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Study on Comparative Analysis of Basic Woven Fabrics Produced in Air-Jet Loom and Determining Structure for Optimum Mechanical Properties and Production

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ABSTRACT

This analysis was directed at dissecting the impact of the structure of the fabric on different properties of the fabric, for example tear strength, tensile strength, shrinkage, elongation, skewness, and so on. The work demonstrated how various structures of the fabric influence these properties. Fabrics with a fundamental woven structure, namely plain, twill, satin and a couple of their subsidiaries, were produced to explore the influence of the structure on different properties of the fabric. The examination built up an approach to gauge the mechanical conduct of the fabric dependent on its structure. The exploration accentuated the structure and detail of the fabric to decide the underlying driver of the change in the mechanical conduct. The properties of the fabric, such as tear strength, tensile strength, elongation, shrinkage and skewness, were extraordinarily affected by the structure of the fabric. It likewise demonstrated to having more noteworthy mechanical properties for firmly interwoven structures, such as plain and twill. The analysis led to the conclusion that the plain structure has the best mechanical properties among different structures.

KEYWORDS

Air-jet loom, Woven fabric, Mechanical properties, Tear strength, Tensile strength, Shrinkage

INTRODUCTION

Woven fabric is any textile formed by the interlacement of many warp and weft yarns at right angles to one another. The most versatile structure of all fabrics is the woven fabric which is created by the interlacement of two sets of yarn, where one set is called the warp yarn, which is longitudinal, and the other is weft yarn, which is transverse. It is the most advanced and refined fabric available, with various designs. It is conceivable to create different designs, like plain, twill, satin, etc. by varying the interlacement. These basic structures have numerous derivatives and designs. These variations of the designs have some effect on the mechanical properties of woven fabrics [1]. Virtually all types of textile fibres and threads can be used to make woven fabric. In antiquated occasions, woven fabrics were produced utilizing handlooms and the activity was completely manual. Nowadays there are numerous sorts of modern looms developed which are completely programmed and able to create the most extreme measure of fabric in the briefest conceivable time.

Air-jet is a cutting-edge loom which is boundlessly used to produce woven fabrics throughout the whole textile industry. It is a very popular loom due to its higher efficiency, lower power consumption and maintenance cost than other looms present in the market [2]. In a typical air-jet loom the picking process into the warp shed is done by compressed air, rather than any projectile or shuttle. A special type of reed called “profile reed” [3] is used to help pick the insertion. Upon picking the insertion, the weft yarn goes through the main air nozzle which provides the initial acceleration of the weft yarn [4], and the profiled reed guides the weft yarn onto the other side of the loom for a successful pick insertion. From the focal air tank an adequate amount of air pressure is delivered, which changes into kinetic energy in the nozzle and conveys the weft yarn in the diversely formed air channels [5].

The purpose of this study is to find an optimum structure of the woven fabric produced in the air-jet loom. There are many structures of the woven fabric available now; however, there hasn’t been much concern about the suitability of the structure of the fabric produced in the air-jet loom [6]. This study shows the mechanical properties of different fabrics according to their structure and analyses the change in those properties. The findings of this study will be of benefit to the woven fabric industries in regard to the efficient production of high-quality fabrics.

Woven fabric is the most sophisticated and aristocratic fabric, available in numerous variations in design. Due to the variation in the interlacement, different structures can be produced, such as plain, twill, satin, etc. Results from a research paper “Effect of Fabric Structure on the Mechanical Properties of Woven Fabrics” [7] show that these variations of structural designs tend to have some effect on the mechanical properties of the woven fabric. For textile fabric, it is described as a result of the material’s resistance to the activity of external forces causing the change of shape [8]. The test results from a research journal from Mehdi Kamali Dolatabadi “Anisotropy in tensile properties of plain weave fabric–Part I: The meso-scale model” shows that in design engineering, mechanical properties play a vital role in resisting the permanent deformation under applied stress and subsequent use [9]. From all of these journals the following results were concluded:

a) The strength of a plain-weave fabric is higher than that of a twill-weave fabric.
b) Warp way plain is stronger than twill and, also, weft way plain is stronger than weft way twill.
c) Warp-wise tensile strength of the plain weave is higher than the twill weave. Similarly, weft-wise tensile strength of the plain weave is also higher than that of the twill weave [8].
d) The value of COF (Crossing Over Factor) is higher in the plain than in the twill and satin. Oppositely, the value of FYF (Floating Yarn Factor) is higher in the satin than in the twill and plain.
e) Tearing strength is higher in the 2/2 twill than in the 3/1 twill due to the double yarn being inserted as weft.
f) The greater the difference in warp and weft yarn density, the greater the difference in tearing resistance [10].

MATERIALS AND METHODS

Raw materials

The woven fabrics produced in the air-jet loom are as follows:

Table 1. Air-jet loom fabric sample

No.	Sample Name	Construction ((EPI × PPI)/ (warp count × weft count))
1.	Sample 1 (Dobby)	128×60/30×16+70D
2.	Sample 2 (Dobby)	154×82/40×20+40D
3.	Sample 3 (Canvas)	124×60/20+20D×14
4.	Sample 4 (Oxford Canvas)	90×34/10+10D×6
5.	Sample 5 (Cotton Sheeting)	60×60/20×20
6.	Sample 6 (Herringbone)	165×85/20×10+70D
7.	Sample 7 (2/2 S Twill)	206×98/40×30+40D
8.	Sample 8 (2/1 S Twill)	168×68/30×30+40D
9.	Sample 9 (Herringbone)	130×54/30×30+40D
10.	Sample 10 (Satin)	188×74/30×20+40D

Dobby

Dobby fabric is a derivative of the plain fabric. It differs from other plain derivatives by construction (which is generally similar to (128×60/30×16+70D)). This fabric is generally small, with frequently repeated woven-in designs and textured.

Canvas

Canvas is also a derivative of the plain-woven fabric. It is extremely durable and used for making marquees, sails, tents, shelters, backpacks and canvasses as a support for oil painting etc.

Oxford Canvas

Oxford canvas is another derivative of the plain-woven fabric. It is suitable for cushion covers, curtains, and other more rugged fabric needs.

Cotton Sheeting

Cotton sheeting is a lightweight, plain fabric used in costume making, stagecraft, garments manufacturing, home décor etc.

Herringbone

This is a V-shaped twill weaving pattern. It is called like that because it looks similar to the skeleton of the herringbone fish.

2/2 S Twill

This is another twill pattern with the repeat of 2 warp up and 2 warp down. The structure runs in the shape of the letter ‘S’. Twill is a diagonal rib pattern.

2/1 S Twill

This is another twill pattern with the repeat of 2 warp up and 1 warp down. The structure runs in the shape of the letter ‘S’.

Satin

Satin is a warp face weave and it has a rather dull texture on the back. The number of floats in satin is also high.

Machine

Shower type/multi-jet (main nozzle and relay nozzles) air-jet loom
Brand name: Picanol OptiMax

Testing methods

The research was conducted by testing the above-mentioned specimen according to the following procedure:

1) Tear Strength (ISO 139371)
   This test method is known as the ballistic pendulum (Elmendorf) method for the determination of tear force of textile fabrics. The specimen is fastened in the clams and the tear is started by cutting a slit in the specimen between the clamps. The pendulum is then released and the specimen is torn completely as the moving jaw moves from the fixed one. The tear force is measured.
2) Tensile Strength (ISO 139341)
   This test method specifies a procedure for the determination of the maximum force of textile fabrics known as the grab test. A fabric test specimen, gripped in its centre part by jaws of specified dimensions, is extended at a constant rate until it ruptures. The maximum force is recorded.
3) Skewness (ISO 163222)
   Skewness is the displacement of filling yarns from an imaginary line perpendicular to the fabric in an angular form. It disturbs the grain line of the garment patterns and causes discomfort and improper functioning of the final garment. To measure the skewness, a steel tape may be used. The straight edge of the steel tape is placed across the fabric width to measure the distance between the two points

   $$\text{Skew } (\%) = 100 \times \frac{\text{AB}}{\text{BC}} \;, \tag{1}$$

   where a selected weft yarn or course of fabric meets the two edges or selvedges. Then the straight line of distortion of the marked filling from a line perpendicular to the selvedge is measured.
   where *AB* is the fabric width perpendicular to the selvedge; and *BC* is the skew depth.
4) Shrinkage Measurement (AATCC 135)
   Shrinkage is a common problem in fabric production where fabric becomes smaller, usually after the process of laundering. This problem is a result of high tension during the production of fabric generally.

Normally, shrinkage is measured in percentages (%) and the standard acceptable shrinkage is less than 5%, but it can be changed at the request of the buyer.

$$\text{Fabric shrinkage (\%)} = \frac{\text{Length before washing} - \text{Length after washing}}{\text{Length before washing}} \times 100$$

5) Elongation Measurement (ASTM D 5034)
Average breaking strength and elongation or the increase in the fabric length under force to the point of rupture expressed in percentages (%) is the breaking strength and elongation percentage of the fabric. Greater breaking strength and the elongation of fabric means better fabric quality as it can bear more stretch and still not tear. This is basically the ratio between length at breaking point and length of the fabric when produced from the loom.

$$\text{Breaking elongation (\%)} = \frac{\text{E}-\text{L}}{\text{L}} \times 100\,, \tag{2}$$

6) where *E* is the extended length of the specimen after applying force; and *L* is the initial length of the specimen.

RESULTS AND DISCUSSION

The above-mentioned tests were done on fabric specimens and the results are discussed as follows:
Plain-weave structure: the samples 1-5, which represent the plain-weave structure, were taken and tested in order to compare their mechanical properties. The results are shown below.
Tear strength: the tear strength of the plain weave samples 1-5 was analysed and the results are shown below.

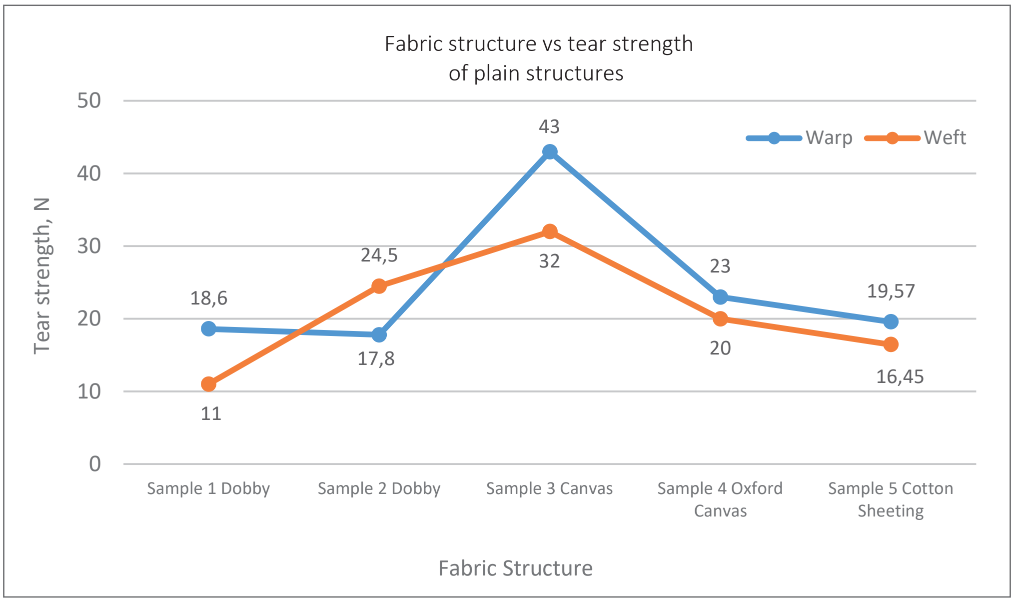

Figure 1. Tear strength of various plain fabric structures

Figure 1 shows that Sample 3, canvas fabric, has the highest amount of tear strength both in warp and weft direction. The other plain-weave structures show much lesser tear strength. This is because of the warp and weft yarn density of the fabric. This test results are parallel to the findings of Krook and Fox [11]. They discovered that the tear strength of the fabric increases as the density of longitudinal yarn is decreased.

Looking at Table 1, we can see that the canvas fabric has much lower EPI and PPI than other derivatives. That is why it has much greater tear strength.
Tensile Strength: the tensile strength of the plain weave samples 1-5 was analysed and the results are shown below.

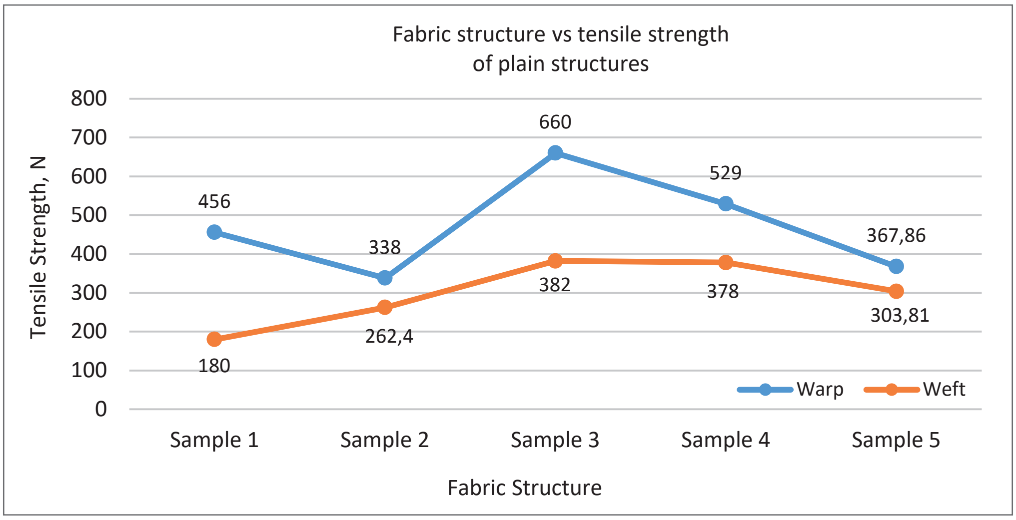

Figure 2. Tensile strength of various plain weave structures

Figure 2 shows that the canvas fabric (Sample 3) has much greater tensile strength than the other derivatives of the plain structure. This happened due to the fact that the canvas fabric had much greater warp way and weft way strength, which directly contributed to the greater tensile strength than in the other fabrics [12].
Skewness: the skewness percentage of the plain weave samples 1-5 was analysed and the results are shown below.

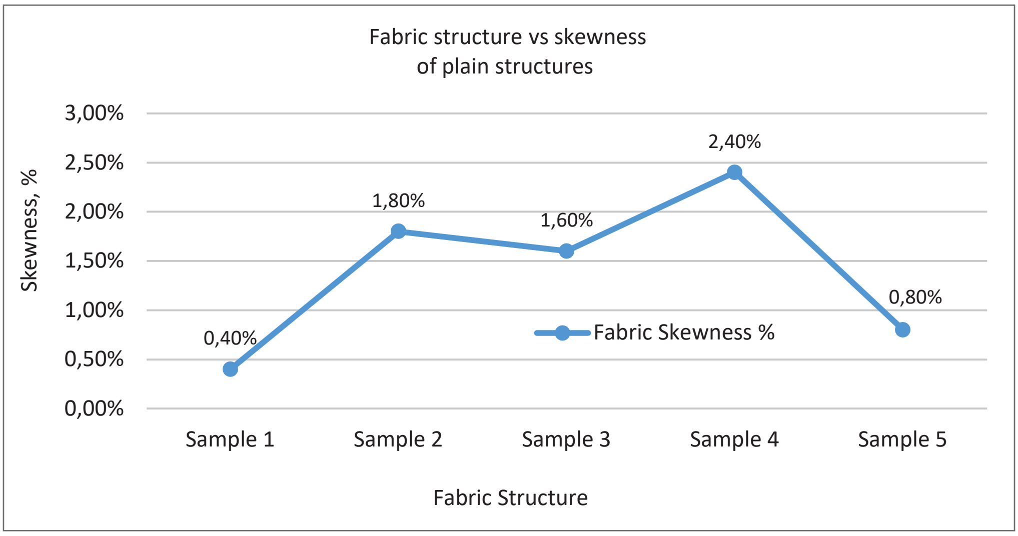

Figure 3. Skewness (%) of various plain weave structures

Figure 3 shows that the dobby fabric (Sample 1) has the lowest percentage of skewness out of all the plain structures. This happened due to the fact that the interlacement of the dobby design is more congested than it is in the other designs. This property tends to result in the lower value of skewness [13]. The canvas fabric (Sample 3) has an average skewness compared to the other derivatives.

Shrinkage: the shrinkage percentage of the plain weave samples 1-5 was analysed and the results are shown below.

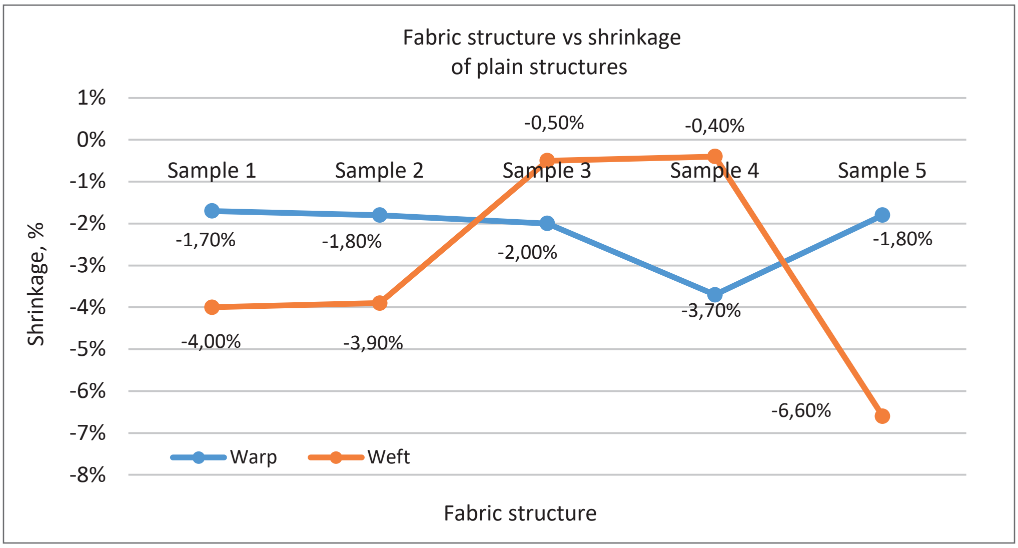

Figure 4. Shrinkage (%) of various plain weave structures

Figure 4 shows that the canvas and the oxford canvas fabric (Samples 3 and 4) have the lowest shrinkage percentage in weft direction. This is due to the fact that the weave pattern with a higher number of interlacements has lower shrinkage value [14].

Elongation: the elongation percentage of the plain weave samples 1-5 was analysed and the results are shown below.

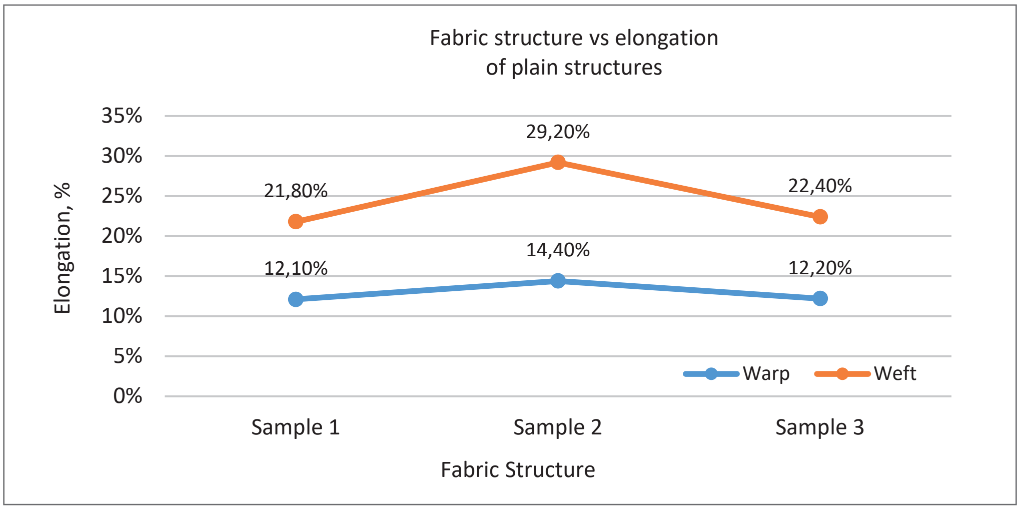

Figure 5. Elongation (%) of various plain weave structures

Figure 5 shows that the dobby fabric (Sample 2) has the highest percentage of elongation. The reason behind this is the high weft density [15]. Looking at Table 1 we can see that Sample 2 has the highest PPI value out of all the other fabrics.

From the above analysis we can come to a conclusion that Sample 3 (canvas fabric) has the best elongation percentage compared to the other plain structures.

Twill-weave structure: Samples 6-9, which represent the twill-weave structure, were taken and tested in order to compare their mechanical properties. The results are shown below.

Tear strength: the tear strength of the twill-weave samples 6-9 was analysed and the results are shown below.

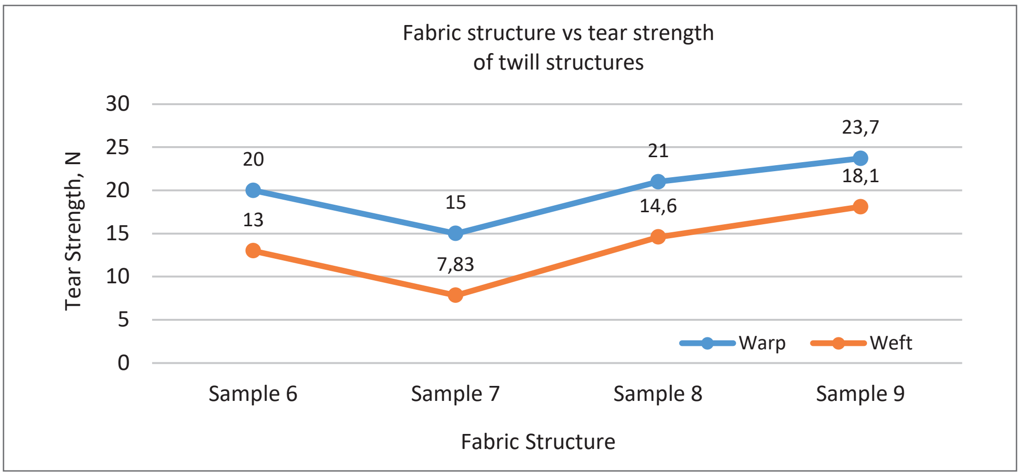

Figure 6. Tear strength analysis of various twill fabrics

Figure 6 shows that Sample 9, herringbone fabric, has the greatest amount of tear strength, both in warp and weft direction. The other twill-weave structures show much lesser tear strength. This is because of the warp and weft yarn density of the fabric. This test results are parallel to the findings of Krook and Fox [11]. They discovered that the tear strength of the fabric increases as the density of the longitudinal yarn is decreased. Looking at Table 1 we can see that the herringbone fabric has much lower EPI and PPI than the other derivatives; that is why it has much greater tear strength [16].

Tensile strength: the tensile strength of the twill-weave samples 6-9 was analysed and the results are shown below.

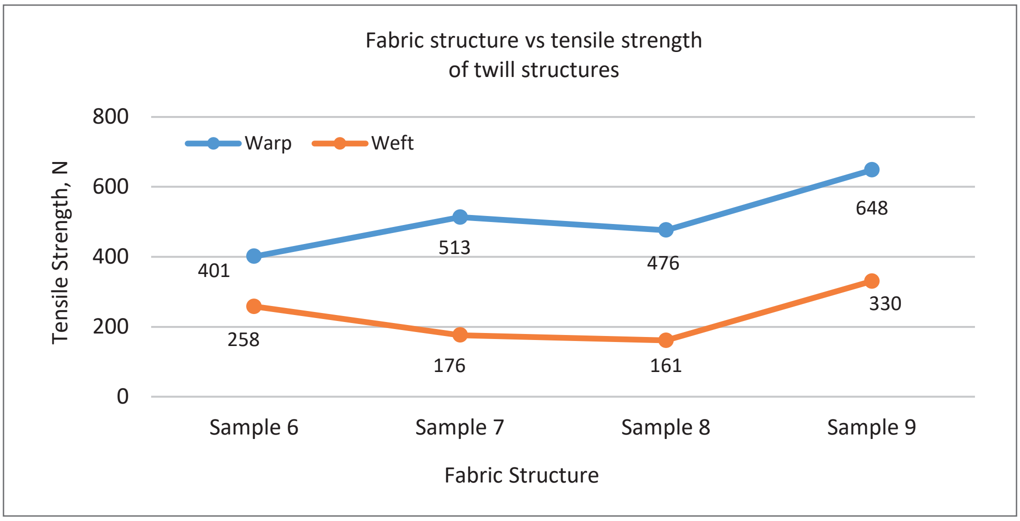

Figure 7. Tensile strength analysis of various twill fabrics

Figure 7 shows that the herringbone fabric (Sample 9) has much greater tensile strength than the other derivatives of the twill structure. This is due to the fact that the herringbone fabric has much higher warp way and weft way strength, which directly contributes to greater tensile strength than in the other fabrics [12].

Skewness: the skewness percentage of the twill-weave samples 6-9 was analysed and the results are shown below.

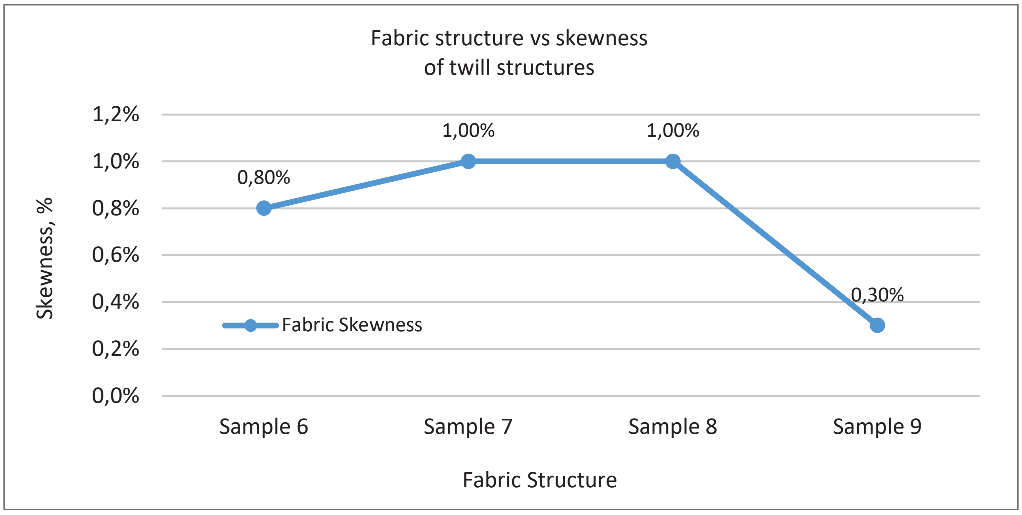

Figure 8. Skewness (%) analysis of various twill fabrics

Figure 8 shows that the herringbone fabric (Sample 9) has the lowest percentage of skewness. This is because the herringbone or any other type of the zigzag twill (in which the diagonal lines do not follow the same direction across the width of the fabric) eliminate the risk of the fabric becoming skewed. This is because, in such weaves, floats (in-plane levers) act in opposition to each other [13].

Shrinkage: the shrinkage percentage of the twill-weave samples 6-9 was analysed and the results are shown below.

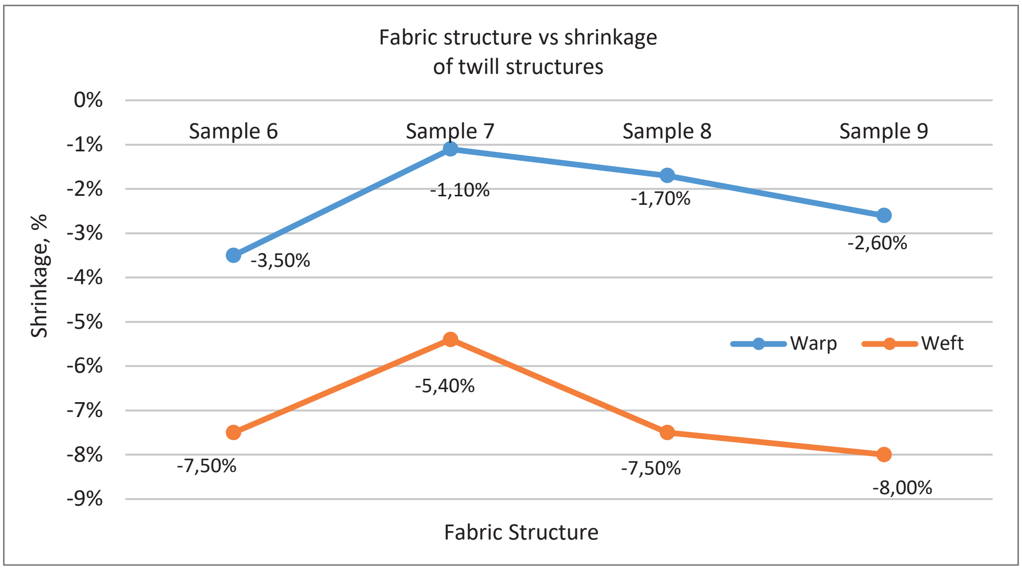

Figure 9. Shrinkage (%) analysis of various twill fabrics

Figure 9 shows that 2/2 S twill and 2/1 S twill fabrics (Samples 7 and 8) have the lowest shrinkage percentage. This is due to the fact that the weave pattern with a higher number of interlacements has lower shrinkage value [14].

Elongation: the elongation percentage of the twill-weave samples 6-9 was analysed and the results are shown below.

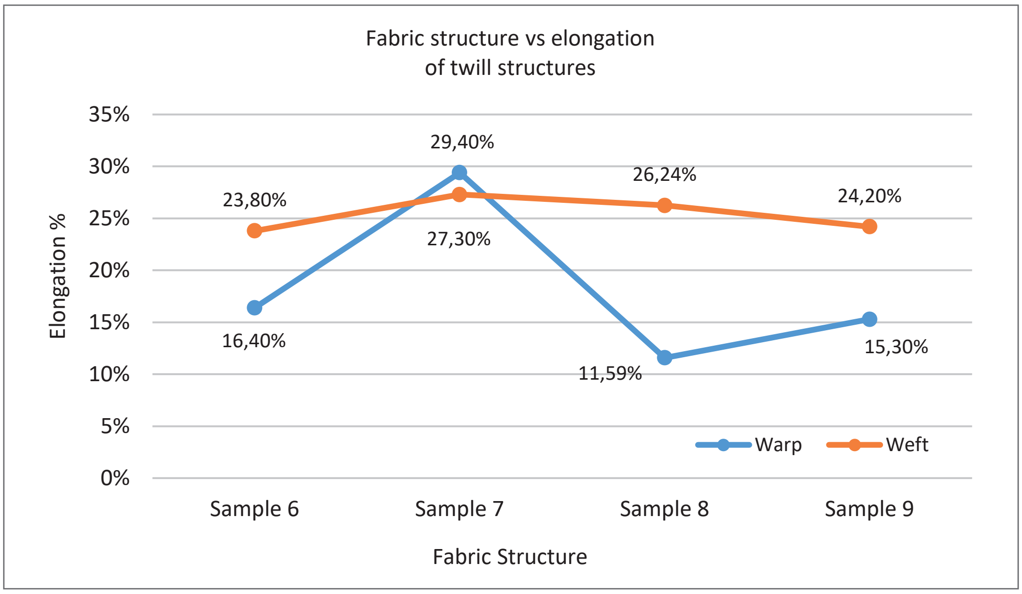

Figure 10. Elongation (%) analysis of various twill fabrics

Figure 10 shows that 2/2 S twill fabric (Sample 7) has the highest percentage of elongation. The reason behind this is the high weft density [15]. Looking at Table 1, we can see that Sample 7 has the highest PPI value out of all the other fabrics.
From the above analysis we can come to a conclusion that Sample 9 (herringbone fabric) shows the optimum property compared to the other twill structures.

Plain, twill and satin combined analysis
On the basis of the above analysis, Sample 3 of the plain structure, Sample 9 of the twill structure and Sample 10 of the satin structure are taken for the combined analysis of the mechanical properties of those fabrics.
Tear strength: the tear strength of the derivatives of the plain (Sample 3), twill (Sample 9) and satin (Sample 10) fabric was analysed and the results are shown below.

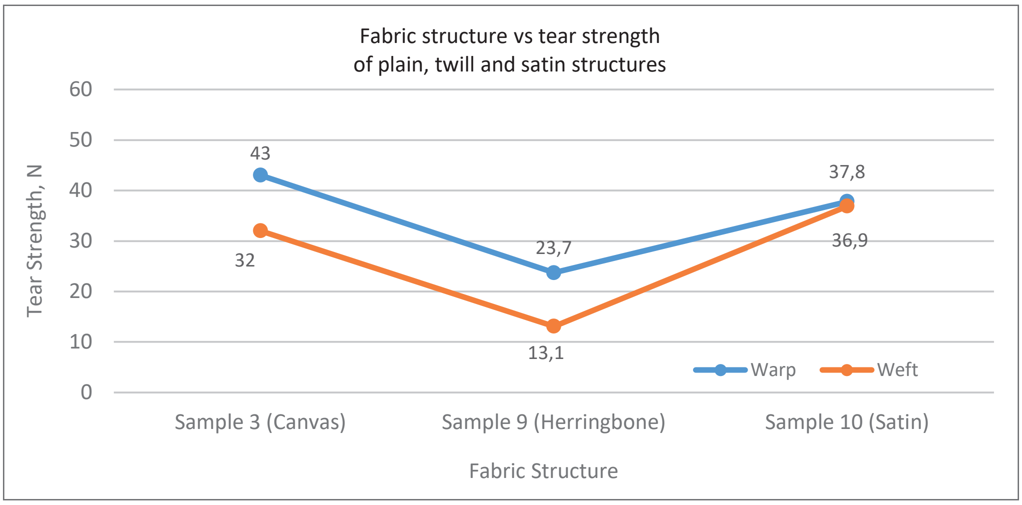

Figure 11. Tear strength analysis of plain, twill and satin fabrics

Looking at Figure 11, we can see that Sample 3, which is a plain fabric, has the greatest tear strength. Tear strength of the plain weave is greater than that of the twill weave because the plain weave is less porous

and has a higher number of warp and weft interlacements. The plain weave has the greatest strength in warp way due to the increased number of crossover points compared to other weave types [7].
Tensile strength: the tear strength of the derivatives of the plain (Sample 3), twill (Sample 9) and satin (Sample 10) fabric was analysed and the results are shown below.

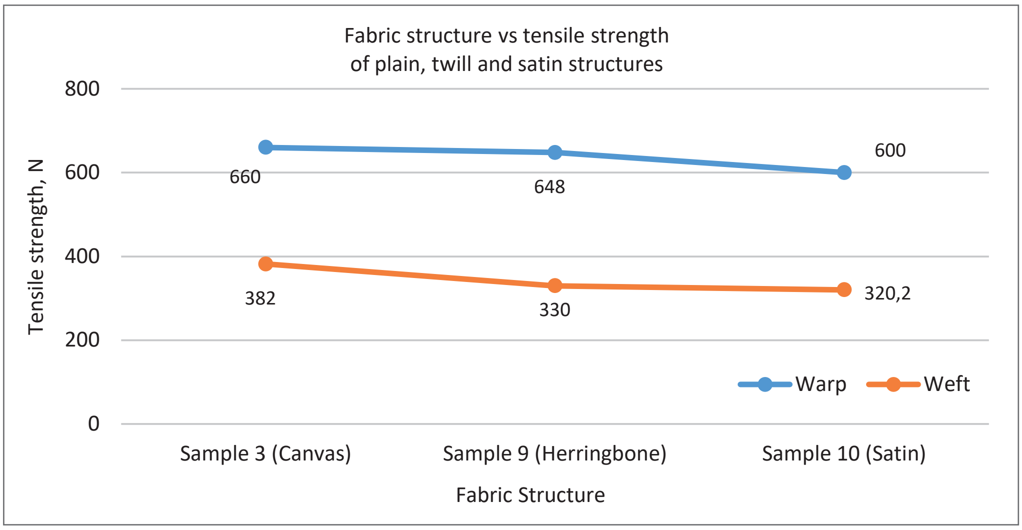

Figure 12. Tensile strength analysis of plain, twill and satin fabrics

Looking at Figure 12, we can see that Sample 3, which is a plain fabric, has the greatest tensile strength. This is due to the fact that the interlacement points of the plain fabric are greater in number compared to other weave structures. Because of the increased number of interlacements, the frictional point in the yarns also increases, which contributes to the greater tensile strength of the fabric [17].
Skewness: the skewness percentage of the derivatives of the plain (Sample 3), twill (Sample 9) and satin (Sample 10) fabric was analysed and the results are shown below.

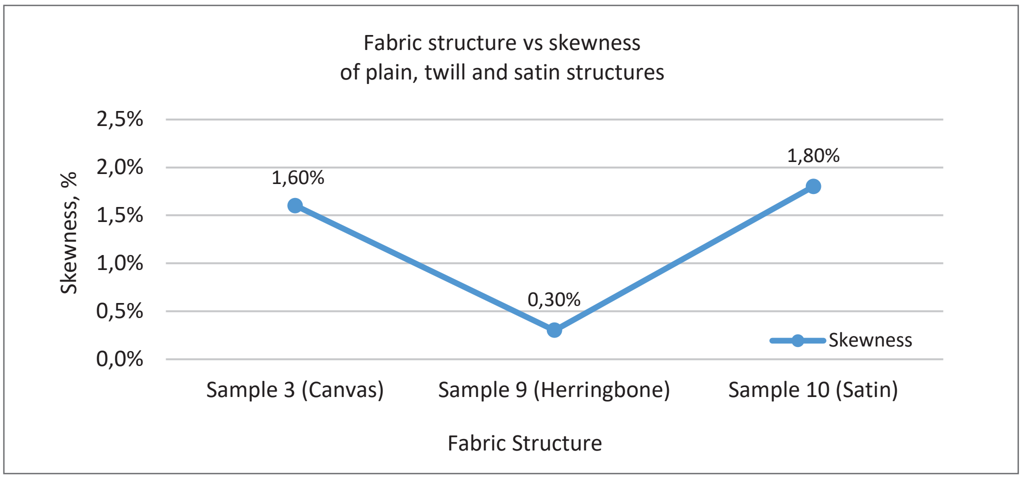

Figure 13. Skewness percentage analysis of plain, twill and satin fabrics

Figure 13 shows that Sample 9 (herringbone fabric) has the lowest skewness percentage compared to the plain and satin structure. Generally, the plain weave tends to show lower skewness percentage than the twill weave. But the herringbone or any other type of the zigzag twill structure (in which the diagonal lines do not follow the same direction across the width of the fabric) eliminate the risk of the fabric becoming skewed. This is because, in such weaves, floats (in-plane levers) act in opposition to each other [13].

Shrinkage: the shrinkage percentage of the derivatives of the plain (Sample 3), twill (Sample 9) and satin (Sample 10) fabric was analysed and the results are shown below.

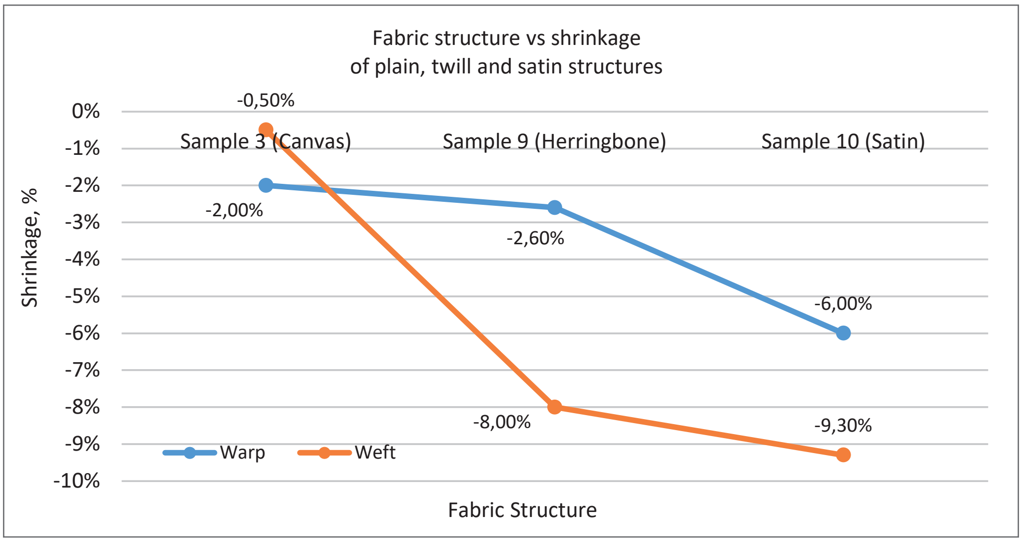

Figure 14. Shrinkage percentage analysis of plain, twill and satin fabrics

Looking at Figure 14, we can see that Sample 3, which is a plain weave, has the lowest shrinkage percentage compared to the twill and satin weave. This is because the increased number of interlacements causes lower shrinkage values [14]. The twill and satin structures have comparatively lower number of interlacement points, which is why they have higher shrinkage values.

Elongation: the elongation percentage of the derivatives of the plain (Sample 3), twill (Sample 9) and satin (Sample 10) fabric was analysed and the results are shown below.

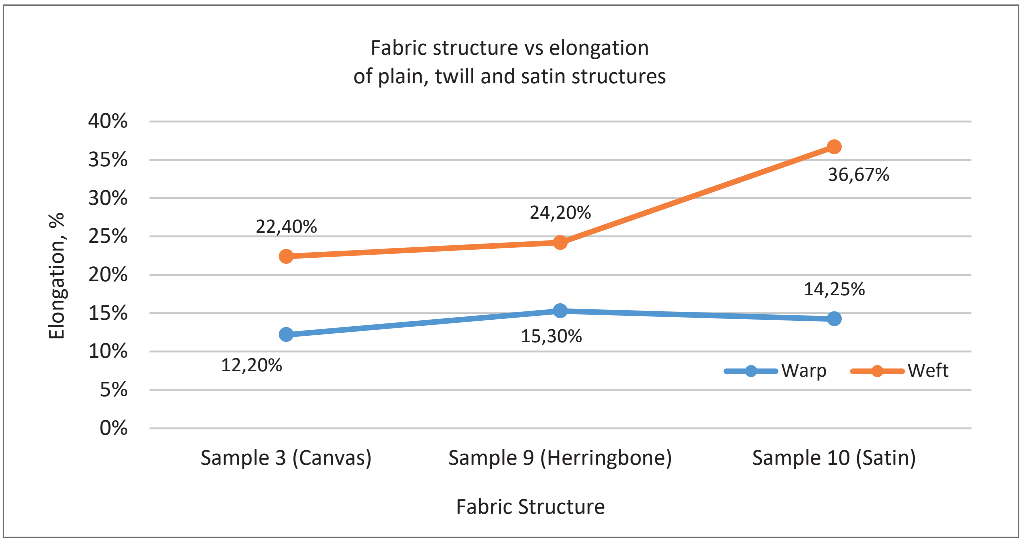

Figure 15. Elongation percentage analysis of plain, twill and satin fabrics

Figure 15 shows that Sample 3, which is a plain weave, has the lowest elongation percentage and Sample 10, which is a satin fabric, has relatively higher shrinkage percentage than the other two structures. This is due to the fact that plain fabrics have higher number of interlacements between warp and weft yarn in the fabric structure compared to the twill and satin structure. This high number of intersecting points contributes to the lower elongation percentage of the plain fabric [15].

From the above discussion and the analysis, we can come to a conclusion that the canvas structure produced in the air-jet loom shows significantly better mechanical properties than the twill and satin fabrics produced in the same loom.

CONCLUSION

The woven fabric has a much broader scope of end utilization than other kinds of fabric. That is why the manufacturing process should be adjusted to fulfil those performance prerequisites. The physical structures and the chemical properties of the woven fabric will determine how it will perform and whether it will be acceptable for a particular use or not. Fabric testing plays a crucial role in guaranteeing product quality, regulating compliances, and the assessment of the performance of a textile material. Creating a clear concept of the various mechanical properties of the woven fabric can lead the path of further improvement of the woven fabric structure, which will be beneficial for many end-use applications, especially for technical textiles and protective clothing. In this research, the effectiveness of mechanical properties of varying weave structures was shown. It should be noted that, even if the fabric parameters remain the same, a more complex mechanical behaviour of fabrics can be implanted and studied as well. More advanced research work on this topic can be done in order to increase the knowledge even further.

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