PRINTED MATERIAL AND FABRIC

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ABSTRACT

As wearables get more complex and closer to the skin, so do the requirements for the packaging and the placement of the electrical components. The advent of 3D-printers and flexible printing materials provide means of building fabric-like structures. We tested a flexible material without moving micro- or meso-structures, as the material itself would be fabric-like. Tests were conducted according to SFS-EN ISO 13934-1, suggesting directions for using printable materials. In the end, we created a corselet and a corset, along with a connector suited for attaching various materials together.

INTRODUCTION

Wearables have been developing over time, more rapidly in the last few years. There have been developments in usability and feel, starting from the study in the wearability as conducted by Gemperle et al. (1998), which basically showed that it is important to understand the characteristics of the body, in order to have a usable container. The forms and contours of the proposed casings are possible to build with CNC and vacu-forming, but also with the rapid manufacturing methods. Even though these casings were intended to be wearable, the focus was not on the textile itself.

The advent of rapid manufacturing methods gave new possibilities to the development and the concept of textile itself. The key interest areas for using rapid manufactured textiles are seen as “high-performance textile market and the smart of intelligent textile market”, as explained by G. A. Bingham et al (2007). The paper also suggested that such structures could be designed to house the electric components.

Form giving using 3D-printers has already found a way to fashion industry, as originally used by Freedom of Creation, and more recently Iris van Herpen, to name a few. There are even printed bikinis already the on sale by Continuum, getting even closer to the skin. These approaches are based on rigid micro- or meso-structures, where the textile-like behaviour is achieved by using chain-mail like structures, or otherwise flexible movement created with rigid components achieved with SLS rapid manufacturing. On the other hand, Bickel et al. (2010) have used 3D-printed materials to create controlled deformation behaviour in a shoe.

As mentioned earlier, there has been a strong indication of the electronics to be very much closer to the surface, I.e. Skin or clothing fabric of the user. There are for example button casings by Hännikäinen et al. (2005), which are attached loosely on the surface, sewable constructs by Buechley (2008) and flexible circuits for having them directly at the surface as demonstrated by Linz (2008), and even wearable systems that withstand water and can be washed have been presented by Iso-Ketola et al.(2005). The ways of integrating functional circuitry to a garment vary from being housed in a clearly external casing, to sewing it as a part of the fabric.

It would seem that there is room for a lot of interesting combinations of 3D-printing and fabrics, and for that end, naturally flexible materials and some practical examples that are easy to adapt should be explored. By having a 3D-printed material as a relatively equal substitute to a fabric, the possibilities for prototyping and development might be increased. This might allow the design of the electrically functional parts to be more intimately integrated to the design of the garment, thus removing the artificial feeling of the material. It would also have the added benefit of enabling the use of traditional garment design methods, where the pattern and clothes designer can use the same skills as with fabric.

Having a goal of standardised approach on wearable development, the very first steps that are needed, is to understand the material properties and the behaviour of the printable material. For this end, we propose that the materials should be evaluated as they would be fabrics, and built with as such.

ON MATERIALS AND PRODUCTION

Even as the 3D-printer, or rapid manufacturing machine is a device capable of constructing three dimensional objects, even hollow or arbitrary ones, we chose to start with flat, thin pieces resembling fabric. There are different ways of operation for the 3D-printers, but with the inkjet-based printing one can create naturally soft and flexible materials. This means, that the produced material is similar to soft rubber, if it would be printed out as a homogenous block.

Objet Connex 350 3D-printer was used to print out different test samples, as it has possibility for a variety of material qualities. The maximal printing volume is roughly a cube of 35cm x 35cm x 20 cm. The printer can print one or two materials, along with support material at the same time. There is a possibility to use digital materials, which are a mixture of two materials, a hard nylon-like called VeroWhite+ and a soft rubber-like, called TangoBlack+. The material mixtures vary by having different Shore values, flexibility, and a colour as a byproduct. The material that was chosen for the test was the TangoBlack+, which is the most flexible material, and therefore seen as the most similar to fabric in general. As it is also used in a variety of material mixtures, it provides a good base for future comparisons.

The surface quality of the material being printed can be selected as glossy or matt. With a glossy surface, the printed object appears to be much stronger than similar object with a matt surface, as verified with manual testing and discussing with the printer manufacturer. One distinct characteristic of the glossy finish is the selectiveness: only the top surface of the object being printed is glossy. It is not uniform on all sides and therefore not suitable for the tests. There were no other limitations for the usage of the glossy finish that we could see, but chose to use matt for its uniform result.

The chemical properties are also very important, but were seen as less relevant as a starting point. Materials are intended for hand held prototypes anyway, and thus can have brief skin contact. On the other hand, the surface area of the hand is very small compared to the body and garments are worn for longer periods of time, and therefore caution should be taken when using something with a large surface area. There is also a material that is suitable for medical use, but is impractical for the purposes of the test, as it is rigid and impractically hard if printed as solid blocks. Since the flexible material can be covered with actual fabric if needed, the chemical properties were not seen as inhibiting factor.

Figure 1. Preliminary samples

The material is printed with inkjet printheads, and cured with UV radiation. This creates distinct patterns which, by visual inspection, would appear to have an effect on the properties of the object. As the moving inkjet heads deposits the material, stripes and layers parallel to the direction of movement of the print heads are formed. The layered structure forms the overall object, and suggests directional differences in durability. In order to get an estimate before printing, a set of preliminary samples were printed. There were some differences that are visible at the surface, as seen in the Figure 1, when the light reflects from the surface. The samples were printed as having a matt surface, and thus were covered with support material from all sides during print. The size of the samples was roughly 10cm x 10cm x 3mm patches, with a variable pattern of parallel holes.

The preliminary samples were visibly different in outlook. Depending on the print direction, the outside surface appeared either smooth or fuzzy and the printing direction was clearly visible in some samples. Judging from the samples, it appeared that there was a considerable difference in the output quality of the different printing directions.

Since the samples were varied in quality, it was decided that all possible configurations should be tested in order to find out what kind of differences there were in the physical durability, feel and outlook.

TESTING TENSILE STRENGTH

As textiles in clothing are prone to forces when the wearer moves, it was decided that the pieces should be tested according to standardised methods. We also chose to test the material with textile methods to see how well it behaves "as a textile". As such, we chose to use standardised methods to determine the elongation and the breakage force of the materials under inspection. It was seen important to have a reproducible and unambiguous measurement method, and as such could provide additional insight by suggesting requirements for the durability of built-in electronics.

ABOUT THE TEST

In order to determine the breakage force and elongation before breakage, the SFS-EN ISO 13934-1 was used. While it is not recommended to be used for anything else than somewhat non-elastic materials, there are no explicit restrictions for that. Since we wanted to test the material as a fabric, the method was accepted as a good starting point, especially since there was no prior work to be found.

The standard consists of stretching the fabric sample, until it rips apart or otherwise breaks. During the stretching and breaking, the forces pulling the sample apart are measured. The samples are attached with one sample-wide-clamp at each end, which hold it in place by squeeze on both ends. The tests are repeated with at least six similarly prepared samples, first of which will be used for calibrating and setting the system.

According to the standard, the fabric should be tested separately by stretching it from two directions: parallel and orthogonal to the yarns it has been constructed with. Since there are no yarn directions in printed materials, we decided to create the artificial holes and to test all possible combinations. We counted six directions of printing, and decided to have the artificial holes as parallel and as orthogonal. Before testing, all samples are held in constant conditions for 24h.

For the test, measured distance was set to 100mm, stretching speed to 100mm/min and the initial load to 0N. The tests were conducted at Tampere Polytechnic textile laboratory, using Zweigle-machinery. The test setup, with a sample under test, is shown in figure 2.

MATERIAL PREPARATION

Although we wanted to test all possible printing directions, the dimensions of the machine restricted some. As the standard requires at least 20cm long samples, the printer was unable to print samples when it would be built straight upwards. Otherwise there weren't any issues, and samples were built using matt surface for uniform surface quality. The material samples were 3mm thick, 20cm long and 5 cm wide, with a square weight of 223g/m^2. The thickness should also accommodate placement of simple sensors, thin circuits and flexible circuit boards, for future work.

There were three different separate patterns: with parallel holes, orthogonal holes and a plain, solid piece. The dimensions of the holes were the same in all samples: 12.5mm long and 2mm wide, rounded rectangles. The holes were placed in a symmetrically tiled pattern. Since all patterns were tested in all possible print directions, there were four layers for the printing directions, with three patterns for each layer.

Figure 2. Sample under test

Each pattern was printed 5+1 times, as required by the standard. One sample was used to calibrate the system for each individual pattern-layer combination, and five samples were tested to get a variety of results. Total of 72 samples were printed for tests. The layers were labeled A, B, C and D. “A” is the most used and the default placement in the software, flat on the surface and parallel to the movement of the printhead. “B” is otherwise the same, but orthogonal to the printhead movement. “C” is standing one side with the wide side up, again parallel to the printhead movement. Finally, “D” is similar to “C”, but orthogonal regarding the movement. The ends of a set of samples are shown in

Figures 3. to 5., where the plain samples, orthogonal and parallel are shown, respectively.

Figure 3. Outcome of four different print directions on plain pieces

Figure 4. Outcome of four different print directions on orthogonally patterned pieces

Figure 5. Outcome of four different print directions on parallel patterned pieces

The differences in the print direction are most visible in the orthogonally striped samples. The “C” and “D” directions are considerably fuzzier than the “A” and “B”. The surfaces of the “C” and “D” samples are also much softer to touch, almost suede-like. The others feel like soft, non-polished rubber, without any remarkable characteristics.

RESULTS FROM THE TEST

In general, the samples with orthogonal holes were the weakest, with breakage values around 9.4 Newtons. The samples with the parallel holes had over four times the strength, breaking on average at 42 N. The strongest samples were the plain ones, with an average withstanding a force of 60 N. The strength results are summarized in table 1, and elongation in table 2.

Table 1. Strength of the samples

A	**Orthogonal**	**Parallel**	**Plain**
Avg[N]	9,3 ± 0,2	41,8 ± 1,2	65,7 ± 7,3
%	2,1	2,9	11,1
B			
Avg[N]	9,1 ± 0,3	38,5 ± 1,4	65,7 ± 5,0
%	3,8	3,7	7,6
C			
Avg[N]	9,5 ± 0,4	42,3 ± 1,5	54,9 ± 4,7
%	4,6	3,6	8,6
D			
Avg[N]	9,5 ± 0,3	44,2 ± 2,6	53,3 ± 10,3
%	3,0	5,8	19,3

The plain test samples were the most durable. Layers “A” and “B” were somewhat more durable, with values of 65.7 N, than the “C” and “D”, with values between 53.3 N to 54.9 N. The layer “B” had the most even distribution with 7.6% variability, and the “D” layer had the most varied, with 19.3%. The elongation of the samples were greater with “A” and “B”, between 124.3 - 124.7 mm, than “C” and “D”, between 103.0 - 105.1 mm.

The parallel test samples, regardless of the printing direction, were very similar in breakage force. They vary between 38.5 - 44.2N, with “B” having the weakest value, and the “D” with the strongest. The variation of the results was smallest with “A” at 2.9%, and the greatest with “D”, at 5.8%. The elongation of the samples varies from 108.4mm with “B” to 126.9 mm with “C”. Most varied is the “D” with the variability of 6.2%, and most constant with “A”, with a variability of 2.6%.

Table 2. Elongation of the samples

A	Orthogonal	Parallel	Plain
Avg[mm]	186,5 ± 3,5	117,4 ± 3,0	124,7 ± 15,9
%	1,9	2,6	12,7
B			
Avg[mm]	181,6 ± 4,0	108,4 ± 4,7	124,3 ± 13,1
%	2,2	4,4	10,5
C			
Avg[mm]	184,0 ± 3,9	126,9 ± 4,9	105,1 ± 11,7
%	2,1	3,9	11,2
D			
Avg[mm]	172,8 ± 6,8	121,8 ± 7,6	103,0 ± 24,7
%	3,9	6,2	24,0

The orthogonal test samples were also very similar on different printing directions, with the values ranging from 9.1 N to 9.5 N. The results were most varied with samples from direction "C", with 4.6%, but least varied with "A", at 2.1%. The "A" had also the greatest elongation before break, at 186.5mm. The smallest was with "D", at 172.8mm. Least variability was at direction "A", at 1.9% and the most with "D" at 3.9%.

The graph plotted during the test displays the elongation as a function of force. All three similar sample sets with different print directions exhibit similar characteristics, although there were minor differences. Graph of the test for direction "A" with parallel holes was shown in Figure 6, plain ones in Figure 7, and the orthogonal holes in Figure 8. It should be noted, that the parallel and plain samples exhibit abrupt behavior for breakage, but with the orthogonal one the breakage event takes a longer. While comparing the graphs to the numerical values, it can be verified that the orthogonal holes were most consistent in behavior.

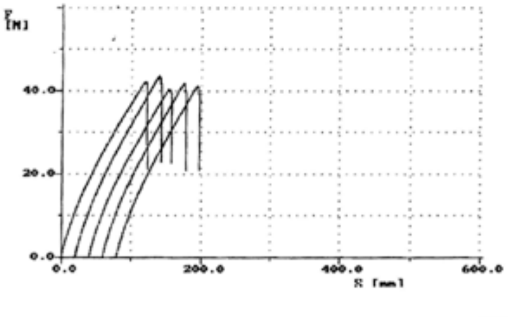

Figure 6. "A" set with parallel holes.

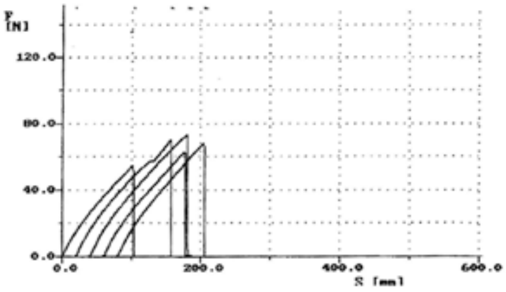

Figure 7. Plain "A" samples

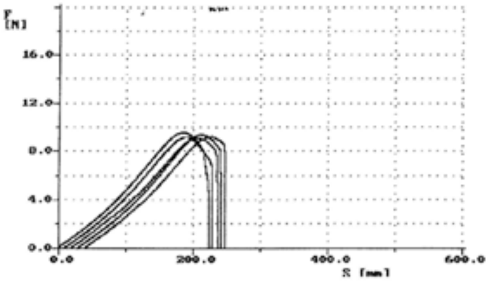

Figure 8. "A" samples with orthogonal holes

By visual inspection, with orthogonal samples, printing direction "A" had three of the samples broken from more than one line of holes, with very neat breaks. Only one of them had a rip elsewhere other than the breaking point. In general "B" was cut in the most controlled fashion, with just one or two lines of holes broken and only one that had a small rip not in the locality of the breakage point. The breakpoints however, exhibited small dents at the points of breaking. Level "C" had only two one line breaks, and the breakage points resembled small dents. With "D", the rips were very random, and the breaking points were large dents. Typical breakage can be seen at figure 9.

The parallel samples were cut almost always either diagonally or in V shape, as shown in figure 10. There were few instances were the sample was cut at the very end, against the clamp, producing a straight line. The visual outlook between different printing directions with parallel samples was minimal.

Finally, in Figure 11, there can be seen a very typical breakage point of a plain sample. These were very uniform with the visual inspection, although there were a few samples that had been cut against the clamp. Similar to parallel ones, there weren't any major differences in the breakage between the directions.

Figure 9. Typical orthogonal breakage

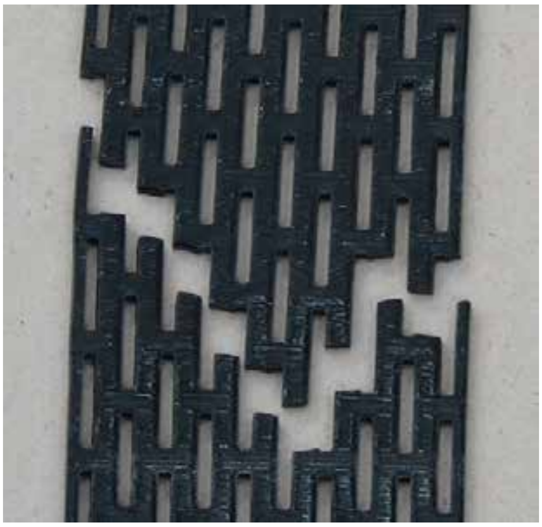

Figure 10. Typical parallel sample breakage

Figure 11. Typical plain sample breakage

ANALYSIS

According to the data we collected, the sample set "A", printed with sample direction parallel to the print-head movement, was the most uniform regarding the strength and the elongation, and should be used when designing garments.

Introduction of the holes to the material created consistency in the behavior due to more uniform elongation, but weakened it noticeably. With parallel holes, the material was similar in durability to plain samples, when stretched at the direction of the samples. By sacrificing a small amount in breakage force for pattern, uniform behavior and material breathability could be achieved. If there would be a need for controlled expansion, or to set a limit for the durability, then a pattern could be designed specifically for that. Furthermore, materials with directional holes seem to have their macro-level behavior similar to knitted fabrics, being that they stretch considerably more to one direction, and much less to another.

The plain samples were the most durable, but lacked in flexibility. In this form, the material behaves a bit like woven textile, with very little elongation to any direction. Another problem was the solid surface, which does not allow any air exchange. The samples might be made thinner by using glossy finish, if the same durability would be needed.

Figure 12. 3D-printed connector as a functional part of a garment

MAKING GARMENTS AND ACCESSORY

In order to test the suitability of the printed material in full garment creation, corsets and corselets [13] were designed using traditional pattern drawing methods. As they were seen as the most difficult to get correctly close to skin and fit, they were chosen as a reference. To experiment with the usage of the material with textiles, we designed a 3D-printable connector and started by creating a soft fabric corselet, as shown in Figure 12.

As seen, the connector was initially attached by sewing it directly to the fabric with a direct stitch. Due to the softness, the material in the 3D-printed connector tends to rip from the ends, where the sewing edges are. To overcome this, we partially re-designed the connector for attaching different textiles together. In order to have more uniform approach, we decided to have the locking mechanism as generic and common to all uses, and the rest of the connector specific for different uses. For the fully printed garment, connectors would be integrated to the materials, as it allows seamless connectivity.

Since manual sewing tends to be time-consuming, a button-like version was made. While possible to be sewn by hand, it was intended to be attached with the button stitching machines. The button-stitchable connector was created by having a normal button as a starting point, to have as little changes to the existing methods as possible. Decorative function was seen as secondary, as this was the first time creating such objects. Utilising a cardboard mock-up and the 3D-printed connector mechanism, the final connector was developed. All parts involved in the process are shown in Figure 13, along with the printed connector. As intended for the automatic stitching machine, the connector being stitched to a fabric can be seen in Figure 14. The connector was also utilized as a part of a smaller accessory, and was used in a bracelet, an underside of which is shown in figure 15.

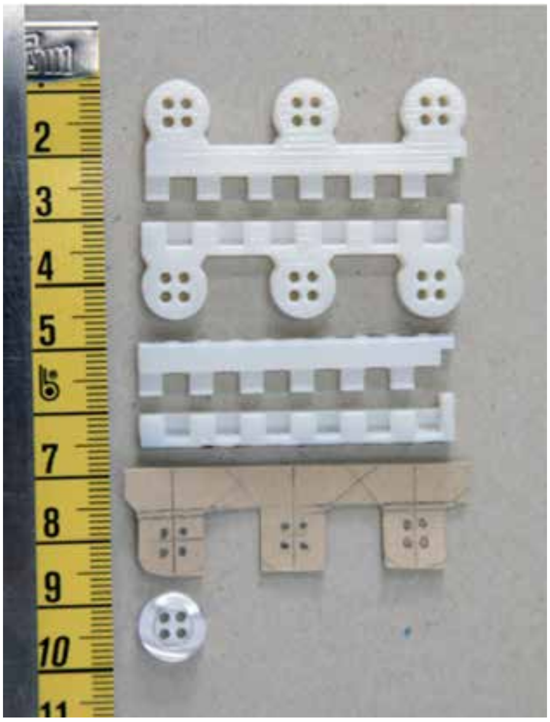

Figure 13. Connector development

Figure 14. Attaching the connector with a machine

Figure 15: Bracelet with fabric and printed connector

In order to see the suitability for full 3D-printed corset, we started by creating the patterns by hand. The individual pattern pieces were then taken to Rhino in a digital form. The biggest problem was the adjustment seam, but it was decided that it would be compensated directly with the placement of the connectors. The corset pieces were filled with the same pattern as the orthogonal samples, and as per our test findings, would allow for small amounts of movement and deformation without breaking.

As corsets normally have bones that give the garment its distinctive shape, we chose to utilize and interpret it as means to attach the pieces together. We used the connector seamlessly integrated to the material for attaching the pieces. Although bones usually are within the length of the corset, we decided to split them to smaller pieces to overcome problems of the curves in the body and to allow the flexibility to be utilized, and to see how the material seams behave. The constructed full corset can be seen in Figure 16. The material in the body was flexible even in the meso- and micro-level, although the connectors were made from hard, non-flexible materials.

While the fully printed corset was a good fit towards the mannequin body, it was quite heavy. This eventually caused the some breakages while assembling. Surprisingly, the material appeared to behave in brittle manner if bent too much, something that could not be seen in the standardized test we chose to use. The corset on the other hand, does stretch and move slightly, following the findings from the test. If the material was kept close to the 3D-printed shape, it kept the stretchy property without being brittle. This should be noted more while designing garments, and can be avoided by changing the surface quality to glossy, as it strengthens the material. Finally, using the connector and the button structure, 3D-printed parts can be attached to textile parts interchangeably, as can also different materials be used for the printing. One such example can be seen on Figure 17, where a transparent soft material corset piece has been connected to a textile piece.

Figure 16. The full corset printed with flexible materials

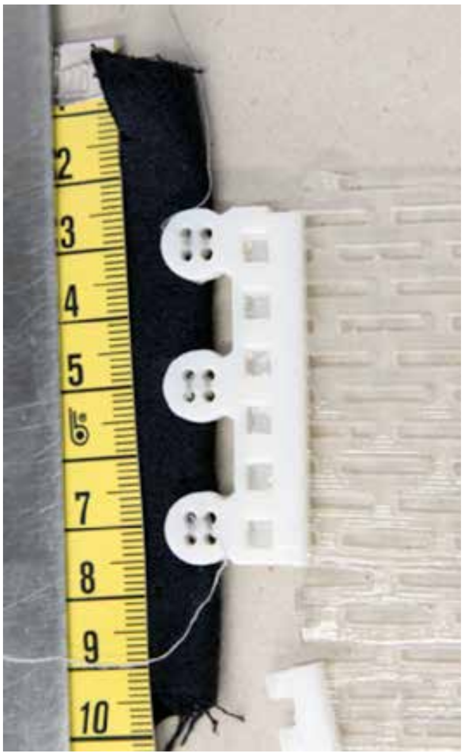

Figure 17. Textile and 3D-printed piece

DISCUSSION

The 3D-printed flexible materials can be seen as usable, fabric-like material, even without complex micro- or meso-structures creating the feeling of flexibility. It might be made thinner by using the glossy finish, and suggests a direction for future work. Due to the fundamental nature of this work, we chose to test the material as homogenously as possible. The standard we used gave us directions for evaluating flexible 3D-printed materials, and in overall the process seems to give new possibilities for getting closer to the skin, by allowing it to be seen as a fabric.

To demonstrate the applicability, a functional garment was printed and built, using a combination of flexible materials and rigid connectors.

Further work is needed to probe the possibilities and methods for connecting the material to the fabric, and evaluate how it alters the durability, behavior and feel of the overall construct. There are also a lot of interesting possibilities in taking the aesthetic qualities into the design: 3D-printed shapes are not constrained to any specific shape, other than for functional requirements.

Wearable electronics should be further explored, embedding them to the materials, and as the material behaves like a fabric, we have the benefit of co-creating with traditional pattern creation methods.

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