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Glowing felt textile [Invited]

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Abstract: We demonstrate a new technology–a combination of side glowing (or side emitting) plastic optical fibers with seamless felting technology–that addresses the challenges of smart textiles related to cutting and stitching together with the ability to be washed. The technology was explored for the development of a collection of dresses called "Deep Sea Life" that exhibit versatile designs and styles and so can advance modern fashion design.

1. Introduction

The concept of illuminative fabrics emerged in 1970 as a result of progress in the development of polymeric optical fibers (POFs) in the 1960s [1]. Integration of POFs in textiles enabled the merger of design and functionality towards so-called "smart textiles" in the form of the light distribution systems, flexible flat panel displays, and optical fiber fabric displays which targeted applications covering industrial sectors ranging from medical, healthcare, earthworks, construction, to civil engineering and transport [2–16]. Besides, smart clothing fabricated from smart textile has broad applications including phototherapy and three-dimensionally fitted low-level light therapy [8–15], wearable sensors [5,6,8,10,11,16] as well as in fashion design [6,8,9,16–20].

For data transmission applications, POF is guiding light along the fiber based on the total internal reflection in the fiber core [6]. However, POF in smart textiles has to be side emitting (glowing) to provide illumination functionality [6–20]. Side glowing can be achieved by launching light into the fiber at angles larger than critical or by fiber modification. Modification minimizes total internal reflection, either by raising the refractive index of cladding or by lowering the refractive index of the core or by enabling scattering to change the critical angle of incident light. The scattering can be enhanced by various techniques including multiple micro-bending of the fiber; mixing of scattering or fluorescent additives into the core or cladding material; creating asymmetries in the core/cladding geometry; chemical processing or laser ablation of the POF surface to create notches [6,8–20].

The flexible thread-like characteristics of POF may give it the appearance of being a material easy to weave, knit or stitch into fabrics, but in practice, the fibers have proved far more difficult to handle than regular threads. The task is complicated further by the need for fibers to be connected to a light source and an electrical power supply, and to ensure that the ensemble can be washed [8]. In textile, choosing the shape of optical fibers is very important. The fiber diameter has to be optimized: a diameter that is too large can cause inflexibility, while a diameter that is too small induces low shear resistance and loss of light intensity. Choice of textile technology is essential too. For example, optical power losses for fibers are less in fabrics which are made by weaving than by embroidery (soutage and shiffli weaving) [8,9,17–20]. Impressive aesthetic results have also been demonstrated by using an RGB-method to create an image on the fabric by using traditional weaving textile technology [8,9,17–20]. The fiber can also be integrated with woven structures through handloom, narrow fabric weaving and Jacquard technology to produce plastic optical fiber (POF) woven fabrics as a flexible alternative to lighting elements [8,9,17–20] and special purpose clothing [17–20]. Interesting styles can be obtained by combining conventional fabrics with cut pieces of POF-fabric, but some problems can arise with the power source and light feed for every

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piece. The textile cannot be cut arbitrarily to avoid interruption of light delivery from the light source across the fabric. Each pattern piece has to be individually cut flat on the POF textile thus incurring a more labor-intensive process [18]. Lumigram [19] is one of the leading commercial producers of glowing garments made by woven technology, but there are certain restrictions on cutting and sewing.

We present here another textile technology- felting - which gives good results in combination with POF. The goal is to connect optical fibers and fabric, to achieve a new type of "smart textile" that helps to address the smart textile challenges related to cutting and sewing along with the ability to wash an item. In an aesthetical context, we explore the technology advantages, i.e. accessing versatile designs and styles, for the development of a collection of illuminative dresses called "Deep Sea Life".

2. Glowing felt

2.1 History and technology of felting

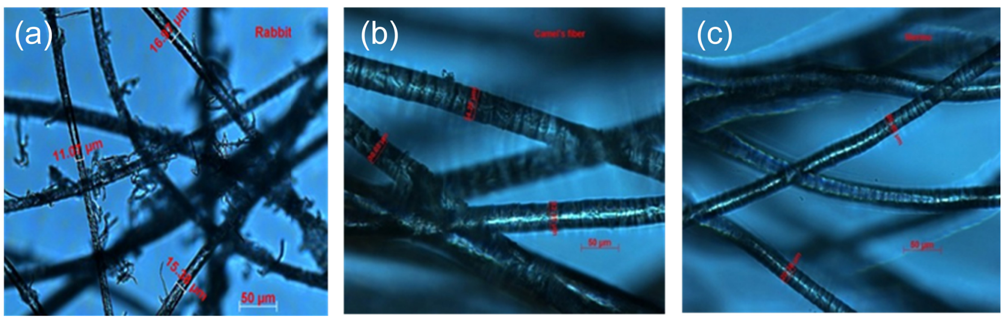

Fig. 1. (a) Fibers of rabbit's wool diameter of 11-16 µm; (b) fibers of camel's wool: diameter of 30-35 µm; (c) fibers merino sheep's wool: diameter of 20-21 µm wool. Images obtained by using Zeiss Axioskop 2 Mot Microscope.

Felt, as a nonwoven fabric, is the most ancient method of textile manufacturing based on matting, condensing and pressing fibers together [21]. It is the first fabric technology dating from about 3-5 thousand years ago [21]. For making felt, wool of different animals (sheep, camel, alpaca, rabbit, etc.) can be used. Wool fibers are very thin with a thickness varying from 10 µm for rabbit wool to 40 µm for the Gotlands sheep's wool (Fig. 1).

The technology of felting is quite simple: wool fibers intertwine under the influence of alkali (soap), warm water as well as mechanical pressure. As seen in the photo (Fig. 1), wool fibers have a heterogeneous structure and are covered with "hooks" and "scales". Under the influence of hot water and alkali, the fibers become more elastic and under mechanical pressure intertwine with each other. At the same time, "hooks" and "scales" open and cling to each other. With subsequent cooling, the "hooks" and "scales" close and interlock with each other tightly and form dense textiles. Different types of wool have a different structure and different felting ability, and so the type of wool has to be chosen to match the task. Even

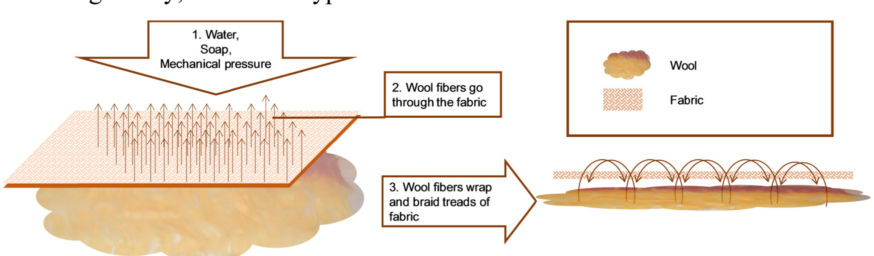

Fig. 2. Technological scheme of nuno felting.

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though wool fibers are very thin, they can also wrap and braid other fibers and materials. An undoubted advantage of the felt garment is washability, as would be expected from a production technology based on water.

2.2 Nuno felt

In 1994 Polly Stirling, a fiber artist from New South Wales, Australia and her assistant Sachiko Kotaka developed a technique named "Nuno Felt" [22]. The name originates from the Japanese word "nuno" that means cloth. The technique bonds wool fiber into a sheer fabric such as silk gauze, creating a lightweight felt. This technology consumes much less wool than traditional felting, and so the felted fabric has characteristics entirely different from traditional felt. Nuno felt is lightweight with drape and flexibility [22].

The manufacturing technology for nuno felt is shown in Fig. 2. First, the fabric is placed on a thin layer of wool. This "sandwich" is wetted with a weak solution of soap. Then mechanical pressure is applied to enable the wool fibers to penetrate the fabric, wrapping and braiding threads of fabric and forming a new material – nuno felt.

2.3 Felting POFs

In the same way, wool fibers can braid optical fibers (or/and metal thread) to create a piece of fabric with integrated optical/electrical elements. However, optical fibers, as well as electrical threads, are quite stiff and it is necessary to add more wool on top to tightly fix the optical fiber inside the felt. However, wool is not transparent, and so the light is attenuated. Therefore, it was decided to use nuno felt technology in combination with thin and transparent fabrics (Fig. 3).

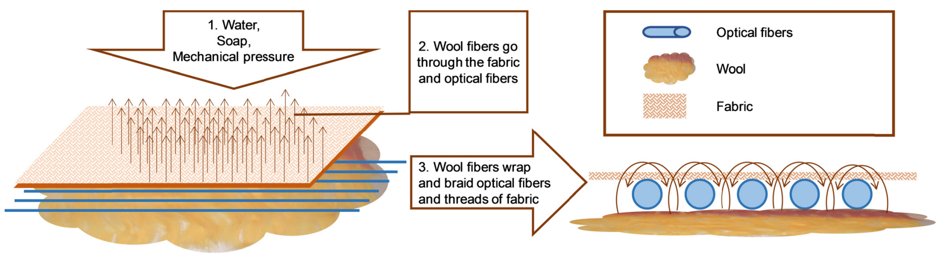

Fig. 3. Technological scheme of nuno felt with integrated optical fibers.

In this case, fabric helps the wool fibers to clamp and braid the optical fibers. The losses of light power from the side glowing POFs are minimal due to the transparency of the fabric. On the contrary, the fabric beautifully diffuses the light due to its texture.

In the process of felting, wool shrinks, with the coefficient of shrinking depending on the type and breed of animal as well as the thickness of the fiber. For example, for merino wool, this coefficient is approximately 30% (Fig. 2). Thus, wool fibers and fabric form tunnels around the optical fibers. Moreover, during shrinkage, these tunnels shrink too and tightly and reliably clamp the optical fibers. Also, if the garment is shrinking at all, that bends the fibers and increases their luminosity. For finishing a felt sample, POFs have to be integrated into a bundle, and the POF bundle has to be connected with the light and power sources (LED and battery).

2.4 Materials and components

In this project several different types of plastic optical fiber were used: (i) flexi side glowing fiber (fiber optical cable 2.2 mm diameter); (ii) fiber optic lights - 1mm plastic optical cable, side glowing, dotted, sparkling fiber; (iii) side glowing plastic optical fiber cable, 3.0 mm, material: PMMA; (iv) plastic optical fiber cable, side glowing, 2 mm diameter; (v) plastic optical fiber, 0.75 mm diameter. Some of them were too stiff and so can be used only as a

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skeleton for the garment and so allowed us to create unique three-dimensional dresses that exactly fit the concept of the collection.

We also used 10 mm LEDs of different spectral range, ultra-bright, round. LEDs were mounted in a box with a switch and battery (6 V). Luminous Intensity was as follows: (i) white – 30000 mcd, (ii) blue – 5000 mcd-6000 mcd, (iii) green, yellow, and red – 4000 mcd-5000 mcd.

2.5 Preparing the optical circuit

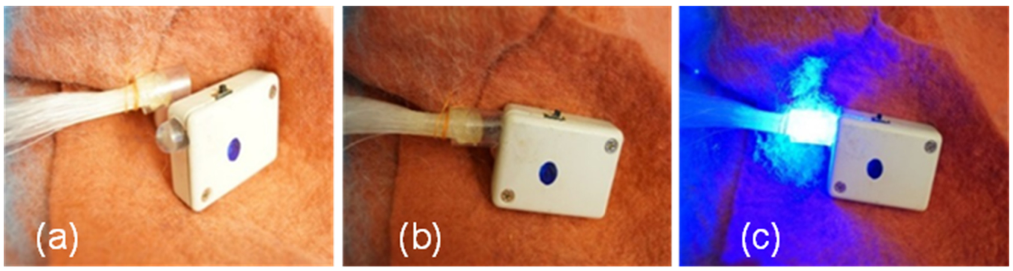

Fig. 4. Fibers bundle with a power source: (a) disconnected; (b) connected; (c) switched on.

Fibers of different lengths, and sometimes – different thicknesses were gathered in bundles, the diameter of which corresponded to the diameter of the light source. This bundle was fixed with epoxy glue – epoxy achieved a much better result than other types of glue. Also, the refractive indices of the optical fiber and epoxy resin are comparable which allows the connecting fibers to bind firmly together as well as reducing the loss of light from the LEDs. The bundle was placed and fixed with epoxy glue in a segment of PVC pipe, which was mechanically connected with the LED (Fig. 4).

2.6 Optical fibers in felting

As follows from Fig. 3, the first level of the "sandwich" is wool. In this project, we used Australian merino wool with a thickness of 21-23 μm and different colors [23,24]. The wool fibers have to be placed on a horizontal surface, and adjacent layers (two layers minimum) have to be perpendicular to each other for good interweave and high quality felt. The thickness of the layers, as well as the number of them, can be varied depending on technical and aesthetical needs. The second level comprises a combination of fiber bundles (distributed in the level according to design and aesthetics), and the third one is a piece of fabric. To maximize the luminosity of the garment, nuno felt technology based on the following sorts of fabrics was used, namely chiffon (silk), pongee (silk), organza (polyester).

The next step is to wet the "sandwich" with an alkali solution. A domestic liquid soap was used for this solution with a volumetric concentration of 5 ml/l. About one liter of solution is required for 100 grams of wool. The working temperature of the solution has to be maintained in the range of 30 - 60 C^0. If the temperature is lower, the process of felting slows. At higher temperatures, the wool fibers shrink too quickly and so cannot penetrate through the layers of optical fiber and fabric to create good-quality felt.

The next step is the mechanical processing of the wet sandwich by using pressure and friction. Friction helps the wool fibers to penetrate through each other and other materials; pressure transforms the wet sandwich into a homogeneous material (prefelt). To enable fast processing, a vibro-sander (without sandpaper) was used for processing both sides of prefelt. When the prefelt thickness goes down to 1-2 mm, the mechanical processing can be stopped, i.e. the felt is ready. If the thickness exceeds 2 mm, additional mechanical processing is required through pressure and rolling. The last step is rinsing, drying and carefully ironing (to avoid damaging the optical fibers).

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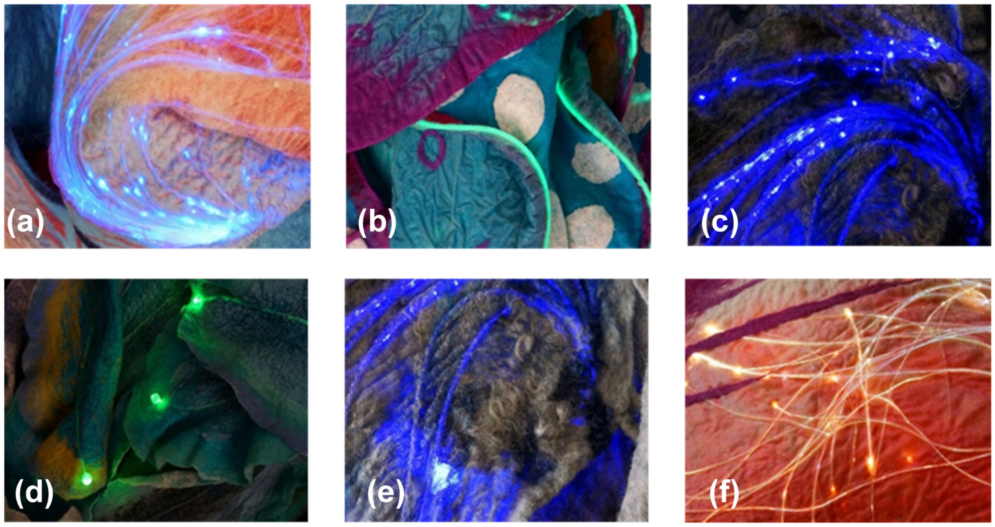

Fig. 5. Different types of optical fibres in felt. (a), (c), (e), (f) – patterns of chaotic combinations of thick and thin fibers; (b) – thick (2mm) and soft side-glowing fiber; (d) - glass beads on the ends of fibers.

As was mentioned above, felt shrinks about 30% during the wet-felting process and so optical fibers are bending inside the felt and glow better. Unfortunately, the more thick and stiff types of fiber did not interlace well and so sometimes could go outside of the garment. However, such fibers created a rigid "skeleton" for the dress, and protruding fibers can be easily cut (Fig. 5).

Felting technology allowed us to use a free design for the layout of fiber bundles. It can be regular, as in woven technology, or chaotic – it depends only on the designer's idea (aesthetic or technical). However, the chaotic layout of fibers (which is impossible in other textile technologies) has some advantages.

First, bundles can be accurately placed in the garment to make sophisticated light pattern in different colors. A combination of different colors and different operating modes of the LEDs allows the creation of a unique changeable light pattern. Second, if some fibers have been damaged (during the production process or usage), this does not destroy the light pattern. By contrast, for a regular pattern (for example, woven or knitted fabric) when one of the fibers is broken, all pieces look damaged. Third, felting technology minimizes the use of cutting and sewing. The technology allows us to make a seamless garment, "in one piece" by using templates of soft plastic. Therefore, unlike the other textile technologies, felting enables the design of more sophisticated styles with embedded optical fibers in a more creative way.

2.7 Collection "Deep Sea Life"

The result of this project is the "Deep Sea Life" fashion collection (Fig. 6). As follows from the name, the idea of the collection was inspirited by sea life forms. Many of these can generate light exhibiting unusual forms and colors. However, the goal of this collection was not in mimicking real life forms but in creating some moving 3D sculptures of color and light. The collection was demonstrated at Lightfest (Birmingham, 2015) and the ICTON conference (Trento, 2016).

3. Conclusions

We have demonstrated that felting technology has some advantages over other textile technologies in the context of smart textile fabrication. This seamless technology gives a

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designer more opportunities to choose versatile design and forms. A designer does not need to think about cutting and stitching and can work with the 3D-object right away. Items can be art

Fig. 6. Pieces of collection "Deep Sea Life": (a) Sea slug; (b) Actinia; (c) Flying fish; (d) Coral; (e) Octopus; (f) Nudibranch mollusc; (g) Jellyfish.

objects as well as casual and functional clothes. Also, these garments become washable by removing light and power sources which can be replaced easily upon failure. The rigid fibers can be used as a skeleton of the garment. A combination of stiff and soft as well as thin and thick fibers allows the design of unique patterns. If any fiber in the bundle is broken, patterns continue glowing and do not appear damaged.

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