness and lower temperatures and speed will lower the resistance value. However, when we tried to replicate those "ideal parameters", the results were not corresponding, and the resistance varied randomly. The second series of tests printed 3 samples under the same settings (210ºC, 35 mm/s and 0,4 mm layer thickness), printed on different days (samples 6 and 7). The results varied considerably (from 26,2 kΩ to 56,8 kΩ), meaning that the resistance depends on other conditions e.g. humidity, first or last print of the day, room temperature etc. It isn't easy to replicate the results using the same conditions.

3.3. Piezoresistive properties

Given that the preliminary tests samples showed some kind of piezoresistive properties, samples were inserted into a universal testing machine, stretched and electrical resistance was measured. Unfortunately, several problems with strong electrical noise hindered the experiment. Even when noise was within acceptable bounds, the behaviour of the sample was somewhat unpredictable, not showing a resistance behaviour proportional to the strain applied.

Table 5. Print temperature dependence on the print quality

	Print Temperature (ºC)	Layer thickness (mm)	Print Speed (mm/s)
T1	210		
T2	215		
T3	220		
T4	225	0,3	35mm/s
T5	230		
T6	235		
T7	240		

Table 6. Print temperature dependence on the print quality – results

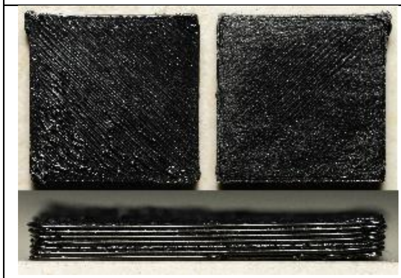
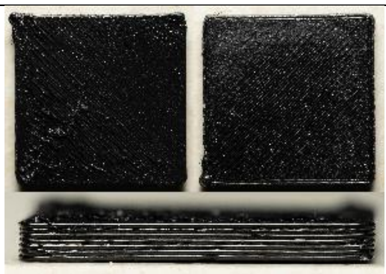
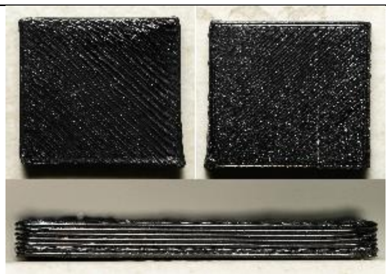
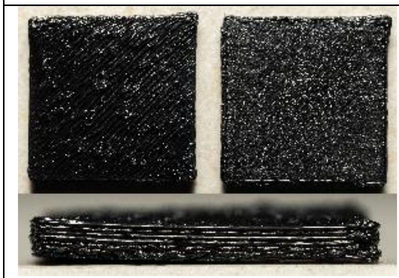
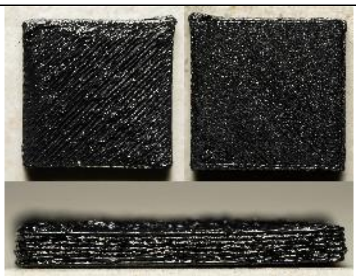
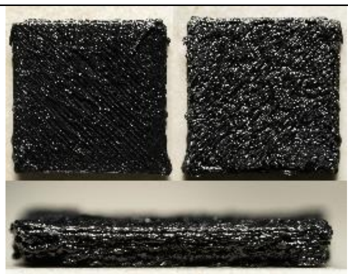
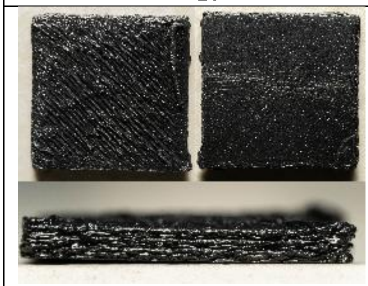
T1	T2	T3
		
T4	**T5**	**T6**
		
T7		
		

Table 7. Print settings and resulting resistance

Sample	Print Temp. (ºC)	Print Speed (mm/s)	Layer Thickness (mm)	Resistance (kΩ)
1	220	25	0,4	6,5
2	220	25	0,3	27,8
3	210	25	0,3	7,4
4	215	20	0,25	45,4
5	215	15	0,25	45,1
6	210	35	0,4	26,2
7	210	35	0,4	56,8

3.4. Adhesion to the textile substrate

A preliminary print test on a textile substrate was done to obtain a first impression of the result. A rectangle of dimensions 50 x 20 mm with a 2 mm thickness was printed on a 100% CO jersey fabric. The extruder temperature was set to 220ºC and the printing bed temperature to 50 ºC. The layer height was 0,3 mm and the print speed was 30 mm/s. For filling the sample, a linear pattern was chosen. It was satisfying to observe that the sample adhered quite well to the textile, although with low adhesion force. Figure 3 shows one of the samples printed. More investigation regarding this aspect will be done in future work.

Figure 3. PI-ETPU sample printed on textile

4. CONCLUSIONS

In order to understand the filament's behavior with different print settings, several tests were conducted. Due to its flexibility, the main obstacle was the difficulty in working with PI-ETPU. Overall, the range of values that shows a good result with this printer and filament are: temperature between 210 – 220 ºC; print speed between 25 - 35 mm/s and layer thickness 0,3 - 0.4 mm. One crucial aspect verified is that the print speed should be increased for lower print temperatures to avoid nozzle clogging. Another aspect mentioned is that it is advisable to add a skirt to the print.

The analysis of electrical resistance of the samples and the relation with the printing parameters seemed to be quite straightforward on a first glance. However, the attempt to replicate the result with the same printing parameters at different occasions and conditions showed that more variables influence this property.

This work is still in progress, and only preliminary results are being reported. Future work will include testing another conductive filament, Filaflex, a filament with the same hardness but with a much lower volume resistivity of 3,9 Ωcm. Further tests on the piezoresistive properties will be carried out as well. The use of this filament for electrodes to detect biopotentials e.g. eletrocardiography (ECG) and electromyography (EMG), will also be studied. A complete work plan for investigating the parameters that influence the adhesion of the flexible polymers on textiles is being set up. Adhesion tests will be performed according to DIN 53530.

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