Indian Journal of Fibre & Textile Research
Vol. 50, September 2025, pp. 260-267
DOI: 10.56042/ijftr.v50i3.12062

Effect of braiding parameters on physio-mechanical properties of braided structures

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Received 26 June 2024; revised received and accepted 24 June 2025

This study investigates the effects of braided samples composed of polyester filament yarns simultaneously for variables like braid structure (1/1 and 2/2) and take-up rate on braiding angle, braid diameter, braid fineness, pick count, pitch length, total mass, tensile strength, elongation and bending stiffness. This study indicates how changes in braid pattern and take-up rate affect the mechanical properties of polyester tubular braided structures. The braiding machine's take-up speed directly impacts the braid's formation speed, and it is possible to modify this speed without affecting the carriers' sequential motion. To determine the significance of the difference in results, statistical analysis is performed at each state of observation.

Keywords: Braid pattern, Braided structure, Physical properties, Polyester, Take-up rate

1 Introduction

Braiding is a distinct and unique type of textile fabric. According to the Encyclopaedia Britannica, braiding means the interlacing of three or more yarns that cross each other diagonally to form flat or tubular fabric strips [1]. While different methods can be used to manufacture braids, the basic structure of braiding remains constant and easily accessible[2–3]. The braid structure is formed by rotating components, and the "take-up" process is facilitated by linear motion. The construction of braids is based on this interlacing mechanism of yarn carriers. The number of carriers in the braiding process plays a significant role in determining the density and porosity of the braided structure. A higher number of carriers leads to a greater number of fibre interlacements per unit area, resulting in a tighter and denser braid. In the case of porosity, it is inversely related to the number of carriers. The porosity of the braiding fabric decreases with the increase of the number of spindles or the diameter of the braiding yarn, as well as increases with the increase of the cylindrical mandrel radius or the braiding fabric take-up speed[4-5]. Braid mechanical properties are greatly affected by various yarn interlacing patterns, such as Diamond (1/1), Regular (2/2), and Hercules (3/3)[1,6-9].

The geometry of the braid structure is dependent on numerous factors, including pick count, diameter, and braid angle[10–13]. A typical braid geometry is shown in Fig. 1, which consists of the braiding axis, line (l), stitch (S), and braiding angle (θ). Picks or plaits, also called stitches, define the make-up of the braid.

Every single stitch created by the yarns coming together is referred to as a pick, and each pick creates a braid repeat that is measured along the braid axis [1]. Pick count is the number of picks per unit length in a line parallel to the braid axis, whereas pick spacing, also known as plait spacing, is the distance between subsequent picks. A single pick is represented by the letter "S," and the pick count is the number of "S" units along the braid's length. The direction in which the braided fabric is formed is indicated by the braid

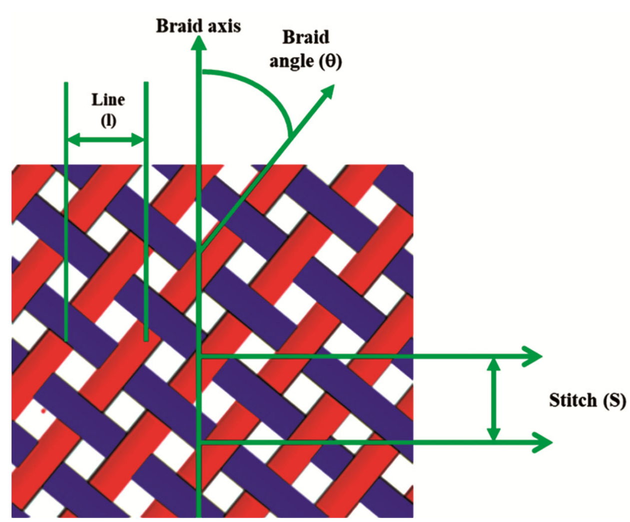

Fig. 1 — Illustrative diagram of a braid structure

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axis[3]. One repetition of the braid structure perpendicular to the braid axis is referred to as a line. The number of carriers in the braiding machine is correlated with the number of lines in a braided structure[11]. The braid angle is represented by half of the angle created between the interlacing yarns in a vertical direction. The braid angle between the threads is determined by the ratio between the bobbins' angular speed and the take-up speed[6,8,10-12]. Additionally, the braid's cover factor is determined by its braid angle[13]. There is a direct proportional relation between these two. The higher the angle, the denser the fabric will be. Braiding angle can be between 1° and 89°, but the achievable range is 10° –85°[2,9]. The braid's size is determined by the number of carriers, yarn diameter, yarns per carrier, yarns per unit length, and take-up speed[14] and the design and analysis of the track change mechanism in braiding machine have been explored by Cei *et al.*[15].

Assi *et al.*[16] introduced a new horn gear, track, and plate design to enable braiding in the vertical plane. Li *et al.*[17] developed a 3D braiding machine with a robotic arm to individually regulate each yarn and create square and round braids. Krauskopf *et al.*[18] utilised discrete simulation and modelling of the maypole braiding machine to detect and eliminate carrier collisions. Additionally, Emonts *et al.*[19] presented the latest advancements in 3D braiding, machine development, and software and simulation techniques. Moreover, several researchers created braided sutures by adjusting manufacturing variables like yarn count, take-up speed, and braiding machine type, then examined how these variables affect the mechanical characteristics of the braided sutures[20,21]. The linear regression method and response surface methodology have also been used to examine the simultaneous effects of braided structure[22,23].

Due to the shortage of literature regarding the interaction between braiding structural parameters and their effect on mechanical properties, further investigation is required to find the influence of braiding parameters on the physical properties which is necessary for further technical applications. This study examines the correlation and interaction among various structural parameters of the braiding process, including take-up speed, number of carriers settings, and braid pattern. The objective is to investigate the impact of these parameters on polyester tubular braided structures in terms of braid angle, linear density, diameter, pick count, pitch length, and total unit mass, as well as mechanical properties such as tensile strength, tenacity, elongation, and bending stiffness.

2 Materials and Methods

2.1 Materials

This work is carried out by using two different dyed non-texturizing polyester filament yarns purchased from Madura Coats Private Limited, India. Different dyed yarns are used to understand the path of the yarn in the braid structure. The details of polyester yarns are given in Table 1.

2.2 Methods

2.2.1 Preparation of Braided Structure

There are twelve different types of braid samples produced by varying braid pattern (1/1 and 2/2), yarn linear density (81 tex and 162 tex), and take-up speed (20 cm/min, 40 cm/min and 60 cm/min) with the help of the SEMCO circular braiding machine (Geesons International, Ahmadabad) in NIT, Jalandhar. The details of the braid samples are given in Table 2. The original images of the braided structures are shown in Fig. 2. Moreover, the take-up rate was varied by changing gears.

Table 1 — Properties of polyester filament yarns

Property	Values
Yarn type	Multi-filament
Number of filaments	20 and 40
Yarn linear density, tex	81 (20 × 4.05) & 162 (40 × 4.05)
Breaking strength, N	43.64 & 83.43
Tenacity, cN/tex	62.3 & 59.6
Elongation, %	32.69 & 34.89

Table 2 — Braided structure details

Sample	Tex	Carriers used	Braid pattern	Take-up speed
S1	81	8	1/1	Low, 20 cm/min
S2	81	8	1/1	Medium, 40 cm/min
S3	81	8	1/1	High, 60 cm/min
S4	162	8	1/1	Low, 20 cm/min
S5	162	8	1/1	Medium, 40 cm/min
S6	162	8	1/1	High, 60 cm/min
S7	81	16	2/2	Low, 20 cm/min
S8	81	16	2/2	Medium, 40 cm/min
S9	81	16	2/2	High, 60 cm/min
S10	162	16	2/2	Low, 20 cm/min
S11	162	16	2/2	Medium, 40 cm/min
S12	162	16	2/2	High, 60 cm/min

Fig. 2 — Original braided structures

2.2.2 Characterisation Techniques Used

2.2.2.1 Determination of Diameter and Braid Angle

Braid diameter and braid angle are measured according to the previously published method[21]. These two parameters are measured by Leica digital microscope, Danaher, Germany. Each sample is tested at least ten times for the determination of the above-mentioned parameters.

2.2.2.2 Determination of Pick Count, Pitch Length, and Linear Density

Pick count is defined as the number of strands rotating in one direction for a unit length of a braid. Pick count is measured as per ASTM D 3775-17**.** Pitch length is the length of the desired number of complete turns of the same strand. Linear density is the mass (g) of the braid in 1000-m length, which is denoted as tex or kilotex. Pitch length and linear density of the braided structure are measured as per ISO 2307-2019[24,25].

2.2.2.3 Determination of Tensile Properties

Tensile properties are assessed as per ISO 2307:2019 standard using a universal tensile testing machine[6,25]. Each sample is tested at least ten times, with a constant gauge length to compare tensile strength and elongation with different patterns.

2.2.2.4 Determination of Bending Stiffness

Bending stiffness is measured as per a previously published method[26]. The corresponding bending stiffness is calculated by using the below equation:

$$\text{Bending stiffness, EI} = \frac{qL^4}{8\partial_B} \quad \ldots (1)$$

where q is the weight of sample per unit length (g/m); L, length at 41.5 ° (m) and δ_B, tip deflection (mm).

3 Results and Discussion

The braid angle is measured according to the standard procedure described earlier, and the data are presented in Table 3 and Fig. 3. It is evident that the braid angle increases at lower take-up speeds, regardless of the braid pattern. For example, in braided structures made of 81 tex polyester yarn with a 1/1 pattern, the braid angles are 32.43°, 23.09°, and 14.60° for S1, S2, and S3, respectively. Similarly, for

Table 3 — Braid angle and diameter of braided structures

Sample	Braid Pattern	Take-up speed	Braid angle, °	Diameter, mm
S1	1/1	Low, 20 cm/min	32.43 ± 0.037	0.139 ± 0.0002
S2	1/1	Mid, 40 cm/min	23.09 ± 0.028	0.156 ± 0.0003
S3	1/1	High, 60 cm/min	14.60 ± 0.062	0.178 ± 0.0003
S4	1/1	Low, 20 cm/min	32.12 ± 0.062	0.198 ± 0.0006
S5	1/1	Mid, 40 cm/min	23.41 ± 0.040	0.220 ± 0.0003
S6	1/1	High, 60 cm/min	14.03 ± 0.028	0.257 ± 0.0002
S7	2/2	Low, 20 cm/min	32.20 ± 0.055	0.209 ± 0.0002
S8	2/2	Mid, 40 cm/min	23.06 ± 0.031	0.238 ± 0.0001
S9	2/2	High, 60 cm/min	14.23 ± 0.039	0.276 ± 0.0004
S10	2/2	Low, 20 cm/min	32.11 ± 0.035	0.310 ± 0.0003
S11	2/2	Mid, 40 cm/min	23.10 ± 0.025	0.349 ± 0.0004
S12	2/2	High, 60 cm/min	14.11 ± 0.034	0.392 ± 0.0004

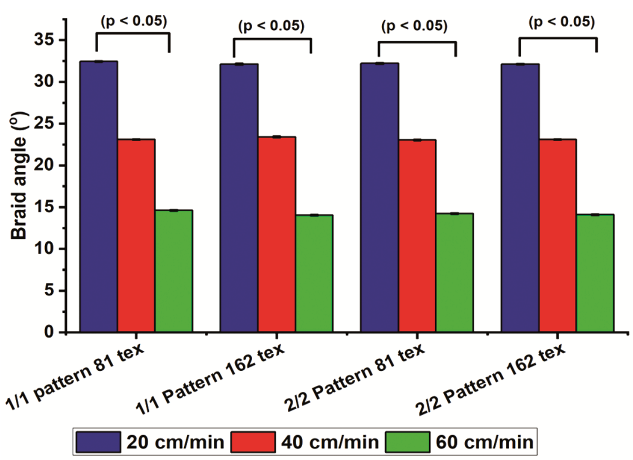

Fig. 3 — Braid angle of braided structures of different braid patterns and take-up speed

the 2/2 pattern, values of 32.20°, 23.06°, and 14.23° are observed for S7, S8, and S9, respectively. This trend can be explained mathematically using below equation:

$$\tan\theta = \frac{r\omega}{V} \qquad \ldots (2)$$

where r is the the radius of mandrel (cm); V, take-up speed (cm/s) and ω, angular velocity of bobbins (rad/s).

At lower take-up speeds, the braid is pulled slowly, allowing yarns to interlace more tightly and form higher braid angles. Conversely, at higher take-up speeds, the intertwining speed remains constant, but the faster pulling motion straightens the braided strands, thereby reducing the braid angle[9,27]. These variations in braid angle influence the mechanical behaviour of the structures. Flexural strength, or the ability of a material to resist deformation under load, is affected by this braiding angle. Previous studies report that higher braid angles (30°–50°) reduce flexural strength, as fibres are oriented more transversely and offer lower load-bearing capacity along the braid axis[28]. Lower braid angles (13°–25°), however, orient fibres longitudinally, resulting in higher flexural strength[29]. In contrast, impact resistance improves at higher braid angles due to a more compact and interlocked fibre arrangement that distributes impact forces effectively.[30,31]. Statistical analysis (ANOVA) confirms that differences in braid angles between interlacement patterns are significant ($p < 0.05$).

The diameter of the braided structures is also examined (Table 3). A direct relationship is observed between take-up speed and diameter: at low take-up speeds, diameters are smaller, whereas higher take-up speeds result in larger diameters. For instance, samples S1, S2, and S3 exhibit diameters of 0.139 mm, 0.156 mm, and 0.178 mm, respectively. The same trend is followed for all the other samples. If the take-up rate is faster, the diameter is also increased when removed from the machine. This behaviour is linked to braid angle, since lower take-up speeds with higher braid angles form more compact structures. The cogwheel ratio of the machine also plays a critical role, as it regulates take-up speed and, consequently, the running speed of the braid. Therefore, when the take-up speed is high, the braid is not compact enough, resulting in a higher diameter of braided structures[21,23,27]. However, the thickness of the braid increases with the increase in the braid angle. Statistical tests further confirm significant differences ($p < 0.05$) in diameter values across sample groups (S1-S3, S4-S6, S7-S9 & S9-S12).

Table 4 — Linear density, total unit mass, pitch length & bending stiffness of braided structures

Sample	Linear density, tex	Total unit mass, g/m	Pitch length, cm	Bending stiffness, $\times 10^{-6}$ Nm^2
S1	882.3 ± 0.725	0.882 ± 0.0007	0.50 ± 0.001	1.72 ± 0.025
S2	767.5 ± 0.964	0.767 ± 0.0009	1.00 ± 0.004	0.38 ± 0.004
S3	699.2 ± 0.568	0.699 ± 0.0005	2.15 ± 0.004	0.27 ± 0.007
S4	1706.2 ± 0.890	1.706 ± 0.0008	0.78 ± 0.002	3.35 ± 0.10
S5	1468.2 ± 0.505	1.468 ± 0.0005	1.45 ± 0.004	1.04 ± 0.02
S6	1325.2 ± 0.617	1.325 ± 0.0006	2.16 ± 0.004	0.49 ± 0.010
S7	1792.1 ± 1.690	1.792 ± 0.001	0.51 ± 0.001	4.38 ± 0.043
S8	1557.8 ± 0.975	1.557 ± 0.0009	1.00 ± 0.003	2.16 ± 0.03
S9	1303.4 ± 0.596	1.303 ± 0.0005	2.12 ± 0.003	0.93 ± 0.007
S10	3357.1 ± 0.568	3.357 ± 0.0005	0.80 ± 0.003	6.25 ± 0.139
S11	2871.1 ± 0.595	2.871 ± 0.0005	1.49 ± 0.003	2.10 ± 0.026
S12	2597.6 ± 0.555	2.597 ± 0.0005	2.24 ± 0.002	1.59±0.030

Table 4 presents the linear density, total unit mass, pitch length, and bending stiffness of the braided structures. Linear density decreases with increasing take-up speed. For instance, in the 1/1 pattern, sample S6 displays a reduction of 381 tex compared with S4 and 143 tex compared with S5. A similar trend is observed in the 2/2 pattern, with S12 showing a reduction of 760 tex from S10 and 274 tex from S11. A similar trend is seen for the remaining group of samples. This may be due to the extension that happened in the braid length, which resulted in a reduction of the diameter[32]. At lower speeds, yarns are packed more densely within a given length, which explains the higher linear density values[6]. Statistical analysis ($p < 0.05$) confirms significant differences in linear density across groups.

A similar trend is observed for total unit mass. At lower take-up speeds, the braid accumulates more yarn per unit length, leading to higher mass values (e.g., 0.882 g/m for S1 vs. 0.699 g/m for S3). It is clear that the total unit mass goes downwards with the increase in take-up speed for every group of samples. During low take-up speed, as the braid is pulled slowly, a higher amount of yarn is present in one meter of the braid, which helps in increasing the mass of the braided structure[33]. The interrelationship between braid angle, pick count, and mass supports this observation, as higher braid angles and pick counts increase the total mass. Again, differences between samples are statistically significant ($p < 0.05$).

Pick count values are shown in Fig. 4. The pick count is unaffected by braid pattern but strongly influenced by take-up speed. Low take-up speeds produce higher pick counts (e.g., S1, S4, S7, and S10). Comparatively, low pick count is observed in

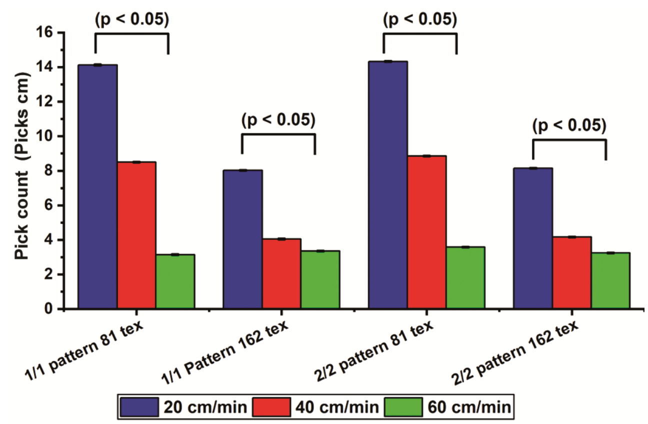

Fig. 4 — Pick count of braided structures in different braid patterns and take-up speed

S2, S5, S8, and S11 for medium braid speed, as well as for S3, S6, S9, and S12 samples processed in high braid speed. That means a low pick count is caused by high braid running speed, as the interlacing speed is constant throughout the process[1,9,21]. In addition, when the braid angle increases in low take-up speed, it means the repetition of yarns in the same direction for a unit length is higher, and the pick count has also increased accordingly. Increasing the number of picks increases the efficiency of torque transmission, whereas decreasing the number of picks enhances flexibility and enables radial expansion. It is evident that as the picks per inch increased, the braid angle increased and the braid diameter reduced[34]. This is a universal feature found in all interlacement structures. When the braid angle decreased, due to the lower crimp, the strand length in the unit length of the braided material also decreased. Statistically significant differences ($p < 0.05$) are also found between sample groups.

Pitch length, summarised in Table 4, is also unaffected by braid pattern but increases with take-up speed. The pitch length is high for S3, S6, S9, and S12. The highest pitch length of 2.24 cm is observed in S12 (2/2 pattern, high speed), as yarns travel longer distances per braid repeat compared to a low take-up rate sample like S1, S4, S7, and S10[33]. Pitch length is inversely related to braid angle: as braid angle and yarn interlacements increase, pitch length decreases while the other dimensions remain constant[35]. Furthermore, the *p*-values show there are statistically significant differences between the mutual values of pitch length of each group.

Bending stiffness values (Table 4) are highest at low take-up speeds, where yarns are more tightly packed and braid angles are greater. For instance, the stiffness value for S7 (2/2, 81 tex) is 4.38×10^{-6} Nm^2 for low speed, which decreases to 2.16×10^{-6} Nm^2 at medium speed and 0.93×10^{-6} Nm^2 for high speed. The value of the bending stiffness of the remaining samples also follows a similar trend. During the experiment, it was found that the values of q (weight /unit length in gm/m) and L (length for 41.5 ° in m) of Eq. 2 are high for the structure with a higher braid angle. In comparison to braid structures with low stiffness, braid structures with high bending stiffness values were found to deflect at high length values to approach the slope limit established at 41.5° in this study. It is evident that the smaller braiding angle constructions were too weak to support their own weight when put through a bending test. Extremely low carrying ability in the transverse direction is the probable reason for their low bending values. However, the structure with a braid angle of 32.43° can bear more transverse load than the structure with 14.60°[26,36]. This can also be explained by following the pick count. As the number of picks increases, the filaments inside the structure get denser. Because of the difficulty in filament mobility, the bending stiffness increases, and lateral deformation decreases, as a result of the smaller gap between the filaments[21,37]. In addition, these results are statistically significant ($p < 0.05$).

Tensile strength values (Fig. 5) show an inverse relationship with braid angle: strength increases as braid angle decreases. For example, tensile strength values of 150.74 N, 196.26 N, and 263.43 N are observed for S1, S2, and S3, respectively. A similar change is observed between other groups of samples. This could be because of the force applied to the structure and the helical profile in the braided construction, which causes filaments to run parallel to the braid axis[22].

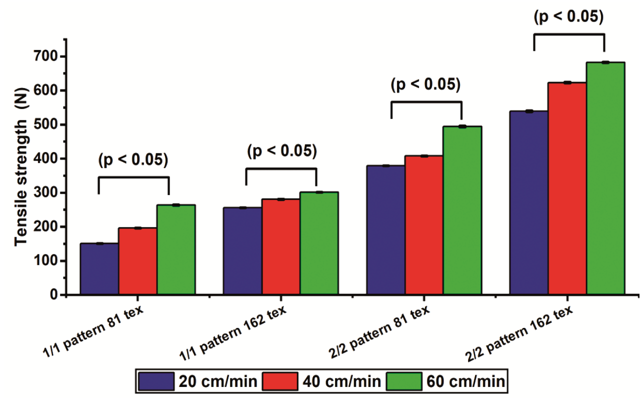

Fig. 5 — Tensile strength of braided structures in different braid patterns and take-up speed

This behaviour is consistent with the fibre obliquity phenomenon, where the high angles between the fibre axis and the yarn axis contribute to lowering the fibre strength to yarn strength to such a degree that yarn strength as a whole degrades. As per Pan and Lin, when the oblique angle increases, the applied breaking load will decrease[38]. A similar trend is observed here. Similar findings are reported by Zhang & Cheng[39], who attributed that the tensile strength of 2D braided ropes exhibited an initial increase with longer pitch lengths. However, beyond a certain length, the strength may start to decrease due to the possibility of raising a large fatal flow within the yarn test length[40]. Statistical analysis confirms significant differences in tensile strength ($p < 0.05$),

The tenacity values are measured and shown in the Fig. 6. The tested sample's yarn length is longer at high braid angles than it is at low braid angles. A decrease in yarn length within the braid may account for the increase in tenacity observed when the braid angle is decreased[40]. Mathematically the tenacity of a textile material is calculated as breaking load in cN divided by linear density in tex[41]. It is mentioned previously that when the braid angle decreases, the breaking load increases and the linear density decreases. Therefore, the tenacity will be increased with the lowering of the braid angle. As per Omerglu (2006)[9], if the pattern remains consistent, the braided ropes exhibit higher values for maximum tenacity, as the take-up rate is increased. When the braid angle decreased at a high take-up rate, the axial tensile forces applied to the braided material resulted in lower loads on the strands[9].

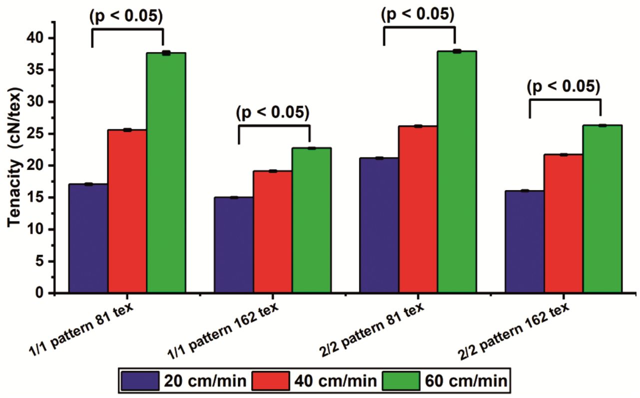

Fig. 6 — Tenacity of braided structures in different braid patterns and take-up speed

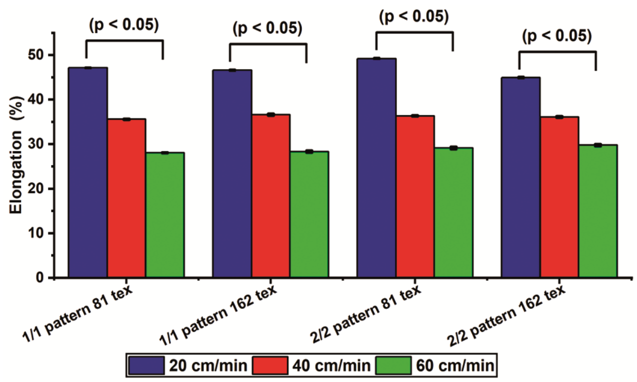

Fig. 7 — Elongation, % of braided structures in different braid patterns and take-up speed

Elongation results (Fig. 7) indicate that samples braided at lower take-up speeds exhibit higher elongation percentages than those produced at medium and high speeds. It is noted that as the take-up rate and pitch length increase, the strain on the samples decreases gradually, regardless of the sample groups. The high take-up speed of the sample causes the yarns to be pulled up and stretched when subjected to a load, while the low take-up allows the yarns to be packed tightly and gives them more space to extend when exposed to extension[6,34,42]. As per Zhang and Cheng[39], the breaking elongation decreased as the unit length increased. According to Brunnschweiler (1954), a braid's breaking length can be up to 50% longer than the singles yarn it is made of, and its breaking extension can also be up to four times longer than the yarn. The greater the breaking length, the lower the breaking extension[43]. Statistical tests again confirm significant differences ($p < 0.05$).

Lastly, not only the yarn, but also the fibre tension plays a crucial role in the braiding process, significantly impacting the quality and properties of the final product. Proper fibre tension ensures the alignment and uniformity of fibre distribution throughout the braided structure. Higher fibre tension leads to better compaction of the fibres, resulting in a denser and more compact braided structure, which increases density and enhances the mechanical properties of the structure, such as its strength and stiffness[44,45]. It also maintains the dimensional stability and reduces the likelihood of defects such as fibre waviness, gaps, and misalignment.

4 Conclusion

This study demonstrates that take-up speed and braid pattern significantly influence the structural and mechanical properties of braided polyester yarns. The braid angle increases at lower take-up speeds, leading to more compact structures with higher diameter, linear density, unit mass, pick count, bending stiffness, and elongation. Conversely, higher take-up speeds reduce the braid angle, producing looser structures with improved tensile strength and tenacity due to fibre alignment closer to the braid axis. Pitch length shows a direct relationship with take-up speed and an inverse relationship with braid angle, confirming its critical role in determining structural geometry. Statistical analysis ($p < 0.05$) validates that differences across take-up speeds and interlacement patterns are significant for most parameters. The results establish that braid angle, governed primarily by take-up speed, is the key factor dictating both structural compactness and mechanical performance. Low braid angles favour higher strength and tenacity, while higher braid angles enhance impact resistance and bending stiffness. These findings may be helpful during the fabrication and optimisation of different braided structures like sutures, parachute cords, climbing ropes, etc. which have diverse technical applications.

References

1 Brunnschweiler D, *J Text Inst Proc*, 44 (1953) 666. doi.org/10.1080/19447015308687874.

2 Kyosev Y, *Braid Techno Text*, (Woodhead Publishing) (2015) 1.

3 Alagirusamy R & Padaki N V, In braided structures and composites Production, Properties, Mechanics, and Technical Applications, Eds. Rana S & Fangueiro R, (CRC Press, Taylor & Francis Group) (2015) 3. doi.org/10.1201/b18787.

4 Geng C, Xiong F, Liu Y, Zhang Y, Xue Y, Xia T & Ji M, *Buildings*, 15 (2025) 1. doi.org/10.3390/buildings15010101.

5 Li C, Wang X, Zhao F, Wang F, Ting Z & Wang L, *E-Polym (De Gruyter)*, 17 (2017) 221. doi.org/10.1515/epoly-2016-0060.

6 Hamouda T, Aly N M & Elshakankery M H, *J Ind Text*, (2020) 1. https://doi.org/10.1177/1528083720960732.

7 Branscomb D, Beale D & Broughton R, *J Eng Fiber Fabr*, 8 (2013) 11. https://doi.org/10.1177/155892501300800202.

8 Rawal A, Potluri P & Steele C, *J Ind Text*, 35 (2005) 115. https://doi.org/10.1177/1528083705057574.

9 Omeroglu S, *Fibres Text East Eur*, 14 (2006) 53.

10 Alpyildiz T, *Text Res J*, 82 (2012) 443. https://doi.org/10.1177/0040517511427969.

11 Guyader G, Gabor A & Hamelin P, *Mech Mach Theory*, 69 (2013) 90. https://doi.org/10.1016/j.mechmachtheory.2013.04.015.

12 Ghamkhar G, Johari M S & Toudeshky H H, *AUT J Mech Eng*, 5 (2021) 571. https://doi.org/10.22060/ajme.2021.18787.5927.

13 Zhang Q, Beale D, Adanur S, Broughton R M & Walker R P, *J Text Inst*, 88 (1997) 41. https://doi.org/10.1080/00405009708658528.

14 Gopalakrishnan D, *Braiding and narrow width fabrics*, (2023). https://www.technicaltextile.net/ articles/printarticle/2668 (assessed on 17 August 2023).

15 Cai G, Meng Z, Zhang Y & Guo Z, *Proc Inst Mech Eng Part C: J Mech Eng Sci*, 238 (2024) 5610. https://doi.org/10.1177/09544062231218806

16 Assi P, Achiche S & Laberge L L, *CIRP J Manuf Sci Technol*, 50 (2024) 228. https://doi.org/10.1016/j.cirpj.2024.03.004

17 Li J, Yin Y, Huang Q, Yang G & Jiang F, *J Text Inst,* 115 (2023) 2011. https://doi.org/10.1080/00405000.2023.2276929

18 Krauskopf J E, Rauh A & Hein A, Heliyon, (2025) 1. https://doi.org/10.1016/j.heliyon.2025.e42917

19 Emonts C, Grigat N, Merkord F, Vollbrecht B, Idrissi A, Sackmann J & Gries T, *Tex*, 1 (2021) 185. https://doi.org/10.3390/textiles1020009

20 Debbabi F & Abdessalem S B, *J Appl Sci*, 11 (2011) 3276. https://doi.org/10.3923/jas.2011.3276.3284

21 Debbabi F & Abdessalem S B, *J Eng Fiber Fabr,* 10 (2015) 121. https://doi.org/10.1177/155892501501000306.

22 Sivanesan N, Venugopal R & Subramanian A, *J Ind Text*, 51 (2022) 5202S. https://doi.org/10.1177/15280837211055128.

23 Debbabi F & Abdessalem S B, *Indian J Fibre Text Res*, 43 (2018) 186. https://doi.org/10.56042/ijftr.v43i2.14310.

24 Annual Book of ASTM Standards ASTM D 3775 (American Society for Testing and Materials Pennsylvania, USA) (2023).https://cdn.standards.iteh.ai/samples/ 115896/3034f7ecd7ef44128d341710f8837b08/ASTM-D3775-17-2023-.pdf (accessed on 22 January 2024)

25 ISO 2307 (International Organization for Standardization,Geneva, Switzerland) (2019). https://cdn.standards.iteh.ai/samples/72076/4c69913781fc4544a4ad60f7004caae6/ISO-2307-2019.pdf (accessed on 22 January 2024)

26 Msalilwa L R, Kyosev Y, Rawal A & Kumar U, in Recent Developments in Braiding and Narrow Weaving, ed. Y . Kyosev, (Springer International Publishing Switzerland) 47 (2016).https://doi.org/10.1007/978-3-319-29932-7_5

27 Rawal A, Saraswat H & Kumar R, *Compos Part A Appl Sci Manuf*, 47 (2013) 150. https://doi.org/10.1016/j.compositesa.2012.12.006.

28 Singh A, Reynolds N, Keating E M, Barnett A E, Barbour S K & Hughes D J, *Compos Struct*, (2021) 261. https://doi.org/10.1016/j.compstruct.2020.113314

29 Dauda B, Oyadiji S O & Potluri P, *Appl Compos Mater*, 16 (2009) 15. https://doi.org/10.1007/s10443-008-9073-3

30 Yan S, Guo L Y, Zhao J Y, Lu X M, Zeng T, Guo Y & Jiang L, *Strength Mater*, 49 (2017) 198. https://doi.org/10.1007/s11223-017-9858-4

31 Gao X, Siddique A, Sun B& Gu B, *Appl Compos Mater*, 26 (2019) 1261. https://doi.org/10.1007/s10443-019-09779-1

32 Sry V, Mizutani Y, Endo G, Suzuki Y & Todoroki A, *Appl Sci*, 8 (2018) 1. https://doi.org/10.3390/app8071096.

33 Yilmaz F & Tercan M, *Usak Univ J Eng Sci*, 4 (2021) 15. https://doi.org/10.47137/uujes.873977.

34 Bicking A, (North Carolina State University, Raleigh, USA) (2011) 1.https://www.lib.ncsu.edu/resolver/1840.16/6736 (accessed on 16 September 2024)

35 Sun X & Sun C, *Compos Struct*, 65 (2004) 485. https://doi.org/10.1016/j.compstruct.2003.12.009.

36 Bilisik K, *Text Res J*, 81 (2011) 1748. https://doi.org/10.1177/0040517511411974.

37 Roy M D, Ghosh S, Yadav A & Roy S D, *J Inst Eng Ser E*, 100 (2019) 131. https://doi.org/10.1007/s40034-019-00146-0.

38 Pan N, Lin Y, Wang X & Postle R, *Text Res J*, 70 (2000) 671. https://doi.org/10.1177/004051750007000803.

39 Zhang J & Cheng L, *Adv Mater Res*, 331 (2011) 52.https://doi.org/10.4028/www.scientific.net/AMR.331.52.

40 Viju S & Thilagavathi G, *Fibers Polym*, 13 (2012) 782. https://doi.org/10.1007/s12221-012-0782-8.

41 Ceven E K & Aytas H, *Fibres Text East Eur*, 24 (2016) 51.https://doi.org/10.5604/12303666.1201131.

42 Ochola J, Malengier B, Daelemans L & Langenhove L V, *Text Res J*, 87 (2017) 1275.https://doi.org/10.1177/0040517516651106.

43 Brunnschweiler D, *J Text Inst Trans*, 45 (1954) T55. https://doi.org/10.1080/19447025408662631.

44 Calba J, Soulat D, Legrand X & Renauld S, *Fibers*, 11 (2023) 1. https://doi.org/10.3390/fib11030030

45 Roy S S, Zou W & Potluri P, in Y Kyosev (Ed.), Recent Developments in Braiding and Narrow Weaving , Springer International Publishing Switzerland, (2016) 1. https://doi.org/10.1007/978-3-319-29932-7