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A STUDY OF FLAT- BED KNITTING TECHNOLOGY FOR THREE DIMENSIONAL PREFORMS

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A STUDY OF FLAT- BED KNITTING TECHNOLOGY FOR THREE DIMENSIONAL PREFORMS

Abstract

To enable shaped preforms to be produced accurately, it is essential to have a full understanding of the geometrical properties of the structure and the effects that the various shaping techniques produce. This publication discusses the technique of three-dimensional shaping and its affects on the geometrical dimensions of a hemispherical form.

In the paper the calculation procedures employed to produce a knitted hemisphere shape are defined and relationships are established between the planar structure and the three-dimensional preform. The first part of the study demonstrates three-dimensional shaping with conventional knitting yarns. However, it was acknowledged that technical textiles employ high or low modulus yarns (performance yarns) to enable the desired properties of the structure to be achieved. Therefore, in the second part the use of technical yarns in creating three-dimensional knitted structures is reported.

The results demonstrate that an interesting phenomenon was occurring involving distortions within the knitted structure. Further research is currently being undertaken to prove the theory that the internal distortions that occur as part of the shaping process are predictable and exact shapes can be produced. This will lead to the modelling of the hypothesis for a variety of structure types.

Introduction

Electronic weft knitting is a fibre conversion process of manufacturing textiles fabrics that is well established. This method of manufacture offers immense flexibility within the binding elements and the various techniques of shaping. It has the added advantage of fibre control, in the form of the amount of yarn delivered to a specified number of needles. Fibre control is especially vital within technical textiles were often the structural properties of the fabric are required to be harmonious throughout the product or form. The 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.

The modern flat-bed knitting machine has the most versatile patterning range (structural). Recent developments in CAD/CAM and machine improvements have made it commercially possible to produce complex mixtures of shaping and structure utilizing a variety of methods. This process has excellent potential for producing shaped three-dimensional preforms with a minimum amount of fibre wastage. Exact shaped preforms may be exploited within a variety of technical textile products and applications and have obvious advantages were raw materials are expensive. This paper discusses three-dimensional shaping and the geometrical relationships that occur as a direct result.

Background

In recent years, there has been an ever-expanding interest in the structural capabilities of textile structures especially in the field of technical textiles. This is 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 form is fabricated from a planar fabric. 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. Various publications have suggested that this deformation could be overcome by producing a loose fabric. However, this would in turn reduce the fibre volume in any given area, which could have a knock on affect on the overall properties of the structure.

The ideal solution is to utilize a method of shaping which could occur during the manufacturing of the initial structure. This would enable the deformation to occur as part of the structural mechanics, and no post draping would be required. Therefore, the shape produced would be far nearer to the final shape of the preform than that of planar fabric. There are various methods of achieving integrated three-dimensional shaping within the identified manufacturing techniques. However, many of the identified methods are limited to the actual shape of the preform that is produced. The most versatile textile manufacturing procedure is flat-bed knitting. The literature demonstrates that the past studies have concentrated on the actual tensile properties of the knitted structures instead of focusing on the technique of shaping and its affect on the structural properties.

It has been acknowledged that the flat-bed knitting machine has the advantage of producing double curved surfaces such as cubes, cones and spheres. 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 and has the added benefit of low set-up costs. However, limited work has been conducted into the affects of three-dimensional shaping in weft knitted structures. Previous studies include product related development which have resulted in various shapes being produced including; tubular elbows, boxes and hemispherical forms. However, the advanced properties of the products appeared to receive more publication than the geometry that was necessary to produce shapes. This provokes the assumption that an empirical procedure was adopted to determine the actual dimensions of the 3-D form. Brief attempts have been made to present some mathematical modelling to determine the course to wale relationships required for various shapes. However, none of these studies have acknowledged the fact that when utilizing different fibre types the structural mechanics during three-dimensional shaping may alter and therefore adjustments are required within the modelling for individual yarns and fibre types.

One identified problem encountered in a past study was the yarn control and the consistency of the amount of yarn delivered in each course. Yarn control is of utmost importance if near net shapes are to be produced. This study attempts to rectify the deficiencies in previous mathematical models by including a variable element, which relates to the modification that occurs within the structure caused by the shaping process. In order to achieve a true geometrical understanding, the stitch length must be controllable.

Aims and Objectives

The paper is a result of two separate studies; the first part examined how three-dimensional knitting affected the resultant fabric properties utilizing a conventional apparel yarn. The latter study examined various high performance yarns to establish a set of parameters on knitability and yarn control. The selected high performance yarns were then assessed in geometrical terms to obtain an understanding of the knitted structures behaviour during its relaxation. Finally, shaping utilizing the technique of flechage (holding or partial knitting) was introduced within the planar structure for a selected high performance yarn and the affects were studied.

Part One: Knitting Parameters

It is a known that it is essential in the engineering of advanced knitted structures and shaping to have a well defined geometry. Within the experimental processes procedures relating to the monitoring of the knitting parameters were addressed, and it was established that the most effective method of maintaining fabric quality was to ensure that the stitch length was consistent throughout the trials. It was acknowledged that the stitch length should be measured from the knitted structure soon after knitting and after relaxation has occurred.

The claim was made during the work that… "It is unlikely for the stitch density to be different on two pieces of fabrics if the stitch length is identical", when utilizing a conventional knitting yarn. However, it was proven that the stitch densities could vary whilst maintaining a constant stitch length. One major factor that accounted for this difference within the stitch densities was the amount of applied force during knitting (take down). During the stitch formation process the yarns that are formed into stitches undergo high stresses. After knitting the knitted structure attempts to return to a low energy state, the process is known as relaxation. This results in the modification of the shape of the stitches causing the stitch density to change. The dynamic yarn tension build up during the stitch formation process is influenced mainly by the yarn run-in tension and yarn frictional properties. However, various publications limit the possible effect of the fabric take down tension on the dynamic yarn-tension built up, at the final phase of forming a loop during weft knitting.

Planar Fabric

An experimental procedure was devised to examine the affects of various take down forces on the resultant stitch densities. A fabric width of 100 wales x 100 courses was knitted with an area of 50 wales by 50 courses marked where the two take down mechanisms applied the force. Seven individual samples were produced with take down forces that ranged from 3 – 9. The knitting constants and yarn properties are underlined,

Knitting Constants
- ❖ 14 gauge Stoll CMS 330.6.50.
- ❖ One knitting system (Leading system)
- ❖ Same feeder (Feeder 2) and yarn path
- ❖ Distance the feeder parked from edge (3-3)
- ❖ Machine Quality (13.0)
- ❖ Speed of carriage (0.5)

Yarn Properties
- ❖ 2/28 Clipper (45% acrylic and 55% viscose) (71 tex)
- ❖ Stitch Length 0.644 cm
- ❖ Tightness factor 1.3
- ❖ Relaxation: 16 hours conditioned environment

It was found that at a force of 6 the take down force or mechanism no longer had an affect on the structures geometrical dimensions (stitch density). The Analysis was further examined by considering different widths of structures ranging from 200 – 600 wales, utilizing an identical procedure as described previously. It was observed that the wider the width of fabric the greater the take down force that was required to enable the fabrics to recover to the same geometrical dimensions (this is illustrated in the Figure 1).

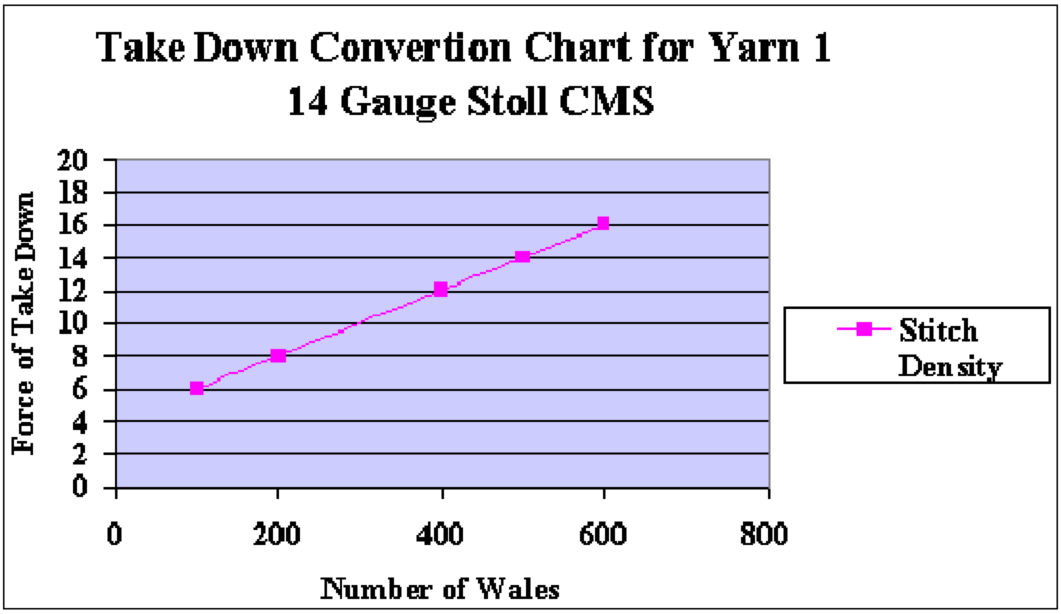


Figure 1

It was therefore concluded that a yarn of true elastic properties and a reasonable coefficient of friction enabled all the structures, independent of the take down force applied during knitting to recover to the same dimensions. However, it has been proven that not all yarns will conform to this theory.

Three-dimensional Shaping

A sphere is one of the most complex forms to produce due to its surface plane passing through an angle of 360°. This is considered to be an extremely severe curve especially within the realms of flat-bed knitting. If a geometrical model could be determined for the complexity of this shape there was a possibly that a similar model could be used to determine less severe forms. The hemisphere illustrated in Figure 2A was flattened out into a 2-D form (Figure 2B). Appropriate dimensions to produce the form can be calculated from the measurement known as the diameter (as indicated in Figure 2C, line AA). Initially the hemisphere was sub divided into six equal portions, therefore, θ in Figure 2D was equal to 180°/ number of segments. The circumference of the sphere was calculated utilizing the equation of πD (where D is the diameter). Therefore, lines AA and BB in Figure 2B are each equal to half of the circumference of the sphere. Knowing the angle θ and the diameter of the sphere allowed, by simple trigonometry substitution, the dimensions of K2, and K3 to be calculated.

The equations shown in Figure 3 were devised to calculate the hemispherical shape illustrated in Figure 2. It was observed that during the 3-D shaping procedure the geometry within the structure of the fabric was changing. The actual loop shape became wider and shorter within the resultant hemisphere than that of the original planar fabric. It was concluded from these findings that when calculating the stitch densities to achieve an accurate hemispherical form, a variable factor should be included within the equations that is a representation of the actual structural dimensions post knitting. This variable factor was found by experimentation for the selected yarn to equal a 14 % reduction in the wale density and a 11 % expansion within the course density. These values could be substituted into the modified equations illustrated in Figure 4.

It was thus concluded that for a balanced amount of the yarn within the structure, different functions could be introduced to define the stitch densities during three-dimensional shaping. The resultant hemisphere is illustrated in Figure 5.

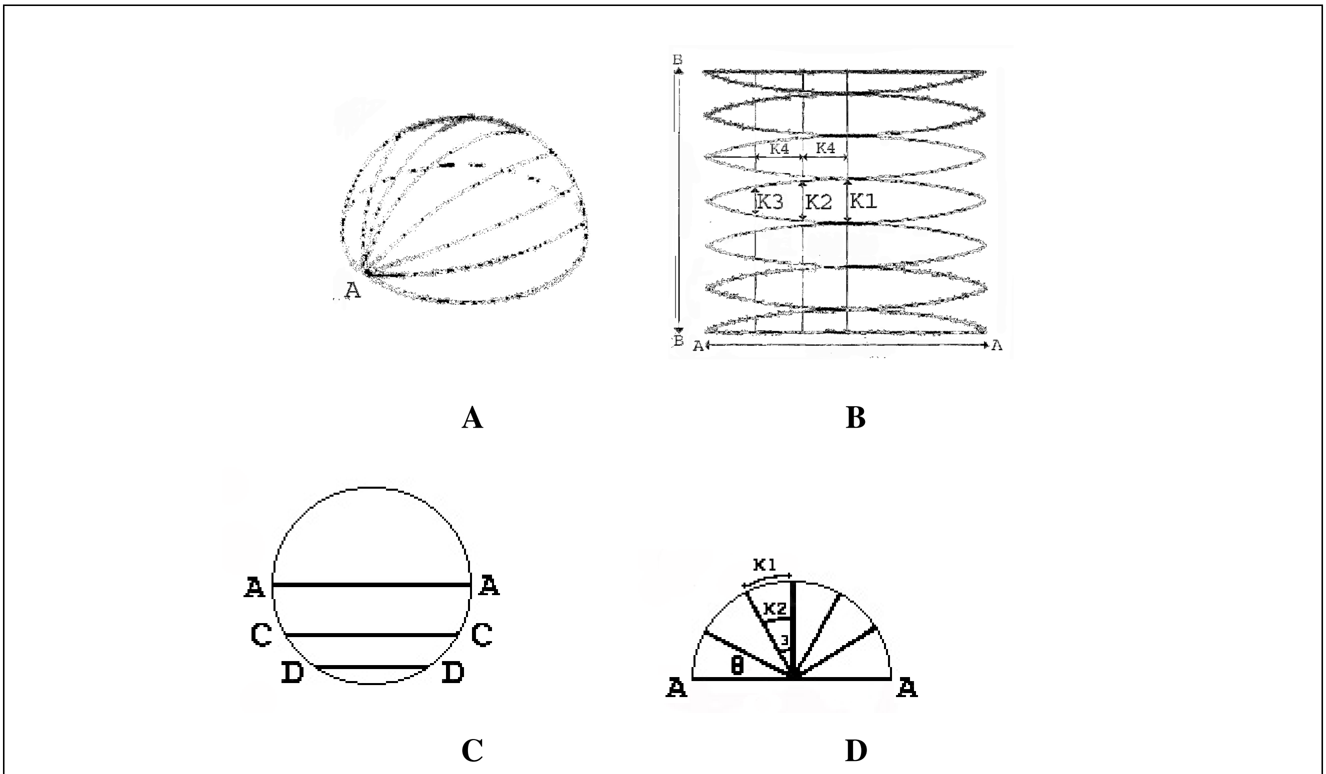


Figure 2

$$AA = \frac{\pi D}{2} \qquad K_1 = \frac{\pi D(\sin 3\theta)}{N}$$

$$K_2 = \frac{\pi D(\sin 2\theta)}{N} \qquad K_3 = \frac{\pi D(\sin \theta)}{N}$$

KEY

AA	See Figure 2B	D	Diameter
K	Dimensions as illustrated in Figure 2	N	Number of segments within 360°
θ	360° / Number of segments in sphere		

Figure 3

$$AA = \frac{\pi D}{2}\left[W - \left(\frac{W}{100} xE\right)\right] \qquad K_1 = \frac{\pi D(\sin 3\theta)}{N}\left[C + \left(\frac{C}{100} xB\right)\right]$$

$$K_2 = \frac{\pi D(\sin 2\theta)}{N}\left[C + \left(\frac{C}{100} xB\right)\right] \qquad K_3 = \frac{\pi D(\sin \theta)}{N}\left[C + \left(\frac{C}{100} xB\right)\right]$$

KEY

AA	See Figure 2B	W	Wales per unit (cm)
K	Dimensions as illustrated in Figure 2	C	Courses per unit (cm)
D	Diameter	E	Constant for selected yarn 14
N	Number of segments within 360°	B	Constant for selected yarn 11
θ	360° / Number of segments in sphere		

Figure 4

Figure 5

Part Two: High Performance Yarns

The second part of the study was split into three sections, calibration, knitted planar fabric and three-dimensional shaping. Three high performance yarns were selected; polyester monofilament, stainless steel multifilament and a special carbon yarn.

1. Calibration

The flat-bed knitting machine (Stoll CMS 330.6) used to produce the samples, consists of three individual knitting systems. To enable calibration of the stitch cams the stitch length was obtained over a predetermined amount of needles (200) for each individual cam system in both directions. It was found that the stitch cams could be balanced on the research machine within a reasonable variation, which amounted to a maximum of 3 cm for all of the trialled yarns. During this work four different yarn-feeding paths were examined. It was found that when utilizing high performance yarns the method of yarn feed was essential to ensure consistency between the individual knitting systems. It was observed in the cases of the stainless steel and carbon yarn that the most effective method of feeding the yarn was using the most direct yarn feed path. This was achieved by employing the NOVA Memminger IRO storage feed units. The feed wheel eliminated peaks in tension that previously inhibited high frictional yarns. By utilizing this method of feed for the stainless steel yarn the amount of frictional contact was significantly reduced and no further twist was introduced to an already twist lively yarn.

2. Planar Fabric

Plain knitted structure was utilized in all the experimental trials. Suitable states of relaxation were determined to examine the affects of take down force applied during knitting. Each high performance yarn was knitted employing different amounts of take down forces (low, medium and high). The fabrics were initially measured after five stages of relaxation, which are defined below. Further stages of relaxation differed for the individual yarn depending on their fibre composition; the stages are defined for each yarn type beginning at Stage 6.

Dry Relaxation

- **Stage 1**: The measurements 15 minutes after knitting.
- **Stage 2**: 24 hours laid flat at room temperature.
- **Stage 3**: A further 24 hours laid flat at room temperature.
- **Stage 4**: 24 hours laid flat in a conditioned environment that varied between 19 - 22 °C at 56 - 64 % Humidity.
- **Stage 5**: A further 24 hours laid flat in a conditioned environment that varied between 19 - 22 °C at 56 - 64 % Humidity.

Carbon yarn: **Stages 6-10**: Static Wet Relaxation

- Fabric laid flat in a tray containing water and a wetting agent for 12 hours, initial temperature of water 30°C.
- Hydro extracted
- Laid flat in a controlled environment for 24 hours.

Carbon yarn: **Stages 11-16**: Wet Relaxation

- Stages 11-16: Machine washed at a wool setting of 40°C.
- Stages 11-15: Dried at room temperature for 24 hours.
- Stage 16: Laid flat in a controlled environment for 24 hours.

Stainless Steel: **Stages 6-8**: Further Dry Relaxation

- A further 24 hours laid flat in a conditioned environment that varied between 19 -22 °C at 56 - 64 % Humidity.

Stainless Steel: **Stages 9-12**: Wet Relaxation

- Soaked in an oil bath for two minutes.
- 24 hours laid flat in a conditioned environment that varied between 19 - 22 °C at 56 - 64 % Humidity.

Polyester Monofilament: **Stages 6-7**: Further Dry Relaxation

- Stage 6: A further 24 hours laid flat in a conditioned environment that varied between 19 - 22 °C at 56 - 64 % Humidity.
- Stage 7: After a months storage at room temperature.

Polyester Monofilament: **Stages 8**: Heat Set

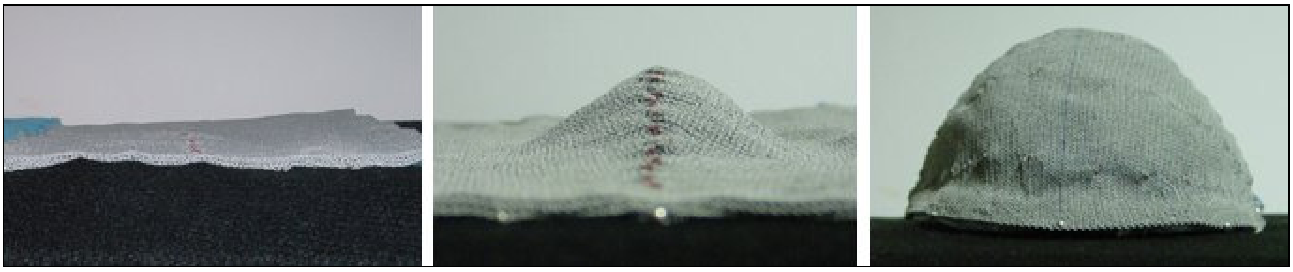
Preheat oven to 200°C, sample placed in oven flat, allow temperature to rise to 180°C, leave for 20 seconds and finally remove from oven and allow to cool.

Results

The yarns were found to be non-comparable, only one of the structures knitted from the high performance yarns (carbon) totally recovered from the affects of the take down tension. Three stable states of minimum energy were thus found for the carbon yarn at Stage 5 (dry relaxed), Stage 10 (static wet relaxed) and Stage 16 (wet relaxed). All the structures knitted from the stainless steel and polyester monofilament did not recover from the force of take down applied during knitting. Within the geometry of the stainless steel yarn a locking occurred in the width dimension during the knitting process and therefore only slight relaxation happened within the length and thickness of the structure. The polyester monofilament yarn was a complex yarn to analysis due problems regarding the controllability of the yarn during knitting. Different stitch lengths were obtained where the various take down forces had been applied. This concluded that the yarn was not controllable enough for precision shaping to occur.

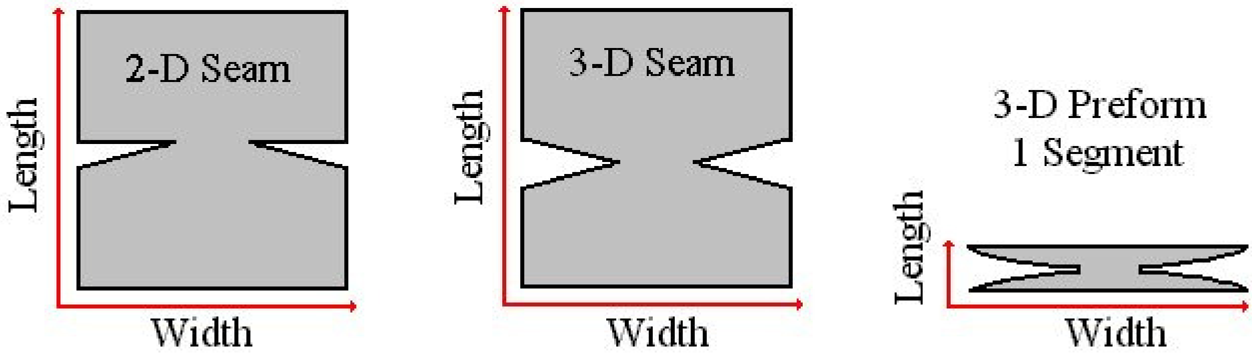
3. Three-dimensional Shaping of the Special Carbon Yarn

The final section examined how the mechanics within the structure during shaping (flechage technique) affected the geometrical dimensions of the fabric. The selected high performance yarn was the carbon, again the plain knitted structure was employed and the dry relaxed state was considered within the experimentation. Three steps of shaping were considered; these were termed the 2-D seam (half of a segment from the hemisphere), 3-D seam (a full segment from the hemisphere) and the 3-D preform (hemisphere = five full segments and two halves of segments). The final fabrics are illustrated in Figure 6. All the results were analysed assuming the flechage line was straight (horizontal), the measurements of the dimensions at each flechage step was determined both above and below the flechage line (Figure 7). It must be noted that within the samples of the 2-D seams and 3-D seams the flechage areas were enclosed in sections of plain knitting (50 or 60 courses).



2-D Seam 3-D Seam 3-D Preform

Figure 6



2-D Seam 3-D Seam 3-D Preform

Figure 7

<u>Results</u>

The results of the 2-D seam showed good agreement with the calculated dimensions within the overall width (see Figure 8). However, the course density was decreasing indicating that the fabric was elongating slightly. Within the 3-D seam (Figure 9) different results were obtained, the overall width of the actual structures fell short of the calculated dimensions. However, the length showed good agreement, with the exception of the selvedge areas (structure elongated). The hemisphere (3-D preform illustrated in Figure 10) generally fell short within the width dimensions and the length. It was thus concluded that when utilizing the technique of 3-D shaping the length and the width measurements do not conform to the calculated dimensions.

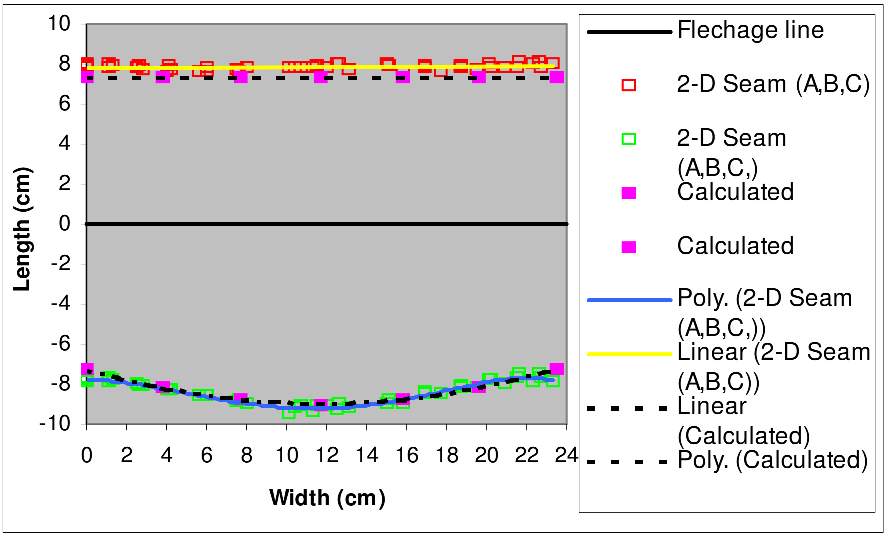


Figure 8: Results of the 2-D Seam

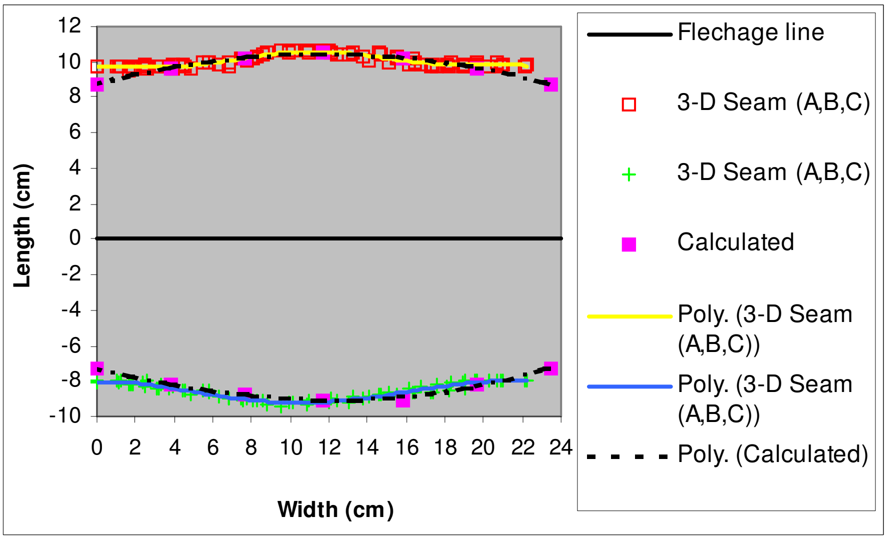


Figure 9: Results of the 3-D Seam

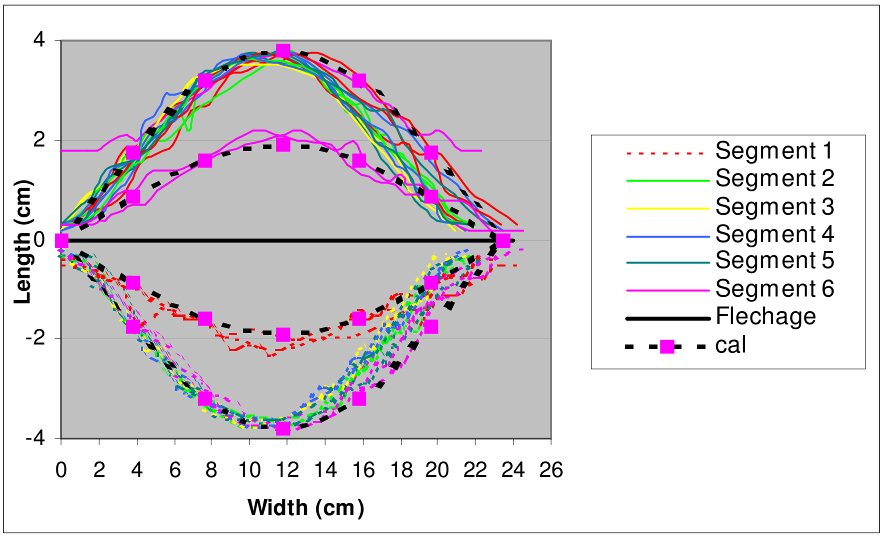


Figure 10: Results of the 3-D Preform

Conclusion

The works described in this paper, met the original objectives outlined. The findings and observations have been summaries in bullet form.

- The knitting machine (Stoll CMS 330.6) could be calibrated to deliver constant stitch lengths between the individual cam systems, within a maximum variation of 3 cm.
- It was found that the selected yarn path was a major influencing factor regarding yarn control (especially within the high performance yarns).
- The plain knitted structures produced from carbon yarn fully recovered from the affects of the various take down forces applied during the knitting process.
- Three stable states of equilibrium existed for the structures knitted from carbon yarn. These were defined as the dry, static wet and wet relaxation stages.
- The stainless steel multifilament and the polyester monofilament yarn did not appear to recover from the affects of the take down force during relaxation.
- It was also found that the fabrics' geometrical dimensions were functions of the stitch length and variables of the loop shape, which was dependant upon the bending within the fabric plane.
- Finally, it was concluded that when utilizing the technique of three-dimensional shaping the stitch densities of the planar fabric are modified thus, the actual dimensions of the hemisphere preform do not conform to the calculated. This is currently under further investigation.

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