DESIGN OF ELASTIC GARMENTS FOR SPORTS IN CIRCULAR KNITTING

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ABSTRACT

The movements involved in most active sports require a certain level of stretch to compensate the difference between skin's elasticity and the lack of elasticity in conventional fabrics. Elastic textiles can improve the ease of movement of clothing and enhance the ergonomic wear comfort. The use of elastane (spandex) in circular knitting allows the production of fabrics that are molded to the body as a second skin and maintain their modeling without deformation during the product life. There are only few studies on knits behavior and especially about the possibilities of circular machine setup and their consequences in the final product. This study aims to show how, through the use of design of experiments (DOE), it is possible to optimize these adjustments in order to obtain certain characteristics in the final product. Using a $2^2$ factorial design, were analyzed and defined the best adjustments of polyamide’s LFA (loop length) and elastane’s tension to achieve the required level of weight per area, thickness and elongation, with the smallest percentage of elastane.

KEYWORDS: Knitting, Sport Garments, Polyamide, Elastane(Spandex), Design of Experiments

INTRODUCTION

The growth in textiles consumption reflects, among others, a significant increase in the interest of the population for sporting goods, especially due to lifestyle.

According Shishoo (2005), sportswear and sporting goods have not only contributed to the diversity of the market, but also for the growth of science and textile technology. The various aspects of performance require different material properties and at the same time, must meet the needs of the consumer. The development of new technologies, fragmented niche markets and the increasing demand of consumer expectations are the factors driving the industry. To be inserted in this context industries are implementing practices to develop new products and in order to expand the market, are improving their strategic positions, productivity, value-added niches and their arrangements.

Voyce, Dafniotis and Towlson (2005) says that optimizing athlete's performance by providing freedom of movement, maximizing comfort, minimizing the risk of injury or muscle fatigue is an important role play by stretch garments for sports. The major applications are:

- Garments where comfort and fit are most important
- Compression garments where stretch garments play an important part in improving several aspects of an athlete's performance (speed, stamina and strength). Moreover, all sports involve the build-up of lactic acid in the muscles, which causes soreness/fatigue. As muscles get tired they become less disciplined, increasing the risk of injury. The compression helps keep muscles in line and in right position to reduce the risk of injury during exercise.

This study aims to show how it can be determined, through the design of experiments, the settings of the circular machine to obtain certain characteristics of comfort and performance in elastic knits with elastane, which will be used for sports.
LITERATURE REVIEW

According McCann (2005), the design of sportswear products can be classified according the diagram in figure 1. This study focused on the "functionality" axis, i.e., in the manufacture of an article that features mesh protection and athletic performance.

![Figure 1: Sportswear Design Source: Adapted from McCann (2005)](image)

Bartels (2005), says that textile comfort rests on three pillars: elasticity, thermal regulation and touch. Vasconcelos (2006) placed as important properties of textile connected to comfort: regain, liquid retention, thermal conductivity, type of yarn, fiber fineness, fiber cross-section, type of tissue, tissue thickness, number and proximity to the body layer. The combination of the factors cited by Vasconcelos (2006) determines the behavior of each of the Bartes’s axes. This study focuses elasticity axis.

The difference between skin elasticity and the low elasticity of conventional tissue results in restriction of movement and loss of comfort (VOYCE, DAFNIOTIS and TOWLSON, 2005).

Stretch fabrics can be manufactured using the following methods:

- Fiber with elongation characteristics, such as rubber and synthetic elastomers due to the geometry of the molecular chain of these fibers.
- Processing the crimp yarn by thermal or chemical means, as well as the texturing method (or false twist method).
- Fabric structure, such as the circular knitting fabric.
- Finish the fabric by fabric compression, addition of silicone rubber or elastic laminate application.

Figure 2 shows elasticity requirements to be minimally assisted by the textile article to accompany certain body movements.

![Figure 2: Body Movements. Source: Voyce, Dafniotis and Towlson (2005)](image)
According to Voyce, Dafniotis and Towlson (2005), simple body movements, like bending your elbows or knees, cause the skin to stretch up to 50%. Movements involved in strenuous sports require stretching further. The dramatic difference between the elasticity of the skin and the lack of tissue elasticity results in conventional restrictions of movement for the athlete and the consequent performance loss. Elastane (spandex), even when applied in small quantities, provides the necessary elasticity so that a piece of sports clothing can respond to each body movement and return to its original size and shape.

However, Umbach (2001) show that the use of elastic yarns should consider that elastane is non-hygroscopic (cannot absorb moisture within their structure) and hydrophobic (cannot be wettable by liquid sweat) which reduces the thermo physiological wear comfort. In addition, elastane yarns are very smooth, which worsens the skin sensorial wear comfort.

The use of spandex in circular knitting has enabled the production of fabrics that are shaped to the body as a second skin and maintain their modeling without deformation during the product life. There is a currently increasing in the number of products containing elastane in the collections of male and female fashion, sportswear and lingerie because of the aforementioned attributes and also due to decrease of elastane prices, mainly caused by increasing of the number of competing manufacturers, particularly in Asia.

Regardless of the fabric fabrication process, the spandex is always used together with another fiber and not individually (Abdessalem et al, 2009). According Marmarali (2003) there are two different ways of use of the spandex in circular machines: bare or covered. When covered, spandex is surrounded by other yarn in coating process. This kind of yarn is not widely used in large-diameter circular machines, limited primarily to those which do not allow the use of an adequate positive feed system (Araujo e Castro, 1986), because its price is high in comparison to bare elastane, which results in a cost/benefit unrewarding.

Thus, the prevailing system in the majority of circular knitwear is the use of bare elastane with another yarn (called rigid yarn) in order to establish a plated loop (Spencer, 2001), where the two yarns form parallel loops and the rigid yarn covers the spandex which is only visible in the underside of the fabric as shown in figure 3.

According Lyer et al (1997), to attend this training, the yarns should be fed at different levels in the same feeder, as shown in Figure 4 with different working tensions.
PRODUCT DEFINITION

The article to be produced should have the following characteristics:

- The article should present high rate of elongation in both directions but not too high to maintain a certain level of compression (VOYCE, DAFNIOTIS AND TOWLSON, 2005);
- Processing will be made in circular knitting to obtain greater stretch (TEZEL and KAVUSTURAN, 2008);
- It should be use synthetic yarn instead of cotton because in sport textiles, a short drying time is one of the main prerequisites for a good wear comfort (BARTELS, 2005);
- Use of polyamide microfiber yarn textured to meet the requirements for thermal regulation and touch (GASI, BITENCOURT AND VASCONCELOS, 2010);
- It must use an elastomeric yarn (to provide greater elastic recovery) in the lowest percentage possible for lower cost and do not affect the others characteristics like touch and comfort (UMBACH, 2001).

MATERIALS AND METHODS

This study aims to determine the optimal setup of the circular machine to get some comfort / performance features in mesh Polyamide / elastane, which will be used for sports, using the method of experimental design, as proposed by Sanches (2006) at flow shown in figure 5.

The following yarns were used:

- Rigid yarn of polyamide 6.6: 80dtex x 2 textured.
- Elastane yarn: 44 dtx (40 den).

Samples were produced in a circular machine with the following specifications:

- Brand / model: Mayer Relanit
- jauge (needles/inch): 28
- Diameter (inch): 30
- Needles: 2640
- Feeders: 96
The study was conducted using a factorial design $2^2$. Concepts of experimental design as replication and randomization of the samples were used (MONTGOMERY, 1991).

In this study the variation factors are:

- polyamide LFA (A)
- elastane tension (B)

The response variables are:

- weight per area (g/m²)
- thickness (mm)
- elastane %
- elongation % in both directions of the fabric.

For definition of the tests a $2^2$ factorial design were used, considering that the relationship between the variables studied are linear (Abdessalem et al, 2009). The variation factors and their levels are shown in Table 1 while the LFA values in cm / revolution are shown in Table 2.

### Table 1: Factors and Levels

<table>
<thead>
<tr>
<th>Factors</th>
<th>Level</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyamide LFA(cm/machine tour)</td>
<td></td>
<td>830</td>
<td>970</td>
</tr>
<tr>
<td>Elastane tension (cN)</td>
<td></td>
<td>3,000</td>
<td>7,000</td>
</tr>
</tbody>
</table>

### Table 2: Design of the Experiments

<table>
<thead>
<tr>
<th>Amostra</th>
<th>StdOrder</th>
<th>RunOrder</th>
<th>CenterPt</th>
<th>Blocks</th>
<th>LFA PA</th>
<th>Tensao EL</th>
<th>PA(mm)</th>
<th>Stich cam</th>
<th>RQ</th>
<th>EL(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>830</td>
<td>3</td>
<td>1</td>
<td>173</td>
<td>11</td>
<td>237</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>970</td>
<td>3</td>
<td>1</td>
<td>173</td>
<td>11</td>
<td>156</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>830</td>
<td>7</td>
<td>1</td>
<td>173</td>
<td>15</td>
<td>188</td>
</tr>
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<td>4</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>970</td>
<td>7</td>
<td>1</td>
<td>203</td>
<td>15</td>
<td>264</td>
</tr>
<tr>
<td>1A</td>
<td>5</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>830</td>
<td>3</td>
<td>1</td>
<td>203</td>
<td>15</td>
<td>264</td>
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<tr>
<td>4A</td>
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<td>1</td>
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<td>3</td>
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<tr>
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<td>830</td>
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<tr>
<td>3A</td>
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<td>7</td>
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<td>1</td>
<td>970</td>
<td>7</td>
<td>1</td>
<td>203</td>
<td>15</td>
<td>264</td>
</tr>
</tbody>
</table>

Note: LFA PA in cm/machine tour; EL Tension in cN

The design shown in Table 2 was carried out with Minitab software with factors and levels of Table 1 and a total of eight runs.

In accordance with the planning in Table 2 were produced samples with the settings in Table 3. Two samples of each setup were produced as a result (run order) in Table 2.

### Table 3: Setup of Circular Machine

<table>
<thead>
<tr>
<th>Samples</th>
<th>LFA PA</th>
<th>EL Tension</th>
<th>RQ PA(mm)</th>
<th>Stich cam</th>
<th>RQ EL(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1A</td>
<td>830</td>
<td>3</td>
<td>173</td>
<td>11</td>
<td>237</td>
</tr>
<tr>
<td>2 2A</td>
<td>830</td>
<td>7</td>
<td>173</td>
<td>11</td>
<td>156</td>
</tr>
<tr>
<td>3 3A</td>
<td>970</td>
<td>7</td>
<td>203</td>
<td>15</td>
<td>188</td>
</tr>
<tr>
<td>4 4A</td>
<td>970</td>
<td>3</td>
<td>203</td>
<td>15</td>
<td>264</td>
</tr>
</tbody>
</table>

RQ = quality wheel diameter
After production, the raw samples were resting for a week and then were washed, centrifuged and dried to allow a relaxation of internal stress as specified in the following Table 4.

### Table 4: Relaxation Process

<table>
<thead>
<tr>
<th>Relaxation Process</th>
<th>Apparatus</th>
<th>Time</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Rest</td>
<td>Table</td>
<td>1 week</td>
<td>room</td>
</tr>
<tr>
<td>2-Wash</td>
<td>Washing Machine</td>
<td>45 min</td>
<td>room</td>
</tr>
<tr>
<td>3-Centrifugation</td>
<td>Centrifuge</td>
<td>1 min</td>
<td>room</td>
</tr>
<tr>
<td>4-Dry</td>
<td>Oven</td>
<td>60 min</td>
<td>60 °C</td>
</tr>
<tr>
<td>5-Conditioning</td>
<td>Table</td>
<td>48h</td>
<td>room</td>
</tr>
</tbody>
</table>

Then the samples were subjected to tests to determine the weight per area, thickness, elongation and elastane percentage.

The weight per area and thickness were determined according to respectively ABNT - NBR 10591 and ABNT - NBR 13383.

The elongation values were determined using JIS - L 1018. To meet the requirements of the knit considered, the loads have changed in relation to the original standard, using the following values:

- \( L = \) measured with pre-load of 30 gf
- \( L_0 = \) measured after 1 min with a load of 600 gf
- \( L_1 = \) measured after 3 min pre-load of 30 gf

The percentage of spandex in the samples was determined according to ABNT - NBR 11914.

### RESULTS AND DISCUSSIONS

The data obtained from tests conducted on sample are shown in Table 5.

### Table 5: Results

<table>
<thead>
<tr>
<th>Amostra</th>
<th>Std Order</th>
<th>Run Order</th>
<th>LFA (cm revolutions)</th>
<th>EL Tension (cN)</th>
<th>Weight per area (g/m²)</th>
<th>Thickness (mm)</th>
<th>Elongation (%)</th>
<th>Elongation Courses(%)</th>
<th>% Elastano</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>830</td>
<td>3</td>
<td>326,6</td>
<td>0,634</td>
<td>73,8</td>
<td>51,4</td>
<td>10,6</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>6</td>
<td>830</td>
<td>7</td>
<td>337,0</td>
<td>0,664</td>
<td>66,9</td>
<td>46,7</td>
<td>8,7</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>10</td>
<td>970</td>
<td>7</td>
<td>361,4</td>
<td>0,808</td>
<td>111,5</td>
<td>81,7</td>
<td>9,3</td>
</tr>
<tr>
<td>1A</td>
<td>5</td>
<td>8</td>
<td>830</td>
<td>3</td>
<td>321,9</td>
<td>0,624</td>
<td>76,0</td>
<td>50,3</td>
<td>10,1</td>
</tr>
<tr>
<td>4A</td>
<td>6</td>
<td>5</td>
<td>970</td>
<td>3</td>
<td>335,0</td>
<td>0,776</td>
<td>111,5</td>
<td>81,7</td>
<td>10,6</td>
</tr>
<tr>
<td>2A</td>
<td>7</td>
<td>1</td>
<td>830</td>
<td>7</td>
<td>334,1</td>
<td>0,648</td>
<td>69,2</td>
<td>48,5</td>
<td>8,4</td>
</tr>
<tr>
<td>3A</td>
<td>8</td>
<td>7</td>
<td>970</td>
<td>7</td>
<td>355,2</td>
<td>0,802</td>
<td>113,9</td>
<td>89,5</td>
<td>9,0</td>
</tr>
</tbody>
</table>

The values obtained were then analyzed with the aid of the program Minitab. Table 6 shows the p values for the influence and interaction of the factors among the five effects studied. P values less than 0.05 are noted in red.
Table 6: ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Weight Per Area</th>
<th>Thickness</th>
<th>Elong.Wales</th>
<th>Elong.Courses</th>
<th>% Elastano</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFAPA (cm/revolution)</td>
<td>0.002</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.052</td>
</tr>
<tr>
<td>ELtension (cN)</td>
<td>0.004</td>
<td>0.007</td>
<td>0.047</td>
<td>0.567</td>
<td>0.001</td>
</tr>
<tr>
<td>Interaction</td>
<td>0.127</td>
<td>0.928</td>
<td>0.069</td>
<td>0.650</td>
<td>0.716</td>
</tr>
</tbody>
</table>

It can be observed, at 95% confidence level, that the factors of influence on the response variables which are statistically significant (p < 0.05) are:

- weight per area: polyamide LFA and elastane tension
- thickness: polyamide LFA and elastane tension
- Elongation at wales (length sense): only polyamide LFA
- Elongation at courses (width sense): only polyamide LFA
- Elastane percentage: only elastane tension

The graphs of Figure 6, show relations of weight per area, thickness, elongation in width and length and the percentage of spandex to both factors, polyamide LFA and elastane tension.

With the above modeling it is possible to define conditions for setting the machine for certain properties in the final fabric. If we consider, for example, produce a fabric having the following characteristics:

- weight per area between 325 and 335 g/m²
- thickness at most 0.7 mm
- elongation in width between 50 and 80%
- elongation in length between 50 and 80%
- elastane percentage at most 10.0%

The Minitab tool “overlaid contour plot”, gives the graph of Figure 7, where the white area is the response surface that meets the conditions proposed. In this graph, the response with less elastane tension and less polyamide LFA elastane that caters to the conditions originally proposed is marked.
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Weight per area = 0,132 LFA + 3,90 TEL + 201,4

Thickness = 0,001 LFA + 0,007 TEL – 0,275

Elongation wales = 0,30 LFA – 173,7

Elongation courses = 0,26 LFA – 167,1

% Elastane = - 0,43 TEL + 11,9

Figure 6: Surface Graphs

Thus, using in the machine setup:

- polyamide LFA of 849 cm/revolution and
- elastane tension of 4.4 cN,
It will be obtained a jersey with the following characteristics in relaxed state:

- 330.0 g/m² of weight per area,
- 0.659 mm of thickness
- 54.5 % elongation in width,
- 77.8 % elongation in length
- 9.8 % of elastane.

CONCLUSIONS

This paper sought to show how to use the procedure for knit development to obtain certain characteristics in the final product. It was applied the Design of Experiments methodology to show the impact of each process variable, both individually and their interaction and to determine the relationship between the machine setup and tissue properties.

It was verified that weight per area and thickness are influenced by rigid yarn LFA and elastane tension. On the other hand, the rigid yarn LFA (polyamide) is the main responsible by the elongation of the knit. The tension of the spandex has its importance mainly in spandex percentage and elastic recovery.

The machine adjustments were optimized and defined to meet previously specified performance properties and cost of the fabric.

It is proposed for future works, applying the same procedure considering a broader set of fabric properties.

REFERENCES

5. GASI, F., BITENCOURT, E., VASCONCELOS, F.B. (2010). Estudo Comparativo Das Propriedades De Permeabilidade Ao Vapor Transporte De Umidade E Proteção Ultravioleta Em Malhas De Poliamida 6.6 E Poliéster Com Elastano, Química Têxtil, ano XXXIII, nº 98.
9. MARMARALI, A.B., Dimensional and physical properties of cotton/spandex single jersey fabrics, Textile Research Journal, vol. 73, p. 11-14