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Investigation of Performance Characteristics of 3D Printing Textiles in Terms of Design and Material

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ABSTRACT

New technologies that are used in the producing and processing of textile surfaces provide significant advantages for the designer. One of the important technologies that offer today's design advantage is three-dimensional "3D" printers. This study attempted to determine the effect of design features used on textile surfaces produced with different 3D printers and materials on performance characteristics. This researchaimed to examine and compare the performance characteristics of 3D printers, the relationships between 3D printers and the different materials required by these printers, and one-piece and multi-pieces designs. Accordingly, textile surfaces were produced with 3D printers and the performance properties of these surfaces were determined. Significant differences were observed in the performance of textiles based on the breaking, bursting and weight determination tests. These differences were discussed in terms of the design's structural characteristics, material and the ways of 3D printing to stacking material. Consequently, although the performances of 3D textiles get the better of one another, their breaking and bursting strengths are found to be lower than the conventional fabrics.

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KEYWORDS

3D printing, Textile Design, Fashion Design, 3D Textile, Performance

1. INTRODUCTION

During thousands of years of textile production, there have been many changes in textile machines and processes, however, the approaches to fabric design to attain the desired properties has remained empirical. It is the skill and experience of textile technologists, backed when necessary by trial and error that dominates the production of fabrics [1]. After World War II, tremendous fiber innovation in both North America and Europe continents gave the push for product development towards man-made fibers in the 1950s. In the 1960s, the mills adapted the new fibers to their systems, providing innovative yarns and fabrics [2]. Meanwhile, innovative designs with effective technological developments have been regarded as a driving force in the marketing process and the work of textile designers has taken on a new significance in regard to bear features, such as authenticity, innovation, compliance with customer expectations, and functionality [3]. In this industry, where personal tastes stand out and tailor-made designs gain importance, the creative process becomes even more significant in regard to, particularly aesthetics elements [4]. Therefore, the designers have obtained the new forms they need by benefiting from science and technology and using new materials and production methods [5,6].

Against the background, three-dimensional (3D) printers are one of the most important technological advances of today, offering new opportunities to designers. Devices that are capable of 3D printing are called 3D printers [7]. 3D printers are one of the primary shaping technologies that enable objects to be generated in various ways with appropriate materials [8]. These printers are machines that

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convert digital data (three-dimensional CAD drawing) into real objects [9]. The basic principle of this technology is the generation of 3D designs by printing them layer by layer [10]. However, formations of the designs by the layers can considerably differ. Therefore, printers that can use different materials have been developed. Accordingly, the materials used in these devices are classified under three main headings. These include; liquid-based materials, solid-based materials and powder materials [11]. 3D production with liquid-based materials is made by exposing the photopolymer material to radiation and solidifying and the printing technologies that commonly use these materials are Stereo Lithography Apparatus and Polyjet [12]. Moreover, solid-based materials are available in filament form or in layers, and such materials are often used in the "Fused Deposition Modeling (FDM)" method [13]. Powder-based materials, on the other hand, are available in granular form, and the most well-known method among others, using these materials, is "Selective Laser Sintering (SLS)" [14].

Three-dimensional printers are also being used in textile production since 2010. The output of these printers differs from conventional textiles for connection types, consist of production form, material and textile. So, they need to develop different parameters to attain different attitudes, such as stretching, flexural, bending and drapability in textiles that are produced with 3D printers. Thus, the designers mostly create different connections to attain these attitudes. The studies have brought up the potentials of this new form of production and the materials used in production in terms of design processes. The designer's knowledge of the performance characteristics of the emerging new product is an important part of the product design scenario.

This research aimed to identify the effects of connection forms, material and printers' stacking/combining ways on the performance characteristics of textile surfaces that are produced through 3D printers. In the study that was conducted in three stages through experimental processes, two different textile surfaces that can be produced with 3D printers were designed and the designs were generated by using Fused Deposition Modeling, Selective Laser Sintering and Polyjet printing. Performance characteristics were identified by doing bursting and breaking strength tests to the 3D textiles produced. The obtained results have been discussed in the context of design, printing process and material.

1.1. The Production of Textile Surface with Three-Dimensional Printers

Three-dimensional printers are used in many fields of industrial production as well as in the textile sector. In the meantime, these methods can be used to produce all kinds of work that can be modelled in three dimensions in the computer and this enables the designers to develop innovative designs [15]. Furthermore, textile and fashion designers have been using this technology in many fields, such as in various fashion shows, conceptual artworks, or wearable art objects.

The design and production process with three-dimensional printers begin with determining the intended purpose of textile and modelling studies. In the second stage, three-dimensional drawings of textile design are being prepared in the features and sizes set by the appropriate CAD programs. Then, the created designs are converted into the STL file format. The STL file format is "an unsorted triangle surface list that represents the outer surface of the design" [16]. The data contained in this file is subjected to some pre-processing, such as error checking and building direction, creating support structures if necessary [17]. Finally, geometric textile data is printed by being sliced and sent to the printing machine, which is considered suitable for production (Figure 1). Textiles produced with a three-dimensional printer may be dimensionally incorrect when compared to conventional technologies. Therefore, "the surfaces of critical objects are finally cleaned, cured and brought to final size" [18].

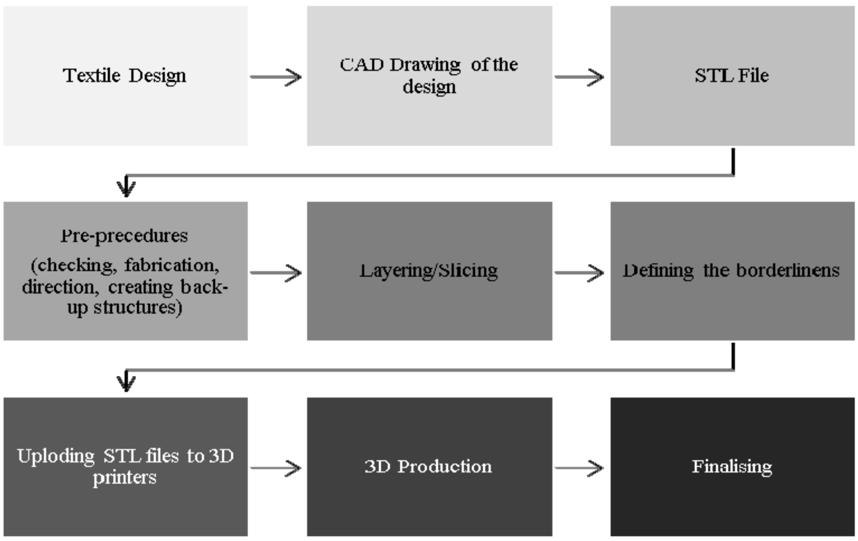

Figure 1. 3D Textile production stages [19].

This research, 3D textiles have been classified from various aspects to clarify the subject (Figure 2). Textiles in literature can be classified in various ways by the structural characteristics of the surface, material, technique, etc. [20,21]. A similar classification is possible within 3D textiles (Figure 3).

Textiles with 3D printers are produced as single-piece or multi-piece (modular). Besides, they can also be used to obtain patterns on conventional textiles or in the brand logo printing process. R&D and Product Development studies related to 3D print textile surfaces continue.

1.2. Related Works

Works on three-dimensional printers in the textile and fashion industry have begun in the 2000s and 234 patent had been obtained in this field by 2014. The next generation of designers, such as the Belgian Materialise firm, the American Nervous System, Iris Van Harpen, Michael Schmidt and American costume designer Ruth E. Carter, who won the Oscar for Best Costume Design in 2019 for her works in Black Panther, are among those using with this technology [22,23,24]. The works that are salient include those projects that relate the tradition of textile construction to code or parametric software to create a 3D printed textile structure. More specifically, the focus is on work that looks at the material behaviour in relationship to that structure rather than focusing on generating the form of the 3D print [25].

In his study, Davis (2012) modelled 3 conventional textile structures with Fused Deposition Modeling (FDM) 3D printers by using Rubber and Acrylonitrile Butadiene Styrene (ABS). He examined the behaviour of 3D textiles from the point of textile unit geometry and material relationship and suggested this as a method that can be used by the textile and fashion designers [25]. Palz, & Thompsen (2009) expand the concept of traditional crafting of textiles by their use of digital modelling and digital 3D printing techniques. In this article Palz and Thompsen explicitly discuss the possible motions that a knit knot unit has as a 3D print [26]. In another study, Melnikova, & colleagues (2014) tried to model the conventional weaving method by using polylactic acid (PLA) and Acrylonitrile Butadiene Styling (ABS) materials through the Selective Laser Sintering method for 3D printers [27]. By the way, Lussenburg and colleagues (2014) indicated that the stretching feature of textiles that are produced with 3D printers can be attained depending on the structure and material (Figure 3).

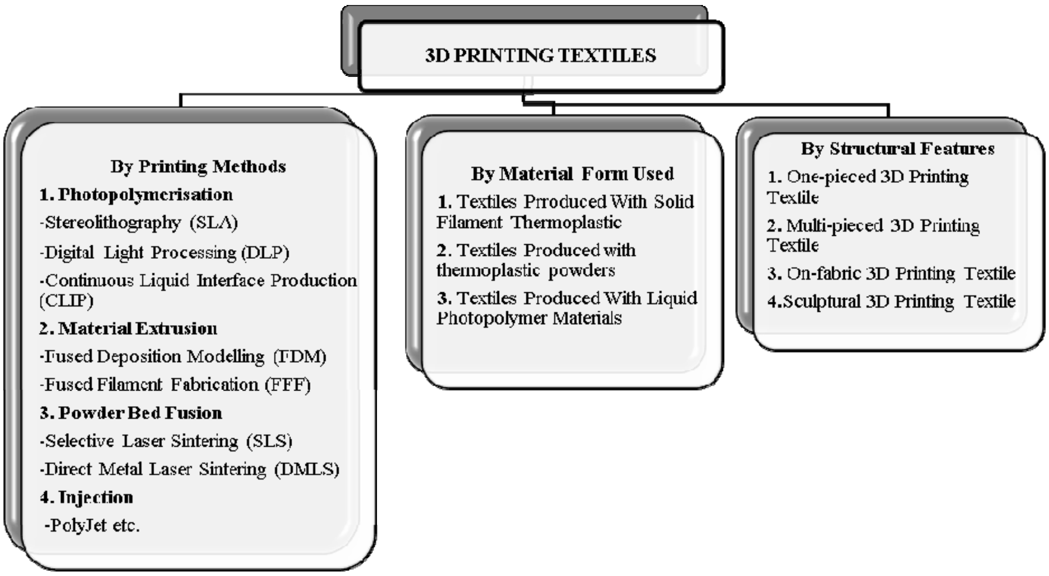

Figure 2. Classification of 3D Textiles [19].

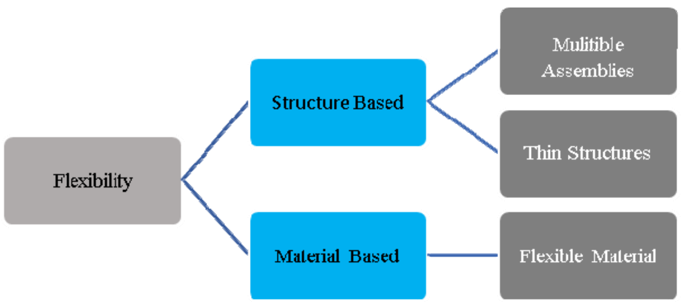

Figure 3. Flexural properties of 3D textiles [28].

Partsch and colleagues (2015) worked to form flexible textile structures with proper tensile, cutting, bending, etc. features by using additive manufacturing (AM) method and they produced three different plain weaving specimens with printers by 3D modelling and evaluate them [29]. Spahiu et al (2016) experienced tailor-made shoe production by using the 3D measurement system with FDM printers and identified the advantages and disadvantages of 3D printing in this field [30]. On the other hand, Safka and colleagues (2016) worked the mechanical testing of polymeric materials (ABSlike, VeroBlack, VeroWhite, VeroClear, Durus) processed using 3D printing and exposed to different chemical compounds [31]. Rivera and colleagues (2017) worked in the printing field on fabric, tried to print conventional textiles by using the 3D method [32].

1.3. Performance Characteristics of Textiles Produced with 3D Printers

Since the beginning of textile crafts, the fabrics with different methods and materials are produced by creating various patterns and connections and these fabrics are analyzed for their performances to determine their compliances with the required standards [33]. Fabric performance is affected by the fibers and thread properties, the structure of the fabric and the treatment of the fabric. The performance of any textile structure highly depends on its resistance to the forces it is exposed to. These forces can include tensile, squeezing, bending, flexural and shearing. Such tests enable us to predict the behaviour of textile materials against resistance.

Several types of research in different disciplines have shown that 3D printers affect product quality and researches are available on examining the effects, such as tensile, twisting and impact resistance [34]. According to these researches, parameters that affect the quality of products produced by printers are filling rate, layer thickness, extruder temperature, printing speed, printing style and material [35]. In 3D textiles, as with each textile structure, the geometry and layout of fibers to each other highly establishes the behaviour of that fabric [25]. However, mechanical properties also depend on the 3D printing procedure's own process and material parameters [8]. The use of these printers in almost all fields of industrial production and differentiation of expectations in each industry makes it difficult to generalize over the outcomes. Therefore, it is important that each industry studies evaluate product quality.

2. MATERIAL AND METHOD

2.1. Material

Two textile surfaces with different structural characteristics in the research were designed in 3D by using Solid Works program.

The Design I; was planned as a one piece and prepared for production in 234.474 x 234.474 x 1 mm by evaluating the preliminary design and prototype productions with the latest arrangements. Figure 4a shows three-dimensional Design I.

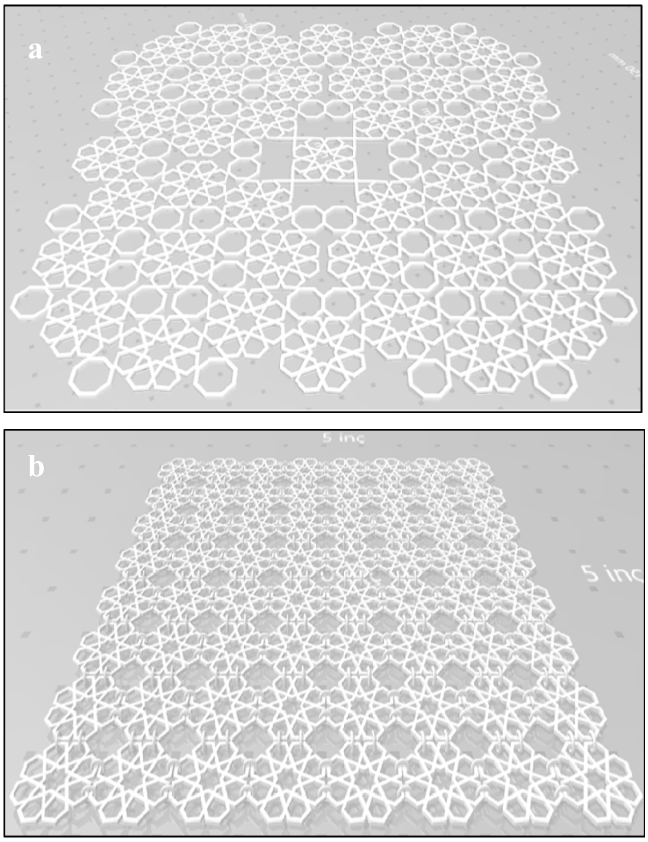

Figure 4 a. Design I STL file view **b**. Design II STL file view

Design II; was planned as a multi-piece, the final design was attained by making arrangements according to the results obtained from the prototype studies. The dimensions of the surface that were formed by connecting the motifs to one another with rings were set as 202.572 x 202.622 x 1 mm. While setting the production dimensions, it is based on the largest production measure that can be done with 3D printers at once. Figure 4b shows three-dimensional Design II.

The Design I and Design II were converted to the Standard Triangle Language (STL) format after the 3D design processes were completed. The designs were prepared for production after setting the boundary lines, layering and pre-processing (process direction, error checking, construction of supporting structures) and both designs were produced by using Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS) and Polyjet printing. Materials may also differ structurally depending on the printing method used in production. In this research, the polylactic acid (PLA) filament material (Figure 8) in Fused Deposition Modeling (FDM) print, the polyamide (PA) powder material (Figure 9) in Selective Laser Sintering (SLS) print and the opaque photopolymer resin (VeroWhite) material in Polyjet print was used (Figure 10).

2.2. Method

The Research model aimed to identify 3D print textiles and performance characteristics and determined three factors that may affect the mechanical performance of 3D textiles. These three factors were used to determine whether there is a relationship between three variables that are thought to affect the performance characteristics of 3D textiles. Hypotheses were also been created to test the authenticity of these recommendations. Accordingly:

H□: "the connection forms of 3D printing textiles affect the performance of textiles"

H□: "the materials used in 3D printing affect the performance of textile surfaces"

H□: "the way of 3D printing machines to stack and combine materials affects the performance of textile surfaces"

Three-dimensional textile surfaces are generated by considering the three-dimensional printing types and the materials used. The research was done in 3 stages: the design, production and execution of performance tests. The textile surfaces that are produced visually and physically with 3D printers compose the population of the research. Sampling consists of 78 3D textiles produced by 3D printing methods with (FDM, SLS, Polyjet) and solid thermoplastic (PLA), powder thermoplastic (PA), solid opaque photopolymer resin (VeroWhite Plus) materials and Stratasy 450 MC, EOS P 396, Staratasy object 500 connex and Zortrax FDM printers.

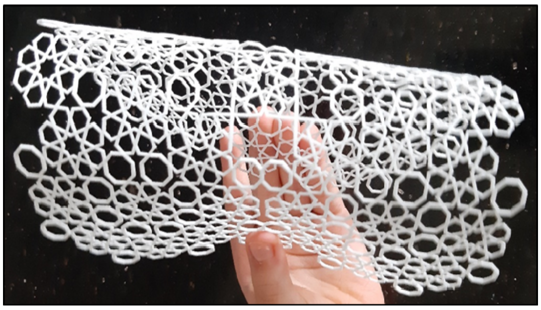

Figure 5 a. Design I, SLS Production

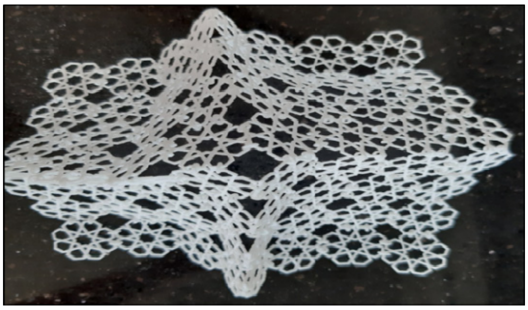

Figure 5 b. Design II, SLS Production

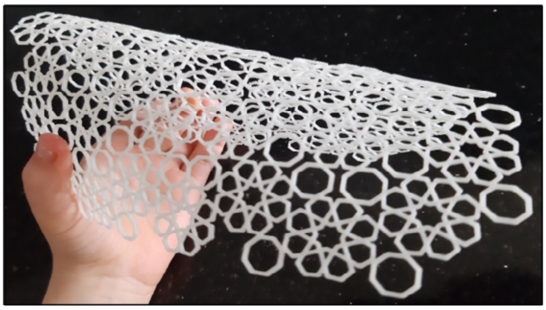

Figure 6 a. Design I, Polyjet Production

Figure 6 b. Design II, Polyjet Production

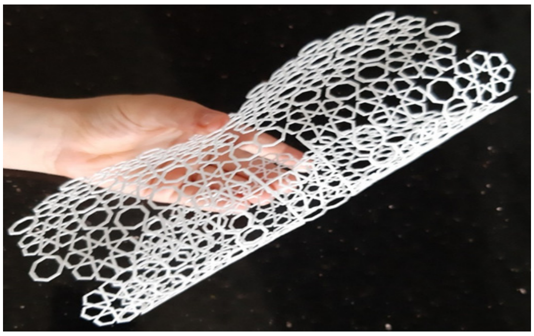

Figure 7 a. Design I, FDM Production

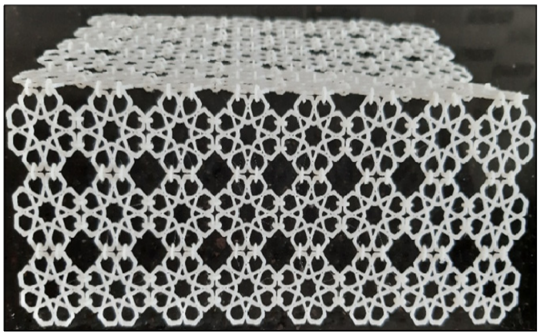

Figure 7 b. Design II, FDM Production

Figure 8. PLA cartridge filament material [36].

Figure 9. PA 2200 powder material [37].

Figure 10. VeroWhite plus resin material [38].

There is no standard test method available for the identification of performance characteristics of 3D textiles. These surfaces are recognized as web-like structures for design and thus, TÜBİTAK[2] BUTAL conducted breaking resistance, bursting strength and weight determination tests. Pre-conditioning and test ambient atmospheric conditions of test samples are set according to ISO 139 (20±2°C, 65±4%).

SDL Testometric M350 measuring device was used to determine the breaking and bursting strength of 3D textiles. 5 samples of 15x15cm average were taken from the samples of each production type of the three designs to be used in tests. The breaking test that was applied in weft and warp direction in standard textiles was done according to the size and width of the sample although 3D textiles do not have these systems. The samples were stretched starting from 20 mm, the breaking force at the time of breakage was stated as Newton, and the elongation of breakage as a percentage.

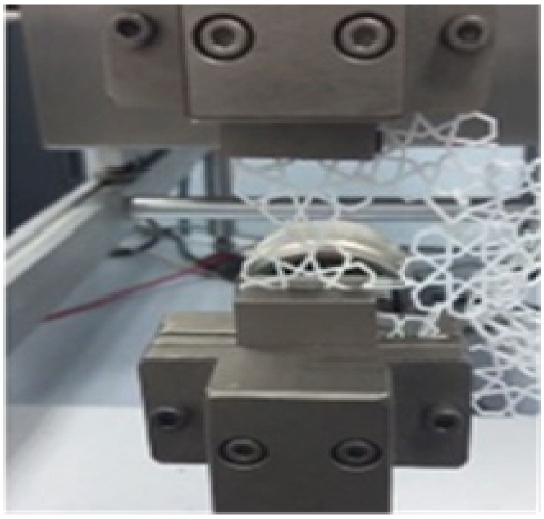

Figure 11. SDL Testometric M350, Breaking Resistance Test

Figure 12. SDL Testometric M350, Bursting Test (Ball)

[2] Scientific and Technological Research Council of Turkey

Breaking Resistance Tests Experiment Conditions

Test device: SDL Testometric M350-5kN, Load cell: 5000N (Constant elongation rate), Distance between claws: 20 mm, Claw speed: 20mm/min., Pre-Voltage: 0.01 N, Claw type: 1-inch claw.

Bursting Test (Ball) Experiment Conditions

Test device: SDL Testometric M350-5kN, Load cell: 5000N (Constant elongation rate), Claw speed: 300mm/ min., Ball diameter: 25mm (sphere-shaped), Ring Claw Inner Diameter: 44.5 mm., Bursting strength pressure values are given as N/mm².

Precision scales were used for weight determination test. 3 samples of 20 x 20cm average were taken from the samples of each production type in maximum sizes, 18 separate samples in total, were measured and their weights were determined. To verify the hypotheses, non-parametric Kruskall Wallis test was used instead of One-Way Anova test, which is a parametric difference test for variables with more than two groups, since the test results did not provide a parametric distribution in the group for which the results were examined. This test is used to compare three or more samples in non-parametric groups. Result of the test showed a significant difference between the groups and the groups that caused the significant difference were tested with Tamhane T2, one of the non-parametric post-hoc tests.

3. RESULTS AND DISCUSSION

The fabric is expected to resist the tests done according to the established standards in the textile industry. It is important that 3D textiles have the flexural and stretching feature that the human body needs, and also resist the tensile during movement. *The Design I* and *Design II* produced with 3D printers were tested for breaking resistance, bursting strength and weight determination and the data from the measurements with the test devices are interpreted as a part of the printing method, material and design.

As depicted in the table, Design 1, which is one-piece, could be produced in the shortest time possible with the SLS method and the lightest product is obtained in this way. The same results apply for multi-piece Design 2. The longest production process in all studies is for Design 2, which is produced with the Polyjet method. The attachment parts used in Design 2 were observed to increase the weight.

3.1. Performance Test Results of 3D Textiles

Breaking, bursting and weight values of Design 1 and Design 2 of FDM, SLS and Polyjet production methods are explained with graphics.

As shown in the graphs, the tensile strength of Design I, produced with the Polyjet method and VeroWhite material, is higher than the others. The Polyjet method is followed by the surfaces produced by the FDM and SLS method, respectively. The breaking force of the surfaces produced by the SLS method is almost half of the Polyjet method. However, the greatest elongation at breaking ratio is seen in the SLS method and the sample produced with PA.

The graphs for Design II shows that the breaking strength of the surface produced with the FDM method and PLA is higher than the others. This method is followed by SLS and Polyjet productions, respectively. The strength of the surface produced by the polyjet method is much less than those produced by the other two methods. Examination of the elongation at breaking indicates that the performance of the surface produced by the SLS method was higher than the others. This method is followed by surfaces produced by Polyjet and FDM method, respectively.

Tensile strength is one of the most important mechanical features for fabrics. Tensile strength is the ability of a material to withstand tensile force [39]. Among these parameters, the filling rate, material type and design properties were identified as the most important factors for the experiment in this article. The different connection properties of Design I and Design II have significantly affected their breaking strength. In breaking tests, while the seams of Design II were immediately broken, Design I has exerted relatively greater strength. The differences in production methods and materials are also important, but the fact that the breaking is always at the same points, that is, in rings that combine motifs, has drawn more attention to the structural and design characteristics of the surfaces. The fact that the Design I is in one piece has relatively brought out positive effects on breaking resistance. Tensile strength of designs produced with 3D printers was found to be lower than conventional textiles. Generally, the designs with a 100% filling rate, designs acted fragilely during tests. Strenght lack of designs attributed to the rigid structure and thinness parameters of the materials used.

Table 1. Design and production details of 3D textiles

Design Code	Production method	Raw material	Material type	Production dimensions	Production time	Weight
Design I	FDM	PLA	Solid thermoplastic	234.5 x 234.5 x 1 mm	27 h 50 min	11.25 g
Design I	SLS	PA	Powder thermoplastic	234.5 x 234.5 x 1 mm	4 h	7.14 g
Design I	Poly-Jet	Opaque photopolymer resin (VeroWhite)	Liquid photopolymer	234.5 x 234.5 x 1 mm	4 h 40 min	13.71 g
Design II	FDM	PLA	Solid thermoplastic	202.6x 202.6 x 1 mm.	32 h 30 min	17.1 g
Design II	SLS	PA	Powder thermoplastic	202.6 x 202.6 x 1 mm	4 h	8.13 g
Design II	Poly-Jet	Opaque photopolymer resin (VeroWhite)	Liquid photopolymer	202.6 x 202.6 x 1 mm	10 h	16.25 g

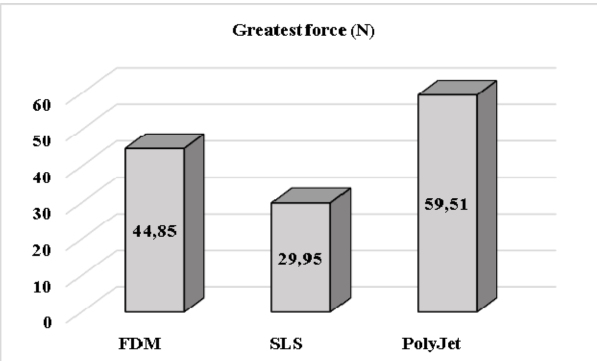

Figure 13. *Design I*, breaking strength, the greatest force

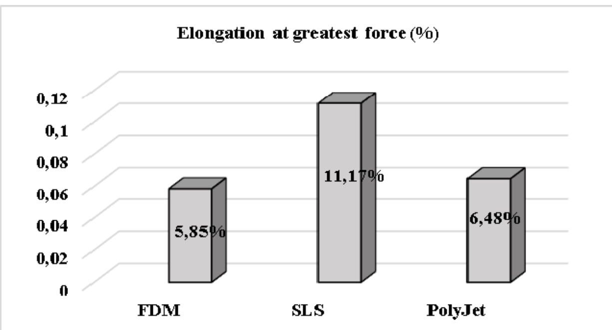

Figure 14. *Design I*, breaking strength, elongation at the greatest force

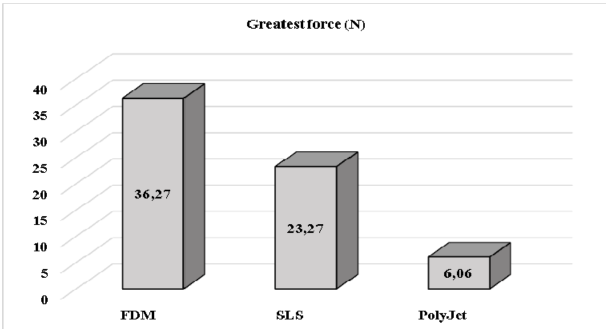

Figure 15 *Design II*, breaking strength, the greatest force

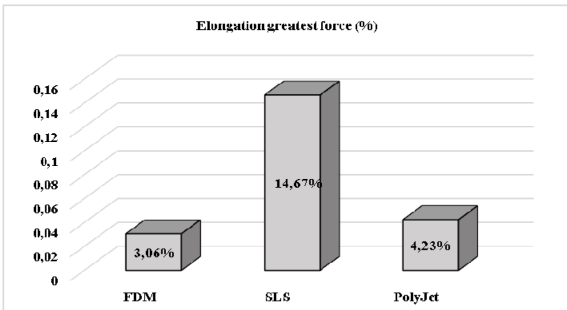

Figure 16. *Design II*, breaking strength, elongation at the greatest force

Design I and Design II were produced with FDM, SLS, Polyjet production methods using suitable materials. The charts below show the bursting strength measurement results of the samples and their mean values. The results of the burst strength pressure values are given as N/mm².

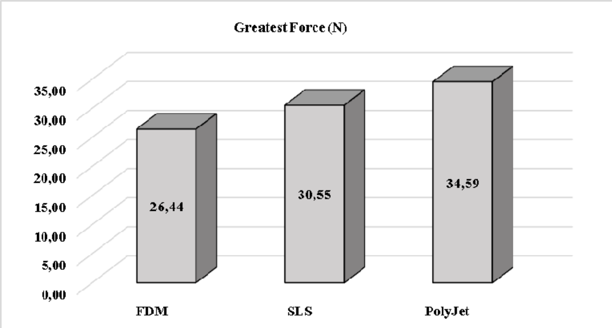

Figure 17. *Design I*, bursting strength, the greatest force

The charts shown in Figure 17 and 18 demonstrates that the surface structure and the material used have an effect on the burst strength pressure values. According to these results, the bursting strength is highest in Design I produced using the Polyjet method. This was followed by surfaces produced by SLS and FDM method, respectively. Although slight differences due to the material were observed for the design with the same tightness setting, these surfaces are considered to be weak in terms of burst strength.

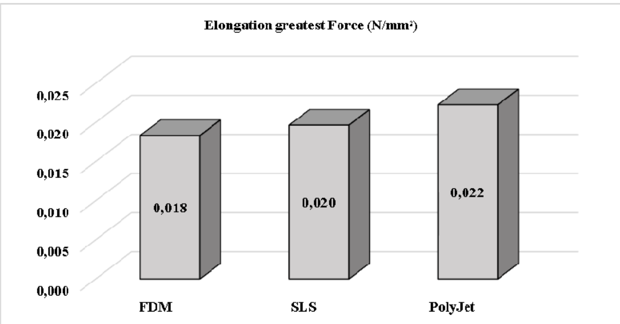

Figure 18. *Design I*, bursting strength, elongation at the greatest force

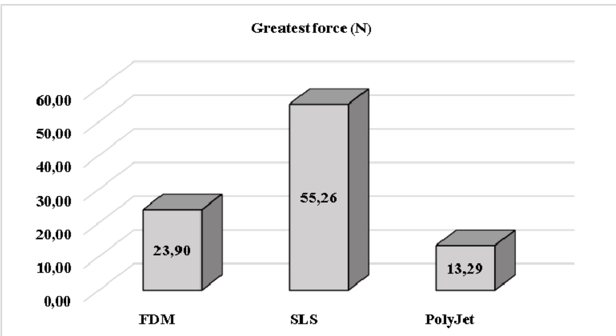

Figure 19. *Design II*, bursting strength, the greatest force

Evaluation of the Design II in terms of bursting strength showed that the strength value of the surface produced by the SLS method is higher than the others. The strength of the surfaces produced by the FDM and Polyjet method was observed to be lower.

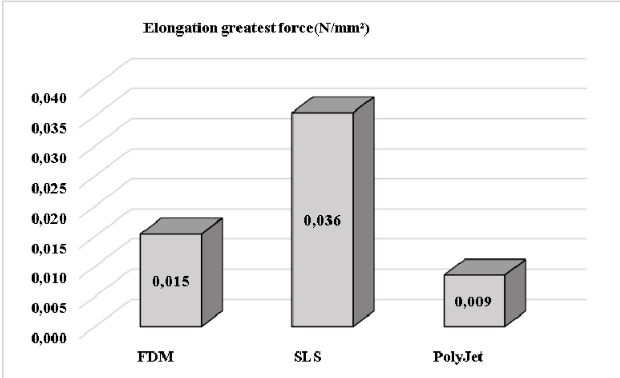

Figure 20. *Design II*, bursting strength, elongation at the greaatest force

The materials used in the production of Design I and Design II have been subjected to various tests by their manufacturers and the performance of these materials has been evaluated as high. However, the performance values of the textile surfaces produced for this study are quite low. It was considered that this situation is caused by the design and the structural properties of the design substantially affect the performance properties of 3D textiles.

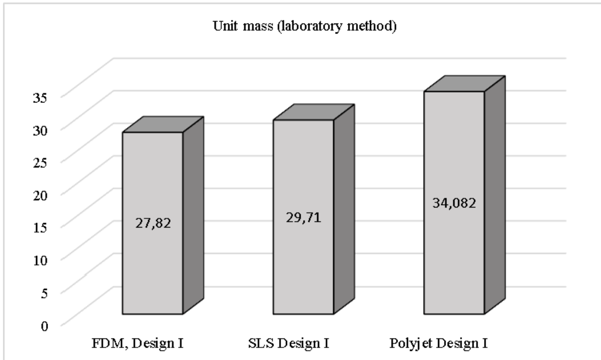

Figure 11. *Design I*, test results of weight determination

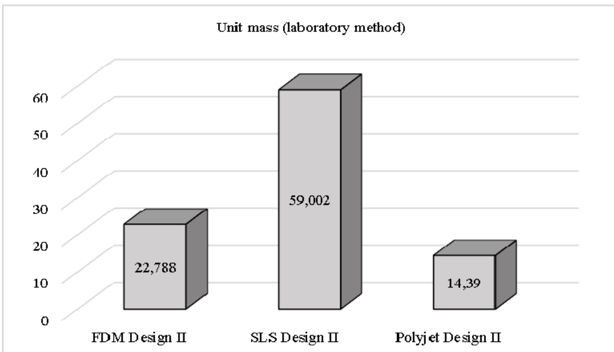

Figure 12. *Design II*, test results of weight determination

According to the weight test results applied to Design I, the lowest weight textile surface was produced with FDM method and PLA material. This was followed by SLS production and Polyjet production, respectively. In the weight tests of Design II, the lowest weighted textile was produced with the Polyjet method and VeroWhite. This 3D textile surface was followed by the textile surfaces produced by the PolyJet method and the FDM method, respectively (Figure 22).

The weight test results of 3D textiles advise the surfaces from their area of use to performance characteristics. Weight tests are important for the area of use of textile surfaces. According to standards established in conventional textiles (TSE 251, EN ISO 3801, ASTM D 3776, BS EN 12127, BS 2471); the weights are expected to be as 30 g/m2 for gauze patches, 80-120 g/m^2 for combed cotton fabric, 200-250 g/m^2 for dress fabrics and around 400 g/m^2 for coated fabric. Based on the weight determination test results of 3D textiles that are produced with different methods and materials, these textiles were found to be heavier than conventional textiles.

3.2. Comparison Analysis

In this study, comparison tests were also needed to test the hypotheses and the fracture, burst and weight values of designs 1 and 2 of FDM, SLS and Polyjet production methods were compared. Breaking, bursting and weight variables have not been distributed normally in a group. The in-group values of kurtosis and skewness of variables should be between -1.5 and +1.5 [40]. As can be seen from Table 1, there is no normal distribution by kurtosis and skewness values.

As the normal distribution in the group was not provided, the nonparametric Kruskall Wallis test was used instead of the One-Way Anova test, which is a parametric difference test for variables with more than two groups. In variables where test results are significant ($p < 0.05$) from which groups the difference originates was tested with Tamhane T2, which is one of the nonparametric post-hoc tests. The results are as in Table 3 below.

Table 2. Kurtosis and Skewness Values

Test		FDM Design I	FDM Design II	SLS Design I	SLS Design II	POLYJET Design I	POLYJET Design II
Breaking Strength	Kurtosis	-1.534	0.241	-0.609	-1.280	1.643	0.62
	Skewness	2.682	0.123	-3.077	0.895	3.018	-1.81
Bursting Strength	Kurtosis	0.486	-0.386	1.763	-0.632	1.806	-0.15
	Skewness	-3.112	-2.908	3.336	-3.048	3.719	-1.89
Weight Determination	Kurtosis	0.609	2.135	0.299	-1.736	-0.503	-1.84
	Skewness	-3.333	4.635	-2.718	3.251	-3.146	3.61

Table 3. Comparison of Test Results

Test	Method	Design	M	SD	Z	P
Tensile Strength Test Result (N)	FDM	Design I	43.05 N	5.90	25.71	0.000
	SLS	Design I	29.95 N	5.90		
	Poly-Jet	Design I	59.11 N	15.63		
	FDM	Design II	36.27 N	4.32		
	SLS	Design II	23.27 N	2.43		
	Poly-Jet	Design II	6.06 N	2.45		
Bursting Strength Test Result (N)	FDM	Design I	27.82 N	5.12	21.98	0.000
	SLS	Design I	29.71 N	4.63		
	Poly-Jet	Design I	34.08 N	10.27		
	FDM	Design II	22.79 N	4.16		
	SLS	Design II	59.00 N	19.18		
	Poly-Jet	Design II	14.39 N	4.43		
Weight Determination Test Result (g)	FDM	Design I	11.25 g	0.04	28.31	0.000
	SLS	Design I	7.14 g	0.032		
	Poly-Jet	Design I	13.708 g	0.14		
	FDM	Design II	17.06 g	0.29		
	SLS	Design II	8.128	0.016		
	Poly-Jet	Design II	16.254	0.04		

When Table 1, Table 2 and Table 3 are examined, the breaking, bursting and weight values of the measurements in different methods and designs are seen to differentiate significantly ($p<0.05$). The group in which this differentiation occurs was tested by Tamhane's T2.

The significant difference in breaking test is among the Polyjet method Design II and all other designs and the SLS method Design II and the FDM method Design I and Design II. While the Polyjet method Design II has a lower mean breaking test than all other designs, the SLS method Design II have a lower mean of breaking test than FDM method Design I and Design II. There is no significant difference between other methods and designs for bursting test.

The significant difference in bursting test is between Design II of Polyjet method and Design I of FDM and SLS method. Design II of Polyjet method has a lower bursting test average compared to these two designs. There is no significant difference between other methods and designs for bursting test.

The significant difference in weight testing is between all designs. While SLS method Design I has the lowest weight value, it was respectively ranged as SLS method Design II, FDM method Design I, Polyjet method Design I, Polyjet method Design II and FDM method Design II.

The textiles produced with 3D printers are evaluated as a result of their performance tests in terms of application areas. The Design I and Design II was found to be ineligible for the production of a complete garment. The material must be flexible so that the textiles to be transformed into an adaptable garment to body movements. However, the flexibility in conventional textiles was not attained currently with materials that are used in 3D printers and failed to resist the stretching caused by body movements. Multi-piece designs were also determined to perform poorly in terms of strength requirement, although they provide a certain degree of freedom of movement and drape. Therefore, the use of these textiles as accessories in part of garments produced with conventional textiles can be the best way to be recommended to the designers in the short run. Besides, better performance characteristics of single-piece textile with 3D printers are considered to be used in shoe production, provided that the thinness parameters of this technology are not kept low. The research that was done by Spahiu and his colleagues in the shoe production with 3D printers in 2016 and the fact that Nike Company has focused its innovation efforts on the production of runner shoes with 3D printers since 2016 reinforce our thought.

4. CONCLUSION

This article provides designers with a roadmap for 3D design and 3D print textile production; creates a comprehensive framework to evaluate the relationship between design, 3D printing, material and performance. 3D printed textiles have shown low resistance in the performance tests. Despite the successful performance of the materials used in printing in strength tests, *Design I* and *Design II* failed to resist the force they were exposed to and broken and torn in low force. When a one-piece design to be produced by 3D printing is printed by using hard materials, it will be difficult to use and won't be drapable like conventional textile surfaces. From this aspect, better results can get from designs in this structure by using soft and flexible material. Lack of flexibility in commonly used materials, inability to attain the appropriate fiber thinness in 3D printing for textile are disadvantages for the designers. Also, the speed is of the utmost importance in textile production, however, 3D printing is incomparably slow than the conventional technologies. But from a design point of view, allowing the production forms that cannot be attained through conventional production methods, introducing new initiatives to designers, consumers, and thus the textile industry are considered as the advantage of this technology.

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