KNITTING OF ELECTROCONDUCTIVE YARNS

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ABSTRACT

The advantages of producing 3-D conductive knitted textiles for the purpose of generating heat are enormous. Products may be developed that conform to complex contours providing a uniform heat distribution. Applications can be foreseen in the automotive sector; car seats, driving wheels and the interiors of door panel. Medical usage could involve conforming the knitted structure to the body, providing relief to sports injuries. In fact the development of 3-D knitted heating elements, could apply heat uniformly to any requirement whether technical, medical of merely a fashion aid.

The area of electro-conductive textiles is currently under investigation, partly due to the amount of development that has been undertaken in fibres and yarns. Many textile products including garments are being developed for the purpose of generating heat or for use as electrical conductors. Past investigations in this area have given preference to weaving, due to the lack of awareness of the capabilities of the latest developments in electronic flat-bed knitting technology.

The modern electronic flat-bed knitting machine is capable of producing a variety of structures, which contribute significantly to the fabrics' mechanics and often denote their final application. Recent developments in CAD/CAM and the integration of mechatronic concepts with flat-bed knitting machines have made it commercially possible to produce complex mixtures of shapes and structures utilising a variety of methods.

The prospect of 3-D shaping a conductive textile structure on the flat-bed knitting machine, offers vast potential for both technical and apparel applications. In order to enable 3-D shaped shells to be produced accurately for usage in electro-conductive textiles, it is essential to have a full understanding of the geometrical properties of the knitted structure; and the effects that the various shaping techniques enforce.

INTRODUCTION

The aim of the research presented in this paper was to critically examine the knitting of conductive yarns into 3-D shells. The purpose being to promote an understanding of knitted structures within electro-conductive applications; and to assess the applicability of the electronic flat-bed knitting machine for the development of conductive 3-D shell shapes.

This paper is a result of three separate studies; the first part examined two electro-conductive yarns to establish a set of parameters on knitability and yarn control. The second part of the study assessed the geometrical dimensions to obtain an understanding of the knitted structures behavior during relaxation. Finally, shaping utilising the technique of flechage (holding or partial knitting) was introduced in the planar structure for a selected electro-conductive yarn and the affects on the structure's geometry were studied.

Limited work has been conducted into the affects of three-dimensional shaping in electronic flat-bed knitted structures. Previous studies include product related developments which have resulted in various shapes being produced including; tubular elbows, boxes and hemispherical forms [1]. However, the advanced mechanical properties of the products appeared to receive more publication than the geometry of the products.

BACKGROUND

In recent years, there has been an ever-expanding interest in the structural and functional capabilities of textiles especially in the field of technical textiles. This was primarily due to their properties of strength, damage tolerance and ability to be fabricated to near net shapes. Technical textiles can be categorised according to their manufacturing methods; knitted, woven, non-wovens or braids.

Often the required 3-D shell would be post fabricated from a planar structure. A major problem associated with this method of production is, the amount of wrinkles that occur when draping the fabric. This is a direct result of the sheer deformation, which is highly undesirable for applications in electro-conductive textiles, due to possibilities of electrical surges occurring.

Various publications have suggested that this deformation could be overcome by producing a loose fabric [2]. However, this would in turn reduce the fibre volume in any given area, which could have a knock on affect on the overall properties and the function of the structure, resulting in inharmonious geometries.

The ideal solution is to utilise a method of shaping, which could occur during the manufacturing of the structure. Therefore, the shape produced would be far nearer to the final shape of the form than that of the planar structure and would inherit a more uniform geometry.

There are various methods of achieving integrated three-dimensional shaping within the identified manufacturing techniques. However, many textile production methods are limited to the actual shell shape produced. The most versatile textile manufacturing procedure is electronic flat-bed knitting.

Electronic Flat-bed Knitting. This is a process of assembling fibres in order to create a textile structure, which is well established. This method of manufacture offers immense flexibility within the binding elements and the various techniques of shaping. The technology also enables precision positioning of fibres in three-dimensional space.

Precision positioning of fibre is especially vital in technical/electro-conductive textiles, where often the structural properties of the fabric are required to be harmonious throughout the product or form.

Prior Research. The research presented was derived from a DTI funded project where a pre-cursor yarn was knitted successfully into a 3-D shell shape, and later carbonised for the purpose of generating heat. The process of carbonisation was achieved by a combination of applying heat and pressure to the knitted structure, thus, converting everything into carbon. During carbonisation the dimensions of the knitted structures were modified dramatically. It was identified that there would be difficulties in controlling the dimensional change to achieve a harmonious geometry in complex 3-D shells. Hence, it would be beneficial to knit a conductive yarn into a 3-D shell shape, thus, eliminating the requirement for post knitting treatments in the form of carbonisation.

AIMS AND OBJECTIVES

It has been acknowledged that the electronic flat-bed knitting machine has the advantage of producing 3-D surfaces with double curvatures. It is the only method of textile manufacturing that is versatile enough to perform complex shaping procedures without causing wrinkles and other defects within the structure.

Therefore, it is of benefit to examine the knitted structures applicability to 3-D shell shapes for the generation of heat. However, prior to investigating the electro-conductive elements, it was necessary to study the knitability of electro-conductive yarns and their resultant structural geometries.

Yarn Parameters

In order to generate heat from a low power supply a moderate amount of electrical resistance is required. Hence, copper and aluminium monofilament yarns were not suitable. A stainless steel multifilament and a carbon yarn were investigated which had moderate amounts of resistance that might be applicable to the product application.

It was found that each of the selected electro-conductive yarns/wire exhibited particular brittle characteristics and poor bending properties that were not typical of yarns for textiles applications. This was due to the high E modulus and the general lack of extension in the fibres/filaments.

Stainless Steel Yarn. This was a multifilament yarn made up of individual filaments that measured 14 microns in diameter, and were twisted together. This yarn suffered from twist liveliness, an extremely high coefficient of friction, 0.5 (yarn to metal), a moderately high E-modulus and poor breaking extension. The electrical resistance was 76 ohms/meter. Figure 1 illustrates a magnified section of yarn.

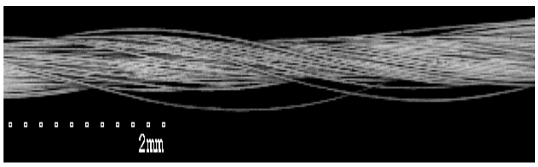


Figure 1: Section of Stainless Steel Yarn

Carbon Yarns. The most common form of carbon yarn was in the filament form; usually an extremely brittle yarn made up of many individual filaments, which have poor bending properties. Due to the complexity of the knitting process, generally yarns with good stretch and bending properties are used. Hence, there was difficulty in selecting a carbon filament yarn, due to its poor bending properties and constantly fracturing fibres (fibre fly) when forming the stitch shape. It also resulted in yarn breakages at any slight change in the knitting tension.

An alternative yarn was found, which had more tactile properties and an electrical resistance of 240 ohms/meter. The selected yarn was a spun carbon yarn, which had a relatively normal coefficient of friction, 0.29 (yarn to metal), a high E-modulus and low elongation properties.

One of the main problems identified with the spun carbon yarn was the electro-conductive fibre fly that was generated during processing. It can be observed from the magnified section of the yarn illustrated in Figure 2, that the carbon fibres were not aligned during the yarn manufacturing process. Hence, there was a high probability that fibres would frequently break away from the main yarn during knitting. Thus, potentially creating a serious health and safety risk.

In an attempt to reduce the occurrence of fibre fly a double nylon wrapping was applied to the yarn to enclose the fibres during knitting. The resultant yarn is illustrated in Figure 3. It was observed in the experimentation that the wrapping process considerably reduced the fly.

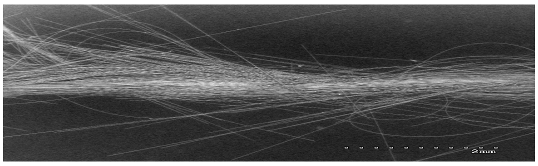


Figure 2: Section of Carbon Yarn

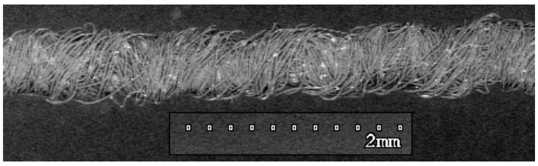


Figure 3: Section of Wrapped Carbon Yarn

Knitability

The two selected electro-conductive yarns were assessed for knitability on the 10-gauge Stoll CMS 330.6 knitting machine. Initially many problems were identified in terms of abrasion in areas were high frictional contact occurred. In an attempt to minimize the frictional forces generated the knitting machine was run at slow knitting speeds during the experimentation.

Stainless Steel Structures. This multifilament yarn presented many knitting problems regarding yarn delivery. Snarling (yarn twisting upon itself) occurred during the knitting process, which is highly undesirable. There was also a general problem identified due to the particularly high coefficient of friction.

To reduce yarn friction a more direct path was created which eliminated the areas where extremely high frictional forces were generated. This was achieved by using alternative yarn delivery equipment. In an attempt to minimize tension peaks during knitting, the friction and forces were reduced by use of a lubricant; this also eliminated the occurrence of snarls in the yarn. An example of a knitted stainless steel structure is illustrated in Figure 4.

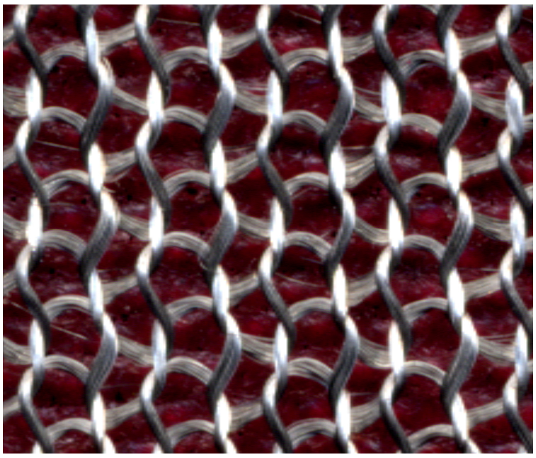


Figure 4: Knitted Stainless Steel Structure

Covered Carbon Structure. Despite the rigid appearance of the nylon covered carbon yarn; it was knittable using the most direct yarn feed path to eliminate any unnessacery frictional contact that would have disturbed the outer covering. Figure 5 illustrates the resultant structure, which is extremely uniform in appearance.

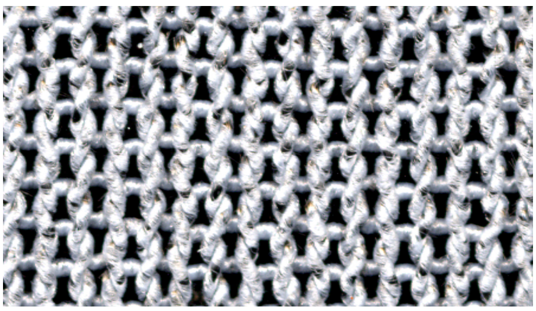


Figure 5: Knitted Carbon Structure

Fabric Dimensions

In a knitted structure the size of the stitch and the shape of the stitch influence the dimensions. The stitch length defines the size of the stitch. This is the length of yarn in a stitch and is usually measured over a group of stitches for accuracy. The shape of a stitch is defined by the physical dimensions of a stitch in terms of height and width and can be expressed as wale and course density (the amount of stitches or rows per centimeter).

Size of a Stitch. To obtain the size of a stitch a course of stitches is unroved and the resultant yarn length is measured. This is a useful method to determine if the amount of yarn delivered to the needles is identical, independent of the direction the yarn carrier is traveling.

The selected knitting machine has three individual knitting systems. It was important that each system delivers an equal amount of yarn, if a controllable / predictable geometry is to be achieved for 3-D shaping of electro-conductive yarns.

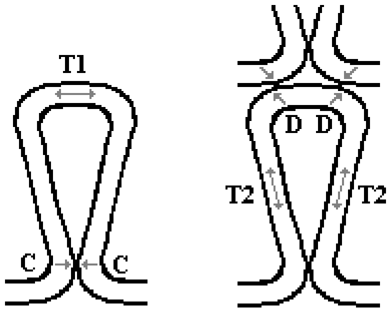
By experimentation it was proven that each of the three knitting systems could be calibrated to deliver within a maximum variation of +/- 1.5 cm over 200 needles. However, a more practical solution to minimize course length variation was to knit utilising the same knitting system throughout the product.

Shape of a Stitch. It was essential to understand that the shape of a stitch has to be defined three-dimensionally.

The plain knitted structures illustrated in Figures 4 and 5 were assessed to determine if various knitting parameters used to assist in the stitch formation had a permanent affect on the geometry. Other factors were considered such as; the position at which the stitches jammed. In other words the point of contact between two adjacent stitches where the frictional contact was so great that a locking occurred (see Figure 6).

The areas where the jamming occurred were of particular interest if the structure is modelled as a matrix to generate heat. It was therefore, essential that the locking point was consistent and external factors during the knitting process did not disrupt the structures ability to reach this state.

One of the first experimental investigations was to determine the affect of the take-down with regards to the jamming point. This was assessed in terms of obtaining the wale and course density at various stages of relaxation. Specimens of the planar structure were knitted in both electro-conductive yarns and their overall dimensions were measured in five states of relaxation and the wale and course densities calculated. The states of relaxation that were considered are defined in Table 1.



A **B**

A - Jamming in the width direction
(T1 – Tension, C – Compressive forces)
B - Jamming in the length direction
(T2 – Tension, D – Compressive forces)

Figure 6: The Points of Jamming [3]

Relaxation Stage	Relaxation Procedure
1	The measurement 15 minutes after leaving the knitting machine
2	24 hours laid flat at room temperature
3	A further 24 hours laid flat at room temperature
4	24 hours laid flat in a conditioned environment that varied between 19–22 °C at 56-64 % Humidity
5	A further 24 hours laid flat in a conditioned environment that varied between 19-22 °C at 56-64 % Humidity

Table 1 – Relaxation Procedures

The wale and course densities obtained during the various stages of relaxation are illustrated in Figure 7 and 8. It was observed that the carbon structure increased in the width and decreased in the length as the point of jamming occurred. Gradually as the energy within the structure was displaced the stitch sizes of the samples recovered to a stable state of minimum energy, which was independent of the take-down force applied during knitting.

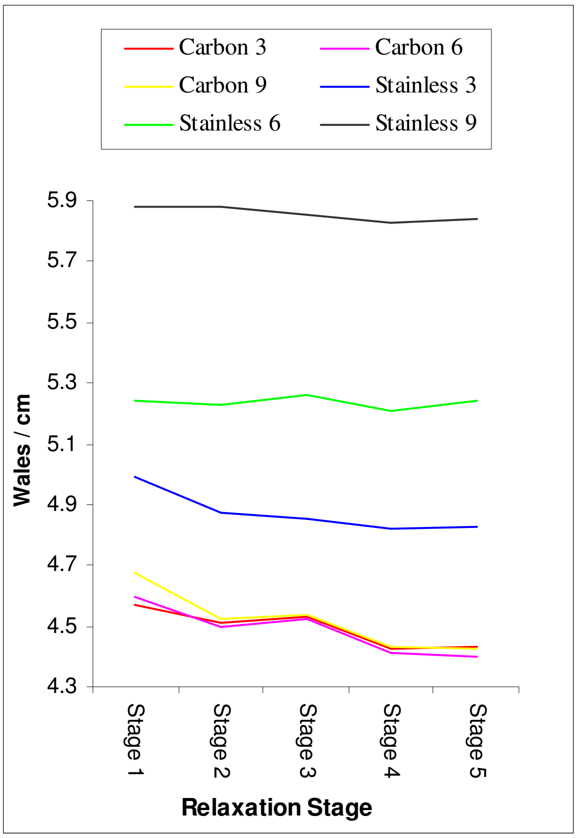


Figure 7: Wale Densities During Relaxation for Different Take-down Values

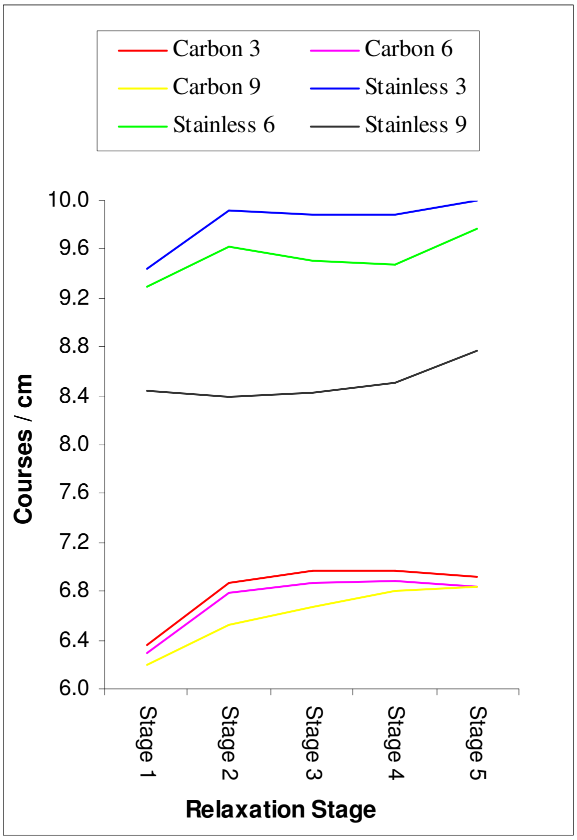


Figure 8: Course Densities During Relaxation for Different Take-down Values

The wale and course densities obtained from the stainless steel structure illustrate when jamming occurred, the structures were permanently affected by the take-down force during knitting.

This experimental study proved that the stitch shape was not solely dependant of the stitch size; various factors during knitting could influence the shape without having any affect on the length of yarn in the stitch. This highlighted a new factor that was previously not considered, the stitch orientation.

It was therefore, of fundamental importance that the orientation of the stitches be considered during structural analysis, due to it having possible affects on the flow of the current in electro-conductive applications.

Stitch Orientation. Illustrated in Figures 4 and 5 are samples of the structures knitted in each of the conductive yarns. It was observed that the carbon structure illustrated in Figure 5 was extremely uniform and it was proven that it had a good axis of symmetry along the wales. However, the stainless steel structure illustrated in Figure 4 did not have any axis of symmetry along the wale. This was due to the amount of energy within the structure causing the stitch to twist and lock at the point were maximum frictional forces occurred. It was thus, concluded that the structures knitted from the stainless steel yarn were not harmonious.

3-D Knitting the Covered Carbon Yarn

It was decided to knit the covered carbon yarn into 3-D shells in order to determine if shaping affected the balanced structural geometry. The chosen shell shape was a hemisphere; this was selected on the basis of its complexity. The surface plane passed through an angle of 180 °, which was considered an extreme curve, especially within the realms of flat-bed knitting. It was considered that if a model could be determined for the complexity of this shape; there was a possibility that a similar model could be used for less complex shell shapes.

The selected hemisphere was knitted to achieve a diameter of 150 mm and was based on the geometrical dimensions (wale and course densities) obtained from the planar fabric. The knitting plan of the hemisphere was calculated segment by segment and shaped utilising the technique of flechage to ensure a continuous electrical circuit could be obtained in further work. Figure 9 illustrates the 2-D knitting plan for a single segment of a six-segment hemisphere.

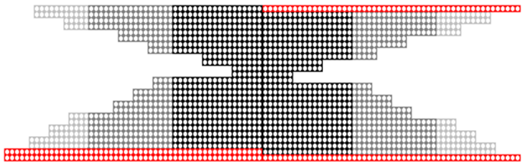


Figure 9: A Single Segment Knitting Plan

The resultant 3-D hemispherical shell knitted problem free, with slight modifications to the take-down values in various areas. However, this was not a major concern as it was proved prior that the carbon structure in the stable state of equilibrium was unaffected by the take-down force during knitting. The resultant hemisphere knitted from the carbon yarn is illustrated in Figure 10. It can be seen from the marked areas (blocks) of stitches that the geometry in different positions of the hemisphere was varying.

Figure 10: Covered Carbon Hemisphere

In order to prove how much this geometry was varying across the structure, the hemisphere was modelled around a 3-D former. The former was produced to the actual calculated dimensions of a hemisphere with a diameter of 150 mm. The geometry of the structure was obtained from various positions on the 3-D surface plane. Hence, the orientation of the wale was being included in the analysis.

It was found that the structural geometry was modifying as a result of the shaping that occurred integrally. It was also noted that the degree of the modification was dependant on the frequency and the shaping angle.

The wale and course densities were obtained in various areas around the hemisphere in order to assess the degree of structural change. It was found that the areas where the least shaping occurred (the middle segment shaded black in Figure 9) demonstrated only slight differences from the structural geometry obtained from the planar fabric in both the width and length. Generally as the divisions approached the selvedge areas (shaded light grey in Figure 9) they decreased in the width and increased in the length. It was therefore, concluded that the orientation of the stitch does affect the shape of the stitch enough to modify the fabrics' geometry significantly, which could have an adverse affect within electro-conductive textiles.

CONCLUSION

This paper discussed various issues regarding the knitability of conductive yarns. It has highlighted some of the problems associated with the delivery of the high modulus yarns; including high friction and lack of extensibility.

Past research identified that there are two possibly methods of controlling the dimensions of knitted fabrics. These were identified to be the stitch size and the stitch shape. This study concluded that a third factor was necessary to engineer the geometrical dimensions; the orientation of the stitch. It was found that there was a relationship between stitch shape and stitch orientation, which was reflected in the resultant fabric geometry. During the 3-D shaping of the hemisphere the wale and course densities were examined in various areas around the knitted shell shape. The resultant structural geometries obtained in these areas varied significantly depending on the amount of shaping that occurred in the surrounding stitches. This proved that 3-D shaping disrupted the stitch orientation enough to modify the locking point within the stitch shape.

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