Geometrical and Mathematical Analysis of the Elongation of Woven Fabric Structures

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Abstract:

It is very important when choosing a textile material to consider that the fiber and yarn structure types meet the functional requirements of the end-use product. Therefore, their choice will particularly influence the fabric's chemical, physical, and mechanical behaviors. In the shadow of a world dominated by scarcity and/or high cost of raw materials, specialists in all fields of textiles must seriously research and develop new alternatives that can be used in manufacturing operations. The raw material's poor physical properties, especially the elongation property, usually lead to its exclusion from use. Theoretically, it is not feasible for use in textile fields. As it is known, yarn elongation has deep effects during production operations and for final use. Also, some of the raw materials that are already used need to develop their production methods, to reduce waste rates and make better use of materials. This is achieved by studying the behaviors of these textile materials during manufacturing and processing operations to monitor the effectiveness of their physical properties on the quality of operations. For professionals in the field of textile engineering, the study of this important physical property comes at the heart of our scientific research interest. That is due to its close connection with all textile processes. Where the elongation of textile material plays an active role in the quality of the operating processes, starting from the initial operation stages until the final processing stage, passing through the weaving process, which is the focus of this research study. In addition, the elongation feature is associated with many other properties associated with the end uses, including properties, such as drapability, flexibility, recovery, and comfort, all of which make it suitable for use as a material for clothing and other uses. Although much research was achieved in the past to relate weave structure to the mechanical characteristics of woven fabrics, they were lacking in detail and did not offer relevant insights. These studies relied on the interpretation of elongation based on the test results and did not really penetrate the behavior of the sample under the influence of stress during the test. Therefore, this paper focuses on the study of elongation based on previous engineering concepts of the interlacing shape of the Peirce concept which is the closest geometric figure to the structure of the woven fabric, especially using synthetic fibres due to its regularity compared to other natural fibers. This research study also focused on studying the characteristic of yarn elongation from both theoretical and practical perspectives, based on the scientific importance of that physical property related, especially concerning the acceptance or rejection of the use of the material in the textile fields.

Keywords:

Weaving parameters, Yarn diameter, Weft density, Crimp, Extension, Fabric elongation, Weight, Fabric construction, Fabric thickness, Cover factor, Tensile strength.

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1. Introduction

There are many parameters very important to evaluate the woven fabric concerning warp and weft yarns, including raw materials, count, fabric sett, and the weave construction. All these parameters represent the structural elements of the woven fabric, that directly affect the properties and qualities of woven fabric. Although many studies have been conducted to link the weave structure to the physical characteristics of woven fabrics, they lack detail and do not offer clear perceptions. Fabric elongation is one of these important characteristics.

The elongation at the break depends on the fabric weave construction, and it increases as the rigidity of the woven fabric increases. This is due to the higher crimp in yarn generated from the rigid weave construction, which eventually resulted in a higher elongation.

Sometimes the loss of tensile strength is caused by increasing the weft setting and at the same time the elongation at break is increased.

The yarns elongation in the weaving field is divided into two items:

1. The elongation during the weaving process.
2. The elongation of the woven fabric.

The elongation during weaving is limited to the elongation of the weft and warp yarns. The elongation of the weft yarn is adjusted by determining the length that is prepared on the device of the weft storage unit (accumulator). It is the length equal to the width of the fabric on the weaving machine, in addition to the rate of weft crimp related to the interlacing with the warp yarns. As for the elongation of the warp yarns during weaving, it can be determined at the stage of the shed formation, as it is the most important stage in the weaving process, and very close to the quality of the weaving process. Accordingly, it is possible to identify the elongation sources of the warp yarns

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in three sources:

1. The first and most important related to the let-off process, in addition to the simultaneous forward movement of the swinging backrest roller. It is responsible for presenting the extra length of warp yarns which are required for shed formation, and later for the interlacing between warp yarns and the inserted weft. That means the distance occupied by a weft in addition to the crimp rate.
2. The second source for the elongation of the warp yarns is related to the natural elongation rate in the warp yarns, which is limited to maintaining the elasticity of the warp yarns.
3. Finally, the third source is related to the elongation of the woven fabrics in the distance between the beat-up point and the front rest of the weaving machine. This limited elongation ratio is shared in shed formation with a very small amount through the backward movement of the weave, although many references ignore that source.

The research study is concerned with predicting the expected elongation rate of the warp yarns during the shed formation, in connection with some important factors, that are determined in the:

1. The natural elongation rate of the warp yarn material.
2. The maximum height of the formed shed.
3. The horizontal length of the back and front shed. In addition to the crimp percentage for the warp yarns of the fabric sample that is prepared for the weaving operation.

According to all the previously given data, the ability to choose the appropriate weaving machine is determined, especially in the case of using special materials that are sensitive to use in the weaving process, especially those that are used in industrial fields. On the other hand, the motion performance of the let-off device is adjusted, to ensure the high-quality degree of the weaving process.

The second important part of the research is concerned with the behavior of the woven samples during the tensile and elongation test, and from another side the effect of the research variables on the elongation rates of the samples.

2. Background

Elongation is known as the rate of change in length under the influence of tensile forces in relation to the original length. There are three types of elongation that always occur in textile materials, elastic, permanent, and breaking elongation. The elastic elongation returns after the force is removed, the permanent elongation is the change in length that remains after the load has been removed and the breaking elongation is the elongation value at the breaking point. Purely elastic elongation only occurs with rubber threads (including elastane, etc.).

From a technical point of view, the change in length under the tensile forces in relation to the original length is defined in different terms as follows:

a. Elongation

Elongation is the change in length in relation to the original length. It`s measured in units of length (e.g., millimeters, centimeters, inches):

$$Elongation = extended\ length - initial\ length$$

b. Strain

Strain expresses the elongation as a fraction of the original length:

$$Strain = \frac{elongation}{initial\ length}$$

c. Extension

Extension expresses the elongation as a percentage of the original length:

$$Extension = \frac{elongation}{initial\ length} \times 100\%$$

Elongation rates:

Both natural and synthetic fibers have very different elongation ranges, which can be divided as follows:

1. Very low extension (2-6%) in flax, hemp, and other soft and hard fibers.
2. Low extension (6-10%) for cotton.
3. Medium to high extension (15 – 20%) wool and animal hair.
4. High extension (20 – 30%) silk.
5. Extreme extension (100 – 200%) rubber.

The physical and chemical properties of textile products are generally influenced by very important different elements, which are in order:

1. The structural composition of used textile fibers and their chemical, and physical properties in addition to the geometrical shape of the fibres.
2. The geometry of the fabric construction, based on the product manufacture mechanism (woven, knitted, braided, non-woven, etc.).
3. Processing of preparation and treatment of the final textile product.

From all these precious elements, it is concluded that the second element directly concerns the subject of this research paper. The study of the fabric geometry with its important elements affecting it, and the reflection of this effect on the internal friction force between the warp and weft yarns and hence their impact on the mechanical force rates needed for weft beating-up on the weaving machines.

2.1 Different preconceptions of the geometric shape of woven fabric

Fabrics aren't regular structures capable of description in mathematical forms based on geometry, but they can be idealized the general characters of the materials into simple geometrical forms and physical parameters to arrive at mathematical conclusions. As geometrical models are the sole solution to providing geometrical information about woven fabrics for finite element (FE) models for performance simulation. To represent the configuration of yarns in woven fabrics, many different geometrical forms have been put forward by textile researchers /1, 2/.

2.1.1 Peirce's assumptions

Peirce's work is regarded as the beginning of modelling woven fabric geometry. Under certain assumptions, including circular yarn cross-section, complete flexibility of yarns, incompressible yarns, and arc-line-arc yarn path. In the cross-section of plain-woven fabric based on Peirce's assumption as shown in Fig. 1, the subscripts 1 and 2 are used to denote warp and weft. In this model, a two-dimensional unit of repeated fabric was built by superimposing linear and circular yarn segments to produce the desired shape. Derivation of the relationships between the geometrical parameters and such parameters as yarn spacing, weave crimp, weave angle, and fabric thickness forms the basis of the analysis.

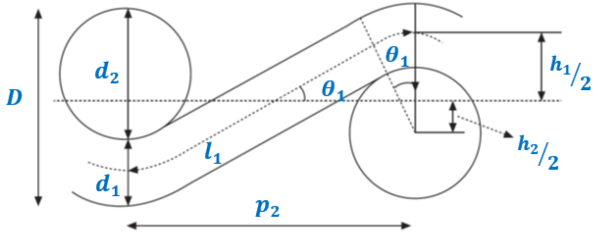

Fig. 1: Peirce's assumption for the circular cross-section of plain-woven fabric /1/

This model is convenient for calculation and has been found useful in the ordering and interpretation of observation; it is especially valid in very open structures. Peirce derived the following equations describing the geometry of plain-woven fabrics:

$$D = d_1 + d_2, \tag{2.1}$$

and:

$$D = h_1 + h_2 \tag{2.2}$$

$$C_1 = \frac{l_1}{p_2} - 1, \tag{2.3}$$

and:

$$C_2 = \frac{l_2}{p_1} - 1. \tag{2.4}$$

The yarn cross-section in a real fabric is hardly circular because of the pressure between the warp and weft yarns during the weaving process. Peirce proposed an alternative model for the plain-woven fabric, as shown in Fig. 2, assuming the yarn cross-section to be elliptical.

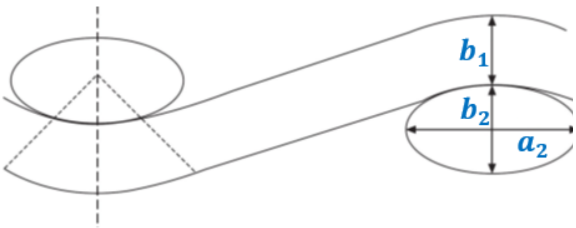

Fig. 2: Peirce's assumption for the elliptic cross-section of plain-woven fabric /2/

It proved to be mathematically too complicated to describe the relationship between the structural parameters. The used symbols in all figures are listed in table 1 as follows:

Table1: The used symbols in all figures

Symbole	Designation	Symbole	Designation
1	warp yarn	*K*	cover factor
2	weft yarn	*N*	cotton count of yarn
a	major diameter of the flattened yarn	*N*	the average number of yarns per unit length (*n* = *1/p*)
b	minor diameter of the flattened yarn		
e	yarn flattening coefficient	*p*	average yarn spacing for the fabric as a whole
c	yarn crimp(*a/b*)		
h	height of crimp wave	*l*	length of yarn axis between planes containing the axes of consecutive
d	yarn circular diameter		
D	sum of circular diameters (d1 + d2)	*θ*	maximum angle of the yarn axis to the plane of fabric in radius
T	fabric thickness		

Peirce's model (1937) of plain-woven fabrics was extended by others, notably Kemp (1958), who assumed that the yarn cross-section is racetrack-shaped, and Shanahan and Hearle (1978) who proposed a lenticular yarn cross-section. These extended models retained all the assumptions Peirce used except for the yarn cross-section and are regarded as Peirce derivative models, as it is clarified in the following:

2.1.2 Kemp's assumption

The cross-section shape of a plain-woven fabric related to Kemp's assumption is illustrated in fig.

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3, where the yarn cross-section is racetrack shaped. The racetrack is formed by tangentially connecting two parallel lines with two half circles facing each other. The part between the plane *S1* and *S2* is identical to the diagram of Peirce’s circular cross-section model, so the racetrack model can be converted into Peirce’s model and equations solved similarly /3/.

In this figure, $a_1$and b_1 are the width and height of cross-section of warp yarns, a_2 and b_2 are the similar of weft yarns. The variables h_1, h_2, c_1, c_2, p_1, p_2, l_1, l_2, θ_1 and $\theta_2$have the same definition as for Peirce’s model. The variable p'_2 is the distance between *S1* and *S2* and$\acute{l}_1$ the length of the path between *S1* and *S2*. The variable$\acute{c}_1$is the crimp of the weft between the S1 and S2. From this definition, we have:

$$p'_2 = p_2 - (a_2 - b_2)\,, \qquad (2.5)$$

and: $$\acute{l}_1 = l_1 - (a_2 - b_2), \qquad (2.6)$$

hence: $$\acute{c}_1 = \frac{\acute{l}_1 - \acute{p}_2}{\acute{p}_2} = \frac{c_1 p_2}{p_2 - (a_2 - b_2)}\,. \qquad (2.7)$$

and also: $$p'_1 = p_1 - (a_1 - b_1), \qquad (2.8)$$

$$\acute{l}_2 = l_2 - (a_1 - b_1), \qquad (2.9)$$

Then: $$\acute{c}_2 = \frac{\acute{l}_2 - \acute{p}_1}{\acute{p}_1} = \frac{c_2 p_1}{p_1 - (a_1 - b_1)}. \qquad (2.10)$$

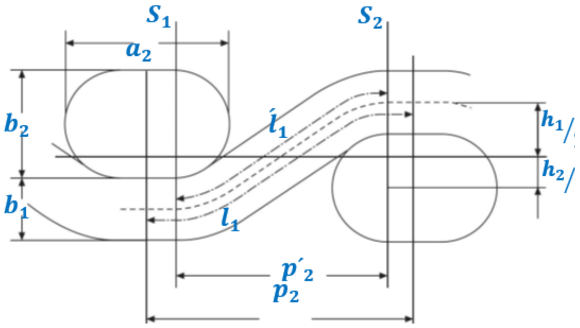

Fig. 3: Kemp’s racetrack section geometry of plain-weave fabrics

2.1.3 Shanahan and Hearle’s assumption

Shanahan and Hearle’s plain woven fabric model with lenticular yarn cross-section is illustrated in Fig. 4. A lenticular shape is formed by joining two identical arcs facing each other.

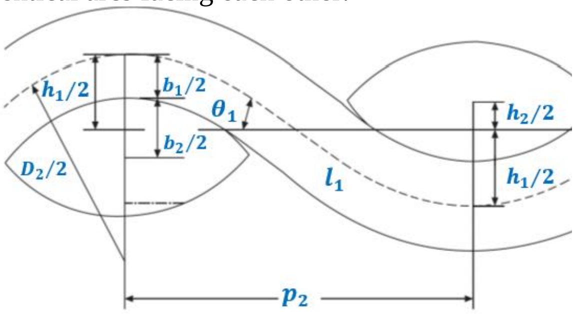

Fig. 4: Shanahan and Hearle’slenticular section geometry of plain-weave fabrics /3/

$$h_1 + h_2 = b_1 + b_2\,, \qquad (2.11)$$

and: $$c_1 = \frac{l_1}{p_2} - 1, \qquad (2.12)$$

then: $$c_2 = \frac{l_2}{p_1} - 1, \qquad (2.13)$$

and: $$D_2 = 2\,R_2 + b_1. \qquad (2.14)$$

All other assumptions used in the Peirce model also apply to this model apart from the fact that the yarn cross-section in this case is lenticular. Similar to Peirce’s model, the following equations have been derived to describe the relationships of the fabric parameters:

Whereh_1, h_2, c_1, c_2, p_1, p_2, l_1, l_2, θ_1 and $\theta_2$have the same definition as those used for Peirce’s model. In addition, b_1 and b_2 are the crimp heights of warp and weft yarns and R_1, R_2 are the radii of the lenticular arcs representing the warp and weft yarns. Also because of the similarities to the Peirce model, the fabric geometry can be definitely defined when seven of the parameters are specified.

2.2 Structural parameters of woven fabrics

From the previous studies on the geometric theories introduced above, several parameters could be extracted to characterize the fabric geometry. The following section presents a general description of every parameter; some of them don't need to be calculated but can only be measured.

2.2.1 Yarn diameter

According to Peirce’s circular yarn section, $1/d$ and the number of diameters per inch in the cotton system:

$$\frac{1}{d} = \frac{29.3\sqrt{N}}{v}\,, \qquad (2.15)$$

and:

$$d = \frac{1}{28\sqrt{N}} = \frac{0.0357}{\sqrt{N}}(inch) = \frac{\sqrt{Tex}}{269}\,(cm). \qquad (2.16)$$

where v, the specific volume, is the ratio of the volume occupied by a material to that of the same weight of water under compression of the woven structure, $v = 1.1$ cotton yarn.

2.2.2 Thickness

Fabric thickness is given by t_1 or t_2 whichever is greater, where $t_1 = h_1 + d_1$, $t_2 = h_2 + d_2$. When yarn diameters are assumed to be circular:

$$t = \max\,(t_1, t_2). \qquad (2.17)$$

The condition that the two yarns project equally produces a smooth surface and gives the minimum thickness (t_{min})

$$t_{min} = h_1 + d_1 = h_2 + d_2$$
$$= \frac{1}{2}\,(h_1 + h_2 + d_1 + d_2) = D, \qquad (2.18)$$

Where: $h_1 = D - d_1$.

So the minimum thickness is the sum of the yarn diameters.

The maximum thickness is attained when one or other of the yarns is straightened as far as possible. In an open fabric, where either may be straightened to zero crimp, this thickness should be:

$$t_{max} = D + d_{max}\ , \qquad (2.19)$$

d_{max} is the diameter of the thicker yarn, and it is attained by straightening the thinner yarns.

If: $d_1 = d_2$, (2.20)

then: $t_{min} = 2d = Dt_{max} = 3d.$ (2.21)

2.2.3 Cover factor

Fabric cover is defined by Hamilton (1964) geometrically as the proportion of fabric area overed by actual yarns. In practice, cover factors are normally calculated for warp and weft independently. For example, a fabric having 50 warp yarns per centimetre, each 0.01 cm in major diameter, would have a warp cover factor (K_1) of 0.5 or 50 %. In the case of circular section yarns, warp and weft cover factors are given by:

The primary geometrical parameter is the crimp magnitude. It provides a good basis for investigating many complicated phenomena, such as stress-strain relations, hand, and creasing. And, in particular, crimp has been used as a fundamental parameter for calculating other geometrical parameters such as crimp height or weave angle which are not easy to measure. Therefore, to study fabric structure or related problems, measuring yarn crimp in the fabric is essential. But the actual difficulty in measuring this parameter is not entirely solved or recognized, perhaps, by many researchers /5, 6/.

3. Methodology

3.1 Analysis of the Problem

The research problem is limited to studying the interrelationship between the elongation of warp yarns and their crimp in woven fabrics, from the first side, and the elongation of woven fabrics in the longitudinal direction, from the other side, both theoretically and practically. That is for the scientific importance of this physical property of fabrics.

3.2 Theory of research method

The research method depends on:

- The theoretical studies related to the form of interlacing in fabric constructions.
- The mathematical analysis of the yarn crimp of woven fabrics.
- Fabric samples' behaviors during tensile strength and elongation test.
- A comparative analytical study between the theoretical studies and the results of practical work.

3.3 Weaving of Standard Experiment Samples

This important part of the research was identified in weaving experimental samples with different elements of fabric structures. The fabric structures were limited to plain weave 1/1, Hopsack 2/2, twill 2/2, 1/3, and satin 8 weaves.

3.4 Laboratory Measurements

The laboratory measurements were limited to measuring tensile strength and elongation test (or tension test) in the longitudinal direction of the woven samples, in addition to the manual measurement for the warp yarns' crimp percentage of the woven fabric.

4. Experiments

The experimental work has been carried out on dornier rapier weaving machine p2, equipped with two warp beams and a dobby device up to 24 heald frames.

The experimental works were divided into two phases:

1. Weaving of experimental samples.
2. Laboratory measurements.

$$K_1 = n_1 d_1 K_2 = n_2 d_2\ . \qquad (2.22)$$

For flattened yarns, warp and cover factors for plain weave are thus given by

$$K_1 = n_1 a_1 K_2 = n_2 a_2. \qquad (2.23)$$

And overall cover factor K is calculated from K_1 and K_2 as follows:

$$K = K_1 + K_2 - K_1 K_2. \qquad (2.24)$$

The cover factor thus indicates the degree of closing or cover. Increasing the projection of the area covered by yarns through using yarn with greater 'ooziness', or by flattening in finishing and more regularity will improve the cover of fabric /4/.

2.2.4 Crimp

Crimp is the percentage of excess of length of the yarn axis over the fabric length:

$$c_1 = \left(\frac{l_1}{p_2} - 1\right) \times 100\ \%$$

$$c_2 = \left(\frac{l_2}{p_1} - 1\right) \times 100\ \%. \qquad (2.25)$$

Material	**PP (Twisted yarn) 200 t/m**	Count **denier**	ε - F_{max} **%**	F_{max} **Gram**	F_{max} **g/den**
		450	24.1	1593	3.54

Experimental samples` specifications

	Fabric set / **Construction**	**Warp density [yarn/cm]**	**Weft density [weft/cm]**

Fabric	**Plain**	**1/1**	22	20	22	24
		H 2/2				
	Twill	**T 2/2**				
		T 1/3				
	Satin	**S 8**				
	Cover factor (of the fabric)	**Warp/weft**	16.19	14.72	16.19	17.65
		Fabric		22.40	23.02	23.64

Table 2: Structure elements of the experimental samples

4.1 Weaving of experimental samples

The main purpose of this process is to weave standard test specimens, with different woven-fabric structure variables, as represented in Table 2 and Fig. 6

The main elements of the woven fabric structure variables were:

1- Fabric constructions:
  - Plain weaves1/1 and hopsack 2/2.
  - Twill weaves1/3, and 2/2.
  - Satin weave 8.

2- Warp yarns density: 22 yarns/cm.

3- Wefts density: 20, 22, and 24 wefts/cm.

4- Warp and weft yarn material: Polypropylene (CF) twist yarn denier 450.

Woven samples' fabric constructions were determined as represented in Table 2. On the other hand, Fig. 6 shows the design, draft system, and lifting plan of the experimental samples.

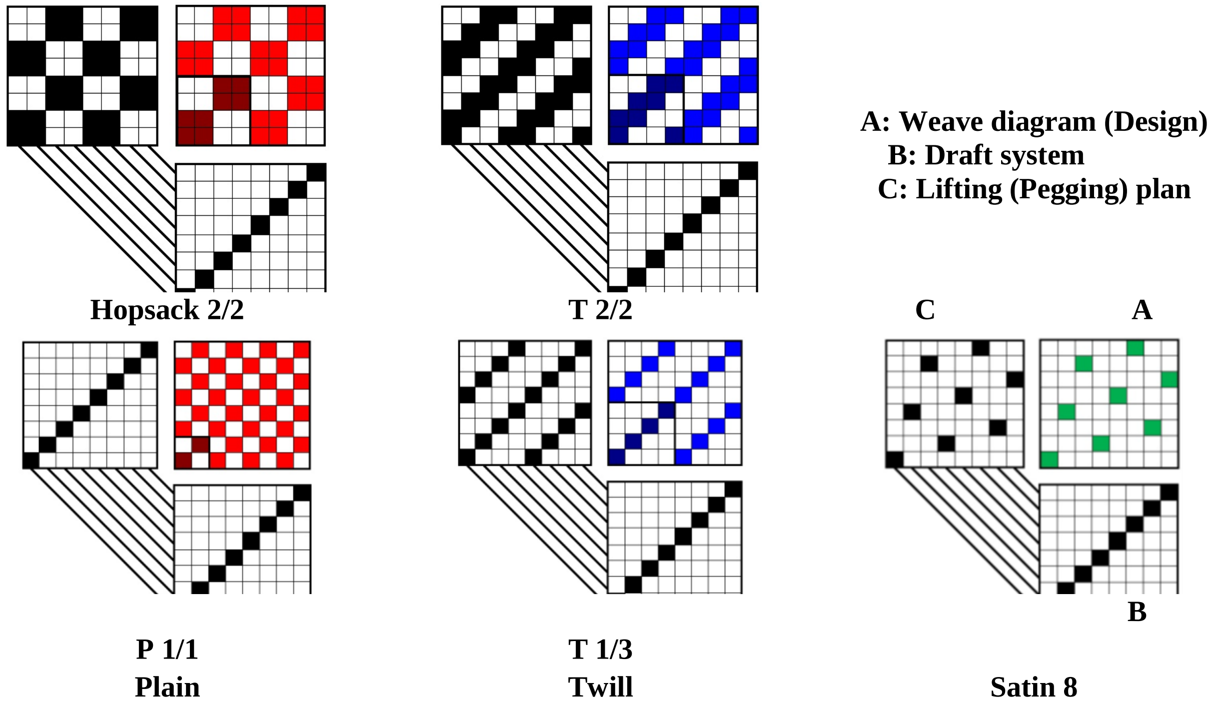

Fig. 6: The weave diagram, draft system, and lifting plan of the experimental samples

4.2 Laboratory Measurements

The laboratory measurements were limited to measuring tensile strength and elongation test (or tension test) in the longitudinal direction of the woven samples. The measurement values have been measured by using a tensile testing Machine (Zwick/Roell Model: Z100). Laboratory tests had been performed in accordance with standard procedures, which are recommended by the German Institute for Standardization (Deutsches Institut für Normung, DIN) ISO 13934-1:2013(en), and also A.S.T.M (American Standards on Textile Materials), Designations: D 5035 – 06:2008). The manual measurement for the warp yarns crimp percentage of woven fabric had been performed in accordance with standard procedures, which are recommended by the A.S.T.M, Designations: D 3883-04(2020). Table 3 represents the different values of tensile strength, elongation and also warp yarns crimp in the longitudinal direction of the woven fabric samples.

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Fabric Construction	Nr. of warp	Nr. of wefts	Warp-crimp	Tensile Strength	Extension at Break

		yarns [yarn/cm]	[weft/cm]	%	[Kg/5cm]	%
Plain Weave	**P 1/1**	**22**	20	19.9	152.5	35.2
			22	21	153.6	36
			24	21.8	154.9	37.3
	Hop-sack 2/2	**22**	20	9.8	141.5	32.5
			22	10.5	142.2	33
			24	11.1	143	33.6
Twill weave	**T 2/2**	**22**	20	9.8	142.9	33.6
			22	10.5	143.8	34.4
			24	11.2	145.6	35.2
	T 1/3	**22**	20	9.9	143.1	33.7
			22	10.6	144	34.6
			24	11.3	145.8	35.3
Satin Weave	**S 8**	**22**	20	5.2	138.7	30.2
			22	5.3	139.2	30.8
			24	5.6	140	31.2

Table 3: The different values of fabric crimp, tensile strength, and extension at break in warp direction for all fabric constructions

5. Results and discussions

5.1 Geometric description of the interlacing between warp and weft yarns

The geometric description of the interlacing angles between warp and weft yarns, with the aid of specific microscopic photography of the experimental samples, was drawn up, based on Peirce's assumption of fabric geometry as shown in Fig. 7. A square fabric set was used, in addition to a cover factor of 16.19 for the warp yarns and wefts (that equals 23.02 for the fabric cover factor), to approximate the shape geometry of the samples to the aforementioned Pierce description. It is noted, the stability of the sum of the interlacing angles values between the warp and the weft yarns within a repeat of all fabric constructions, whose sum was determined to be 240° in either direction. All the woven fabric constructions under study contain only two intersections, despite the differences in the number of yarns in weave repeat.

This is despite the difference between woven samples structures in the following:

1- The difference in the number of yarns in woven fabrics repeats in either direction, which are varied between two yarns for plain weave 1/1, 4 yarns for plain weave hopsack 2/2, twill weaves 2/2, 1/3, and 8 yarns for Satin weave 8.

2- The difference in the number of interlacing angles within the fabric construction in either direction between two equal interlacing angles for plain weave 1/1, the value of each one is 120°, three equal interlacing angles, the value of each angle is 60°, and the third is 120° for twill 1/3 and satin 8 weaves, 4 equal interlacing angles with a value of each angle is 60° for plain hopsack 2/2, and twill 2/2 weaves.

The longitudinal sample unit was determined with eight wefts to study the variation in properties between all woven structures on a scientific basis. That value is equal to the number of wefts for one construction repeat of satin weave 8, two repeats for hopsack 2/2, twill weaves 2/2, 1/3, and 4 repeats for plain weave 1/1 as shown in Fig. 7.

- Figure 7a shows the interlacing angles values between the yarns and wefts for plain weave 1/1, which achieved the highest rate of interlacing with equal two angles with a sum of 240° for the weave repeat. Plain weave 1/1 is distinguished by this tight composition, as it contains only two intersections repeated on two yarns in both directions. That makes it the highest rate of crimp values between warp and weft yarns for all woven constructions, and thus the highest rate of elongation for woven fabrics as well.
- Figure 7B shows the interlacing angles values between the yarns and wefts for plain weave hopsack and the twill 2/2, which achieved the rate of interlacing with equal 4 angles with a sum of 240° for the weave repeat of consists of 4 yarns in both directions.
- Figure 7C shows the interlacing angles values between the yarns and wefts for twill weave 1/3, which achieved the rate of interlacing with 3 angles with a sum of 240° for the weave repeat of consists of 4 yarns in both directions.
- Figure 7D shows the interlacing angles values between the yarns and wefts for satin 8 weave, which achieved the rate of interlacing with 3 angles with a sum of 240° for the weave repeat of consists of 8 yarns in both directions.

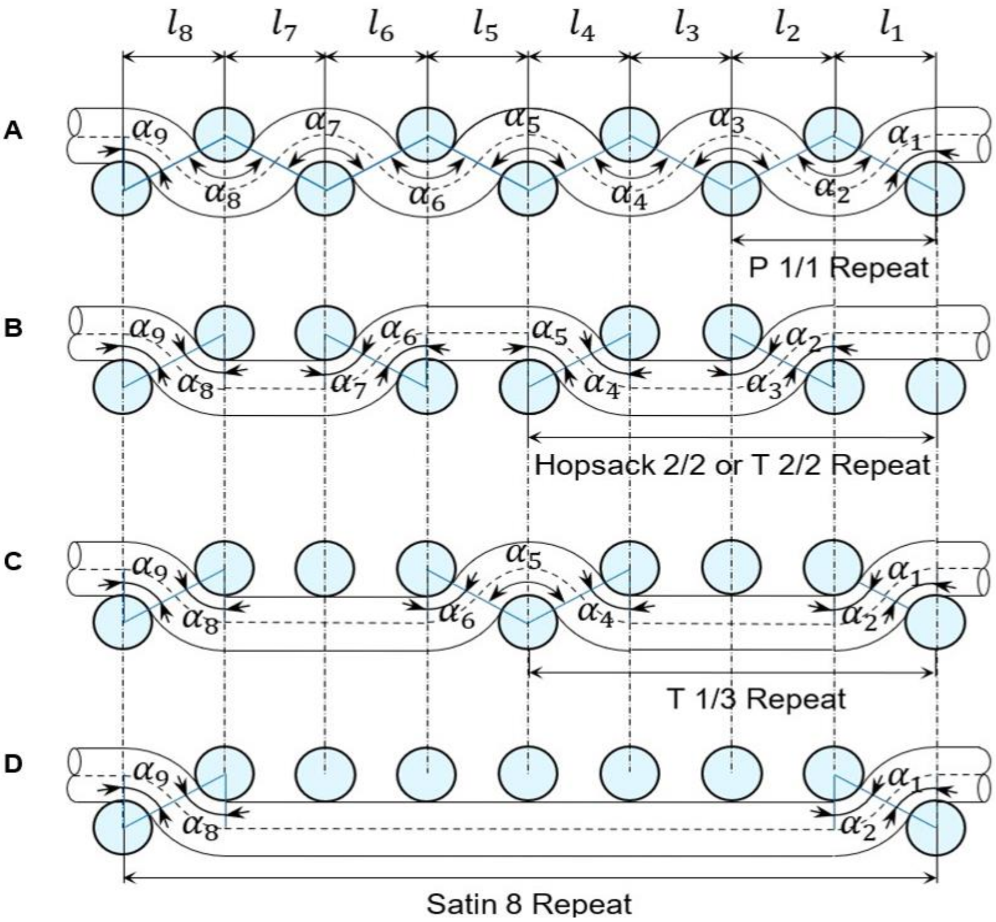

Fig. 7: The geometric description of the interlacing between warp and weft yarns, based on Peirce's assumption of fabric geometry

5.2 The research results analysis

As mentioned before, the main research point is to study the elongation property of the fabric in the longitudinal direction, and it is well-known that the test of this physical property is closely related to the tensile strength test. Beside the effect of warp yarns crimp in the results. Therefore, the influence of subsequent factors on the results of textile elongation tests had to be studied as follows:

5.2.1 The warp yarns crimp

The variation of warp yarn crimp values for the woven samples according to the difference in fabric constructions and weft densities, as illustrated in Tab. 3 and Fig. 8. The highest average value of warp yarn crimp percentage was achieved by using plain weave 1/1 with a rate of 20.9%. The plain weave hopsack 2/2, twill weaves 2/2, and 1/3 achieved average rates of 10.5%. On the other side, the standard satin weave 8 achieved the lowest average value of crimp percentage with a rate of 5.4%.

Furthermore, the warp yarn crimp values of the woven samples varied with the differences in weft density, as there was a gradual increase in the crimp percentage values with the increase in weft density. The lowest average value of warp yarn crimp percentage was achieved by using 20 wefts/cm, with a rate of 10.9%. The average value was achieved by using 22 wefts/cm with a rate of 11.6%. On the other side, the highest average value of crimp percentage was achieved by using 24 wefts/cm with a rate of 12.2%.

5.2.2 Fabric tensile strength in the longitudinal direction

The tensile strength in the longitudinal direction values of the woven fabrics varied with the differences in fabric constructions and weft density, as illustrated in Tab. 3 and Fig. 9. The highest average value of warp tensile strength was achieved by using plain weave 1/1 with a rate of 153.7 kg. The plain weave hopsack 2/2, twill weaves 2/2, and 1/3 achieved average rates of 143.5 kg. On the other side, the standard satin weave 8 achieved the lowest average value of warp tensile strength with a rate of 139.3 kg.

As well, the warp tensile strength values of the woven fabrics were varied with the differences in weft density, as there was a gradual increase in the tensile strength values with the increase in weft density. The lowest average value was achieved by using 20 wefts/cm with a rate of 143.7 kg. The average value was achieved by using 22 wefts/cm with a rate of 144.6 kg. On the other side, the highest average value of the warp tensile strength was achieved by using 24 wefts/cm with a rate of 145.9 kg.

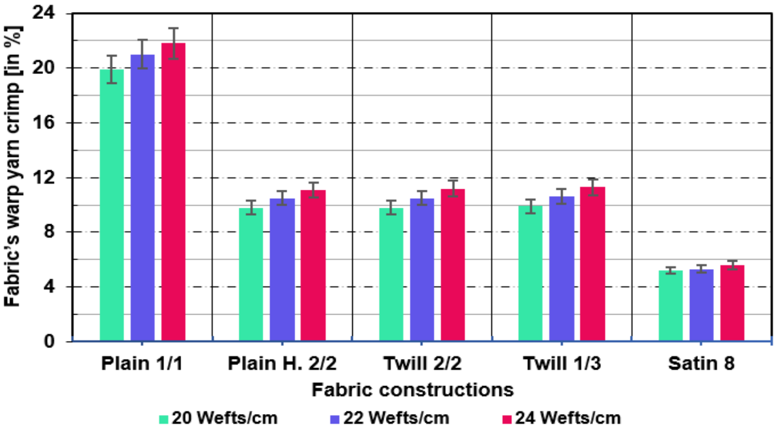

Fig. 8: The relation between fabric construction elements and the crimp values of warp yarns in woven fabrics

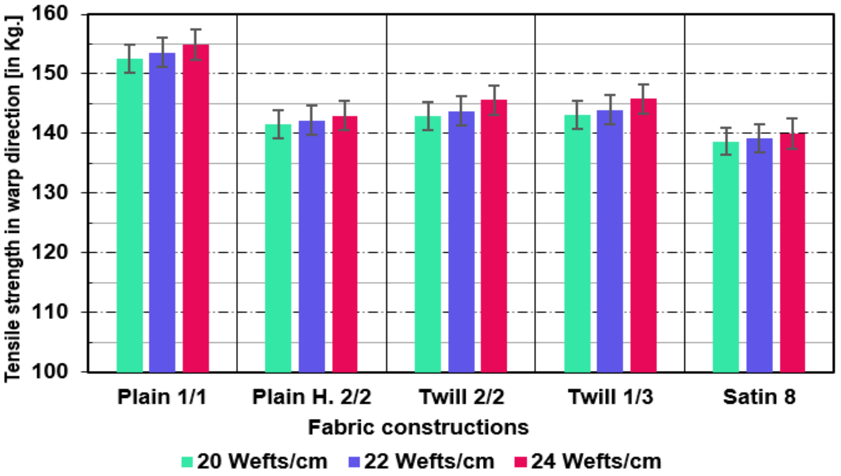

Fig. 9: The relation between fabric construction elements and the tensile strength values of woven fabric in warp direction

5.2.3 Fabric elongation in the longitudinal direction

The elongation in the longitudinal direction values of the woven fabrics varied with the differences in the fabric constructions and weft density, as illustrated in Tab. 3 and Fig. 11. The highest average value of extension percentage (elongation) in the longitudinal direction was achieved by using plain weave 1/1 with a rate of 36.2%. The plain weave hopsack 2/2, twill weaves 2/2, and 1/3 achieved average rates of 34%. On the other side, the standard satin weave 8 achieved the lowest average value of extension in the longitudinal direction, with a rate of 30.7%. As well, the elongation in the longitudinal direction values of the woven fabrics varied with the differences in the weft density, the lowest average value was achieved by using 20 wefts/cm with a rate of 33%. The average value was achieved by using 22 wefts/cm with a rate of 33.8%. On the other side, the highest average value of the extension percentage (elongation) in the longitudinal direction was achieved by using 24 wefts/cm with a rate of 34.5%.

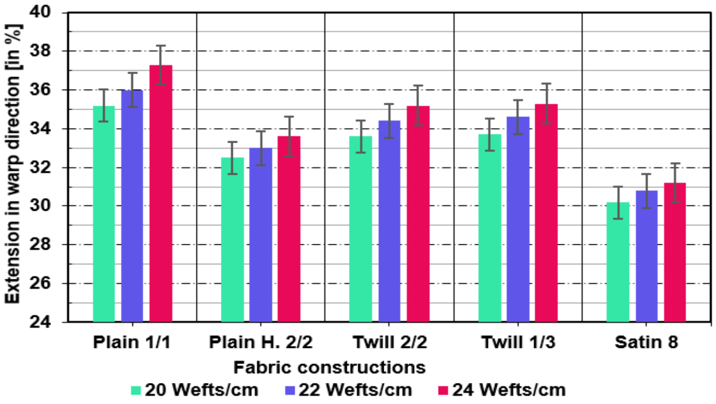

Fig. 10: The relation between fabric construction elements and the extension percentage values of warp

yarns in woven fabrics

5.3 The relationship between the interlacing angles values between the warp and weft yarns and the elongation rates of woven fabrics

To realize the effect of the variation of interlacing angles between the warp and weft yarns on the elongation rates of the experimental samples, the behavior of the sample had to be studied during the tensile strength and elongation test, as shown in Figure 11. It can be concluded from this figure that the test procedures contain three stages:

A. **Initial elongation**: The elongation of the sample under the influence of the vertical tension of the upper clamp for the test device. This initial elongation of the whole length (20 cm.) between upper and lower clamps is dominated by internal friction between warp and weft yarns in intersection points of fabric constructions.

B. **Decrimping length**: After the initial elongation of the sample, it continues to elongate, but the sample behavior in the middle area for a distance of 4-5 mm. begins to eliminate the interlacing between warp and weft yarns. The warp yarns become independent and taut, then they are extended under the effect of vertical tension as shown in Figures 11B and 12.

C. **Sample deformation**: The tensile and elongation load at that stage falls fully on the decrimped warp yarns, which represented then the weak points of the sample under the tension load, while the greatest value of tensile strength and elongation was recorded, the extended warp yarns were deformed later.

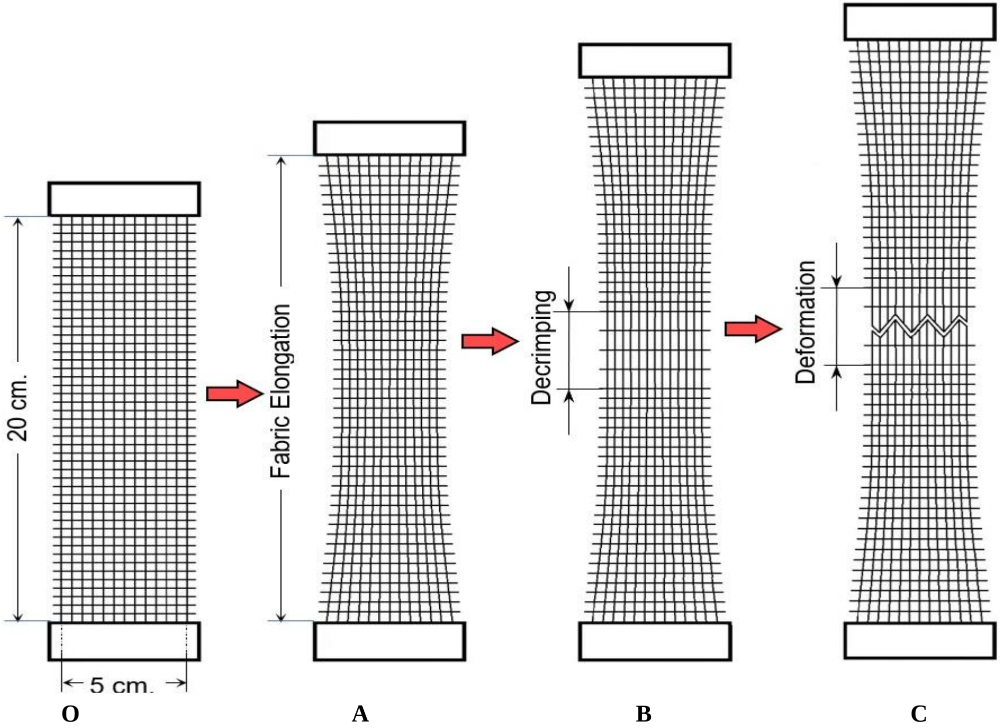

Fig. 11: The behavior of the sample during the tensile strength and elongation test

Referring to the above-mentioned results, and linking them with the behavior of the fabric samples during the tensile strength and elongation test, the following results have been concluded:

1- The extension-percentage rates of the plain weave hopsack 2/2 and the twill 2/2, 1/3 weaves had approximately similar rates. That is due to the equality of all of them in the sum of the interlacing angles values between the warp and the weft yarns within their fabric constructions, as well as their equality in the number of yarns in the weave repeat. This affected the significant convergence in the elongation values for the experimental samples of the three fabric constructions.

2- There were significant differences in the rates of crimp percentage of the warp yarns between the weave 1/1 and all other constructions, where the crimp percentage for plain weave hopsack 2/2, and the twill 2/2, 1/3 weaves are 50%, and also the Atlas 8 is 25%, compared to the value of a similar plain weave 1/1. In spite of this, the elongation values of the experimental samples for the plain weave hopsack 2/2, and the twill 2/2, 1/3 weaves are 94%, and also satin 8 is 85%, compared to the value of a similar plain weave 1/1.

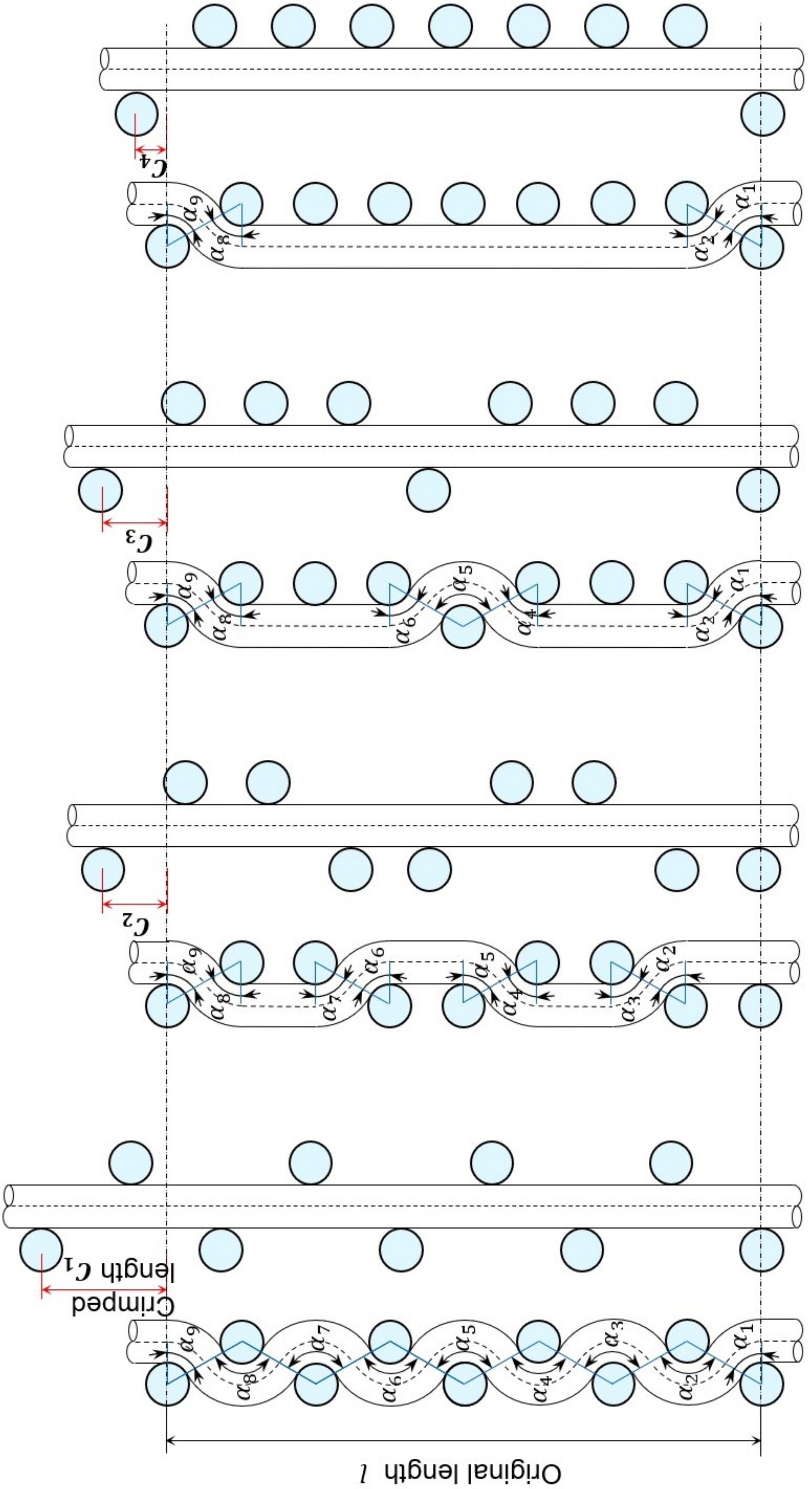

Fig. 12: The behavior of the sample during the tensile strength and elongation test for the second stage (decrimping in Fig 11B)

3- The small differences between the elongation values of the different weaves referred to above and the plain weave 1/1, compared to the large variation in the difference in their crimp percentage rates, confirms that a large percentage of the result of the elongation test of the fabrics under test results from the elongation of the fabric itself and not as a result of its complete elimination of the crimp between the warp and weft yarns. That was confirmed by observing the samples during the test, as shown in Figure 12.

4- There was a small effect on the elongation results relating to the difference in the weft density, whether in the crimp rates of the warp yarns or the elongation of the woven fabrics, but the general trend tended to increase the rates as a result of the increasing the weft density, but at simple rates compared to the results relating to the difference of fabric constructions.

5- The tensile strength values of the woven samples in the warp direction, as illustrated in Tab. 3, were recorded in the same trend of increase compared to the elongation of the fabrics.

6. Conclusions

In fact, elongation physics has not been studied widely by researchers previously. As previous studies have adopted the interpretation of elongation based on the results of the test and did not really penetrate the behavior of the sample under the influence of stress during the test. Therefore, this research paper focuses on studying elongation based on the previous geometry conceptions of the interlacing shape of Peirce's conception is the closest geometrical to the woven fabric structure, especially by using man-made fibers due to their regularity compared to other natural fibers.

From the previous results' analysis, it can be concluded that the sum of interlacing angle values in fabric construction's repeat plays the main role in the elongation values. There are many other factors that affected positively elongation values as the number of intersections between warp and weft yarns, hence the plain weave 1/1 achieved the highest values more than plain weave hopsack 2/2, twill weaves 2/2, 1/3, and satin weave 8. As plain weave 1/1 consists of two intersections for two yarns at any fabric direction, the other fabric constructions have also two intersections, but for 4 yarns/repeat (plain weave hopsack 2/2, twill weaves 2/2) and for 8 yarns/repeat (satin 8). For that reason, the average values for the interlacing angles of fabric constructions as mentioned earlier, and as illustrated in Fig. 7, are varied between 980° for 4 repeats of plain weave 1/1, 480° for 2 repeats of plain hopsack 2/2, twill 2/2, 1/3, and 240° for 1 repeat of satin 8. That means the mean value of interlacing angles for plain weave equals two times compared with plain 2/2, twill 2/2, 1/3, and four times as satin 8 weave with the same number of yarns at any fabric directions. That is confirmed by the results of crimp percentage, which are shown in Table 3. As the crimp values of plain weave are approximately two times as plain 2/2, twill 2/2, and 1/3 weaves and four times as satin 8 weave. It was expected that the difference between elongation values for different fabric constructions would be like the difference between crimp values, but the research results assured the wrong of this assumption. The behavior of the samples under the upper tension force during the tensile test was different from what was expected, as shown in Figure 11, which presents the accepted and logical explanation for this.

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