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Published in:
Autex Research Journal

Link to article, DOI:
10.1515/aut-2009-090204

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

FLAT KNITTING OF A LIGHT EMITTING TEXTILE WITH OPTICAL FIBRES

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Abstract:

Knitted products have a flexibility that offers many attractive possibilities. Combined with technical fibres, this gives interesting and innovative possibilities. Many technical fibres and yarns has however properties such as high stiffness and brittleness which are difficult to process in the practice of weft knitting. This paper is about the experimental product development of a light radiating textile lamp in which optical fibres are used as the only illumination source. The lampshade is produced on an electronic flat knitting machine with special equipment suitable for the feeding of yarn with high stiffness. The work was divided in two parts: exploring the possibilities to knit the desired shape on one hand and experimenting about knitting with optical fibres as a weft insertion on the other hand. The method is an inductive approach; a literature survey, information from suppliers of knitting production equipment and experimental work on a flat knitting machine at The Swedish School of Textiles, Boras, Sweden. Results show that the diamond shaped structure can be knitted in one piece with transparent monofilament yarns. Furthermore it also shows that difficulties occur when knitting with stiff and brittle optical fibres therefore the paper ends with a discussion with suggestions of how to overcome these challenges.

Key words:

Optical fibres, shape knitting, knittability and handability of brittle fibres, flat knitting technology, light radiating textiles.

1. Introduction

Textiles are today more and more widely used for new purposes. An example is shape knitting that is becoming more interesting with the fast progressing development of flatbed knitting machines. This technique makes it possible to knit 3-dimensional technical textiles. In addition textile fibres are composed of new materials that have not been used in the textile industry before, such as thin metal threads, glass fibres and optical fibres. The textiles receive new functions and new use areas, also in the area of smart textiles, where the textiles react to a given input from their surroundings. Optical fibres are used in many research fields today, the fibres appear to be offering improvements in many fields but especially in textile applications the special handle of the fibre complicates the manufacturing process.

A company trying to explore some of these new possibilities is the Stockholm based company GloFab. This company makes light radiating textiles and the idea is to create value for the customers by making their venues more attractive. In 2003, architect Torbjörn Lundell, founder of GloFab, created a visionary image showing a man sitting in the dark surrounded by light radiating textiles. The initial idea resulted in a range of different products: curtains, room dividers and a lamp shaped as a globe, all made of big handmade laces in the technique macramé, created from bundles of optical fibres. All products function as either lamps or light sources, see Figure 1 [7].
A way to adapt the handmade macramé concept into an industrial context is offered by the technique of flat knitting. An advantage that comes with knitted fabrics is the possibility of creating 3-dimensional shapes, compared to for example weaving, which gives flat, inelastic fabrics.

Using optical fibres as an illumination source in a textile lamp is an innovation of an already existing concept (a lamp); as the light source is not located in the centre of the construction but in the 3-dimensional textile shape itself. There is no longer need for a light bulb and this creates opportunities to create new kinds of textile light sources for indoor or outdoor applications.

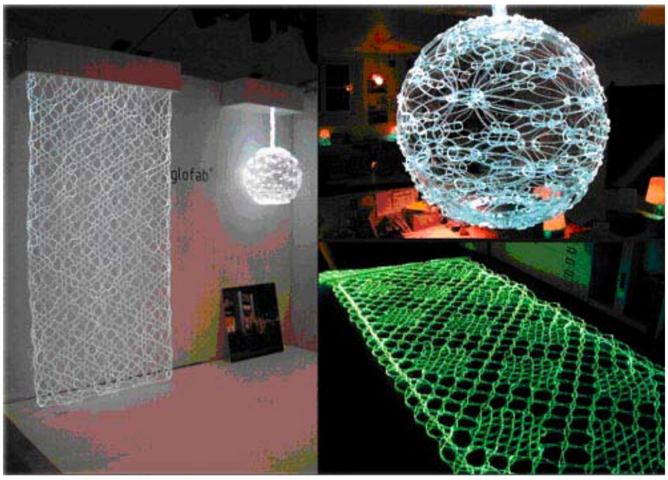

Figure 1. Some of GloFab's products. Clockwise: GloBe, decoration to Cartier's facade and GloCurtain L. Source: Torbjörn Lundell. (c) GloFab.

The described project investigates the possibilities of producing a GloFab product industrially, while keeping a similar appearance as the already existing handmade light radiating textiles. It was in an early stage of the project considered achievable to knit a diamond shaped textile on a flat knitting machine and it was important from a design point of view to explore this further together with the possibilities of knitting with optical fibres.

2. Methodology and research questions

The work was carried out experimentally with an inductive approach; based on a literature survey and information from suppliers of knitting production equipment. The knitting technology, information about optical fibres and design requirements are taken into consideration and implemented in the development of a light radiating textile. The following research questions were formulated:

1. How can a diamond shape be knitted on a flat knitting machine?
2. How can an optical fibre (of 0,25 and 0,75 mm in diameter) be integrated as weft insertion in a diamond shaped flat knitted structure?

This paper examines the knitting of stiff optical fibres and describes the results of development of a diamond shaped flat knitted structure. Conclusions are drawn; suggestions and future perspectives of knitting with stiff optical fibres are discussed.

3. Knittability of brittle fibres

The advantages with knitted products are their outstanding characteristics such as flexibility in production, knitting to shape, superior resistance to impact and finally their high ability to conform to complicated forms [4]. In order to integrate textiles and optical fibres (see Figure 2) for illumination, knitting is an interesting choice because of its positive characteristics mentioned above. The task includes the use of less common materials used in the knitting industry and therefore it is relevant to study the knittability of brittle materials.

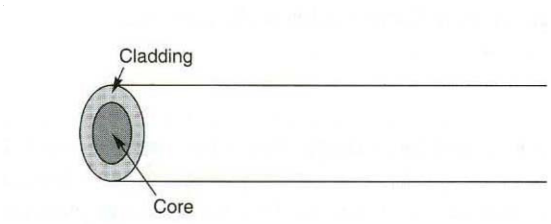

Figure 2. Optical fibre with core and cladding.
Source: Hecht, 1998, p.60.

Products with high mechanical properties are generally produced from high-performance materials, for instance glass, aramide, carbon or even ceramics. Due to their high stiffness and high coefficient of friction, and in some cases brittleness causing breakage in the loop formation process, these materials are difficult to use in the knitting process [4].

According to Savci et al. [5] fabric dimensions and physical properties both depend on the loop length. The important factors for controlling loop length are: the stitch cam settings, yarn input tension settings, fabric take-down tension and yarn-to-metal friction properties. In addition the loop length can also be affected by the knitting speed, which influences the friction. Further more Savci et al. suggest that the knittability of high performance yarns, such as glass fibres, depends on frictional properties, bending stiffness, and yarn strength. This special type of fibres requires low-tension settings, appropriate tension control of both yarn and fabric, and minimal metal surface contact during knitting [5].

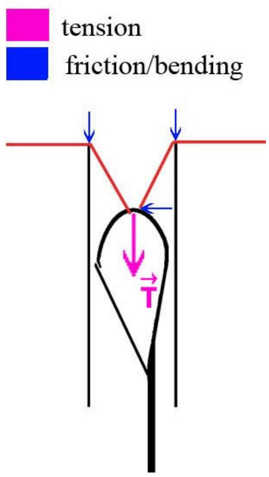

Figure 3. The forces occurring during loop formation.

In a knitting cycle, from old loop to new loop forming, three kinds of forces influence the fibre: tension, bending and friction. Figure 3 shows the three forces when the yarn is put inside the needle hook and the needle pulls down the yarn. The purple arrow (T) shows the pull down force, while the blue arrows show where friction and bending occur. High performance materials often have very high tensile strength, which means a single tensile action along its axe does not cause filament breakage. Still, together with the bending and the friction forces, the degree of filament breakage tends to be very high, due to their brittleness.

The degree of filament breakage also depends on the choice of structure as well as the filament diameter and yarn torsion. Yarn with a smaller filament diameter and a higher torsion has a lower degree of filament breakage with higher loop lengths. [4] When it comes to optical fibres the thickness has an influence on the light emitting properties. In fact, the thicker the fibre, the more light it can transport; but the more difficult it becomes to use in the knitting process [6]. When it is not possible to form loops with a fibre, it can nevertheless be integrated in the knitted fabric by weft insertion, which is done in this project.

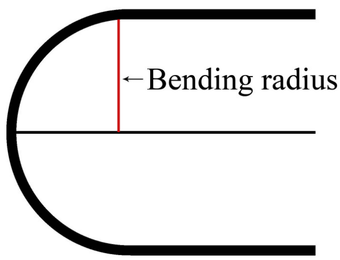

Figure 4. Bent optical fibre.
Source: Linda Oscarsson and Elisabeth Jacobsen Heimdal.

Bending an optical fibre can cause the light to leak out. It can also cause the fibre to break. Therefore, as the optical fibre is integrated in the knitted structure as weft insertion, an important parameter is the distance between two adjacent insertions. It cannot be less than the minimum bending radius (see Figure 4) of the fibre, multiplied by two. The minimum bending radius of a fibre is the smallest possible value of the radius of the arc formed by the fibre as it is bent. If the fibre is bent over this radius it will break immediately. The used optical fibre of 0, 25 mm in diameter has a minimum bending radius of 1,5 mm.

The fibre of 0, 75 mm in this case has a minimum bending radius of 4,5 mm [9,10].

4. Optical fibres for light radiation

Optical fibres are not in their natural state light emitting. In the most common optical fibres, the majority of the data travels inside the fibre and emerges at the end or is lost inside the fibre [3]. However, for illumination purposes, this loss of data, or light in this case, is desirable. There are several ways to modify an optical fibre to become side emitting. By adding a special, light-scattering material to the core of the fibre, the light becomes redirected when it hits the scattering material hence of the light directed into the fibre is spread out along its sides [3]. Light scattering can also be made mechanically, by scratching the surface of the fibre, creating small dints on its surface. These dints will also cause the light to leak out on the sides of the fibre, due to the special properties of optical fibres [2]. Yet another option is to bend the fibre continuously, as the light will leak out of the fibre when it is bent within a certain rate, and if this happens regularly along the fibre the whole fibre will appear as light emitting [6]. The last mentioned alternative is very suitable for textile constructions, hence the chosen option for this project.

5. Methods and materials

The knitting technology and production issues together with information about optical fibres and design requirements were taken into consideration and implemented in the development of the diamond shaped light emitting textile. The main task in the project was to knit the diamond shaped lampshade; being able to obtain the right shape and to integrate the optical fibres into the structure. Finally it was intended to construct a prototype.

Figure 5. The flat knitting machine STOLL CMS 330 TC.

The knitting was performed on an electronic flat knitting machine, Stoll CMS 330 TC (see Figure 5), gauge 12 and needle size 10. In order to facilitate the progression of the work, different yarns were used. In fact, it was expected to be a challenge to work with the optical fibre, and therefore the choice was made to use yarns with better knittability in a first stage. In the first step a three-thread texturised monofilament of polyester was used, which was later changed to transparent monofilament of polyester with the diameter of 0,12 mm, and at the final stage 0,15 mm. For the weft insertion two-thread spun acrylic yarn was used to begin with, and later changed to green monofilament of polyester with the diameter of 0,17 mm. When experiments started with the optical fibres as weft insertion it was fibres of PMMA (Polymethyl Metacrylate) with the diameter of 0,25 mm and 0,75 mm.

In order to facilitate the weft insertion of the optical fibre into the shape knitted lampshade, by minimizing the tension and friction on the optical fibres, a special yarn-feeding device for stiff materials was used (see Figure 6 and Figure 7). The goal with this yarn-feeding device is to introduce the material in the knitting machine with as little tension as possible, which is achieved by making the stiff thread pass through a number of wheels.

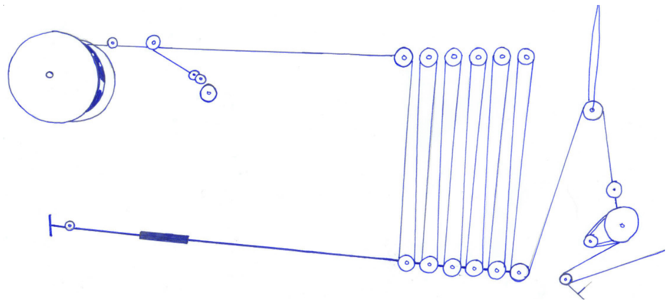

Figure 6. Schematic of the yarn-feeding device. Illustration: Linda Oscarsson.

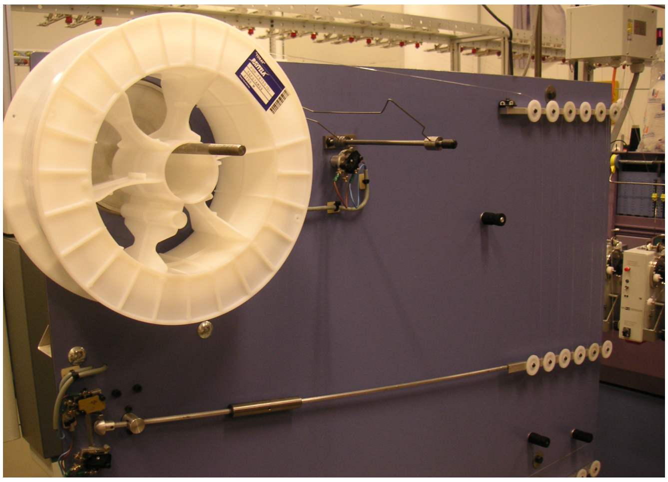

Figure 7. Yarn feeding device. Photograph: Elisabeth Jacobsen Heimdal.

In the final prototype the yarns were transparent monofilament of polyester, transparent for the base yarn with the diameter of 0,15 mm and coloured polyester monofilament with a diameter of 0,17 mm. The transparent yarn used as base yarn reflects light, which gives an aesthetic quality to the product with a lustre effect. The prototype is shown in Figure 8.

As the rest of GloFab's products, it was desired to develop the lampshade as a large product. Its dimensions were defined by the length of a loading pallet, which by European standard has a length of 1200 mm. In an upstanding position many lampshades can be loaded onto a pallet and shipped off. The distance from the roof to the bottom point of the lamp is approximately 300 mm. The hole in the middle is approximately 100 mm, these dimensions later need to be optimized also to include the packaging.

Figure 8. Left: Zoom on the fabric. Right: Half profile of final prototype.

6. Results

A diamond shaped textile can be knitted on a flat knitting machine by form knitting six triangles one after each other by decreasing and increasing the number of wales (see Figure 9). The challenge of this process is the stress appearing on the inner side of the fabric, as a result of the high difference of wales knitted on the inner and outer side of the fabric. (see Figure 10).

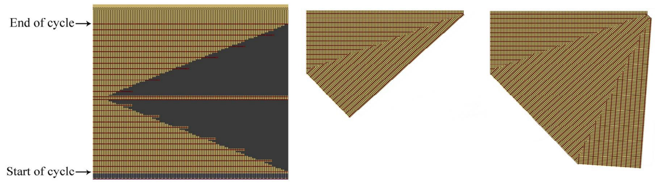

Figure 9. To the left image from the software, showing the cycle that is repeated to obtain the six triangles composing the lampshade. To the right visualising of the knitted result, left: 1 cycle, right: 2 cycles.

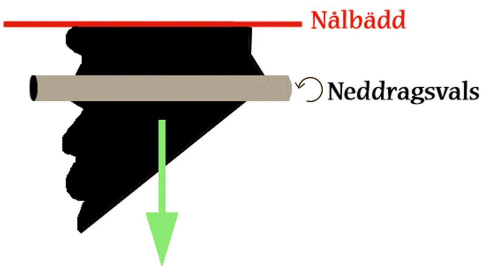

Figure 10. Fabric as it comes down between the needle beds (nalbädd), and is pulled down by the take down devices (neddragsvals). The figure shows that on the left side, a great deal of knitted fabric comes down, while a very small amount comes out on the right side.

This stress causes either yarn breakage where fewer wales are knitted or entanglement at the other side. Though there are other ways to knit the same shape, it was necessary to perform the knitting in such a way that the fibre ends later can be gathered in a bunch in the centre of the diamond and connected to the light supply equipment.

As previously mentioned, optical fibres break immediately when bent above the minimum bending radius, which would happen during loop formation. Therefore it became clear that the fibres had to be integrated in the fabric by weft insertion. Experiments showed that, in rectangular pieces this was quite unproblematic (see Figure 11 and Figure 12), much thanks to the special yarn-feeding device attached to the machine. However when trying to integrate the optical fibres in the form knitted textile, the stress on the inner side of the fabric regularly caused fibre breakage. As the results show that it was possible to integrate optical fibres with diameters of 0.25 and 0.75 mm in rectangular shaped fabrics it became evident that the prospect to create the desired product is good, with some modifications of the flat knitting.

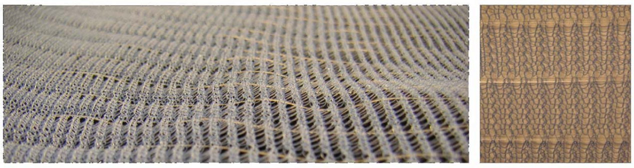

Figure 11. Optical fibres integrated in rectangular pieces.

Figure 12. Optical fibre of 0, 75 mm integrated in rectangular piece.

7. Further developments

Based on the experiments, as well as discussions with teachers and technicians at The Swedish School of Textiles, further development possibilities concerning the polymer choice, the flat knitting machine and new design possibilities have been outlined.

7.1. Choice of polymer

The optical fibre used in the experiments is based on PMMA (PolymethylMetacrylate), a purely amorphous polymer [1]. This clearly is an inconvenient when it is used in fibres that have to be employed in textile applications, as it makes the fibre fragile, and increases the risk for fibre breakage. PMMA has however, good optical properties. There are other polymers with good optical and textile properties that are better suited for the knitting machine. Today, these do not exist as fibres, but a development has been started. Two of these are polyetersulfone (PES) and poly-4-methylpentene-1 (PMP), which has been commercialized as PTX by ICI. Polyetersulfone is amorphous, just like PMMA, but has however better mechanical properties. Poly-4-methylpentene-1 is semi-crystalline, but still has good optical properties as well as mechanical [8]. As the focus on textile products integrating optical fibres increases, the demand of fibres that have properties suited for textiles will most likely increase, and set the pressure of the developed and commercialisation of these polymers as fibres. Unfortunately, both PES and PMP are much more expensive than PMMA. The choice of polymer is critical for the success of the experiment, and it is obvious that the novelty of textile application for optical fibres explains a present lack of suitability of the optical fibres for textile applications.

7.2. Machine limitations

The limitations of the machine (German Stoll) are another technical challenge in the experiment. There is a gap between the textile designers and the product developers on one hand and the machine producers on the other hand; the properties of the machines do not follow the demands of the experimental applications, but rather the more traditional bulk production. The gap between the two parts must decrease and the demands communicated to the machine producers, to decrease the limitations of the machines, so that future machines better can satisfy the requirements set by new design ideas in the areas of smart and functional textiles. Four possible improvements on the machine are (not suitable only for this specific project but for the use of all kinds of stiff and brittle fibres in a flat knitting machine):

- Individually steered take-down rollers.
- Lower machine gauge.
- Holding down sinkers assisting to hold down the optical fibre when it is bent in the transition from one wale to the other.
- Bigger scissors, to cut thicker optical fibres.

It is important that educational institutions, such as The Swedish School of Textiles, as well as designers, product developers and companies working in the area of smart textiles communicate their needs to machine producers, to avoid that the machines become an unnecessary barrier to the realization of their ideas, but rather support the development of new designs. In this experiment, the technical machine improvements are quite simple to realize, and this is probably often the case. As an example, the special yarn feeding-device eased the use of the stiff material.

7.3. New design possibilities

Shape knitting with optical fibres revealed to be a true challenge, and opened our eyes for some new design possibilities. Integrating optical fibres as weft insertion in rectangular pieces turned out to be quite unproblematic, even with an optical fibre of 0, 75 mm in diameter, as shown in Figure 12. These rectangular pieces could be shaped after they have been knitted.

Compared to weaving, knitting offers a more flexible, formable result, but is also seems that the knitting process is tougher to match with optical fibres. Different kinds of lamps could be knitted with optical fibres, just by changing the shape of the product mentioned above and by knitting rectangular pieces the knitting process would be crucially facilitated. This could give flat lamps, hanging directly on the wall, or big tubes, similar in shape to the popular rice lamps we see on the market today, but with a new innovative technique. It is important to remember that optical fibres, just like LED do not emit any heat, this absence of heat emission allows the products to be placed in places where normal lamps cannot. E.g. they can be positioned on textiles or other materials sensitive to heat. The optical fibres still must be connected to light supply equipment which is still quite heavy and big, a bit noisy and emitting heat, though it can be hidden above the roof or other hidden place, and most likely it will be further developed, along with the development of light radiating textiles!

8. Conclusions

The experiments show that a diamond shape can be knitted on a flat knitting machine in one piece with transparent monofilament polyester yarn, which was desired, to add value to the product. The project furthermore shows that a diamond shaped, flat knitted, light emitting textile can be produced but it shows also difficulties to replace the inlay polyester monofilament yarn with optical fibres. Nevertheless it resulted in a number of development suggestions that can make it possible to replace the monofilament with optical fibres in the future. These suggestions are based upon observations during the knitting process. The diamond shape was obtained by knitting six triangles but by increasing the number of triangles, the stress would decrease, which would also be affected by changing the base yarn to a more elastic yarn. By increasing the diameter of the hole in the centre the stress would yet again be reduced. Thicker scissors together with lower gauge of the machine would allow thicker fibres to be utilized. Lower gauge would also give a thicker base fabric, which would add value the current product. This work shows there is a true chance that, light emitting textiles can be knitted on a flat knitting machine.

Acknowledgement

We acknowledge Mr. Folke Sandvik lecturer in knitting technology at The Swedish School of Textiles for all his help and guidance during this project.

Editorial note

Portions of this work were presented at Ambiance 08, Smart Textiles - Technology and Design International Scientific Conference, June 2-3, 2008, Boras, Sweden.

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