

Modeling The Tensile Strength Of A Linen Fabric: Case Of A Dyed Woven Fabric

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Abstract— This article relates the behavior through mathematical models of the tensile strength of a fabric composed of linen. During this work, 3 types of dyed woven fabric composed of linen are sampled. With these 3 types we obtained 63 samples taken and studied, and from these samples we were able to derive the tensile strength behavior of the fabric. The characteristics observed during the experiments which can influence the tensile strength of the fabric are: the width and weight of the fabric, the density of the warp and weft yarns of the fabric, the tensile strength and the kilometer resistance of the yarns, and the actual metric number of the yarns. A mathematical model is developed for each characteristic considered. The mathematical models are presented with their accuracies illustrated by relative and absolute errors.

Keywords— Fabric, Linen, Tensile Strength, Yarn, Woven Dyed.

I. INTRODUCTION

In the textile field, the physical parameters associated with the fabric are increasingly demanded by customers because they are guarantees of quality. Among these parameters, we distinguish the tensile strength of the fabric because it is one of the parameters which determines the fabric's stability.

The tensile strength of a fabric is the parameter which determines the resistance, solidity and ability of the fabric to remain stable and to resist the stretching that it is subjected to without it tearing. In order to understand the phenomenon, we did series of tests carried out on fabrics containing linen.

Then, this article develops the behavior of the tensile strength of a dyed woven linen fabric in relation to other factors of the fabric and yarn such as the width of the fabric, the weight of the fabric, the density of the warp yarns and constituent wefts of the fabric, the correlation with the tensile strength of the yarns, the relationship with the kilometeric resistance of the yarns and the

actual metric number of the yarns. This work proposes mathematical models which are presented with their details in order to better illustrate the phenomenon.

II. METHODOLOGY OF FABRIC RESISTANCE

A. Measuring technique

The strength value of a fabric refers to the force required for a fabric to reach its breaking point. In order to evaluate the resistance of the fabric it is important to carry out a dynamometric study. To do this, the method consists of placing a rectangular test piece between two clamps, one clamp is fixed, and 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. After traction, the measuring cell automatically transfers the measurement data to the computer which then provides us with 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, maximum strain, energy required for breaking and Young's modulus.

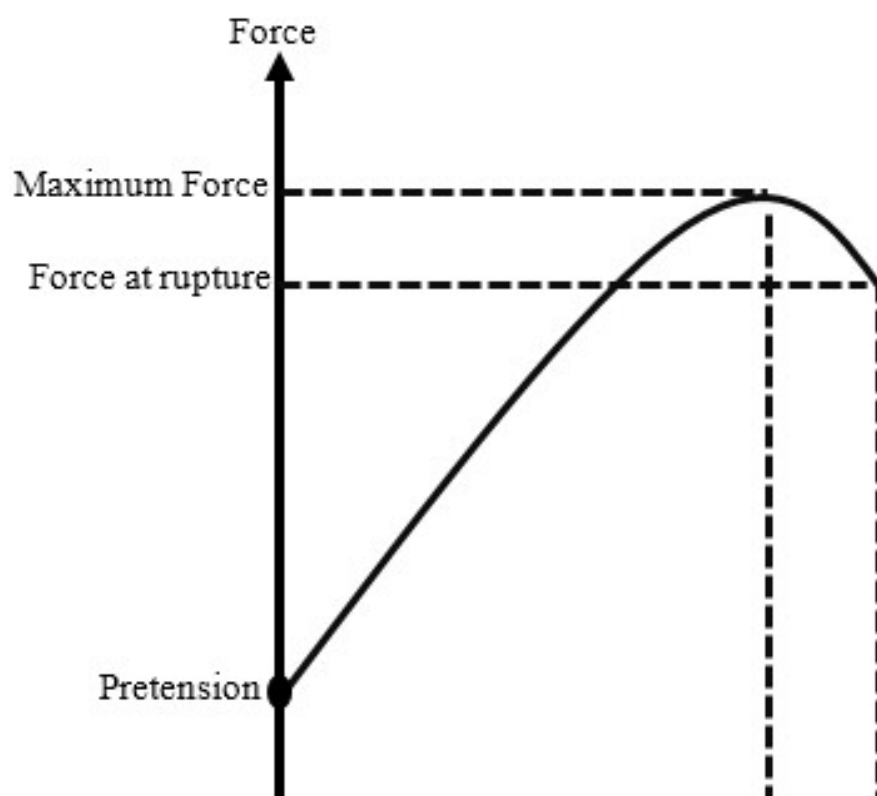


Fig. 1. Curve of the evolution of force as a function of elongation

B. Sampling method

During experiments it is inevitable to respect the standards and principles in order to have reliable results. So, sampling of fabrics done according to the rules of the art respects these following 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 150 mm from the edge of the fabric.

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

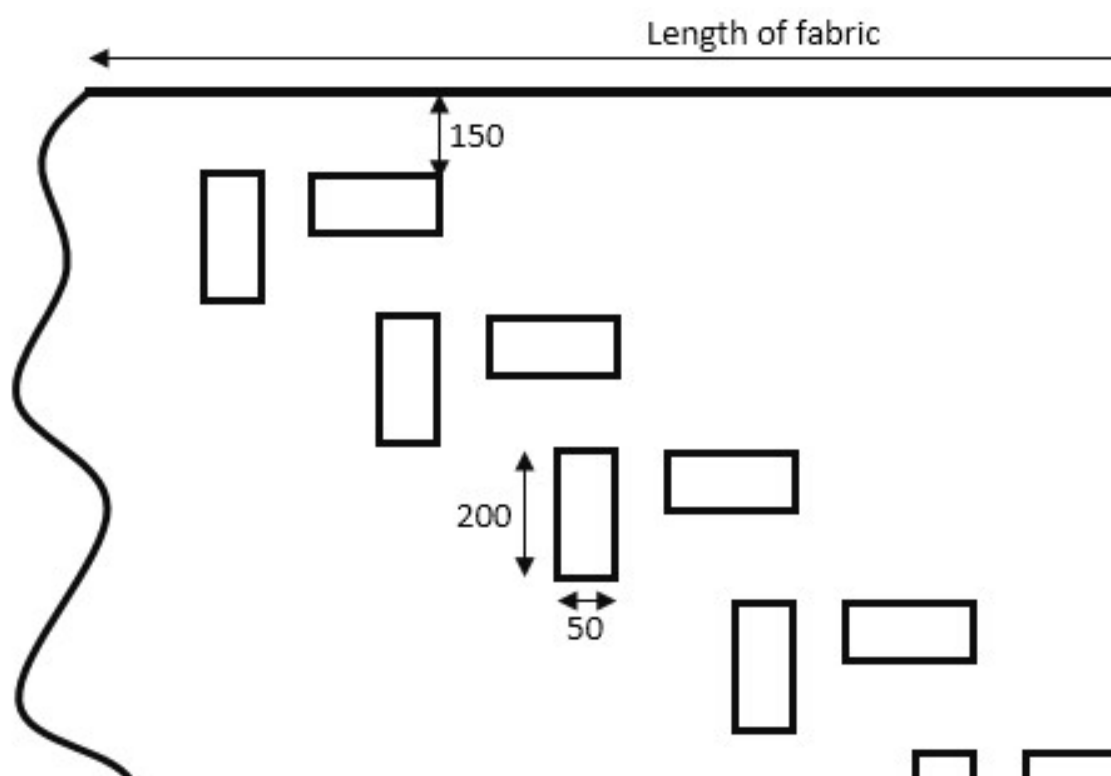


Fig. 2. Sampling a fabric

C. Principle of 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, therefore for the 5 pairs of test pieces.

III. PRESENTATION OF THE FABRIC

This work aims to see the tensile strength behavior of linen-based dyed woven fabric. To do this, we considered 3 types of woven linen-dyed fabric whose composition is 55% cotton and 45% linen. With these 3 types we took 63 samples and we were able to observe the behavior of the tensile strength in relation to the characteristics of the fabrics as well as the impacts of the yarn characteristics on the parameters of the maximum forces of the fabric's tensile strength.

However, the overall characteristics of the constituent yarns of the fabrics are summarized in Table I:

TABLE I. OVERALL CHARACTERISTIC OF THE CONSTITUENT YARNS OF FABRICS

<i>Settings</i>	<i>Warp yarns</i>	<i>Weft yarns</i>
<i>Metric number</i>	34	34
<i>Origin</i>	Pakistan/China	Pakistan/China
<i>Coefficient of variation</i>	2,09	2,09
<i>Finesse</i>	809	809
<i>Size</i>	1526	1526
<i>NEPS</i>	2490	2490
<i>Imperfection</i>	4825	4825
<i>Hair index</i>	4,82	5,8
<i>Elongation</i>	5,55	5,55
<i>Spinning system</i>	Card	Card

IV. PRESENTATION OF THE RESULTS

This work reports the tensile strength behavior of a dyed woven fabric containing linen. To do this, we considered 3 types of linen fabric in which common composition is 55% cotton and 45% linen. With these 3 variants, we were able to carry out the experiments on 63 fabric samples of the same category. In order to better understand the behavior of the fabric in relation to its tensile strength, we considered 6 characteristics of the fabric and the yarns with which the fabric was manufactured, namely the width of the fabric, the weight of the fabric, and the density of the yarns. In warp and weft constituting the fabric, the resistance of the yarns, the kilometric resistance of the yarns and the metric number of the yarns. Therefore, this part is dedicated to the presentation of the concordances between the tensile strength of the fabric and the 6 characteristics considered.

A. Model of tensile strength of fabric as a function of width

1) Warp results:

During the study of the tensile strength of the fabric, the warp measurement of the 56 samples allowed us to develop a mathematical model which is presented by equation 1:

$$T_c(x_1) = 40,43 - 1,9 \cos(0,35x_1) + 8,13 \sin(0,35x_1) \quad (1)$$

x_1 : represents the width of the fabric in [cm]

$T_c(x_1)$: represents the warp tensile strength of the fabric [kgF]

The precision of this model is given by the errors namely:

- Absolute error : $\Delta T = 1,78 \text{ [kgF]}$
- Relative error : $\frac{\Delta T}{T} = 5,64 \%$

The curve representing the tensile strength given by equation 1 is shown in Figure 3:

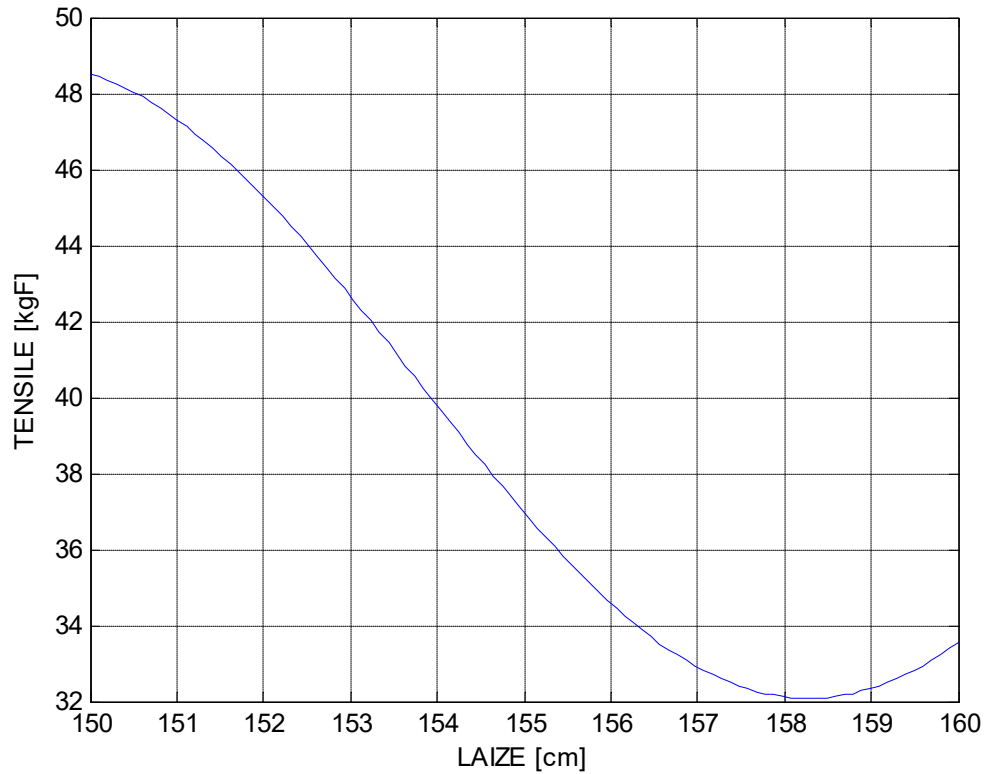


Fig. 3. Warp tensile strength of the fabric depending on the width

We notice that the value increases as the width of the fabric increases, and the tensile strength of the fabric decreases. The widths considered during our experiments being between 142 cm and 160 cm, so, we observe that the tensile strength of the fabric gradually decreases from 45 kgF to 32 kgF. During the measurements carried out during the experiments, the respective maximum and minimum values of the tensile strength are 44 kgF and 27 kgF. The difference between theory and reality is justified by the details associated with the model.

2) Weft results:

Equation 2 represents the tensile strength of linen-dyed woven fabric in the weft direction of the fabric as a function of the width:

$$T_T(x_1) = 32,52 - 5,77 \cos(0,51x_1) + 0,78\sin(0,51x_1) \quad (2)$$

x_1 : represents the width of the fabric in [cm]

$T_T(x_1)$: represents the weft tensile strength of the fabric [kgF]

The precision of this model is given by the errors namely:

- Absolute error : $\Delta T = 1,16 \text{ [kgF]}$
- Relative error : $\frac{\Delta T}{T} = 4,16 \%$

The curve representing the tensile strength given by equation 2 is shown in Figure 4:

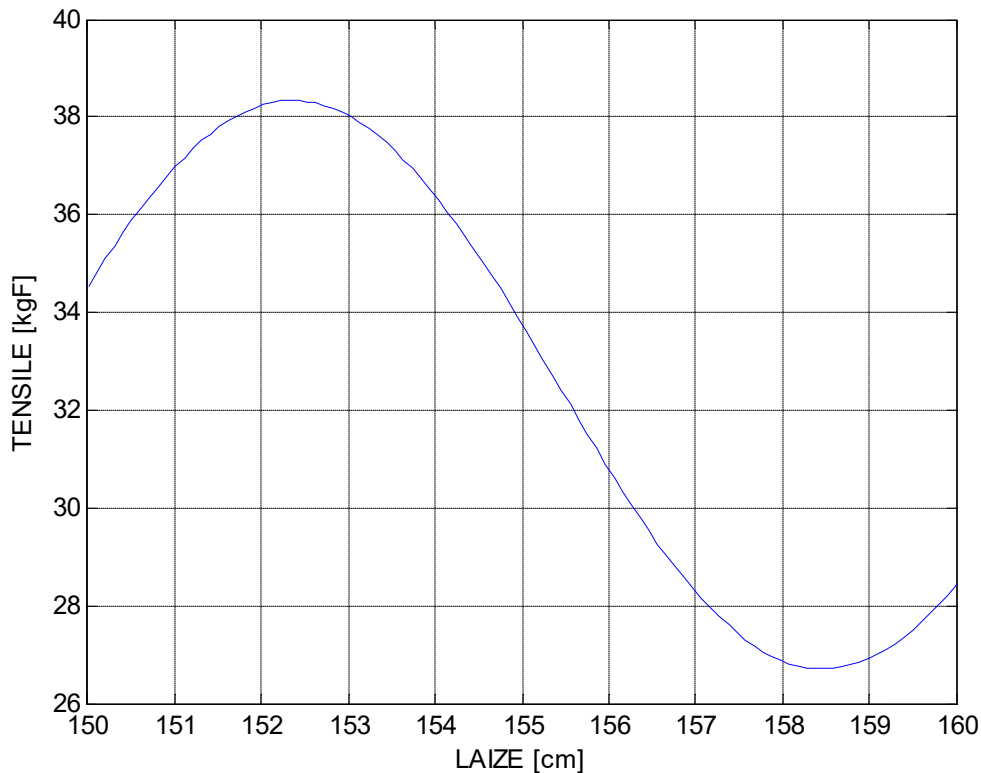


Fig. 4. Weft tensile strength of the fabric as a function of width

On this curve we see that the average value of the tensile strength in weft of the fabric is 32 kgF, this value is reflected for fabrics with a width between 155 cm and 156 cm. The extreme values are 38.5 kgF and 27 kgF respectively. During measurements, these values are respectively 39 kgF and 24.5 kgF which is justified by the precision errors of the equation.

B. Model of fabric tensile strength versus fabric weight

This paragraph is focused on the results of the interdependence between fabric tensile strength and fabric weight. The mathematical models detailed in this section are the result of monitoring 48 fabric articles.

1) Warp results:

Equation 3 represents the mathematical model of warp tensile strength of dyed woven fabric composed of linen:

$$T_c(x_2) = 42,88 + 8,08 \cos(0,09x_2) + 7,89 \sin(0,09x_2) \quad (3)$$

x_2 : represents the weight of the fabric in [g/m²]

$T_c(x_2)$: represents the warp tensile strength of the fabric [kgF]

The precision of this model is given by the errors namely:

- Absolute error : $\Delta T = 0,55$ [kgF]
- Relative error : $\frac{\Delta T}{T} = 1,78$ %

The curve representative of the warp tensile strength given by equation 3 is illustrated in Figure 5:

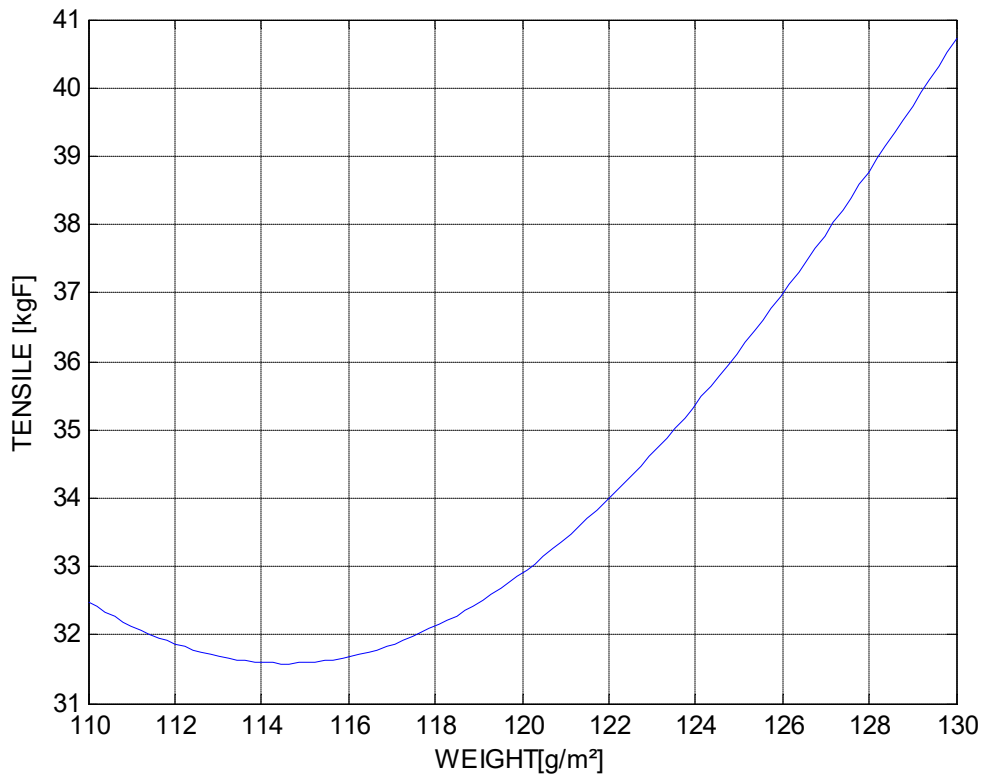


Fig. 5. Warp tensile strength as a function of fabric weight

The tensile strength for fabrics weighing between 110 g/m² and 118 g/m² is generally constant and has a value of 32 kgF. This value represents the lowest value of tensile strength. Above 118 g/m², the more the weight of the fabric increases, the greater the tensile strength of the fabric. The maximum value of tensile strength is reached for fabrics with a weight equal to 130 g/m² and its value is 40.5 kgF. During the measurements, the respective maximum and minimum values of the tensile strength are 42 kgF and 30 kgF which is justified by the precision of the equation.

2) Result in weft:

Equation 4 represents the mathematical model of weft tensile strength of dyed woven fabric composed of linen:

$$T_f(x_2) = 28,77 + 1,91 \cos(0,59x_2) - 0,35 \sin(0,59x_2) \quad (4)$$

x_2 : represents the weight of the fabric in [g/m²]

$T_f(x_2)$: represents the weft tensile strength of the fabric [kgF]

The precision of this model is given by the errors namely:

- Absolute error : $\Delta T = 0,89$ [kgF]
- Relative error : $\frac{\Delta T}{T} = 3,01$ %

The representative curve of the weft tensile strength given by equation 4 is illustrated in Figure 6:

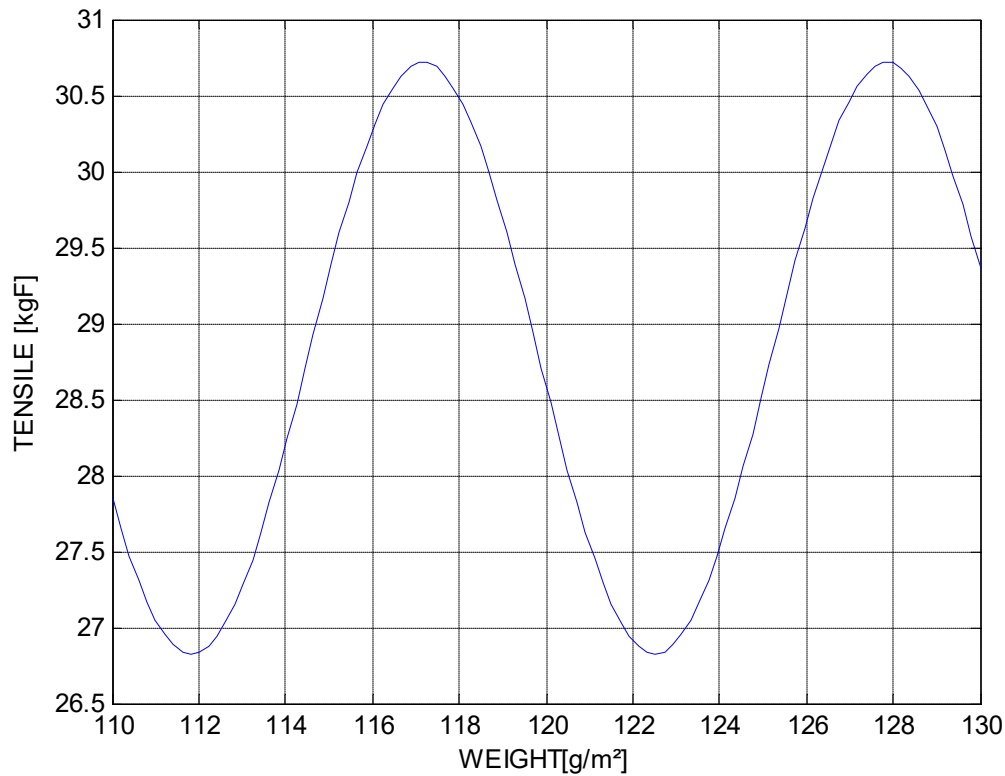


Fig. 6. Weft tensile strength as a function of fabric weight

The curve's shape representing the tensile strength in the weft direction of the linen fabric in relation to the weight of the fabric is sinusoidal. Its period corresponds to an interval of 10 g/m². The values oscillate between 27 kgF and 30.5 kgF and during measurements, these values are respectively 24 kgF and 35 kgF which is justified by the precision errors of the equation.

C. Model of the tensile strength of the fabric as a function of the yarn density of the fabric

This part reflects the relationship between the yarn density of the fabric and the tensile strength of the fabric. Then, the model presented in this result illustrates the relationship between the number of warp and weft yarns per centimeter of the fabric and the tensile strength of the linen-dyed woven fabric. The mathematical models detailed in this section are obtained with measurements taken on 59 fabric items.

1) Result in warp :

Equation 5 represents the mathematical model of the warp tensile strength of the fabric composed of linen as a function of the number of yarns per centimeter of the fabric:

$$T_c(x_2) = 30,95 - 2,52 \cos(0,68x_2) + 2,83 \sin(0,59x_2) \quad (5)$$

x_2 : represents the warp density of the fabric. [Ends/cm]

$T_c(x_2)$: represents the warp tensile strength of the fabric in [kgF]

The precision of this model is given by the errors namely the relative error and the absolute error:

- Absolute error : $\Delta T = 2,83 \text{ [kgF]}$
- Relative error : $\frac{\Delta T}{T} = 10,68 \%$

Figure 7 represents the shape of the curve of the evolution of the warp tensile strength given by equation 5:

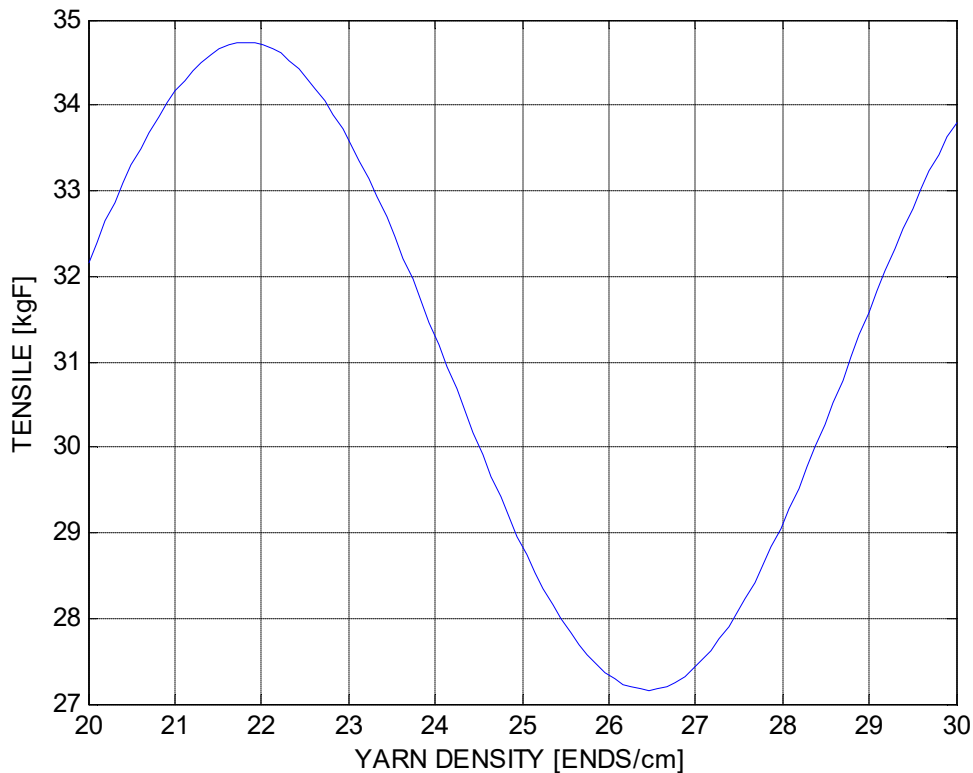


Fig. 7. Warp tensile strength as a function of fabric yarn density

The results obtained in this work were carried out with fabrics having a fabric filament density between 22 and 28 End/cm. Based on these parameters we see that the tensile strength gradually decreases when the yarn density increases. Beyond 26 ends/cm the two values evolve together. During the experiment the minimum and maximum values are 23 and 38 kgF, this deviation from the model is given by the fairly significant errors.

2) Result in weft :

Equation 6 represents the mathematical model of the weft tensile strength of linen composite fabric as a function of the number of yarns per centimeter of the fabric:

$$T_T(x_2) = 27,75 + 1,06 \cos(0,88x_2) - 3,14 \sin(0,88x_2) \quad (6)$$

x_2 : represents the weft yarn density of the fabric. [Picks/cm]

$T_T(x_2)$: represents the weft tensile strength of the fabric in [kgF]

The precision of this model is given by the errors namely the relative error and the absolute error:

– Absolute error : $\Delta T = 1,08 \text{ [kgF]}$

– Relative error : $\frac{\Delta T}{T} = 3,99 \%$

Figure 8 shows the relationship between the weft tensile strength of the linen fabric and the yarn density of the fabric given by equation 6:

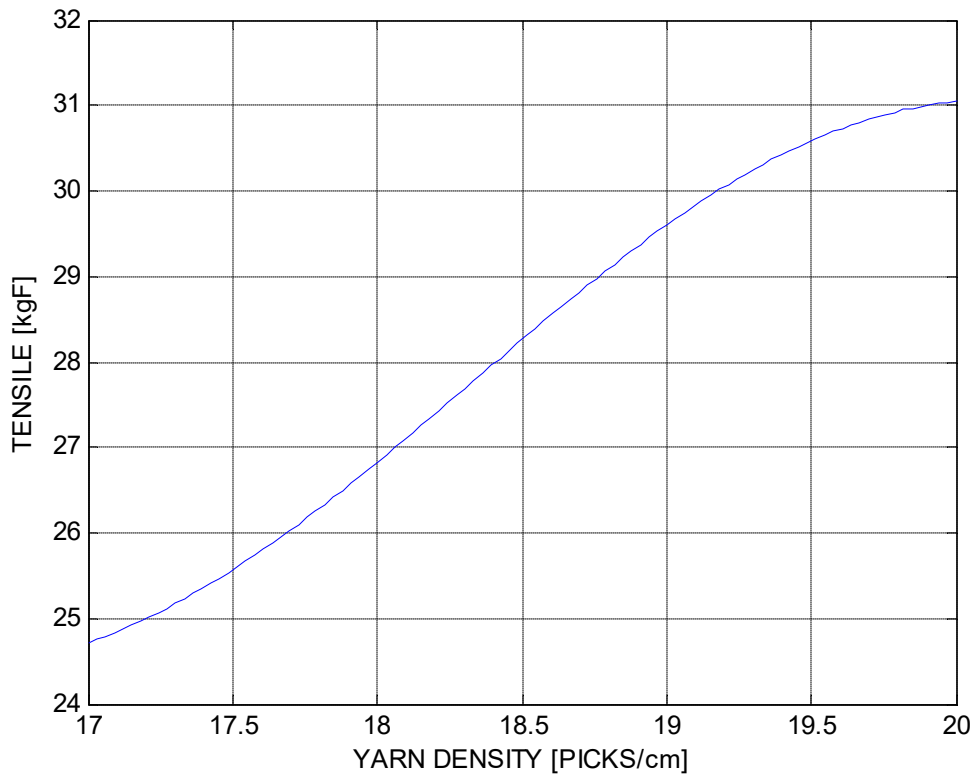


Fig. 8. Weft tensile strength as a function of fabric yarn density

We note the value that the more the yarn density of the fabric increases, the more resistant the fabric is which is justified by the theories. The value of the tensile strength in weft of the fabric varies from 25 kgF to 31 kgF. During measurements, these values are respectively 22 kgF to 35 kgF which is justified by the fairly small precision errors of the equation.

D. Model of fabric tensile strength versus yarn strength

This section relates the relationship between the strength of the yarns constituting the fabric and the tensile strength of the linen-dyed woven fabric. The proposed mathematical models are obtained with measurements made on 59 fabric articles.

1) Result in warp :

The mathematical model represented by equation 7 illustrates the behavior of the warp tensile strength of the fabric composed of linen as a function of the resistance of the yarns which constitute the fabric:

$$T_c(x_4) = 33,09 - 0,14 \cos(0,13x_4) - 3,73\sin(0,13x_4) \quad (7)$$

x_4 : represents the resistance of the warp yarns in [gF]

$T_F(x_4)$: represents the warp tensile strength of the fabric in [kgF]

The precision of this model is given by the errors namely the relative error and the absolute error:

- Absolute error : $\Delta T = 1,54 \text{ [kgF]}$
- Relative error : $\frac{\Delta T}{T} = 4,15 \%$

Figure 9 demonstrates the shape of the curve of the evolution of the warp tensile strength given by equation 7:

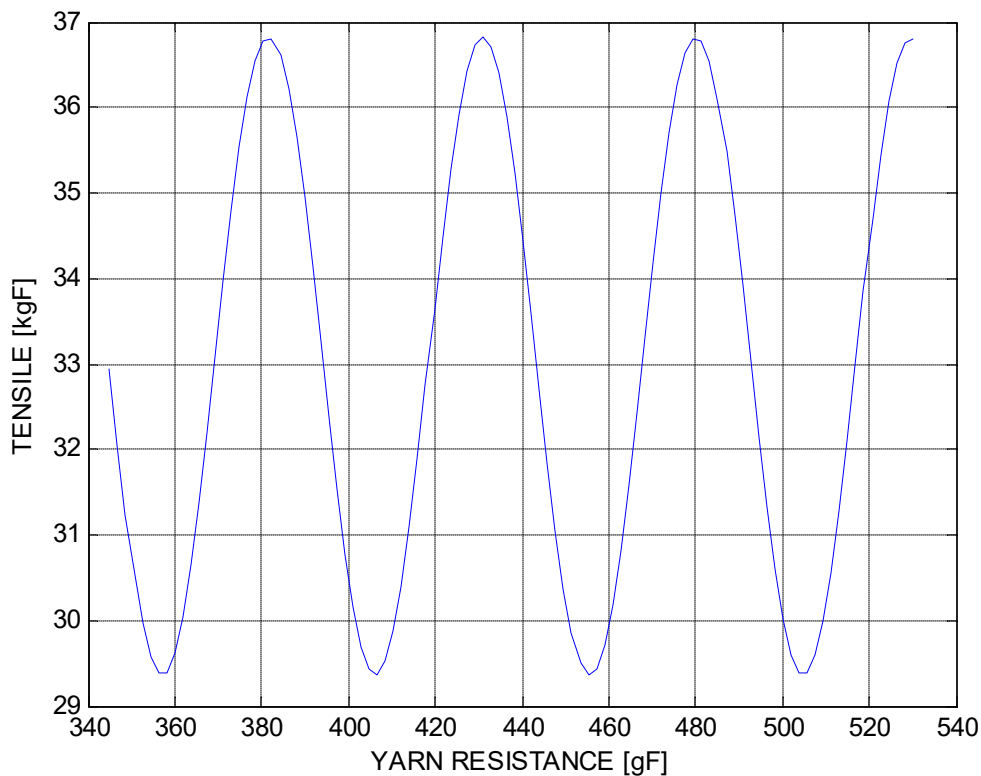


Fig. 9. Warp tensile strength as a function of yarn resistance

The shape of the curve representing the tensile resistance in the warp direction of the linen fabric in relation to the resistance of the yarns which constitute the fabric is periodic sinusoidal and this period corresponds to an interval of 40 gF. The values oscillate between 29.5 kgF and 37.5 kgF and during measurements, these values are respectively 27 kgF and 42 kgF which is justified by the precision errors of the tolerable equation.

2) Result in weft

Equation 8 represents the mathematical model of the behavior of the weft tensile strength of the linen composite fabric as a function of the yarn strength:

$$T_T(x_4) = 27,91 - 3,86 \cos(0,11x_4) - 0,66 \sin(0,11x_4) \quad (8)$$

x_4 : represents the resistance of the weft yarns in [gF]

$T_T(x_4)$: represents the weft tensile strength of the fabric in [kgF]

The precision of this model is given by the errors namely the relative error and the absolute error:

- Absolute error : $\Delta T = 1,2 \text{ [kgF]}$
- Relative error : $\frac{\Delta T}{T} = 3,73 \%$

Figure 10 illustrates the shape of the curve of the evolution of the tensile strength in weft given by equation 8:

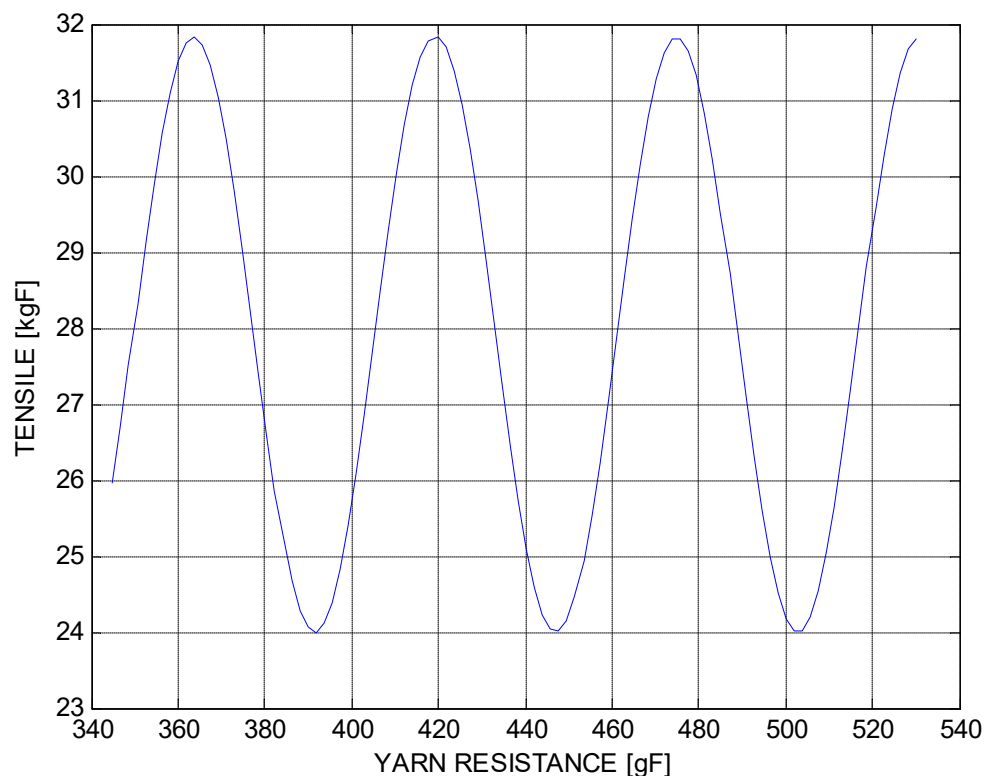


Fig. 10. Weft tensile strength versus yarn strength

The shape of the curve representative of the tensile strength in Figure 10 is similar to that of the warp. The curve is periodic sinusoidal in which oscillation period corresponds to 60gF. The values oscillate between 24 kgF and 32 kgF and during the experiments, these values are respectively 22 kgF and 35 kgF which is justified by the fairly low precision errors.

E. Model of the tensile strength of the fabric as a function of the kilometric strength of the yarn

In this paragraph, we expose the mathematical models according to the experiments the relationship between the RKM of the yarn and the tensile strength of the linen-dyed woven 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 for it to break under its own weight. The mathematical models proposed in this work are obtained with measurements carried out on 60 fabric articles.

1) Result in warp :

The mathematical model represented by equation 9 illustrates the behavior of the warp tensile strength of the fabric composed of linen as a function of the kilometric resistance of the yarns which constitute the fabric:

$$T_c(x_s) = 35,26 + 0,65 \cos(0,4x_s) + 4,74 \sin(0,4x_s) \quad (9)$$

x_s : represents the kilometric resistance of the warp yarns in [km]

$T_c(x_s)$: represents the warp tensile strength of the fabric in [kgF]

The precision of this model is given by the errors namely the relative error and the absolute error:

- Absolute error : $\Delta T = 1,82 \text{ [kgF]}$
- Relative error : $\frac{\Delta T}{T} = 4,78 \%$

Figure 11 represents the shape of the curve of the evolution of the warp tensile strength given by equation 9:

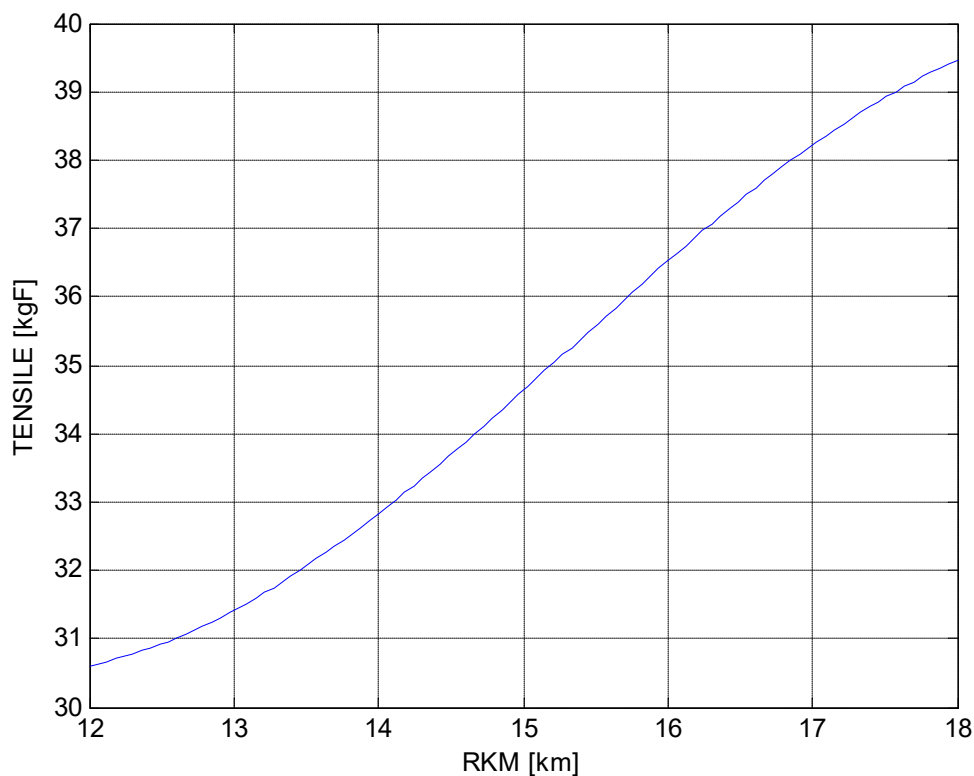


Fig. 11. Warp tensile strength as a function of the RKM of the yarns

Based on the results presented by equation 9 and illustrated in Figure 11 we note that the model shown in this work corroborates with the theory because the higher the RKM of the yarns, the more resistant the fabric. The respective minimum and maximum

values are 30.5 kgF and 39.5 kgF and during the experiments, these values are respectively 24.5 kgF and 40 kgF which is justified by the tolerable precision errors.

2) Result in weft :

The mathematical model represented by equation 10 illustrates the behavior of the weft tensile strength of the fabric composed of linen as a function of the kilometer resistance of the yarns which constitute the fabric:

$$T_T(x_5) = 28,37 + 2,24 \cos(6,17x_5) - 2,66\sin(6,17x_5) \quad (10)$$

x_5 : represents the kilometer resistance of the weft yarns in [km]

$T_T(x_5)$: represents the weft tensile strength of the fabric in [kgF]

The precision of this model is given by the errors namely the relative error and the absolute error:

- Absolute error : $\Delta T = 2,35$ [kgF]
- Relative error : $\frac{\Delta T}{T} = 7,06$ %

Figure 12 represents the shape of the curve of the evolution of the tensile strength in weft given by equation 10:

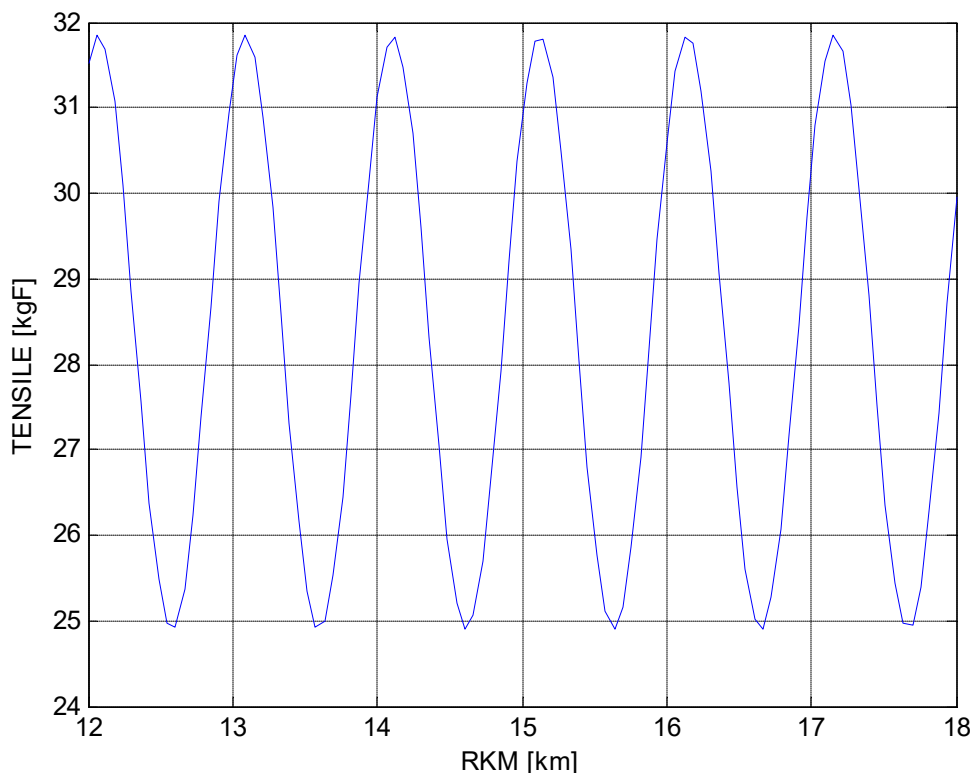


Fig. 12. Weft tensile strength as a function of yarn RKM

The curve's shape representing the tensile resistance in the weft direction of the linen fabric in relation to the kilometeric resistance of the yarns which constitute the fabric is periodic sinusoidal and this period corresponds to an interval of 1 km. The

values oscillate between 25 kgF and 32 kgF and during measurements, these values are respectively 21 kgF and 39 kgF which is represented by the fairly large precision errors.

F. *Model fabric tensile strength versus actual yarn metric number*

In this paragraph, we present the mathematical models of the relationship between the metric numbers also known as the count of a yarn and the tensile strength of the fabric. Knowing that the metric number corresponds to the length in meters of one gram of yarn. The mathematical models proposed in this work are obtained with measurements made on 60 articles of woven linen-dyed fabric.

1) *Result in warp :*

The mathematical model represented by equation 11 illustrates the behavior of the warp tensile strength of the fabric composed of linen as a function of the metric number of the yarns which constitute the fabric:

$$T_c(x_g) = 35,14 - 4,32 \cos(4,75x_g) - 3,85 \sin(4,75x_g) \quad (11)$$

x_g : represents the metric number of the warp yarns

$T_c(x_g)$: represents the warp tensile strength of the fabric in [kgF]

The precision of this model is given by the errors namely the relative error and the absolute error:

- Absolute error : $\Delta T = 1,85 \text{ [kgF]}$
- Relative error : $\frac{\Delta T}{T} = 4,6 \%$

Figure 13 shows the shape of the curve of the evolution of the warp tensile strength given by equation 11:

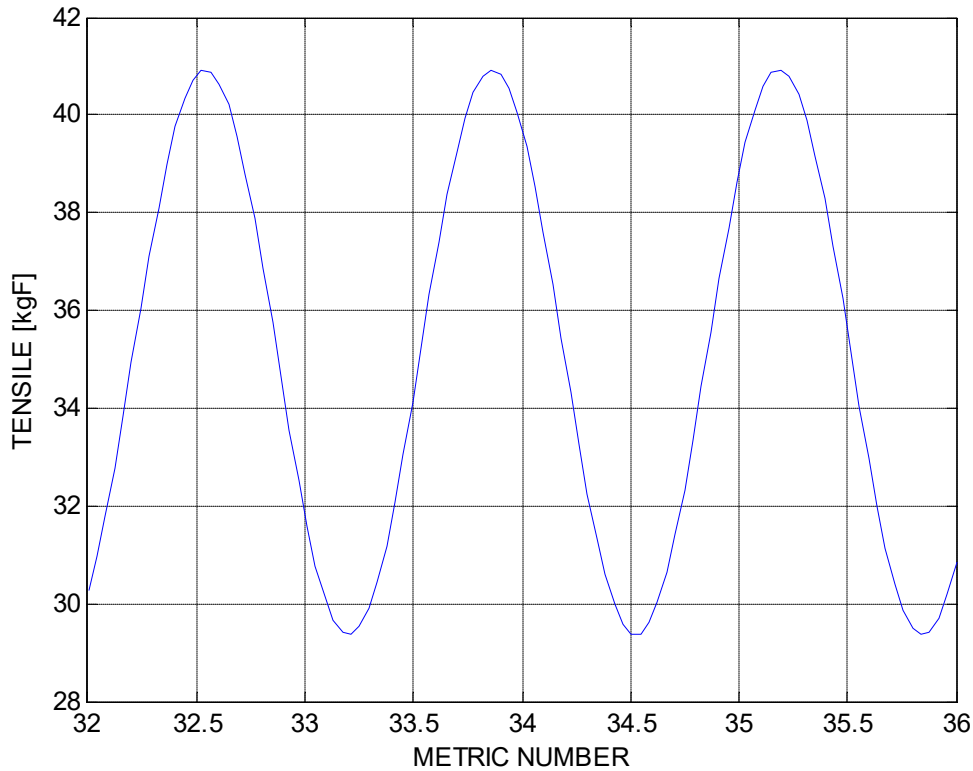


Fig. 13. Warp tensile strength depending on the metric number of the yarns

The theoretical metric number of the yarns is supposed to be 34, during the experiments the metric numbers of the yarns varied between 32 and 36 depending on the origin and climate of the yarns. After the measurements carried out on the 60 articles and their respective constituent yarns, so, we notice according to the established model that the shape of the curve representing the tensile resistance of the fabric is periodic sinusoidal alternation. The oscillation period is equivalent to a metric number 1.3. The respective maximum and minimum tensile strength values are 41 kgF and 29.5 kgF. During the experiments the maximum and minimum values are 40 kgF and 26 kgF so the rather small difference between the model and the measurement is justified by the precision errors.

2) Result in weft :

Equation 12 represents the mathematical model of the behavior of the tensile strength in weft of the fabric composed of linen as a function of the metric number of the yarns which constitute the fabric:

$$T_T(x_g) = 30,07 + 1,7 \cos(4,24x_g) - 4,37\sin(4,24x_g) \quad (12)$$

x_g : represents the metric number of the weft yarns

$T_T(x_g)$: represents the weft tensile strength of the fabric in [kgF]

The accuracy of the model is given by the following errors:

- Absolute error : $\Delta T = 1,05$ [kgF]

– Relative error : $\frac{\Delta T}{T} = 3.1\%$

Figure 14 demonstrates the shape of the curve of the evolution of the tensile strength in weft given by equation 12:

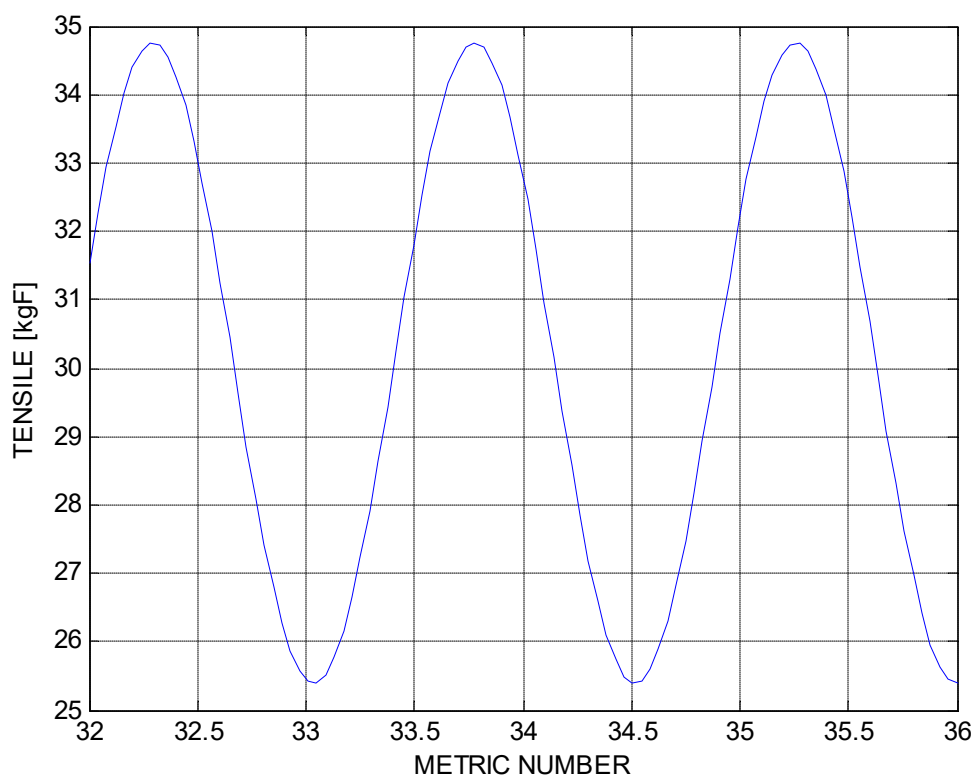


Fig. 14. Weft tensile strength as a function of yarn metric number

The curve representing the tensile strength of the weft is quite similar to that of the warp. The difference between the two curves is the period and the extreme. For Figure 14 the oscillation period corresponds to 1.4 metric number units. The respective maximum and minimum tensile strength values are 34.5 kgF and 25.5 kgF. During the experiments the maximum and minimum values are 38 kgF and 22 kgF and the difference between the model and the measurement is justified by the precision errors.

V. CONCLUSION AND PERSPECTIVES

This article relates the behavior of the tensile strength of woven linen fabrics through mathematical models depending on several characteristics of the fabric and the yarns constituting the fabric, namely: the width of the fabric, the weight of the fabric, the density yarn strength of the fabric, yarn strength, yarn kilometric strength and actual yarn metric number.

The analyzes and measurements carried out on the 63 fabric articles whose composition is 55% cotton and 45% linen made it possible to establish mathematical models relating to the tensile strength of the fabric. The models are associated with their respective accuracies defined by their respective absolute and relative errors.

In perspective, a study on the impact of yarn imperfections on the physical characteristics of the fabric is possible.

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