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Modeling The Started Tear Of A Linen Fabric: Case Of A White Woven Fabric

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Abstract— This article relates the behavior of the initiated tear of a white woven linen fabric. The initiated tearing of fabrics is represented by mathematical models and developed from the physical characteristics of the fabrics and the characteristics of the yarns constituting the fabric. Among the evaluation parameters we distinguish: the weight of the fabric, the yarn density in warp and weft of the fabric, the width of the fabric, the resistance of the yarns, the kilometric resistance of the yarns and the actual metric number of the yarns. The fabrics studied during this work are composed of 55% cotton and 45% also, tests and experiments were carried out with 66 fabric samples of the same composition in order to better understand the phenomenon of initiated tearing. The mathematical models given in this work are associated with their precision reflected by the relative and absolute errors.

Keywords— Initiated Tear, Linen, Fabric, Modeling, Textile.

I. INTRODUCTION

Currently, faced with technical and technological developments and competition, users are more and more looking for quality fabrics which satisfy their requirements. The physical parameters associated with the fabric are increasingly pushed to the extreme to meet customer needs because they are guarantees of quality and exclusivity. Then, a febrile fabric is judged as a poor quality fabric and it is the initiated tearing of a fabric which is the main parameter which determines the feverishness of a fabric.

In order to understand the phenomenon, we carried out series of tests carried out on fabrics containing linen. Two main criteria were the subject of study, namely the tests carried out on the parameters of the fabric through the density, width and weight of the fabric, but also on the yarn parameters (the real metric number of the yarn, the resistance mileage, tensile strength).

So, this article relates the behavior of the initiated tear of a white woven linen fabric in relation to the other factors mentioned previously through mathematical models. It should be noted that the mathematical models given in this work are associated with their precisions.

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II. METHOD FOR ASSESSING INITIATED TEAR

A. Measuring principle

The initiated tear of a fabric is defined as the tearing force necessary to continue a tear of defined length initiated by a cut in a sample by the application of an abrupt force. Generally, the method for determining the initiated tear is carried out by the application of the Elmendorf method.

The principle of measuring the initiated tear consists of the use of a pendulum carrying a clamp which is aligned with a fixed clamp where the pre-cut piece of fabric is placed to measure the maximum force supported before rupture. When the pendulum is released, the movable jaw moves away from the fixed jaw and then the force which represents the tear is measured.

Therefore, the initiated tear represents the physical parameters of a fabric which allows us to know the resistance of a fabric up to the point of tearing.

B. Sampling method

It is necessary to carry out sampling according to the rule of the art. So that a better assessment and reliable results would have. There are four fundamental points for sampling fabric for measurement of initiated tear namely:

- For each sampling, two samples must be cut, one in the warp direction and the other in the weft direction.
- 5 sample pairs 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 1 illustrates an example of taking 5 pairs of samples from a fabric:

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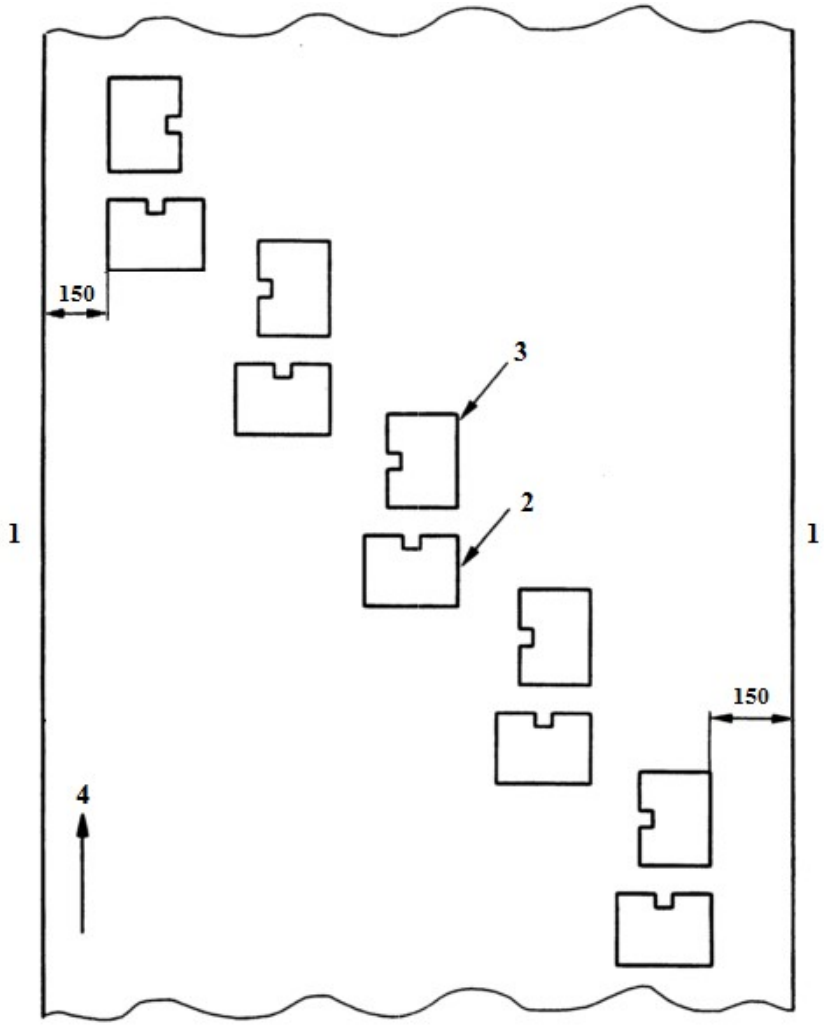

Fig. 1. Example of sampling a fabric

1: Edge;

2: Specimen for tear « across warp »;

3: Specimen for tear « across weft »;

4: Wrap

The cutting dimension of the samples should conform to that shown in Figure 2:

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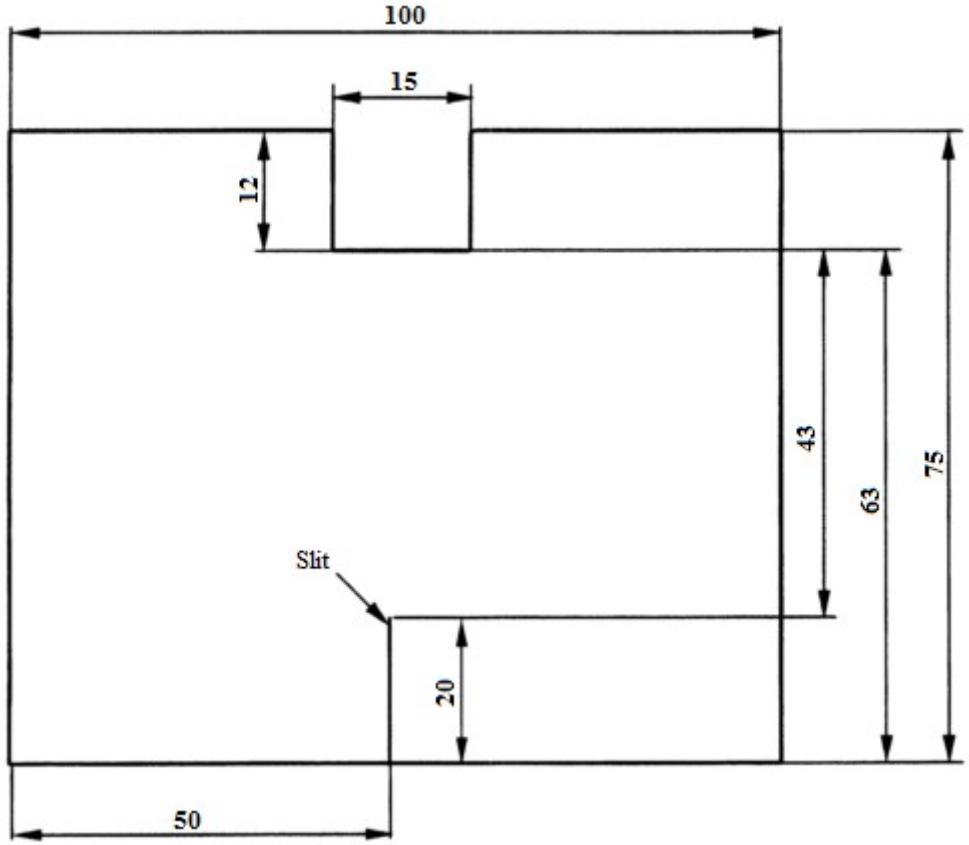

Fig. 2. Standard for cutting a sample

C. Calculation principle

A mass must be chosen beforehand so that the measurement results are between 15% and 85% of the full measurement scale, when measuring the initiated tear of a sample. After releasing the pendulum, we can directly read the value of the force corresponding to the tearing force which will be dimensioned in Newton [N]. In certain cases, depending on the type of device used, coefficients can be considered to obtain the value of the tearing force in Newton.

The tear force results for each direction should be rounded to two significant figures and it would be preferable to consider the arithmetic mean of the values obtained.

During our work, the values of the initiated tear are dimensioned in gram-force [gF] knowing that 1 gF = 9.980665 mN.

III. PRESENTATION OF THE FABRIC

This work aims to understand the behavior of the initiated tear of white woven linen-based fabric. To do this, we considered 3 types of white woven linen fabric whose composition is 55% cotton and 45% linen. With these 3 types, 66 samples were taken and we were able to observe the behavior of the initiated tear in relation to the three characteristics of the fabrics as well as the impacts of the three yarn characteristics on the parameters of the forces necessary for tearing a fabric.

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

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TABLE I. OVERALL CHARACTERISTIC OF THE CONSTITUENT YARNS OF FABRICS

Settings	*Warp yarns*	*Weft yarns*
Metric number	*34*	*34*
Origin	*Pakistan/China*	*Pakistan/China*
Coefficient of variation	*2,22*	*2,19*
Finesse	*3158*	*2557*
Size	*1090*	*1108*
NEPS	*2558*	*2444*
Imperfection	*6806*	*6109*
Hair index	*5,28*	*5,36*
Elongation	*4,9*	*4,8*
Spinning system	*Cardé*	*Cardé*

IV. PRESENTATION OF THE RESULTS

The goal in this work is to reflect the behavior of the tear force necessary to continue a tear of defined length of a fabric also known as initiated tear of a fabric for white woven linen fabric. In that case, we analyzed 66 fabric samples of the same characteristics but of different production. The initiated tears of the fabric are represented by mathematical models according to 6 basic characteristics of the fabric and the yarns namely the weight, the density, the width of the fabric and the resistance, the kilometric resistance, the real metric number of the constituent yarns of the fabric.

A. Relationship between initiated tear and fabric weight

The results shown in this paragraph present the interdependent relationship between the initiated tear of the fabric and the weight of the fabric. The mathematical models detailed in this section are the result of monitoring 63 articles of white woven linen fabric.

1) Result in warp:

Equation 1 represents the mathematical model of the warp-initiated tear of white woven fabric composed of linen:

$$T_c(x_1) = 2005\, exp^{-\left(\frac{x_1-148,5}{52,29}\right)^2} \quad (1)$$

x_1: represents the weight of the fabric in [g/m^2]

$T_c(x_1)$: represents the tear initiated in a warp of the fabric [gF]

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

- Absolute error : $\Delta T = 78,94\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 4,47\ \%$

The representative curve of the warp-initiated tear given by equation 1 is illustrated in Figure 3:

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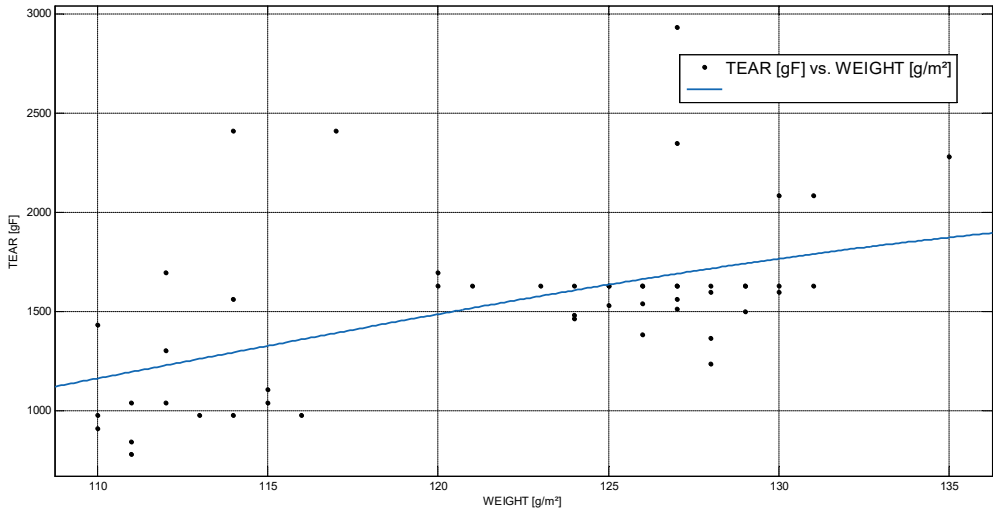

Fig. 3. Tear initiated in warp depending on the weight of the fabric

We note that the shape of the curve representing the initiated tearing of the fabric is exponentially ascending. Therefore, the higher the weight per square meter of the fabric, the greater the force required to tear the fabric. Then, this phenomenon validates theories on the behavior of the fabric according to its weight. The values of the initiated tear of the fabric are between 1 kgF and 2 kgF for fabrics with weights between 110 and 135 g/m^2. During the experiments, the respective maximum and minimum values of the initiated tear are 2200 gF and 980 gF which is justified by the precision associated with the equation.

2) Result in weft:

Equation 2 represents the mathematical model of the tear initiated in the weft of the white woven fabric composed of linen:

$$T_T(x_1) = 1536\, exp^{-\left(\frac{x_1-130}{25,49}\right)^2} \qquad (2)$$

x_1: represents the weight of the fabric in [g/m^2]

$T_T(x_1)$: represents the tear initiated in the weft of the fabric [gF]

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

- Absolute error : $\Delta T = 77{,}3\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 5{,}87\ \%$

Figure 4 represents the tear initiated in weft given by equation 2:

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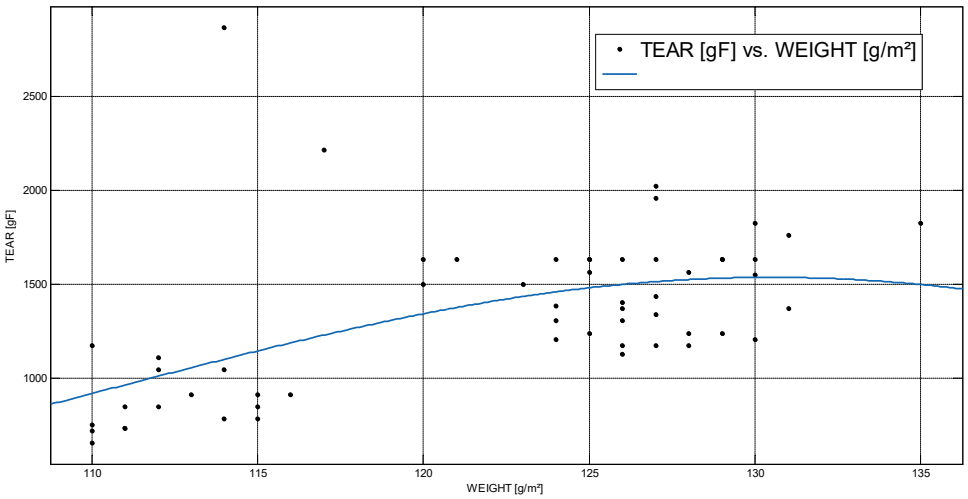

Fig. 4. Tear initiated in weft depending on the weight of the fabric

In Figure 4 we notice that the initiated tear increases with the weight of the fabric for fabrics with weights between 110 and 125 g/m^2. For fabrics weighing between 125 and 135 g/m^2 the force required to tear the fabric reaches its maximum and remains approximately constant. Its value is approximately equal to 1.5 kgF. The maximum and minimum values obtained during the experiments are 2 kgF and 700 gF respectively. The differences in values between the model and the measurements are justified by the precision associated with the equation.

B. Relationship between the initiated tear and the yarn density of the fabric

This section exposes the relationship between the yarn density of the fabric and the initiated tearing of the fabric. So, the model presented in this result illustrates the relationship between the number of warp and weft yarns per centimeter of the fabric and the initiated tearing of the white woven linen fabric. The mathematical models detailed in this section are obtained with measurements taken on 66 fabric items.

1) Result in warp:

Equation 3 represents the mathematical model of the tear initiated in the warp of the white woven linen fabric as a function of the number of yarns per centimeter in the warp of the fabric:

$$T_C(x_2) = 1532 + 29{,}41\cos(1{,}56x_2) + 314{,}5\sin(1{,}56x_2) \quad (3)$$

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

$T_C(x_2)$: represents the warp-initiated tear of the fabric [gF]

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

- Absolute error : $\Delta T = 49.27\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 3.39\ \%$

The representative curve of the warp-initiated tear given by equation 3 is illustrated in Figure 5 below:

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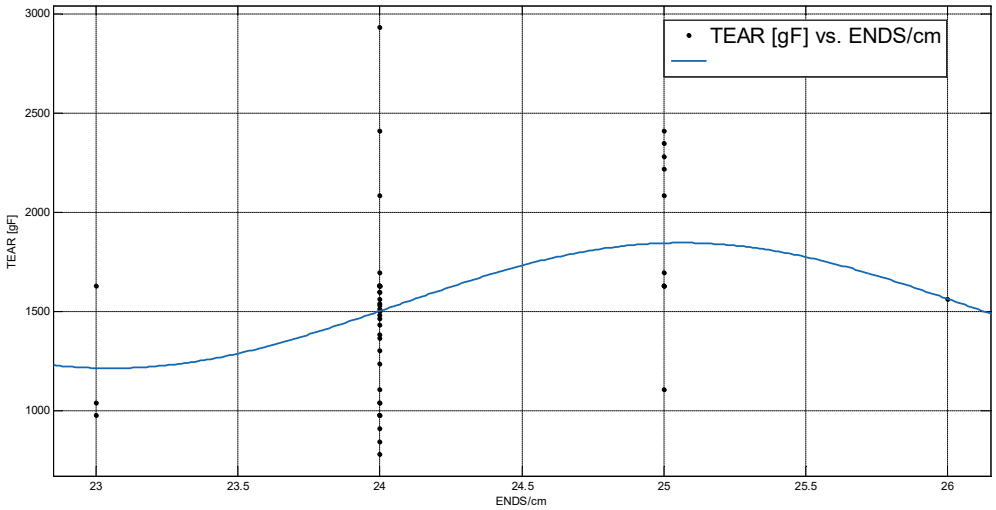

Fig. 5. Tear initiated in warp depending on the yarn density of the fabric

The model represented by equation 3 and illustrated by Figure 5 is obtained with measurements of which the fabric samples have a filament density between 23 and 26 End/cm. Then, We notice that the initiated tearing of the fabric gradually increases with the yarn density until its value reaches its extreme which is 1.9 kgF. Beyond 25 ends/cm, the more the yarn density increases, the more the initiated tearing of the fabric decreases. During the experiment the minimum and maximum values are 950 gF and 2 kgF, this precision is justified by the errors associated with the model.

2) Result in weft:

The mathematical model represented by equation 4 reflects the tear initiated in the weft of the white woven fabric composed of linen:

$$T_T(x_2) = 1989\, exp^{-\left(\frac{x_2 - 22{,}91}{7{,}36}\right)^2} \qquad (4)$$

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

$T_T(x_2)$: represents the tear initiated in the weft of the fabric [gF]

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

- Absolute error : $\Delta T = 173{,}1\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 9{,}9\ \%$

Figure 6 represents the tear initiated in weft given by equation 4:

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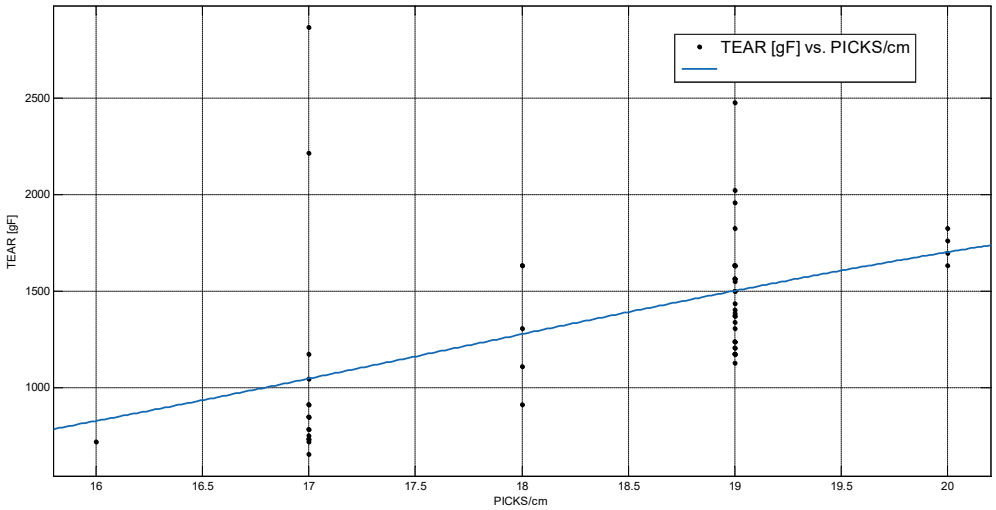

Fig. 6. Tear initiated in weft depending on the yarn density of the fabric

The curve representing the initiated tear of the fabric is linearly ascending. Thus, we see that the higher the number of yarns per centimeter of the fabric, the greater the force required to tear the fabric. This phenomenon then validates theories on the behavior of the fabric depending on the number of yarns per centimeter of the fabric. The fabric initiated tear values are between 800 gF and 1750 gF for fabrics with a filament density between 16 and 20 picks/cm. During the experiments, the respective maximum and minimum values of the initiated tear are 700 gF and 2000 gF. Deviations are reflected by errors associated with the mathematical model.

C. Relationship between the initiated tear and the width of the fabric

This paragraph reflects the results of the interdependence between the initiated tear and the width of the white woven linen fabric. The mathematical models detailed in this section were developed with the monitoring of 61 fabric articles.

1) Result in warp :

The mathematical model represented by equation 5 reflects the warp-initiated tearing of the white woven linen fabric as a function of the width of the fabric:

$$T_C(x_3) = 1453 + 17{,}79\cos(x_3) + 202{,}1\sin(x_3) \quad (5)$$

x_3 : represents the width of the fabric. [cm]

$T_C(x_3)$: represents the warp-initiated tear of the fabric [gF]

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

- Absolute error : $\Delta T = 78.86\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 4.95\ \%$

The representative curve of the warp-initiated tear given by equation 5 is illustrated in Figure 7:

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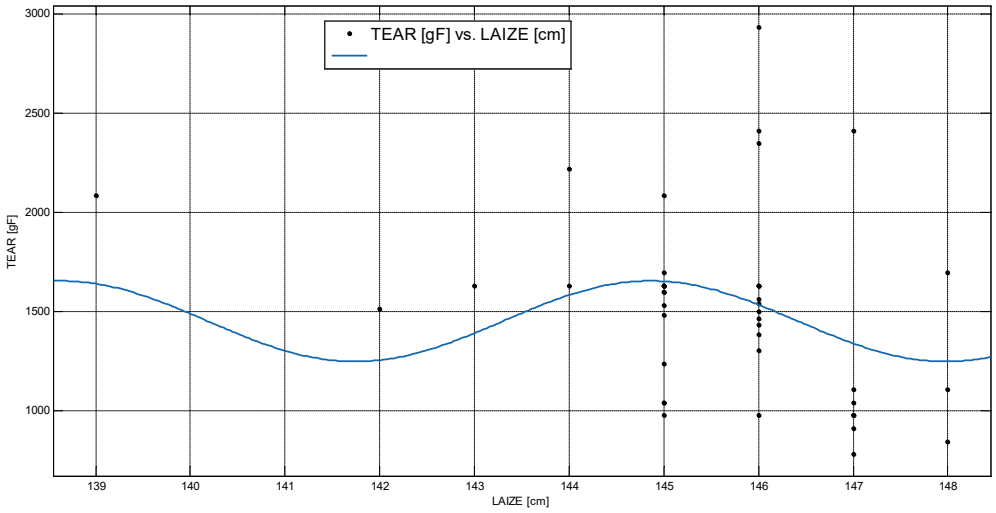

Fig. 7. Tear initiated in warp depending on the width

We note that the shape of the average value of the initiated tear of the fabric is periodic sinusoidal with a period equivalent to 6 cm width. Tear force values range between 1300 gF and 1650 gF. During the experiments the respective maximum and minimum values of the initiated tear are 2000 gF and 1020 gF. Despite the disparity in the values corresponding to the initiated tear, the model presented by equation 5 remains reliable and is justified by the errors associated with it.

2) Result in weft :

Equation 6 illustrates the mathematical model which represents the tear initiated in the weft of the white woven linen fabric as a function of the width:

$$T_T(x_3) = 1282 + 167\cos(0{,}95x_3) - 8{,}83\sin(0{,}95x_3) \quad (6)$$

x_3 : represents the width of the fabric. [cm]

$T_T(x_3)$: represents the tear initiated in the weft of the fabric [gF]

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

- Absolute error : $\Delta T = 76.47\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 5.62\ \%$

Figure 8 reflects the representative curve of the weft-initiated tear given by equation 6:

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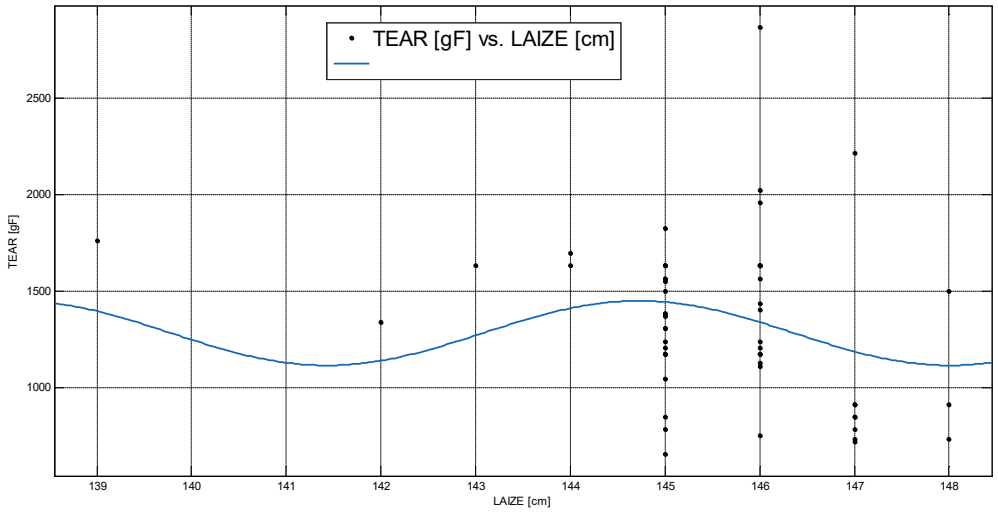

Fig. 8. Tear initiated in weft depending on the RKM of the yarn and the width

The curve and mathematical model representing the tearing force as a function of the warp and weft width of white linen woven fabric are similar. The difference is at the extreme but the oscillation period is the same. For Figure 8 reflecting the curve of the model presented by equation 6, the value of the initiated tear is between 1100 gF and 1450 gF. With the disparity of the values we notice that the precision of the model is quite high but remains acceptable.

D. Relationship between the initiated tear and the strength of the yarn

This paragraph develops the mathematical models in warp and weft of the initiated tear of the white woven linen fabric according to the tensile strength of the yarns constituting the fabric. The results are obtained with measurements carried out on 62 fabric articles.

1) Result in warp:

The model represented by equation 7 illustrates the warp-initiated tearing of the white woven linen fabric as a function of the yarn resistance of the fabric:

$$T_C(x_4) = 1510 - 41{,}63\cos(0{,}09x_4) - 117\sin(0{,}09x_4) \quad (7)$$

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

$T_C(x_4)$: represents the warp-initiated tear of the fabric [gF]

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

- Absolute error : $\Delta T = 83{,}3\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 5{,}55\ \%$

The representative curve of the tear initiated in warp given by equation 7 is given by figure 9 as follow:

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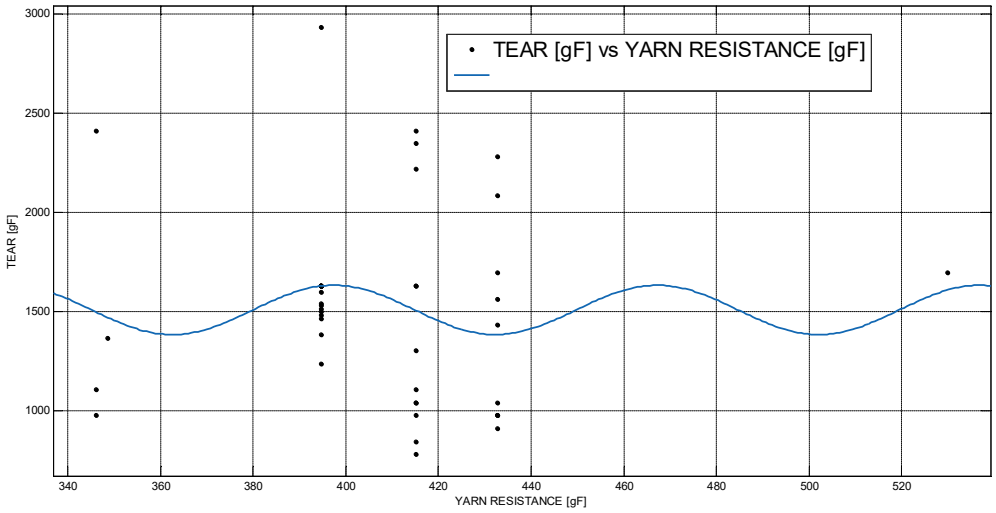

Fig. 9. Tear initiated in warp depending on the resistance of the warp yarns

The shape of the tear started in warp in Figure 9 is sinusoidal. However, the disparity of these values has an impact on the precision of the equation but remains acceptable. The average value of the tearing force oscillates over 1.5 kgF with a period equivalent to 70 gF on the yarn resistance.

2) Result in weft :

Equation 8 represents the mathematical model of the behavior of the tear initiated in the weft of the fabric composed of linen as a function of the yarn resistance:

$$T_T(x_4) = 1228 - 386\cos(0{,}07x_4) - 128{,}7\sin(0{,}07x_4) \quad (8)$$

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

$T_T(x_4)$: represents the tear initiated in the weft of the fabric in [gF]

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

- Absolute error : $\Delta T = 79{,}7\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 5{,}39\ \%$

Figure 10 represents the shape of the curve of the evolution of the tear initiated in weft given by equation 8:

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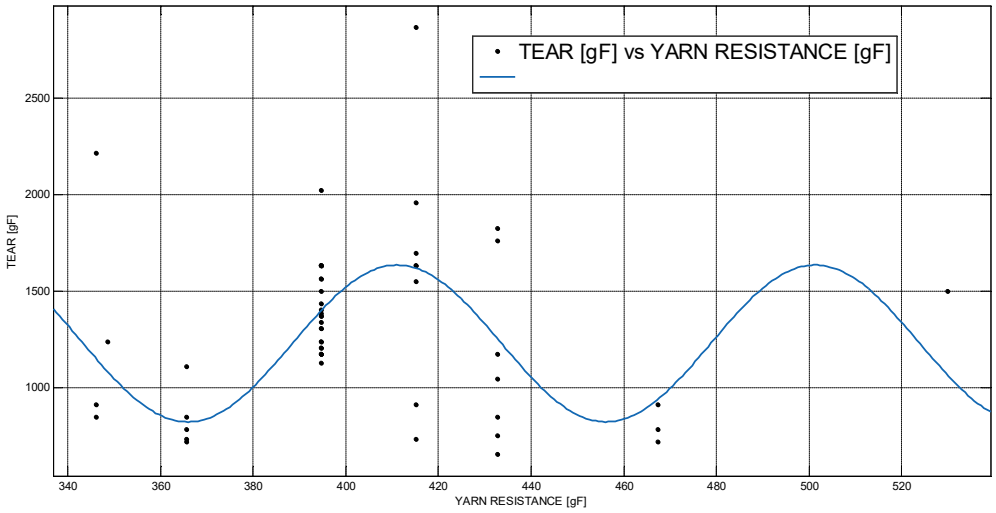

Fig. 10. Tear initiated in weft depending on the resistance of the weft yarns

The curve and the mathematical model representing the tearing force as a function of the resistance of the warp and weft yarns of white woven linen are quite similar. The difference lies in the extreme and the oscillation period. For Figure 10 reflecting the curve of the model presented by equation 8, the value of the initiated tear is between 800 gF and 1600 gF with an oscillation period equal to 90 gF of yarn resistance. The disparity of values is less significant compared to that of the warp, hence the precision of the model.

E. Relationship between the initiated tear and the kilometric resistance of the yarn (RKM)

This section presents the mathematical models according to the experiments the relationship between the RKM of the yarn and the initiated tearing of the white woven linen fabric. Besides, the kilometric resistance of the yarn corresponds to the number of kilometers of yarn necessary to suspend from a yarn so that it breaks under its own weight. The results given in this work are obtained with measurements carried out on 66 fabric articles.

1) Result in warp

Equation 9 represents the mathematical model of the behavior of the warp-initiated tear of the fabric composed of linen as a function of the kilometric resistance of the yarns which constitute the fabric:

$$T_C(x_5) = 1535 + 166{,}9\cos(1{,}98x_5) + 76{,}73\sin(1{,}98x_5) \quad (9)$$

x_5 : represents the kilometric resistance of the warp yarns in [km]

$T_C(x_5)$: represents the warp-initiated tear of the fabric in [gF]

The precision associated with equation 9 is given by:

- Absolute error : $\Delta T = 100{,}02\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 5{,}72\ \%$

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Figure 11 illustrates the shape of the curve of the evolution of the tear initiated in warp given by equation 9:

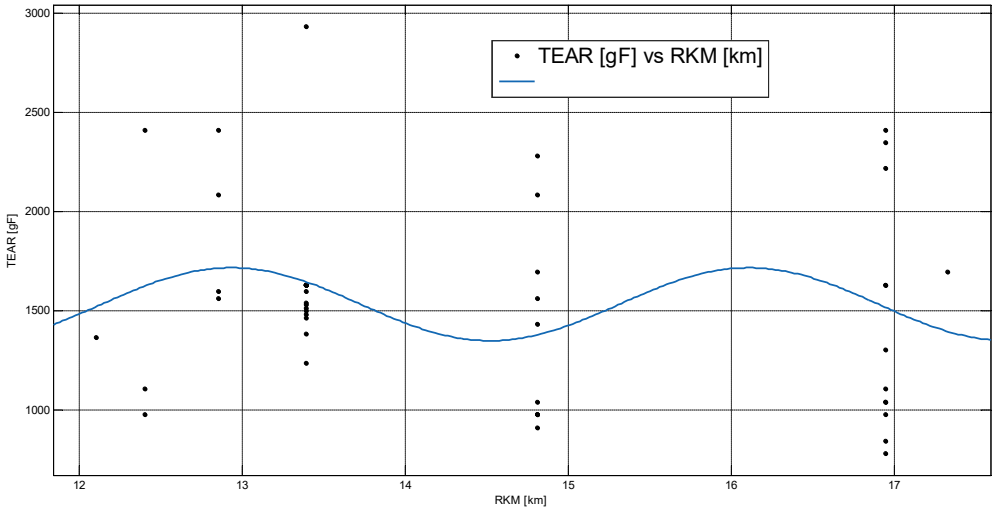

Fig. 11. Tear initiated in warp according to the RKM of the warp yarns

The warp-initiated tear shown in Figure 11 oscillates around the average value which is 1.5 kgF. The difference between the maximum and the minimum is quite small with a variation equal to ±0.25 kgF. Despite, the disparity of measurements obtained during the experiment, the model remains reliable and justified by the precision in which it is associated.

2) Result in weft :

The mathematical model represented by equation 10 illustrates the behavior of the tear initiated in the weft of the white woven linen fabric as a function of the kilometric resistance of the yarns which constitute the fabric:

$$T_T(x_5) = 1223 - 279{,}8\cos(1{,}66x_5) - 93{,}87\sin(1{,}66x_5) \quad (10)$$

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

$T_T(x_5)$: represents the tear initiated in the weft of the fabric in [gF]

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

- Absolute error : $\Delta T = 50{,}79\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 3{,}61\ \%$

Figure 12 represents the shape of the curve of the evolution of the tear initiated in weft given by equation 10:

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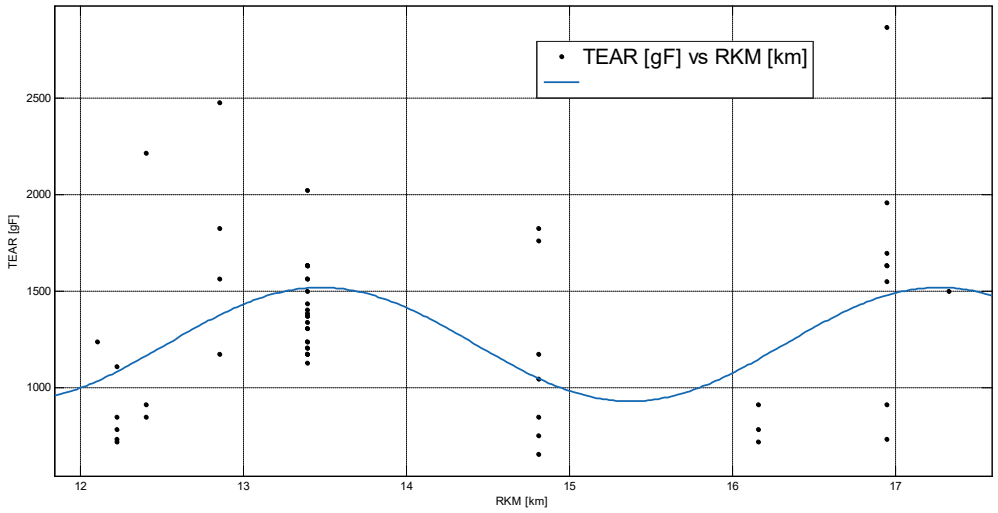

Fig. 12. Weft-initiated tearing as a function of the RKM of the weft yarns

During the experiment, the kilometric resistances constituting the fabrics were between 12 and 17.5 km. Consequently, we notice that the fabrics having an optimal tear strength correspond to the fabric made with the yarns having a kilometer resistance equal to 13.5 km. The minimum initiated tear of fabric corresponds to the fabric whose kilometric resistance value is equal to 15.5 km. The equation obtained during the development of the model is reliable and is justified by the high precision associated with the model.

F. Relationship between the initiated tear and the actual metric number of the yarn

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 initiated tear of the fabric. The metric number is defined as the length in meters of one gram of yarn. The mathematical models proposed in this work are obtained with measurements made on 66 articles of white woven linen fabric.

1) Result in warp

The mathematical model given by equation 11 illustrates the behavior of the tear initiated in a warp of the fabric composed of linen as a function of the kilometric resistance of the yarns which constitute the fabric:

$$T_C(x_6) = 1599 + 43{,}8\cos(5x_6) + 158{,}1\sin(5x_6) \quad (11)$$

x_6 : represents the metric number of the warp yarns

$T_C(x_6)$: represents the warp-initiated tear of the fabric in [gF]

The precision associated with equation 11 is given by:

- Absolute error : $\Delta T = 104{,}59\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 6{,}73\ \%$

Figure 13 represents the shape of the curve of the evolution of the tear initiated in warp given by equation 11:

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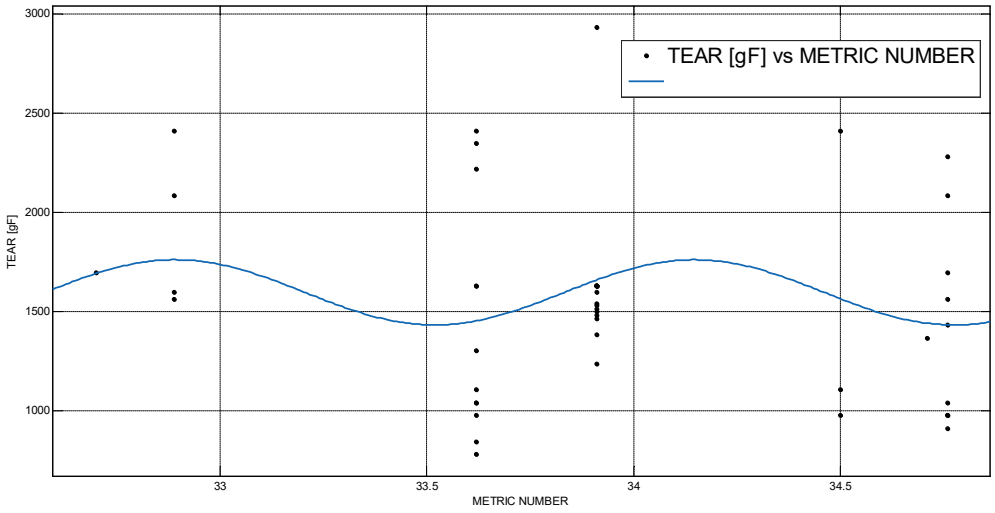

Fig. 13. Tear initiated in warp according to the metric number of the warp yarns

The warp-initiated tear shown in Figure 13 oscillates around the average value which is 1.6 kgF. The average value of the initiated tear is almost constant for all types of yarns during our experiment. The disparity of measurements obtained during the experiment means that the precision of the model obtained is quite low.

2) Result in weft :

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

$$T_T(x_6) = 1448 + 365{,}7\cos(9{,}7x_6) + 116\sin(9{,}7x_6) \quad (12)$$

x_6 : represents the metric number of the weft yarns

$T_T(x_6)$: represents the tear initiated in the weft of the fabric in [gF]

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

- Absolute error : $\Delta T = 43{,}8\ [gF]$
- Relative error : $\frac{\Delta T}{T} = 3{,}61\ \%$

Figure 14 represents the shape of the curve of the evolution of the tear initiated in weft given by equation 12:

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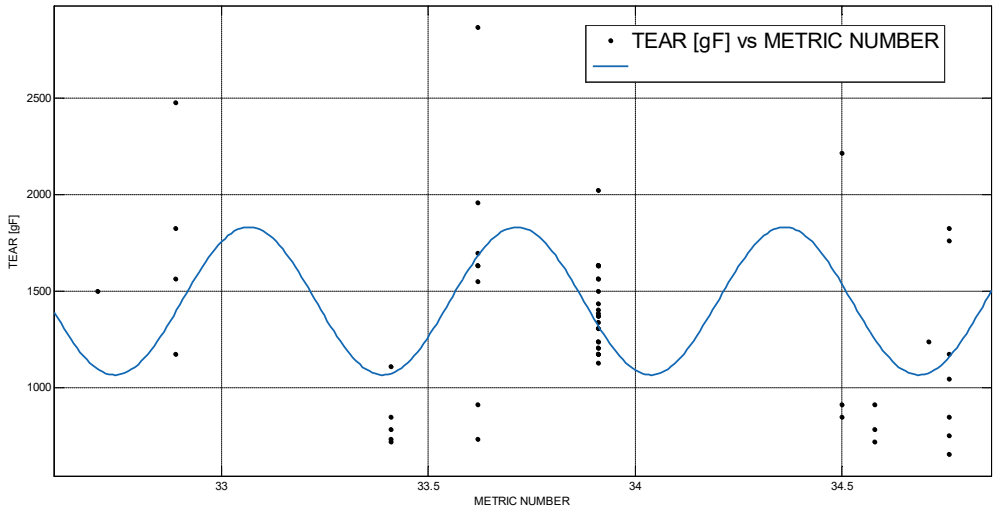

Fig. 14. Tear initiated in weft depending on the metric number of the weft yarns

The theoretical metric number of the yarns considered during our experiments is supposed to be 34, after the evaluations and physical tests carried out the metric numbers of the yarns varied between 32.7 and 34.76 depending on the respective origins of the yarns. After the measurements carried out on the 66 articles and their respective constituent yarns, we notice according to the established model that the shape of the curve representing the initiated tearing of the fabric is periodic sinusoidal alternation. The oscillation period is equivalent to a metric number 0.7. The respective maximum and minimum values of the initiated tear are 1800 gF and 1050 gF. During the experiments the maximum and minimum values are 1650 gF and 990 gF so the rather small difference between the model and the measurement is justified by the precision errors.

V. Conclusion and Perspectives

This article reports the behavior of the tearing force necessary to continue a tear of defined length of a white woven linen fabric. The behavior of the initiated tear is modeled by mathematical equations according to the characteristics of the fabric and its constituent yarns. During this work, the constituent yarns of the fabrics were analyzed according to the rules of the art, then after making the fabrics we measured the value of the tearing force initiated according to the standards.

During this work, mathematical models reflecting the initiated tearing of the fabric were established after analysis of the 66 articles of white woven linen fabric. These models are associated with their respective precision through relative and absolute errors.

Subsequently, it would be possible to study the behavior of the lycra fabric in relation to the variation in speed and treatment temperature during the fixing process.

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