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Correspondence Between Yarn Characteristics And The Tensile Strength Of A Fabric

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Abstract— This article illustrates a study on the tensile strength of a fabric made with a tile reinforcement. More precisely in this work, we will observe the evolution of the tensile strength of a fabric in relation to the characteristics of the yarns which constitute it. During the experiment, an evaluation of the batches of yarns constituting the fabric was carried out and then modeling of the tensile strength of the fabrics based on these yarn characteristics was carried out. Several characteristics are to be considered, namely: the resistance of the yarn, the real metric number, the elongation of the yarn, the kilometric resistance and the hairiness index. Also, this work places importance on the mathematical modeling of the evolution of the tensile strength of fabrics which is associated with these respective precision parameters. The precision associated with the models in this article are represented by relative and absolute errors.

Keywords— Strength, fabric, RKM, Coefficient of variation, elongation.

I. Introduction

With technical and technological developments in textile manufacturing, customers are increasingly demanding, which pushes manufacturers to improve and innovate textile manufacturing processes. In order to know the evolution of the parameters associated with the fabric, tests are carried out and among these tests there is the tensile strength of the fabrics.

The tensile strength of a fabric is one of the main parameters which influences its stability. Generally, this parameter depends on the technical characteristics of the yarns which constitute the fabric. These characteristics vary depending on the type, the origin of the yarns but above all the difference lies in the result of the test done in order to determine its identity, namely: its metric number, its kilometric resistance but also by the characteristics such that these imperfections.

Then, this article illustrates the relationship between the constituent yarn characteristics of a fabric and the tensile strength of this fabric. The work is divided into two parts, the first concerns about the determination of the yarn characteristics of the fabric and the second is the physical test on the tensile strength of the fabric. These two studies will be linked by a mathematical cause and effect model.

II. Methodology Of Fabric Resistance

2.1. Measuring principle

Measuring fabric strength refers to the force required for a fabric to reach its breaking point. To evaluate the resistance of the fabric it is important to carry out a dynamometric study. To do this, a rectangular test piece must be placed between two clamps, one clamp is fixed, the other is mobile and moves at constant speed in order to apply a tensile force on the fabric.

During testing, the entire system must be stable and free from deviation. The measuring cell automatically transfers the measurement data to the computer which then provides us a curve of force as a function of elongation (see figure 1) on which we can record or calculate the breaking force, the breaking stress , the maximum deformation, the energy required for rupture and the Young's modulus.

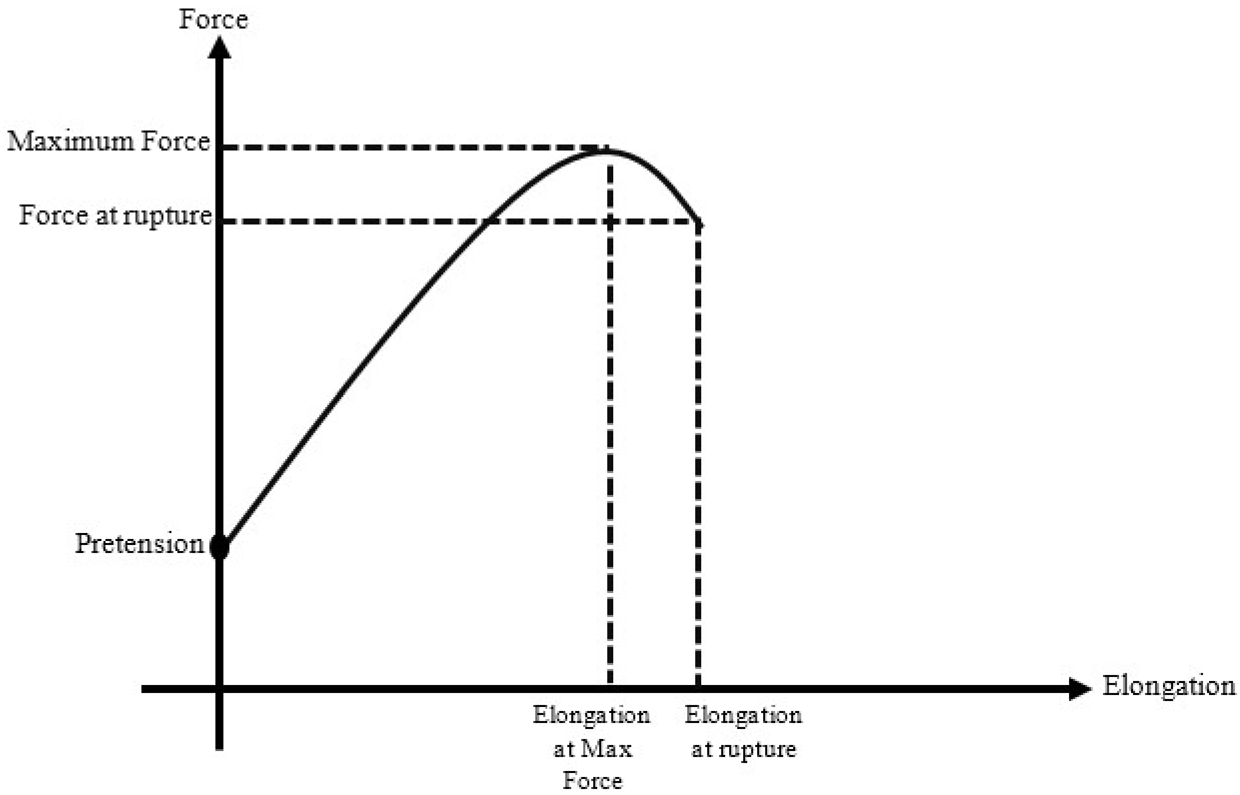

Fig. 1. Curve of the evolution of force as a function of elongation

2.2. Sampling method

In order to have reliable results, it is essential to carry out tissue sampling according to the rules of the art. To do this, the method requires having samples that meet these 6 criteria, namely:

- The dimension of the test piece must be 50±0.5 mm in width and 200 mm in length. However, the length of a test piece can be reduced to 100 mm depending on the desired experiment and the type of fabric.
- For each sampling, two samples must be cut, one in the warp direction and the other in the weft direction.
- 5 pairs of test pieces should be considered when sampling a fabric.
- Pairs of samples should not contain the same longitudinal or transverse yarns.
- No sample should be taken closer than 150mm from the edge of the fabric.

Figure 2 illustrates an example of sampling a fabric for tensile strength testing:

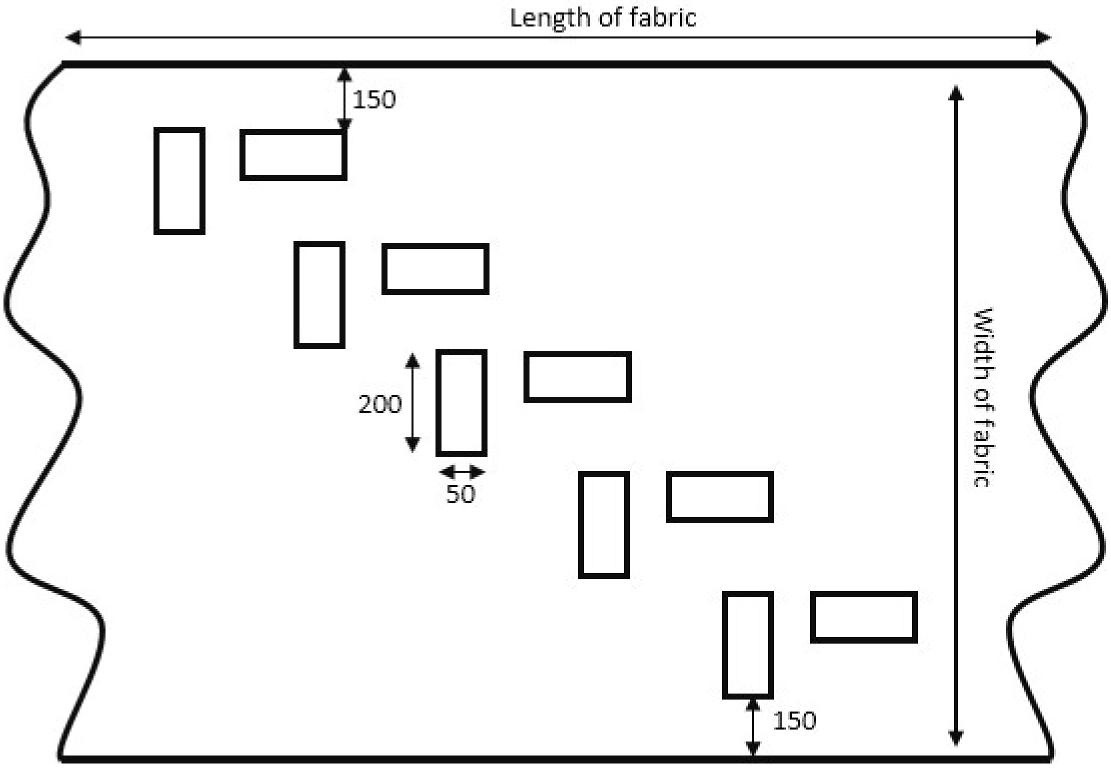

Fig. 2. Sampling a fabric

2.3. Calculation and measurement of tensile strength

Resistance is one of the physical parameters of a fabric which allows us to know the resistance of a fabric to traction. This quantity is a reference for fabric stability which is generally dimensioned in Newton [N].

During our experiments, we used a dynamometer device at constant elongation rate in which values are dimensioned in kilogram – force [Kgf].

For the calculation, it is necessary to take the arithmetic average of the force for each direction tested, which means for the 5 pairs of test pieces.

III. Presentation Of The Fabric

This work aims to see the impacts of the yarn characteristics of the fabrics's constituent yarns of the fabrics on the maximum force parameters of the fabric's tensile strength of a fabric. Nevertheless, the overall characteristics of the yarns used during the experiments are illustrated in Table 1. The fabrics adopted during this work are cotton-based fabrics with an average weight of 117 g/m2. The fabric is composed of 55% cotton and 45% linen.

The specific yarn characteristics of the yarns such as mileage strength, elongation, tensile strength, hairiness index and actual metric number are detailed and studied in order to see their impact on the strength of the tensile strength of the yarn fabric.

TABLE I. . OVERALL CHARACTERISTIC OF THE CONSTITUTING YARNS OF FABRICS

Settings	*Chain yarns*	*Weft yarns*
Coefficient of variation	*1,06*	*1,06*
Yarn density [/cm]	*23*	*19*
Imperfection	*1130*	*1130*
Spinning system	*Card*	*Card*

IV. Presentation Of The Results

This work relates the correspondence between the technical characteristics of the yarns and the force linked to the tensile strength of the fabric. During the experiment, two tests were carried out. The first test consists of analyzing batches of yarn for making a fabric and the second is measuring the force corresponding to the tensile strength of the fabric. Then, this part is focused on the presentation of the concordances between the two tests.

4.1. Relationship between tensile strength of fabric and tensile strength of yarn

4.1.1. Results on the warp direction of the fabric:

For samples taken in the warp direction of the fabric, Figure 3 represents the relationship between the tensile strength of the fabric and the yarn constituting the fabric as well as the useful width of the fabric.

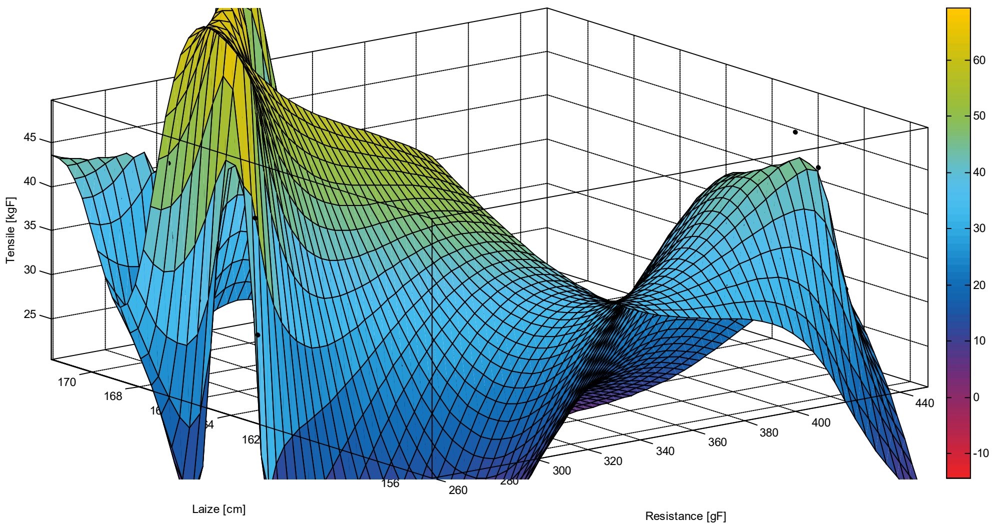

Fig. 3. Warp tensile strength of the fabric depending on the strength of the yarn and the width

We note that the value of the tensile strength of the fabric oscillates around 30 kgF. Removing the fabric width data yields Equation 1 which illustrates the relationship between the tensile strength of the fabric and the strength of the yarn:

$$Ts(x) = 39{,}5 \exp\left(-\left(\frac{x-368{,}7}{170{,}6}\right)^2\right) \qquad (1)$$

x: represents the resistance of the yarn in [gF]

Ts(x): Warp tensile strength of fabric [kgF]

The characteristic curve of this equation is given by figure 4:

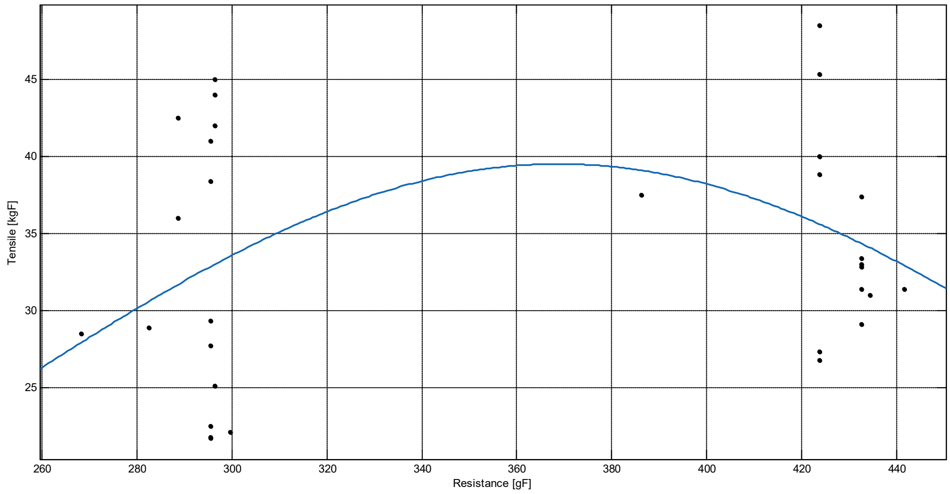

Fig. 4. Resistance of the warp fabric as a function of the resistance of the yarn

The respective absolute and relative errors of equation 1 are:

- Absolute error : $\Delta DS = 2{,}05\ [kgF]$
- Relative error : $\frac{\Delta DS}{DS} = 5{,}63\%$

4.1.2. Results on the weft direction of the fabric:

Figure 5 illustrates the relationship between the tensile strength of the yarn, the useful width of the fabric and the resistance of the yarn for the test pieces taken following the weft direction of the fabric

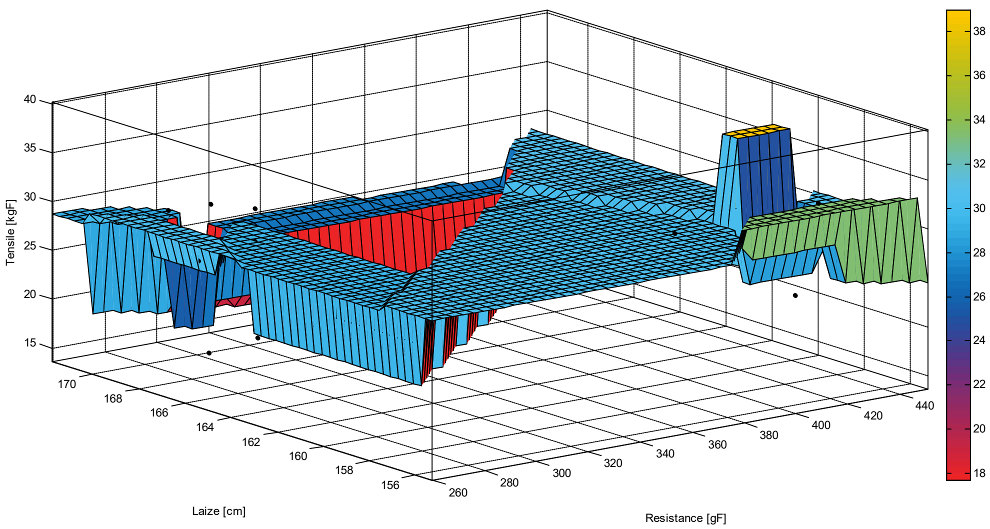

Fig. 5. Tensile strength of fabric as a function of yarn strength and width

In the weft part of the fabric, we see that the higher the resistance of the yarns constituting the fabric, the greater the tensile strength of the fabric so, the fabric is more resistant. The interdependence relationship between the two characteristics is given by equation 2:

$$Ts(x) = 3{,}27 * 10^4 \exp(-\left(\frac{x-2{,}17*10^4}{6245}\right)^2) \qquad (2)$$

x: represents the resistance of the yarn in [gF]

Ts(x): Weft tensile strength of the fabric [kgF]

Figure 5 represents the characteristic curve of equation 2:

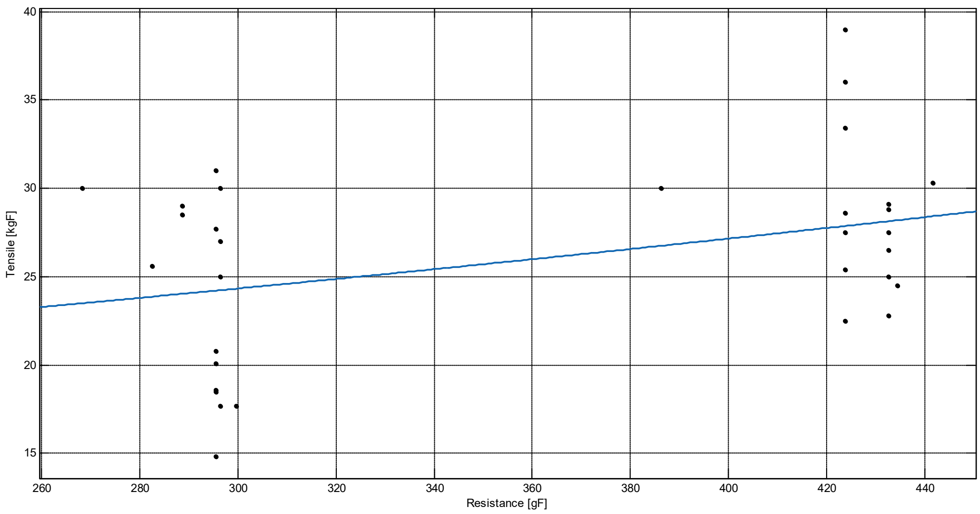

Fig. 6. Interdependence between tensile strength of fabric and yarn

The absolute and relative errors associated with equation 2 are:

- Absolute error : $\Delta DS = 0{,}85\ [kgF]$
- Relative error : $\frac{\Delta DS}{DS} = 2{,}9\%$

4.2. Impact of yarn elongation on fabric tensile strength

This paragraph presents the results of the interdependence between the tensile strength of the fabric and the increase in the length of the yarn due to the breaking strength defined as the elongation of the yarn.

4.2.1. Results on the warp direction of the fabric:

Figure 7 represents the relationship between the elongation of the yarn, the width of the fabric and the warp tensile strength of the fabric:

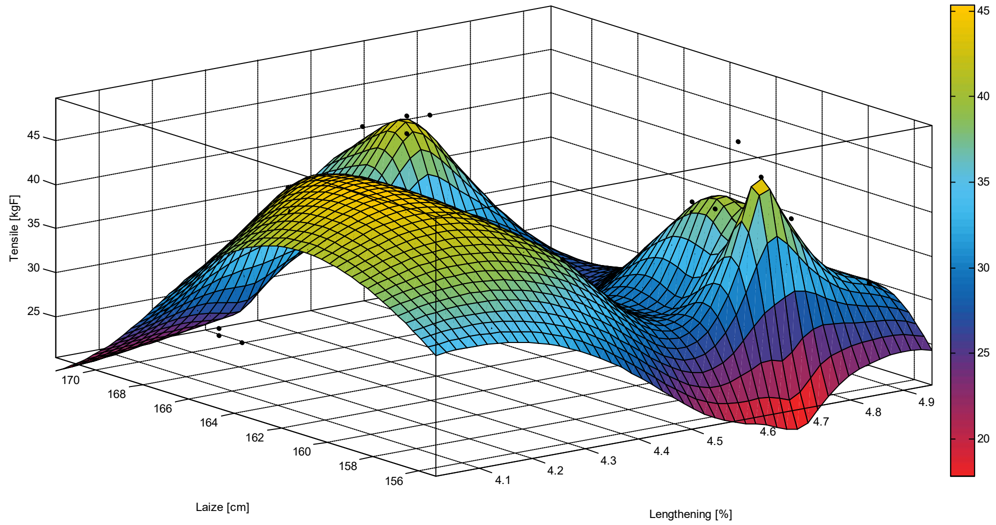

Fig. 7. Chain tensile strength as a function of elongation and width

The tensile strength curve has an inverted parabolic shape with a peak of 45 kgF. The correlation between tensile strength and yarn elongation is represented by equation 3 as follows:

$$Ts(x) = 37{,}57\exp\left(-\left(\frac{x-4{,}58}{0{,}71}\right)^2\right) \quad (3)$$

x: represents the elongation of the yarn in [%]

Ts(x) : Warp tensile strength of fabric [kgF]

Figure 8 represents the characteristic curve of equation 3:

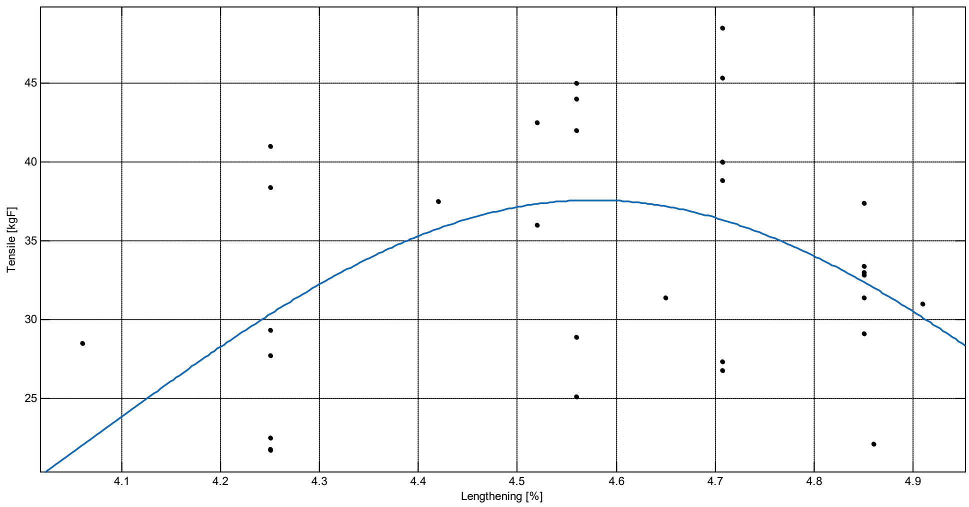

Fig. 8. Chain tensile strength as a function of yarn elongation.

The absolute and relative errors associated with equation 3 are:

- Absolute error : $\Delta DS = 0{,}84\ [kgF]$

– Relative error : $\frac{\Delta DS}{DS} = 2{,}26\%$

4.2.2. Results on the weft direction of the fabric:

The results related to fabric samples taken in the weft direction of the fabric is shown in Figure 9:

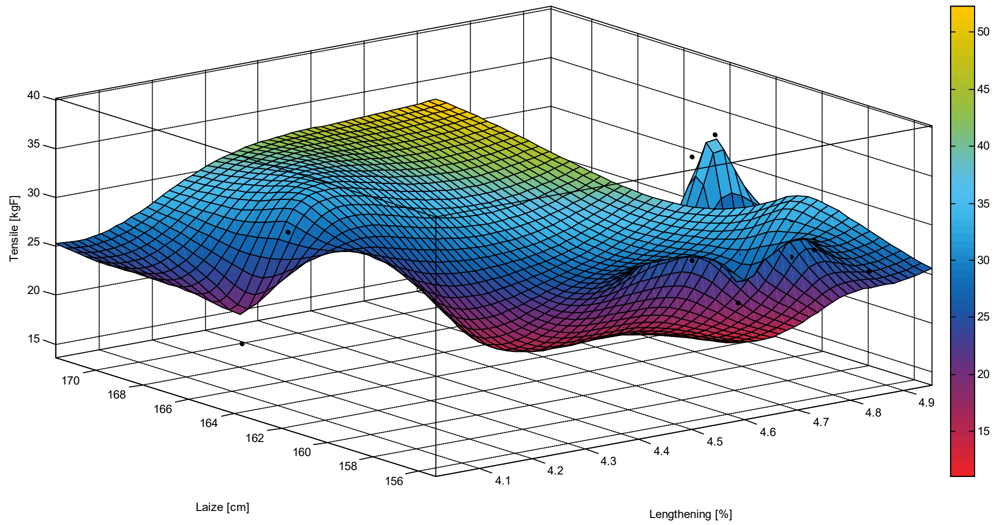

Fig. 9. Weft tensile strength as a function of elongation and width

As for the tensile strength in the chain part, the shape of the curve follows the same trend with a difference between the peak and minimum which is slightly small. Equation 4 illustrates the tensile strength of the weft fabric as a function of yarn elongation.

$$Ts(x) = 27{,}58\exp(-\left(\frac{x-4{,}63}{1{,}02}\right)^2) \quad (4)$$

x: represents the elongation of the yarn in [%]

Ts(x) : Weft tensile strength of the fabric [kgF]

Figure 10 represents the characteristic curve of equation 4:

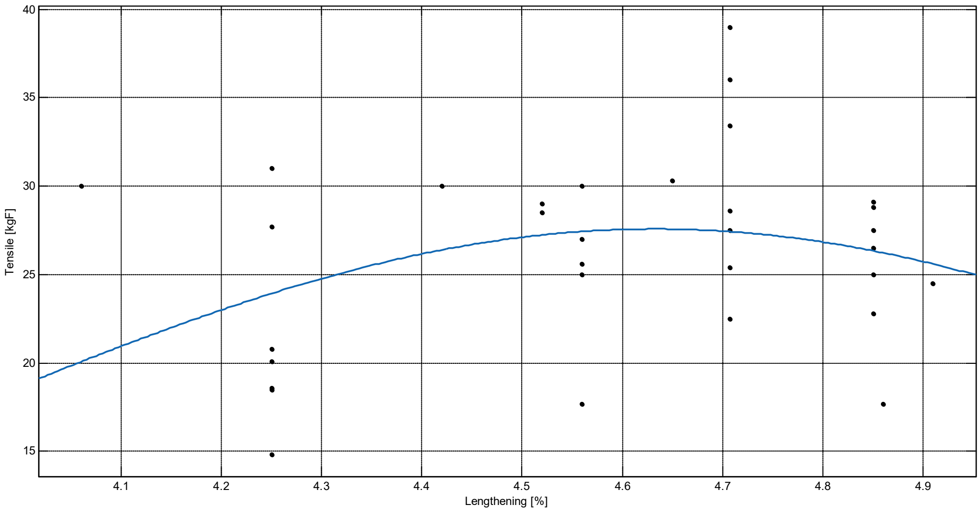

Fig. 10. Weft tensile strength as a function of yarn elongation

The errors associated with equation 4 and illustrated on the interpolation curve in Figure 10 are:

- Absolute error : $\Delta DS = 2{,}89\ [kgF]$
- Relative error : $\frac{\Delta DS}{DS} = 9{,}52\%$

4.3. Influence of yarn kilometric strength (RKM) on fabric tensile strength

In this paragraph, we present according to the experiments the relationship between the RKM of the yarn and the tensile strength of the fabric. It should be noted that the kilometric resistance of the yarn (RKM) corresponds to the number of kilometers of yarn necessary to hang from a yarn as long as it breaks under its own weight.

4.3.1. Results on the warp direction of the fabric

Figure 11 illustrates the relationship between the tensile strength of the fabric, the kilometric strength of the yarn and the width of the fabric for samples taken in the warp direction of the fabric:

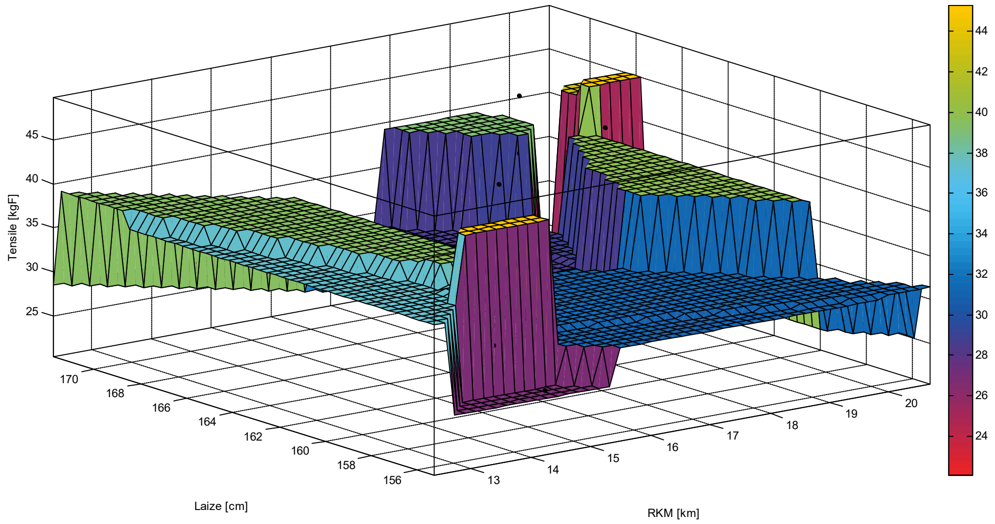

Fig. 11. Chain tensile strength as a function of RKM and width

In the general case, the greater the tensile strength of the fabric is inversely proportional to the kilometer resistance of the fabric. However, there are isolated cases such as for fabrics with widths around 169 cm. Equation 5 reflects the relationship between the tensile strength of the fabric and the kilometric strength of the yarn:

$$Ts(x) = 1{,}09 * 10^{17} \exp(-\left(\frac{x+4327}{726{,}9}\right)^2) \quad (5)$$

x: represents the kilometric resistance of the yarn in [km]

Ts(x) : Warp tensile strength of fabric [kgF]

Figure 12 represents the characteristic curve of equation 5:

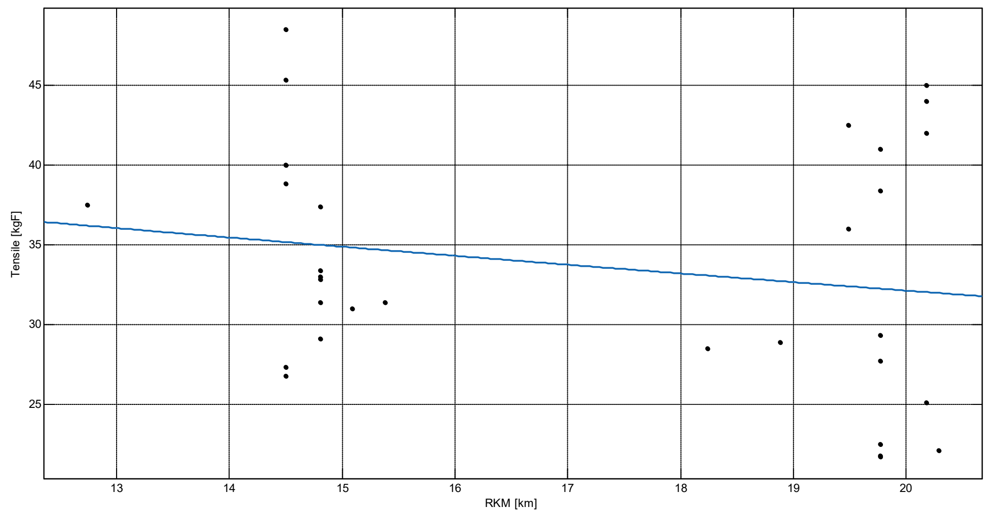

Fig. 12. Chain tensile strength as a function of the RKM of the yarn

The errors associated with equation 5 are:

- Absolute error : $\Delta DS = 2\ [kgF]$

– Relative error : $\frac{\Delta DS}{DS} = 5{,}4\ \%$

4.3.2. Result in the weft direction of the fabric

Figure 13 shows the results of samples taken in the weft direction of the fabric. This figure shows the relationship between the tensile strength, the useful width of the fabric and the kilometric resistance of the yarn.

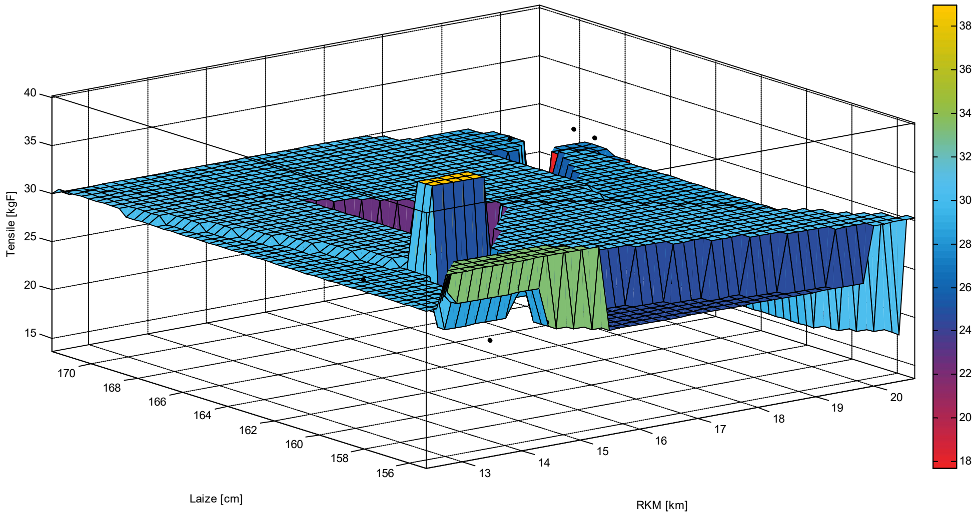

Fig. 13. Weft tensile strength depending on RKM and width

The curve representing the tensile strength of fabric for fabric samples taken in the weft direction of the fabric is similar to that of the warp part. However, the slope of the curve constitutes the difference between the two. Equation 6 represents the connection between the tensile strength of the fabric and the kilometric strength of the yarn:

$$Ts(x) = 29{,}13\,\exp\left(-\left(\frac{x-11{,}91}{17{,}18}\right)^2\right) \quad (6)$$

x: represents the kilometric resistance of the yarn in [km]

Ts(x) : Weft tensile strength of the fabric [kgF]

Figure 14 represents the characteristic curve of equation 6:

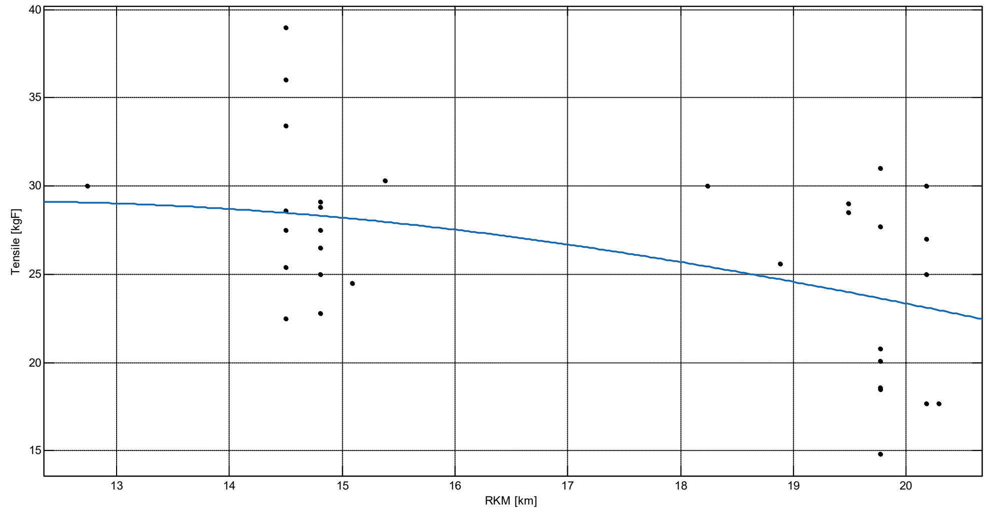

Fig. 14. Tensile strength of fabric versus RKM

The respective absolute and relative errors linked to equation (6) are:

- Absolute error : $\Delta DS = 1{,}14\ [kgF]$
- Relative error : $\frac{\Delta DS}{DS} = 3{,}85\ \%$

4.4. Relationship between fabric tensile strength and actual yarn metric number

This part reflects the relationship between the metric number also known as yarn count and the tensile strength of the fabric. Knowing that the metric number corresponds to the length of one gram of yarn.

4.4.1. Result in the warp direction of the fabric

The results of the samples taken in the warp direction of the fabric which shows the relationship between the tensile strength, the real metric number of the yarns and the useful width of the fabrics are presented in Figure 15:

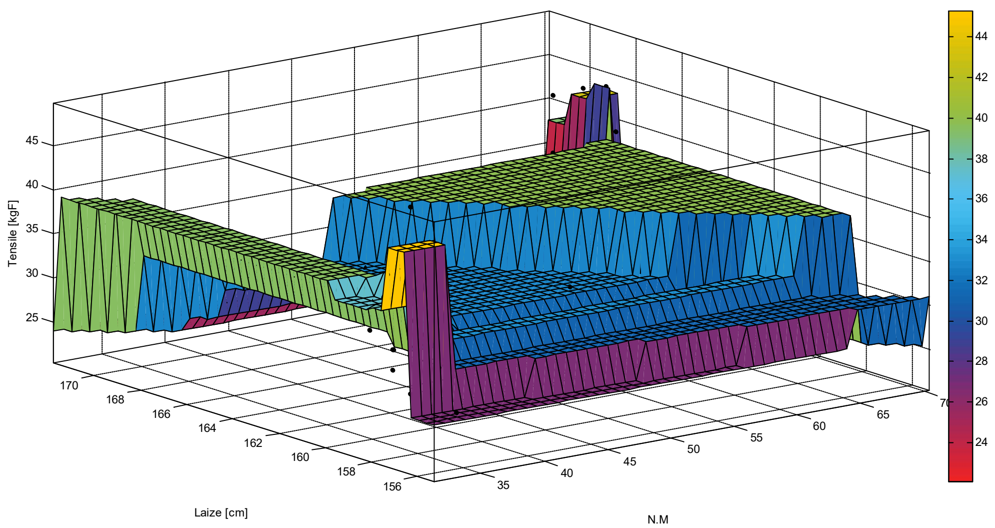

Fig. 15. Chain tensile strength depending on the N.M of the yarn and the width

In the general case, compared to the results obtained, the tensile strength is decreasing in relation to the actual metric number of the yarn and the width of the fabric. However, the decline slope is small and we can say that the metric number of the yarn has a slight impact on the tensile strength of the fabric. The relationship between yarn metric number and fabric tensile strength is illustrated by equation 7:

$$Ts(x) = 1{,}17 * 10^5 \exp(-\left(\frac{x+6472}{2284}\right)^2) \quad (7)$$

x: represents the metric number of the yarn

Ts(x): Warp tensile strength of fabric [kgF]

Figure 16 represents the characteristic curve of equation 7:

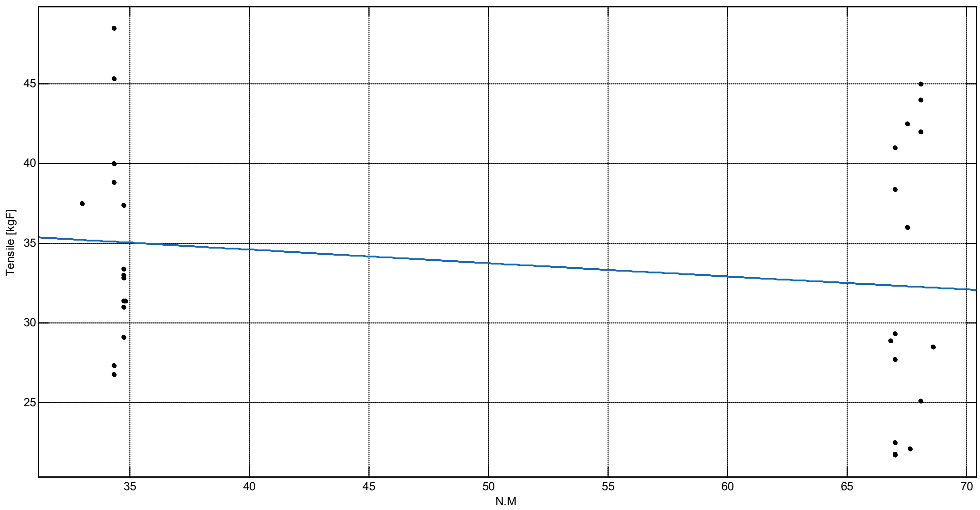

Fig. 16. Resistance to chain traction depending on the N.M of the yarn

The respective absolute and relative errors linked to equation (7) are:

- Absolute error : $\Delta DS = 2{,}99\ [kgF]$
- Relative error : $\frac{\Delta DS}{DS} = 7{,}86\ \%$

4.4.2. Result in the weft direction of the fabric

Figure 17 shows the relationship between tensile strength, the real yarn metric number and effective fabric width for samples taken in the weft direction of the fabric.:

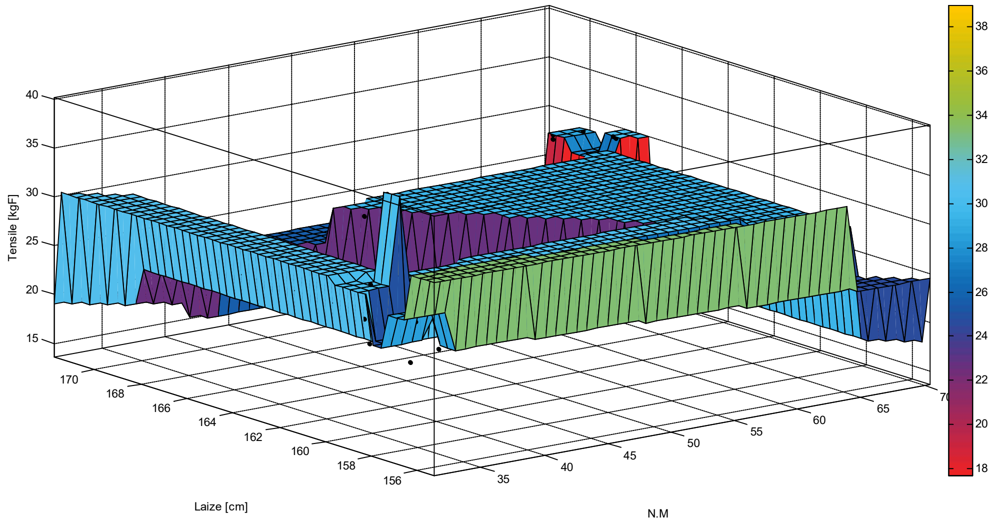

Fig. 17. Tensile strength depending on the N.M of the yarn and the width of the fabric

There is a great similarity between the tensile strength of the fabric taken in the direction of the warp and the weft of the fabric. Equation 8 reflects the relationship between weft tensile strength and actual yarn metric number:

$$Ts(x) = 3{,}58 * 10^{10} \exp(-\left(\frac{x+82}{1815}\right)^2) \qquad (8)$$

x: represents the metric number of the yarn

Ts(x) : Weft tensile strength of the fabric [kgF]

Figure 18 represents the characteristic curve of equation 8:

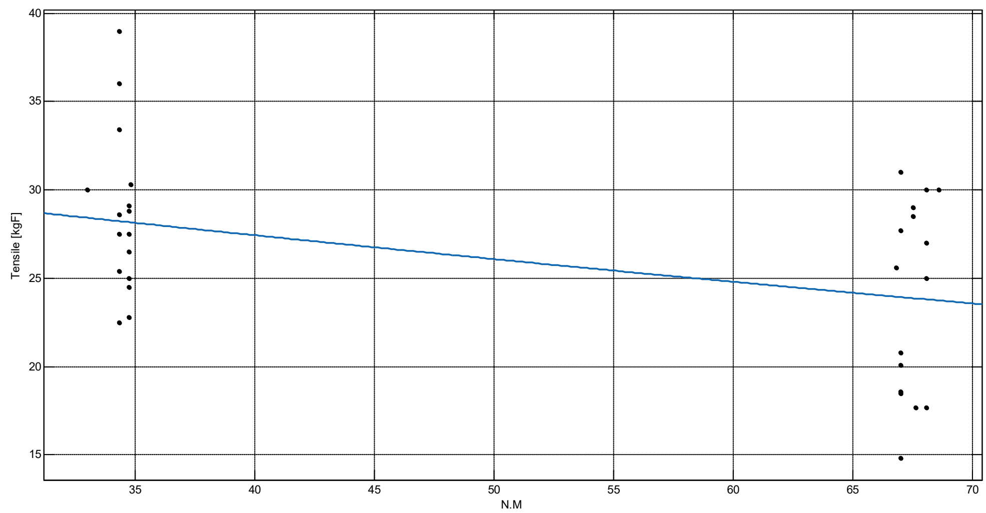

Fig. 18. Tensile strength of the fabric as a function of the N.M of the yarn

The respective absolute and relative errors linked to equation (8) are:

- Absolute error : $\Delta DS = 1{,}9\ [kgF]$

– Relative error : $\frac{\Delta DS}{DS} = 6{,}28\ \%$

4.5. Correlation between the hairiness index of the yarns on the tensile strength of the fabric

The hair index (PI) designates the total length of fibers released from 1 cm of yarn. This part reflects the relationship between the hairiness index of the yarn and the tensile strength of the fabric.

4.5.1. Result in the warp direction of the fabric

Figure 19 represents the relationship between the tensile strength, the hairiness index of the yarns and the useful width of the fabrics for samples taken in the warp direction of the fabric:

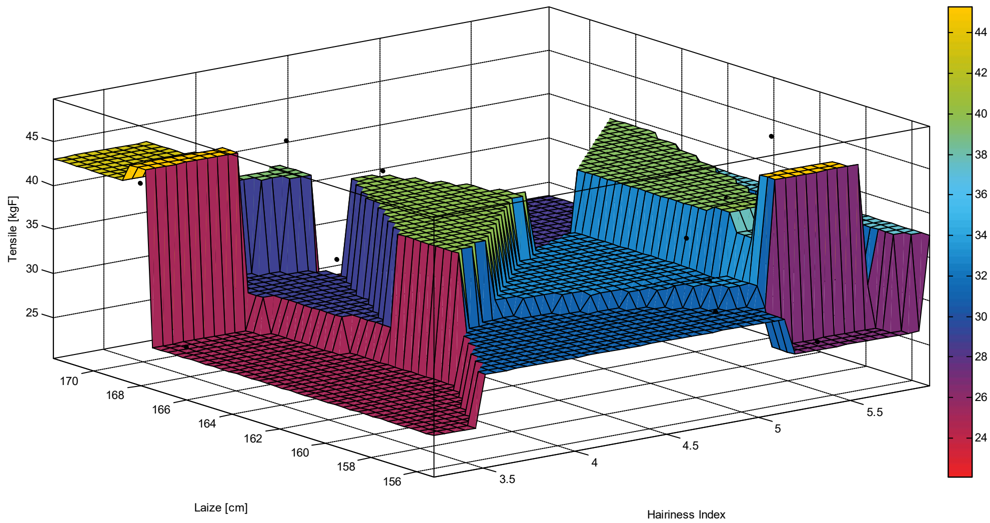

Fig. 19. Chain tensile strength depending on I.P and width

By reasoning in relation to the average value of the tensile strength of the fabric, we see a slight progression which evolves with the hairiness index of the yarns. Equation 9 illustrates the relationship between fabric tensile strength and yarn hairiness index:

$$Ts(x) = 1{,}73 * 10^{7} \exp(-\left(\frac{x-2911}{801{,}6}\right)^{2}) \qquad (9)$$

x: represents the hairiness index of the yarn

T(x): Warp tensile strength of fabric [kgF]

Figure 20 illustrates the representative curve of equation 9:

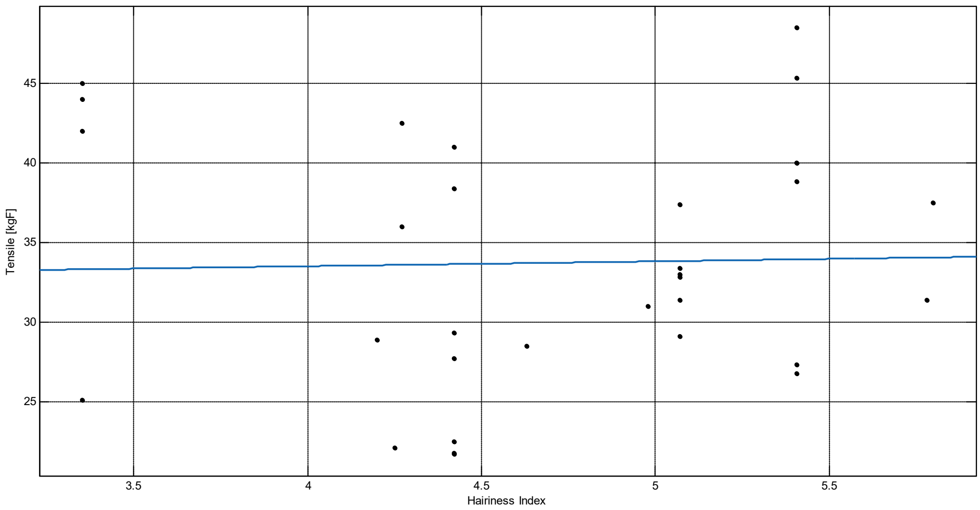

Fig. 20. Tensile strength of fabric as a function of yarn hairiness index

The respective absolute and relative errors linked to equation (9) are:

- Absolute error : $\Delta DS = 3{,}26\ [kgF]$
- Relative error : $\frac{\Delta DS}{DS} = 8{,}75\ \%$

4.5.2. Result in the weft direction of the fabric

Figure 21 represents the relationship between the tensile strength, the hairiness index of the yarns and the effective width of the fabrics for samples taken in the weft direction of the fabric:

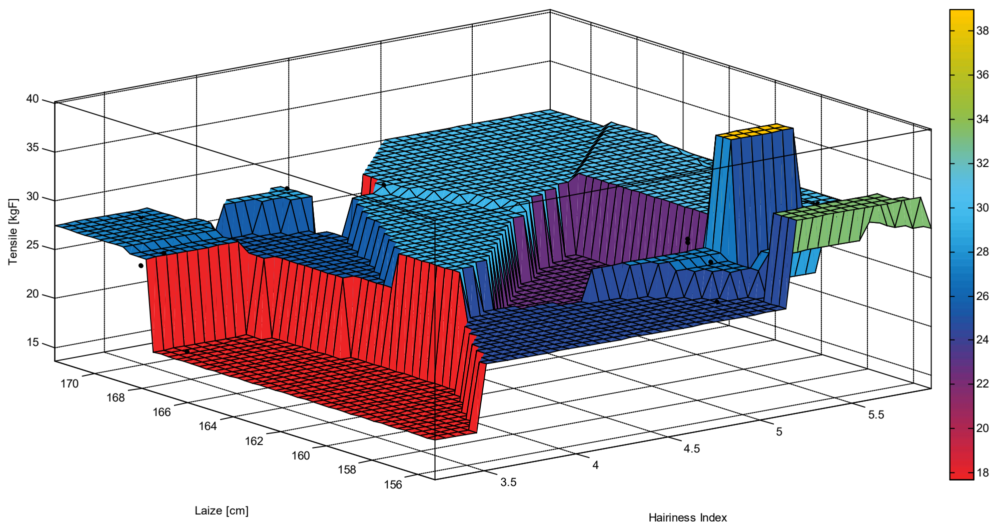

Fig. 21. Weft tensile strength depending on the I.P of the yarn and the width

In the weft part of the fabric we see that the average value of the tensile strength is proportional to the hair index. Equation 10 reflects the relationship between weft tensile strength and hairiness index:

$$Ts(x) = -1{,}4x^3 + 22{,}05x^2 - 109x + 195{,}5 \quad (11)$$

x: represents the hairiness index of the yarn

T(x): Weft tensile strength of the fabric [kgF]

Figure 22 illustrates the representative curve of equation 10:

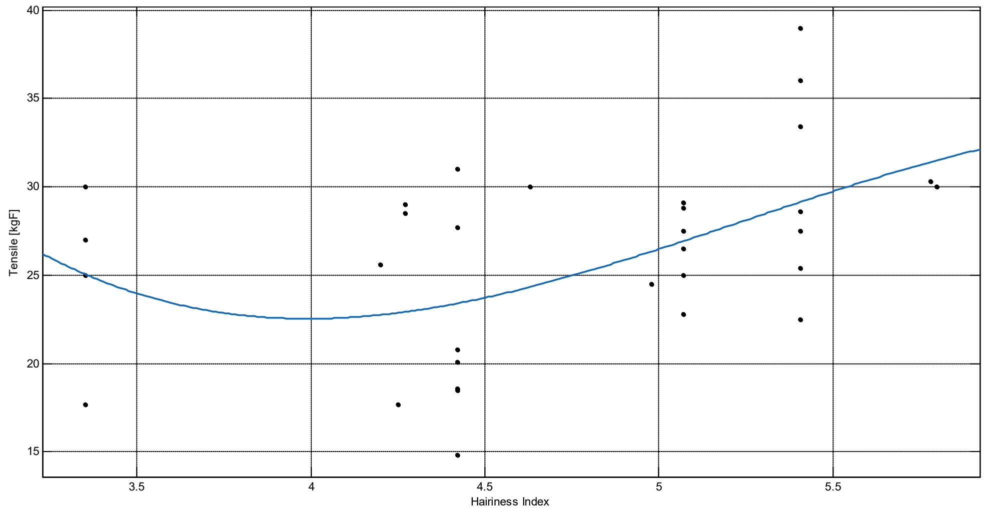

Fig. 22. Weft tensile strength as a function of yarn I.P.

The respective absolute and relative errors linked to equation (10) are:

- Absolute error : $\Delta DS = 0{,}63\ [kgF]$
- Relative error : $\frac{\Delta DS}{DS} = 2{,}07\ \%$

V. Conclusion and perspectives

This article relates the interdependence between the maximum forces of the tensile strength of a fabric and the yarns's characteristics, namely the resistance, the hairiness index, the real metric number and the kilometric resistance. The results of our work are obtained after experiments which are carried out according to the rule of the art in relation to the study of yarns and fabrics.

From the results, mathematical models of interdependence between the tensile strength of the fabric and the technical characteristics of the yarns are established. The models are associated with their respective precisions defined by their respective absolute and relative errors.

In perspective, a study on the correlation between remanence and dimensional stability of the fabric would be interesting.

References

[1] Pietro Bellini, Ferruccio Bonetti, Ester Franzetti, Guiseppe Rosace, Sergio Vago, Textile Reference book of finishing

[2] Physical testing of textiles,B P Saville, The Textile Institute, CRC Press, Boca Raton Boston New York Washington, DC, Cambridge England

[3] Tests results registration book, lab-Rb, SOCOTA.