



EFFECT OF STRUCTURAL ELEMENTS ON THE MECHANICAL PROPERTIES OF HYBRID LENO WOVEN FABRIC

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Abstract: Hybrid leno woven fabrics represent a unique class of textile structures combining the interlacement stability of conventional weaves with the locking mechanism of leno (gauze) constructions. This study investigates the influence of key structural parameters—namely leno weave ratio of hybridization with ground weave, leno warp yarn float number, leno interlacing and weft densities on the structural and mechanical properties of such fabrics. A series of hybrid leno fabrics were engineered with controlled structural variations and tested for tensile strength, tear resistance, bursting strength and bending rigidity. The experimental results revealed that leno weave tends to increase warp crimp but decrease the weft crimp. Eventually it affects the fabric width and unit mass. The nature of loose structure of leno weave appears to have a direct effect on the structural parameters of the hybrid fabric. The hybrid structures significantly influence, durability, flexibility and deformation behaviour of the construction. The findings of the study provide a design framework for optimizing hybrid leno fabrics in applications such as technical textiles, and composite reinforcements.

Keywords: Hybrid weave, leno weave, leno fabric, mechanical properties, textile structures.

1. INTRODUCTION

Textile materials are converted into final products with different forms and functions thanks to multi-stage mechanical and partly chemical operations. The range of conversion starts from fibre stage up to a garment or a 3D preform as the finalized products. By means of the intersection of warp and weft yarns in a specific order of weave, a plenary layer of textile material is produced which is identified as woven fabric [1]. Any possible changes in the basic traits and order of yarns, or in the weave are directly imparted into the appearance and performance of woven fabric. That means any variation in the fabric construction affects the mechanical properties of the woven fabric. Previous studies have already confirmed that the construction parameters also have an effect on the mechanical properties of the fabric to a great extent.[2],[3].

The properties of fabric are essentially a function of fabric structure, which in turn depends on nature of fibres, the density of yarns in the fabric, weave, the characteristics of warp and weft threads like count and twist level and the factors established during weaving such as yarn crimp. As a matter of fact, the weave is the most influential elements of woven fabrics, enabling to design or develop almost limitless forms of fabric. Moreover, the application of 2D or 3D woven fabrics for composite



preforms [4], [5] has boosted the significance of weave, even further. Weave being the most important parameter of fabric structure plays a significant role in deciding the performance of composites.

Because of inherent characteristics of basic and derived weaves, it may often be necessary to combine two or more weaves in one single fabric structure. These structures are often called hybrid weave or hybrid fabric. Therefore, a hybrid fabric being a versatile technique enables to combine weave as well as various fibres within a single fabric to optimize performance, strength, and appearance [5]. The combination of various forms of leno weave with classic plain weave was selected as the object of this study to analyse possible effects on the fabrics structure and basic mechanical characteristics. Since such studies concerning leno weave or hybrid fabric are limited in the literature, this work is likely to raise an interest in leno structure especially for researchers in composite materials.

Leno weave is a specialized weaving technique in which warp threads are twisted together in pairs during the weaving process to securely lock the weft yarns in place. Those twisting warps, called as leno warp yarns cross the weft yarns from each side in successive weaving cycle. This weave structure imparts additional stability to fabric, which is important when using fine yarns loosely spaced. Eventually, an open, mesh-like fabric with relatively large openings maintaining dimensional stability is produced because the twisted warp threads prevent the crossing points from shifting [6],[7].

It is also called as gauze weave or cross-weave. The term *gauze* historically referred to lightweight, open fabrics described by their transparency and handle, with origins linked to early textile trade routes (e.g., Gaza) [8]. In contrast, *leno* emerged later (around 18th century) as a structural classification within textile engineering, denoting a specific warp-crossing mechanism that stabilizes open weaves. While modern usage often treats the two terms as synonymous, they are conceptually distinct: gauze is a functional descriptor, whereas leno is a precise weave structure. Concerning the origin of the word “Gauze”, it is claimed that it was derived from French “gaze,” or possibly from Spanish “gasa” which are attributed to the Arabic word “qazz” meaning “silk”. [9] These words come from their place of origine-the Gaza (gazza) city in the Palestinian territory on the eastern Mediterranean coast. It is believed that this light and loose fabric originally made of silk was launched in the city of Gaza and used for clothing.

The controlled combination of weaves and other components theoretically allow to the emergence of a very wide design range. It should be emphasized that the pattern in woven fabrics is not only a visual element but also an engineering organization that emerges from the controlled interaction of structural parameters [10]. The weaving design process is a holistic approach requiring a joint evaluation of yarn properties, weave structure, production parameters, and the pattern as a structural design element. Hybridization of weaves in the fabric structure by using forms of weaves may be beneficial in obtaining optimum mechanical performance and also minimizing the cost. There exists very limited literature on the mechanical performance of the hybrid leno woven fabric alone. In this article, the breaking strength, elongation, tearing strength and bursting strength of cotton hybrid fabric together with some structural parameters are studied.

2. LENO WEAVE STRUCTURE AND PREVIOUS STUDIES

Leno weave is different from conventional weave in its level of complexity both in terms of fabric formation and structure. It is categorized as compound weave structure and there needs an extra set of warp ends that are divided into leno groups. Among these leno yarns, certain warps termed crossing (or leno) warps are passed from side to side of what are termed standard (or stationary) warps, and are bound in by the weft in these positions. Therefore, the parallel arrangement of warp yarns in the fabric is no longer possible.

Depending on the frequency of leno motion, three leno structures are possible as seen in Fig.1. When the leno warp pair crosses every two picks it is called half leno (Fig 1.a), in the case of crossing at every pick, it is called full leno. The alternating leno (Fig 1.c) which is the combination of both is also possible. Half leno provides looser binding and larger pores in comparison with full leno.

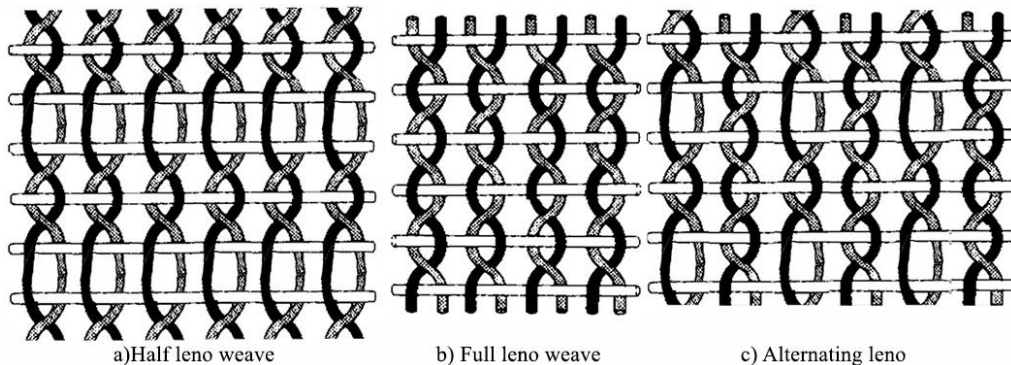


Fig. 1: The types of leno weaves in accordance with the sequence of leno crossing

Different variants of leno weave is possible. Leno arrangement can be positioned all over the fabric width or at certain intervals. The leno and standard warp ends may be arranged with each other in various proportions, such as 1:1, 2:1, 1:2, 2:2 or 1:3 etc., but an essential condition is that each group of leno and standard ends (as well as ground warps) must be placed in one split of the reed [7]. The number of interlacing between leno warp and weft yarn can also be varied. The leno and standard warp ends may be arranged with each other in various proportions, such as 1:1, 2:1, 1:2, 2:2 or 1:3 etc., but an essential condition is that each group of leno and standard ends (as well as ground warps) must be placed in one split of the reed [11]. Among the typical leno fabrics, gauze characterized by a thin and translucent appearance is an all over leno structure and probably the oldest version of leno fabrics. Grenadine is a fine leno-weave with overall leno structure including stripes and merquissette a sheer, light and open meshed fabric used for curtains and mosquito nets. Fancy leno and tulle are other available leno fabric [11].

Production of leno woven fabric is more complicated than producing normal weave fabrics and special shedding equipment is required. The crossing motion of warps are achieved by special devices called doup heald. They should be used addition to the normal heald equipment for the fabric production. The crossing warp yarns are controlled by this leno attachment of the leno heald and by the side-to-side movement of the ground warp yarns. Two warp yarns in the same leno pair cross over each other and interlace with one or more weft threads. Initially twine leno healds were developed and used until the development of metallic leno healds. The twine leno heald is composed of a standard harness and a half heald. While, the metallic leno heald is composed of two standard harnesses and a half heald. An innovative solution against using inverted leno heddles was introduced as developed by Dornier. Dornier EasyLeno system is capable of producing all over leno fabric by using needle bars and a fluctuating reed across the warp yarns. It is claimed to be very high speed and efficient way of leno weaving [12]. Powerleno is also a similar approach for leno fabric production invented by Sulzer. A guide bar and eyeleted reed are introduced into the weaving system, replacing the traditional leno healds to produce all over leno cloth [11].

Leno weave is a novel method of weaving which result in a a specialized textile structure where adjacent warp yarns twist around each other, locking weft threads in place to create a strong, yet open mesh-like fabric. This construction prevents slippage, providing lightweight and breathable nature, often used for curtains, industrial bags, summer clothing, and insect screens. This interlacing produces



high in-plane stability relative to other open weaves while keeping porosity and low areal density. In apparel and home usage, leno fabrics are generally used for ornamental objective. In the case of technical textiles, functional uses come first, particularly the applications where high permeability and shape retention are required. Drying and conveyor belts and filter substrates are typical application fields where air and liquids need to pass through while the main substrate maintains stability under stress. In architectural use, they are used as decorative or functional elements [5].

In the literature there are various studies investigating the mechanical performance of different woven fabrics by varying the weave architecture [3],[4], [5]. They serve as useful guides for ensuring the required quality of fabric and appropriate design and in relation to certain usages. However, studies for leno structures or leno integrated hybrid structures are rather limited. There are many patent applications exploiting the leno structures for various end products such as bags in tubular form, medical bandage, sports shoes and refractor mesh-like fire protecting panel, according to a patent review by Kastacı [13]. The structural part of these materials are entirely leno based or hybrid structures combined with leno and other constructions. There are a number postgraduate thesis focusing on different aspects of leno weave, namely physical properties of leno fabrics [13], [14], possibility of tubular leno weaving [15], adaptation of leno healds into dobby loom [16], new design aspects for leno weaving [17], [18] and for smart textiles application [19].

Leno weave establishes a locked structure that prevents yarn displacement as a result of the crossing of adjacent warp yarns around the weft. This interlacement mechanism distinguishes leno from conventional weaves such as plain or twill where warp yarns remain parallel. The twisting action generates a stable, open structure with minimal yarn slippage, enabling both permeability and structural integrity. It is known that the mechanical behaviour of leno fabrics is governed not only by yarn properties and density, but also by the topological constraint introduced by warp crossing, which enhances frictional interaction and load transfer at yarn junctions. This unique mechanism underpins most of the mechanical advantages reported in the literature. Tensile properties are the most extensively studied mechanical characteristic of leno fabrics. Experimental investigations show that leno fabrics exhibit comparable or improved tensile strength relative to conventional woven fabrics, depending on structural configuration. A key study by Shaker et al. [14, 21] demonstrated that both pure leno and hybrid leno fabrics achieve similar tensile strength; however, tensile behaviour is strongly influenced by weft density and structural design. Increasing thread density improves tensile strength by enhancing inter-yarn friction and reducing yarn mobility.

More recent developments focus on advanced leno architectures. For example, multi-warp leno configurations (e.g., four-warp systems) have been shown to significantly enhance tensile performance due to improved load sharing among multiple crossing warp yarns [22]. These structures increase both breaking force and elongation at break, indicating improved energy absorption capacity. At the composite level, tensile behaviour is further influenced by matrix interaction. Textile-reinforced systems show that fabric geometry, fibre type, and matrix bonding determine tensile stiffness and ultimate strength, with woven structures providing superior load distribution and damage tolerance. Enhanced shear resistance and dimensional stability appear to be a distinctive mechanical advantages of leno fabrics. [23]. Unlike loosely woven plain fabrics, which exhibit yarn slippage under shear deformation, leno fabrics maintain structural integrity due to the interlocked warp system. The crossing of warp yarns creates a self-locking junction, which resists rotational movement and delays shear deformation resulting in reduced fabric distortion and improved resistance to skewing. This property is particularly important in applications involving open mesh structures, where conventional weaves suffer from instability. The enhanced junction stability of leno fabrics has been widely reported in technical textile applications, especially in reinforcement grids and open-mesh fabrics.

Leno fabrics exhibit superior resistance to localized mechanical damage, including puncture and yarn pull-out. This behaviour is primarily attributed to the high frictional locking at warp–weft junctions. Experimental results indicate that pure leno fabrics show significantly higher puncture resistance compared to hybrid leno structures. The twisting of warp yarns tightly secures the weft, preventing yarn displacement and increasing resistance to penetration forces [24]. Similarly, studies on yarn pull-out behaviour in woven fabrics highlight the importance of inter-yarn friction and structural configuration. Higher interlocking and frictional contact increase the peak pull-out force and energy absorption, which are critical parameters in impact and protective applications .

Recent studies confirm that leno weave’s main mechanical advantage is junction stability under load. That stability improves resistance to yarn slippage, pull-out, shear distortion, and local damage. Newer architectures such as four-warp leno show that it is possible to increase both strength and extensibility while keeping the breathable, open nature of the fabric. However, the literature is still fragmented, and direct studies on dry-fabric bending, fatigue, cyclic damage, and standardized comparison between half, full, hybrid, and multi-warp leno remain relatively limited [26].

A significant portion of recent research on leno fabrics is embedded within the field of textile-reinforced composites, where leno structures are used as reinforcement grids. It is claimed that the mechanical performance of the composite in such systems depends on fabric geometry, fibre type, matrix properties and fibre–matrix interfacial bonding.

3. MATERIAL AND METHOD

The hybrid leno samples are woven on a Smit G6300 model rapier loom equipped with a total of 6 frames dobby. Metal heald doup are used for leno warps and classic heald wires for the standard warps. Pure cotton Ne 40/2 combed yarn was used as warp and weft. The actual yarn count was given as Ne 20,45 and the average strength and elasticity ratio were 16,68 cN/tex and 1,19% respectively.

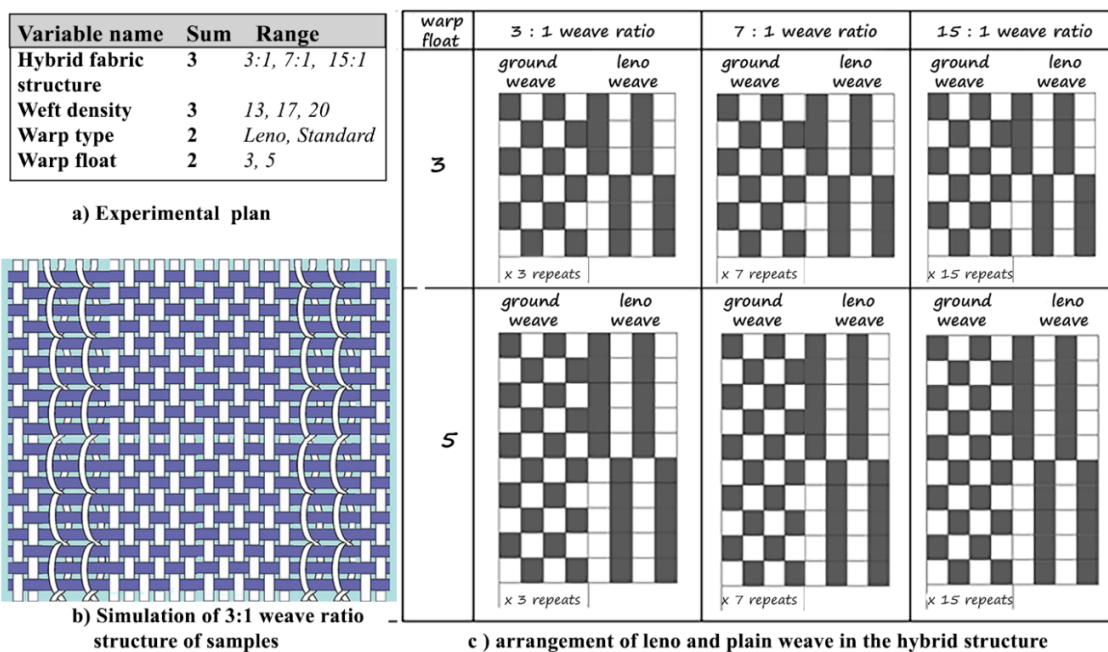


Fig. 2: The experimental plan, hybrid leno simulation and the arrangement of hybrid weave samples



The experimental plan with variables and hybrid weave structures are given in Fig. 2. The total amount of samples reached to 39 with three additional fabric samples of fully plain fabric at the 3 different weft density. The density of warp yarn was fixed at the value of 16,2 ends/cm. To achieve the same mechanical density in the warps, reed threading was performed, thus equalizing the warp densities of all fabrics. The leno weave was integrated with plain weave at three different repeats. Each fabric structure has 2 pairs of leno weave, while the ground weave of plain consists of 3, 7 and 15 repeats. This configuration enables to change the proportion of leno weave against the basic plain weave. With the hope of more precise measurement of the effect of leno warp, the same structures were also woven with standard warp replacing leno warp ends.

The sample coding "A.3L17" comprising 4 variables are arranged as follows:

<i>F. Structure</i>	<i>Float No</i>	<i>Warp type</i>	<i>Weft Density</i>
A	3	L	17
A: Weave ratio 15:1	3 picks over	L: leno warp	17 picks/cm
B: Weave ratio 7:1	5 picks over	S: std. warp	20 picks/cm
C: Weave ratio 3:1			23 picks/cm

The list of the conducted tests and test methods are tabulated in Table 1. Since the three different weave ratio is used, the number of leno weave repeats are varied. Therefore, great attention was paid to keep the samples of the same group identical in order to prevent any possible bias in measurements. In other words A, B and C coded all samples were prepared to contain the same number of leno and non-leno standard warp section. On the other hand, three all plain weave samples are also produced at the three identical weft densities and named as; P17, P20 and P23.

Table 1: The list of conducted tests and test standards

No	THE TEST DEFINITION	STANDARD CODE	STANDARD NAME
1	Determination of yarn density	TS 250 EN 1049-2 :1996	<i>Textiles-Woven Fabrics-Construction-Methods of Analysis-Part 2 Determination of Number of Threads Per Unit Length</i>
2	Unit weight measurement	TS 251	<i>Textile Woven fabrics – Structural Analysis Determining the unit length and unit mass</i>
3	Measurement of fabric width	TS EN 1773	<i>Textile Woven fabrics – Structural Analysis Determining the width and the length</i>
4	Determination of yarn crimp	ASTM D 3883-04	<i>Standard Test Method for Yarn Crimp and Yarn Take-up in Woven Fabrics</i>
5	Measurement of resistance to tearing	TS EN ISO 13937-1 :2000	<i>Textiles – Tear properties of fabrics Part 1: Determination of tear force using ballistic pendulum method (Elmendorf)</i>
6	Measurement of breaking strength	TS EN ISO 13934-2 :2014	<i>Textiles – Tensile properties of fabrics Part 2: Determination of max force using the grab method</i>
7	Assessment of bursting strength	TS EN ISO 13938-2 :2019	<i>Textiles – Bursting properties of fabrics Part 2: Pneumatic method for determination of bursting strength and bursting distension</i>

4. EXPERIMENTAL FINDINGS AND DISCUSSION

A total of 39 samples were tested for some structural components and also for breaking, tearing and bursting strength. The close view of the three group of samples are shown in Fig. 3. The samples of Group A has the lowest leno warp repeats, while Group C has the highest. Warp and weft yarn

densities were accurately calculated and adjusted during the design of samples, and density **measurements** were taken after the fabrics were woven. The average warp density values obtained from the measurements are given with reference to nominal value, in Fig. 4. In the graphics, the first series of column displays the sample group A incorporating minimum leno weave, the middle column belongs to the sample group B and the third column at the back displays the sample group C incorporating maximum rate (3:1) of leno weave. Results for the three plain woven fabrics are given as a separate group at the right side of the graphic.



Fig. 3: The close view of the three main group of samples

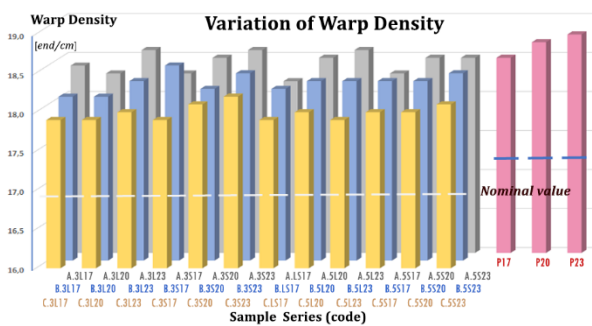


Fig. 4: Nominal and actual warp density variation for all the sample groups

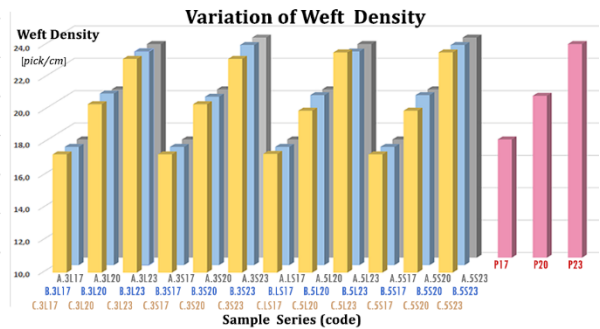


Fig. 5: Actual values of weft density variation for all the sample groups

The warp density of the samples A.3L17, A.3S20, A.3L20, A.3S17, A.5L17, A.5L23 are measured as 17 which is the lowest figure. The highest warp density for the hybrid weaves is recorded as 18,6 for the group A samples and 18,8 for the plain P.23 sample. It is seen that an increase in the weft density rises the warp density, while a decrease in the leno weave content has the same affect. The presence of leno interlacing seems to have a negative affect on the warp density. The effect of floating number do not display a clear effect.

The average weft densities for all the samples are given in Fig.5. It may be easily noticed that variation in weft density is comparatively higher than warp because the samples were woven at three densities. However, the variation between the samples of the same weft density is too low. It is also noticed that weft density of all the samples were recorded slightly above or equal to the nominal setting on the loom. The effect of leno interlacing has not been apparent on these samples.



Comparison of Raw Fabric Width

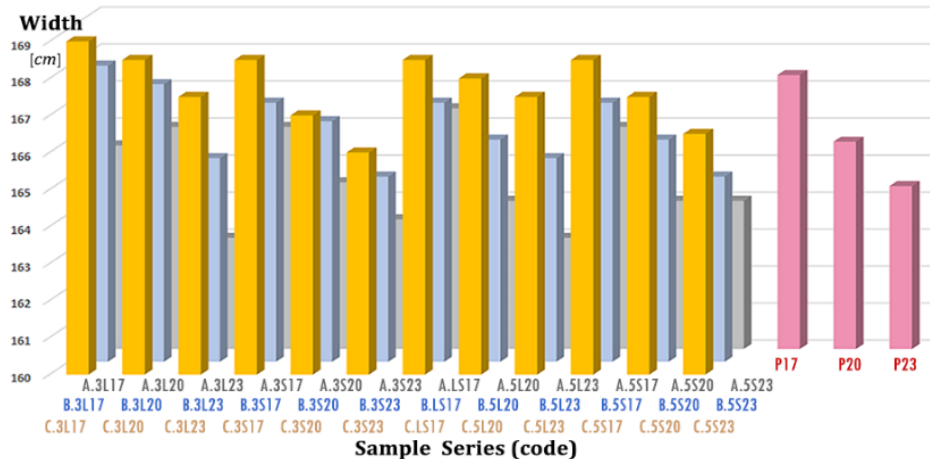


Fig. 6: Actual values of fabric width for all the sample groups

The average values of the raw fabric width measurement are shown in Fig.6. The range of fabric width varied between 163 and 169 cm. As expected, an increase in the weft density results in lower fabric width for all the samples. The affect of the leno content also seems to be decisive, as the incorporation of leno weave slackens the structure leading to the wider cloth width. The samples of group C has the highest widths whereas the samples of the group A has the lowest ones. The effect of floating number and the difference between leno warp and standard warp are not evident. The widths of all plain samples are found lower than group C but higher than the other two groups.

The unit mass values of the samples varied between 109 and 130 g/sq.m. The results are shown in Fig.7. The positive effect of weft density on the fabric weight is clearly visible in the graphics. The effect of leno content is also apparent and it seems to have a tendency to increase the fabric mass. The higher values were obtained with the samples of group C (3:1 weave ratio). There is no clear effect of floating number and the difference between leno warp instead of standard. The widths of all plain samples are found lower than group C but higher than the other two groups. The variation between the samples of the same weft density are found low.

Comparison of Fabric Unit Mass

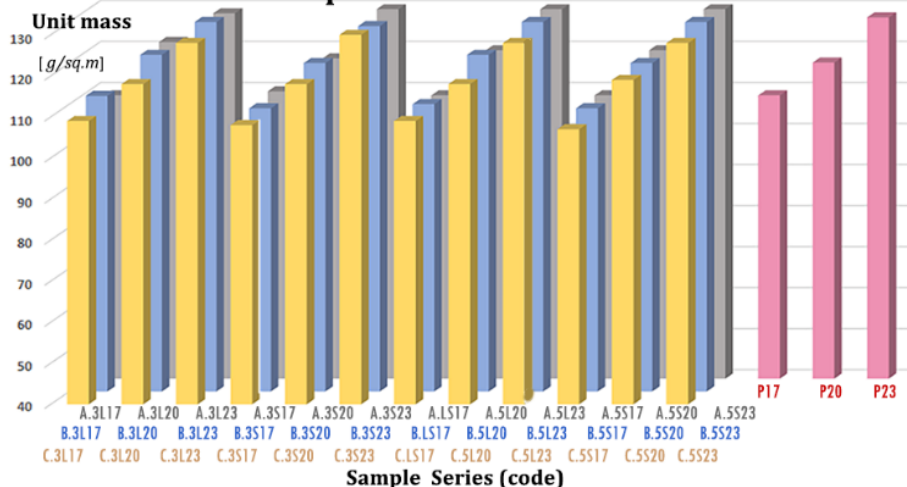


Fig. 7: Actual values of unit fabric mass for all the sample groups



The warp and weft crimps for all the samples are displayed in Fig 8 and Fig.9 respectively. For the sake of measuring the direct affect of leno interlacing, the measurements in the hybrid fabrics were made on the basis of individual warp yarns. The average of a total of 10 measurements are presented. The warp crimp ratios for the all plain fabric were measured as 3,64%, 5,0% and 6,75% in succession for the increasing weft density. The range of crimp for leno and standard warp yarns only varied between 3,24% and 8,76 %. The highest values are measured with the 3 float leno warp construction for all the weft densities. The warp crimp rate of the 3 float leno warp was almost twice

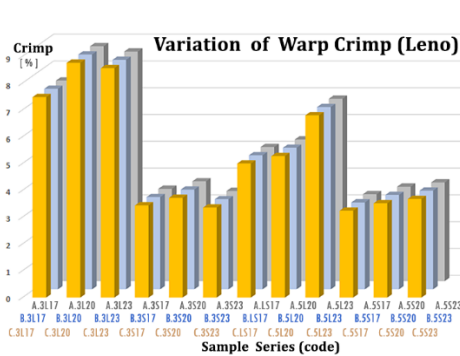


Fig. 8: Comparison of the warp crimp variation for leno and standard warps of all the samples

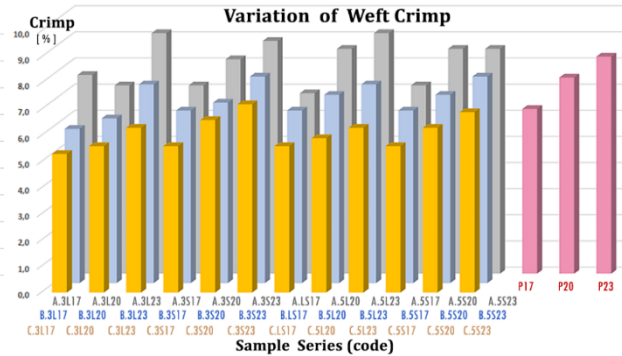


Fig. 9: Comparison of the weft crimp variation of all the fabric samples

the crimp of the standard non-leno warp. The difference between 3 and 5 float is also apparent; the higher the float, the lower the warp crimp. In overall average, the group C fabric structure samples the crimp of the standard non-leno warp. The difference between 3 and 5 float is also apparent; the higher the float, the lower the warp crimp. In overall average, the group C fabric structure samples with the highest leno weave content provide the highest weft crimp for all the cases. The behaviour of the warp

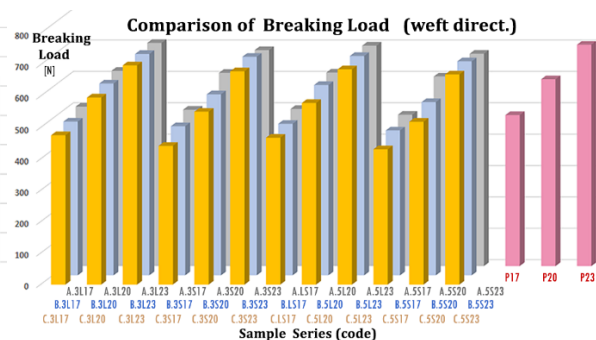
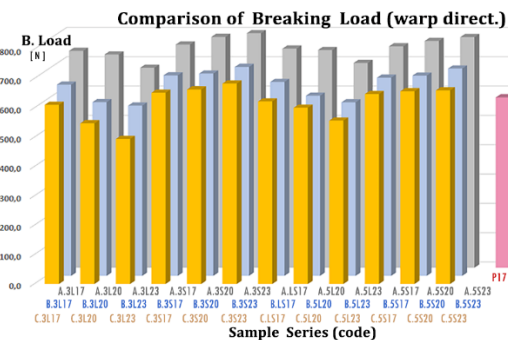


Fig. 10: Comparison of the breaking load of all the samples along the warp and weft directions

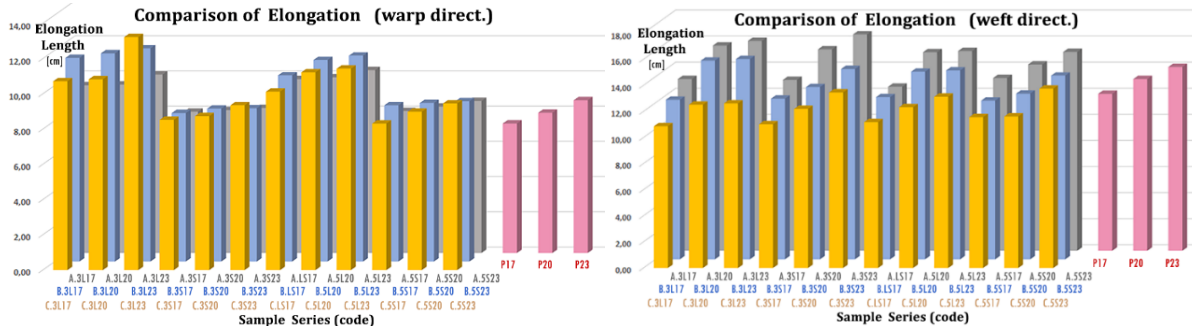


Fig. 11: Comparison of the breaking elongation of all the samples along the warp and weft directions

The mechanical properties of the samples are also tested. The breaking load and breaking elongation of all the sample groups are graphically shown in Fig.10 and Fig.11 for the direction both warp and weft. The range of breaking load varied between 494,6 N and 799,35 N along the warp direction and between 430,9 N and 710,83 N along the weft direction. Despite higher densities of weft yarns, the breaking capacity along the warp yarn are found greater. That clearly shows the positive affect of leno weave integration in the fabric construction. Regarding the elongation, the min and max values are 7,34 cm and 13,23 cm along the warp direction and values are 10,9 cm and 16,58 cm along the weft yarns. The presence of leno warps tends to lower the warp crimp hence reduces the extension through this way. The affect of leno warp or the leno weave is much more apparent on the warp-way fabric strength than the weft way fabric strength. The increasing ratio of leno weave has a positive affect on the warp-way as seen in the first graphic of Fig.10. This affect is not clear for the weft-way strength unlike the positive effect of the weft density. One would expect that leno weave structure will show more rigidity along the warp-way than the weft-way as it was confirmed by these graphics.

The tearing resistance of the samples are also measured and the results recorded along the weft direction was given in Fig.12. Tearing tests along the warp direction was also carried out but failed to tear the fabric samples. The range of tearing force along the weft-way was measured between 10,2 N and 16,5 N. The effect of weft density on the resistance to tearing is very apparent as it increases with increasing weft density. This case is valid for all sample structure types. The effect of integration of the leno structure is not clear, but it seems that there is some inclination of increase in resistance to tearing with higher ratio of leno concentration. The presence of non-leno warp appears to impart a positive effect on the tearing resistance. In the case of floating number, it has a negative effect on the tearing strength since the interlacing and contact points are reduced by increasing float number. The effect of weft density on the tearing strength is also very apparent with reference to all plain samples of P17, P20 and P23.

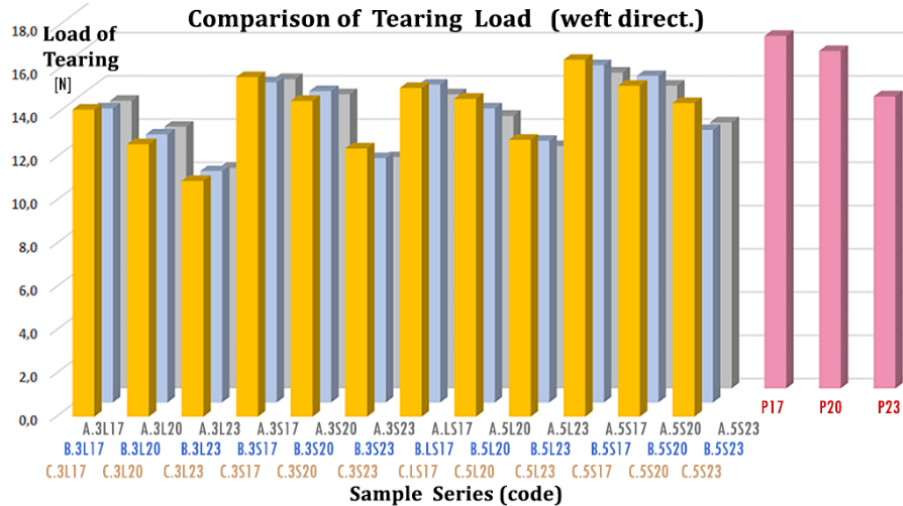


Fig. 12: Comparison of the tearing strength of all the samples along the weft direction

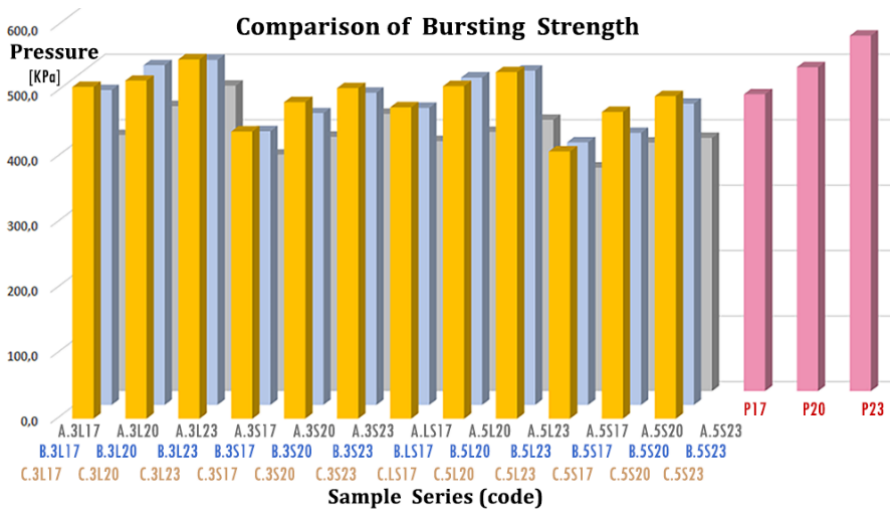


Fig. 13: Comparison of the bursting strength and pressure of all the samples

The bursting measurements for all the samples are shown in Fig.13. The range of bursting varied from 341,5 KPa to 548,8 Kpa. ailed to tear the fabric samples. The max. values are achieved by the samples with higher leno weave ratio. As expected, the presence of leno interlacing and extra contacts between yarns play an important role in improving the bursting pressure. Increases in the weft density also improves the toughness of the structure, unlike the float number which has a negative affect on the bursting reducing the interlacing and contact points.

5. CONCLUSION

The effect of leno weave in a hybrid fabric structure is analyzed with reference to the variables of weave arrangement, weft density, float number and leno warp connection. Among these variables, the effect of weft density appears the most decisive and also similar for both hybrid and the plain weave structures. The presence of leno weave is also visible on both structural and mechanical characteristics.



The difference between leno warp interlacing and standard non-leno interlacing are more apparent on the mechanical characteristics than the structural ones. In the determination of the breaking strength of the fabrics, it is observed that the breaking strength in the warp direction of the samples with 3 floats leno connections is lower than that of the samples with 5 leno float connections. In the case of non-leno interlacing, this situation was reverse. The breaking load of the 3 float standard non-leno construction is higher than that of the 5 float non leno. In other words, the presence of leno warps, increases the breaking strength with increasing float number, unlike the adoption of standard warp which reduces the strength as the number of float rises. It is observed that the integration of leno weave into the structure tends to improve the breaking resistance along the warp direction. As the weft density increases, the breaking strength in the weft way uniformly increases. In the case of bursting strength, the existence of leno interlacing in the construction tends to increase the bursting strength.

The current body of literature confirms that leno weave provides a unique combination of mechanical stability, permeability, and structural integrity. Its defining feature, the crossing of warp yarns, enhances inter-yarn friction and suppresses yarn slippage, leading to improved performance in tensile, puncture, and shear-related properties. Among all woven structures, only leno weave has this unique characteristic ensuring enhanced dimensional stability. It is known that the mechanical behaviour of woven fabrics is intrinsically governed by their structural architecture, where yarn interlacement, density, and material properties interact in complex ways.

In recent years, hybrid woven structures, combining leno with conventional weaves have gained attention for their ability to balance openness, stability, and mechanical performance. Recent advancements in multi-warp and hybrid leno structures demonstrate the potential for tailoring mechanical behaviour for specific applications [26], [27]. However, further systematic research is required to fully exploit the mechanical capabilities of leno fabrics, particularly in emerging areas such as hybrid structures, smart textiles, advanced composites. Typical technical applications are filtration systems, geotextiles, and composite reinforcements, where both structural integrity and permeability are required. It is believed that this study shall enable to quantify the effect of structural parameters on mechanical properties and provide design guidelines for hybrid leno fabrics.

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REFERENCES

- [1] I. Emery, "The primary structures of fabrics". Thames & Hudson. The Textile Museum Washington, D.C. 3rd Edition. 1994.
- [2] J.E. Booth, "Principles of textile testing: An introduction to physical methods of testing textile fibres, yarns and fabrics". Heywood Books, London. 3rd Edition, 1968.
- [3] P. Grosberg. "The Mechanical Properties of Woven Fabrics Part II: The Bending of Woven Fabrics". *Text Res Journal*. 1966; 36: 205-211.
- [4] I. R. Shekar et al., "Hybrid fabrics for structural composites," *Journal of Industrial Textiles*, vol. 41, no. 1, pp. 70–103, Jul. 2011, doi: 10.1177/1528083710396263.
- [5] H. Iftekhhar, M. Umair, S. T. A. Hamdani, S. M. Imran, M. S. Nazir, and Z. Ali, "Effect of Hybrid Weave Patterns on the Mechanical Performance of Woven Fabrics," *Journal of Natural Fibers*, vol. 20, no. 1, pp. 1–14, 2023, doi: 10.1080/15440478.2022.2145411.



ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

- [6] I.C.S. Staff, *Leno Weaves*, 1st ed., vol. ICS 512. Scranton, Pennsylvania: International Textbook Co., 1905. [Online]. <https://www2.cs.arizona.edu/patterns/weaving/monographs/ics512.pdf>
- [7] W. Watson, *Advanced Textile Design*. London: Longmans, Green and Co., 1913.
- [8] D. Harper, "Origin and history of gauze," Online Etymology Dictionary. Accessed: Apr. 02, 2026. [Online]. Available: <https://www.etymonline.com/word/gauze>
- [9] A.Roguin. "Gauze: Origin of the Word," *Journal of the American College of Surgeons* 233(3):pp. 494-495, September 2021. DOI: 10.1016/j.jamcollsurg.2021.05.026
- [10] H.Z. Özek. "Tekstilde tasarım ve ürün geliştirme (LÜ-T.04)" *Postgraduate Course, Lecture Notes (unpublished)*. Namık Kemal University Graduate School. 2017-18 Spring Term).
- [11] Y. Chen, "Developments in leno-weave fabrics," in *Specialist Yarn and Fabric Structures*, R. H. Gong, Ed., Cambridge: Woodhead Publishing Lmt, 2011, ch. 6, pp. 118–140.
- [12] Anonymous, "A touch of Dornier : DORNIER's EasyLeno Technology," Machine Leaflet, Lindauer DORNIER GmbH.
- [13] B.B.Kastacı. "Leno Dokumaşların Yapısal Değişkenleri ile Fiziksel Özellikleri Arasındaki İlişkinin Araştırılması," MSc Thesis, Namık Kemal University, Graduate School of Natural and Applied Sciences 2016.
- [14] A. Y. Ahmed, "Physical Properties of Leno Fabrics," Ph.D Thesis. University of Manchester Institute of Science and Tech. Manchester, 1972.
- [15] A. Cetin and B. Guldemet, "Manufacturing Of Tubular Leno Fabrics By Modified Standard Sampling Loom," *Annals of the University of Oredea Fascicle of Textiles, Leatherwork*, vol. 19, no. 1, pp. 13–18, 2018.
- [16] H. Doğu, "Leno Dokuma Sistemlerinin Analizi ve Tasarım Açısından Yeni Öneriler". MA Thesis, "570853" Mimar Sinan Fine Arts University, Textiles and fashion Dept. Istanbul. 2019.
- [17] Y. Akelma ."Döner Gücü Sistemi ve Eğitim Amaçlı Armürlü Dokuma Tezgahlarına Uyarlanabilirliği", Gazi Üniversitesi Eğitim Bilimleri Enstitüsü, Yüksek Lisans Tezi Ankara. 2007
- [18] N.Redmore. "Embracing nature and the fragility of design. An investigation into outdoor seating materials through the practice of leno weaving. University of Huddersfield. Master thesis, Huddersfield, June 2014.
- [19] L. Ge. "Novel Woven Structure Design for Polymeric Optical Fiber (POF) Textiles" The Hong Kong Polytechnic University Institute of Textiles and Clothing, Ph.D thesis, August 2020.
- [20] Anonymous, "A touch of Dornier : DORNIER's EasyLeno Technology," Lindauer DORNIER GmbH. Accessed: Apr. 02, 2026. [Online]. Available: https://www.manichylla.com/Documentos/DORNIER_Telar%20de%20gasa%20de%20vuelta%20EasyLeno_E.pdf
- [21] K. Shaker, Y. Nawab, M. Ayub Asghar, A. Nasreen, and M. Jabbar, "Tailoring the properties of leno woven fabrics by varying the structure," *Mechanics of Advanced Materials and Structures*, vol. 27, no. 22, pp. 1865–1872, Nov. 2020, doi: 10.1080/15376494.2018.1527964.
- [22] X. Tian, M. Yao, Y. Li, and L. Li, "Design and fabrication of mesh-like four-warp leno cotton fabric based on self-locking effect: outstanding mechanical performance and breathability," *Cellulose*, vol. 32, no. 3, pp. 1979–1991, Feb. 2025, doi: 10.1007/s10570-024-06365-y.
- [23] M. H. Kashani, A. Hosseini, F. Sassani, F. K. Ko & A. S. Milani. "The Role of Intra-Yarn Shear in Integrated Multi-Scale Deformation Analyses of Woven Fabrics: A Critical Review", *Critical Reviews in Solid State and Materials Sciences*, 43:3, 2018, pp.213-232.
- [24] H. Pan, J. Liu, J. Xie, Z. Feng. "A review on the yarn pull-out behavior of high-performance woven fabrics for impact resistance," *Composites Part C: Open Access*, Volume 18, 2025, 100658. <https://doi.org/10.1016/j.jcomc.2025.100658>.



ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

[25] Rampini, M.C.; Zani, G.; Schouler, L.; Colombo, M.; di Prisco, M. Effect of Textile Characteristics on the AR-Glass Fabric Efficiency. *Textiles* **2021**, *1*, 387-404.

[26] Xu, Z. Li, H. Zhu, and H. Shi, “Geometric modeling and simulation for leno fabrics,” *J. of Engineered Fibers and Fabrics*, vol. 19, pp.1–19, Jan. 2024, doi: 10.1177/15589250241291198.

[27] P. Preinstorfer, P., M. El Kadi, G. Dittel, *et al.* “Article of RILEM TC 292-MCC: bond behaviour of textile-reinforced concrete—a review”. *Mater Structure* **57**, 97. 2024.