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An Investigation into the Comparative Performance of Different Splicing Methods under Various Splicing Parameters

Primerjava učinkovitosti različnih metod spajanja koncev predivne preje v odvisnosti od različnih parametrov spajanja

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 3–2025 • Accepted/*Sprejeto* 4–2025

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Abstract

End splicing is necessary to ensure continuity in the production of yarn from staple fibres. This process is essential for maintaining the integrity and quality of yarns during manufacturing and subsequent usage in textile products. For this purpose, the influence of various splicing variables on yarn splicing efficiency was analysed, and several splicing methods were compared. The article focuses on identifying optimal splicing parameters to improve the performance of spliced yarns. The research investigates several splicing variables such as overlap length, blast duration and splicing time for the pneumatic splicing method, and untwisting time, drafting and retwisting time for the mechanical splicing method to join the yarn (100 tex) ends. The performance of the yarns was assessed based on retained splice elongation (RSE) and retained splice strength (RSS). Statistical analysis was performed to determine the significance of variations in splicing variables. The results indicated that both RSE and RSS increased when the value of the splicing variables (parameters) increased for each method. The research found that variations in splicing variables significantly impact the characteristics of the spliced yarn. The study contributes significant insights into optimizing splicing techniques to improve yarn performance in the spinning industry.

Keywords: ring spun yarn, splicing parameter, pneumatic splicing, mechanical splicing, yarn characteristics

Izvleček

Pri proizvodnji preje iz kratkih vlaken je treba za zagotavljanje neprekinjenosti preje spojiti konca pretrgane preje. Postopek je nujen za ohranjanje celovitosti in kakovosti preje med proizvodnjo in nadaljnjo uporabo v tekstilnih izdelkih. Namen raziskave je bil analizirati različne vplivne parametre na učinkovitost spajanja preje. Primerjanih je bilo več metod spajanja. Članek se osredinja na prepoznavanje optimalnih parametrov spajanja za izboljšanje

kakovosti spojenih prej, kot so dolžina prekrivanja, trajanje pihanja in čas spajanja za pnevmatsko metodo spajanja in čas odvijanja, napenjanja in ponovnega sukanja za mehansko metodo spajanja za spajanje koncev preje s finočo 100 tex. Učinkovitost spajanja je bila ocenjena na podlagi ohranjenega raztezka (RSE) in trdnosti (RSS) spoja. S statistično analizo je bil ugotovljen vpliv parametrov spajanja. Pokazalo se je, da sta se pri ob zvišanju vrednosti parametrov spajanja pri obeh metodah spajanja povečala RSE in RSS. V raziskavi je bilo dokazano, da obravnavani parametri spajanja pomembno vplivajo na lastnosti spojene preje. Raziskava podaja pomemben vpogled v optimizacijo tehnik spajanja v predilnicah za izboljšanje kakovosti prej iz kratkih vlaken.
Ključne besede: prstanska preja, parameter spajanja, pnevmatsko spajanje, mehansko spajanje, značilnosti preje

1 Introduction

Yarn splicing is a crucial process in the textile industry that is used to produce continuous lengths of yarn by joining the yarn ends. This process is essential for maintaining the integrity and quality of yarns during manufacturing and subsequent usage in textile products. In yarn manufacturing, the splicing of yarn is critical to joining the yarn ends for producing continuous lengths of yarn, which are necessary for fabric production and other applications [1]. Splicing is a perfect method for joining the yarn ends, and splice strength has a significant impact on the quality of spun yarns during warping, winding, weaving, and knitting [2]. The efficiency of yarn splicing has a significant impact on the final yarn quality as well as the finished products produced from this yarn [1, 3]. The splicing of yarn is a method used to connect two ends of yarn by interlocking the fibre to make it significantly similar in appearance and required characteristics relative to the main yarn [1]. To achieve the desired spliced yarn quality, different methods are applied, such as pneumatic, mechanical, electrostatic, and pneumo-mechanical methods [4, 5].

Mechanical splicing represents the physical intermingling of the fibres of yarn utilizing mechanical operations. Pneumatic splicing uses compressed air to bind the fibres of yarn. The pneumatic splicing technique is the most widely utilized compared to mechanical splicing [6]. The integration of water in the pneumatic splicing technique can improve performance by increasing fibre cohesion [5].

Some researchers have investigated the characteristics of spliced yarn in terms of splicing parameters, splicing methods, and yarn parameters, and found different results. Cheng et al. (2000) investigated spliced yarn strength under several conditions and found that the length and count of yarn have a significant impact on spliced yarn strength [7]. Cheng & Lam (2000) investigated spliced yarn properties under various splicing situations and found different results based on splicing conditions [8]. Nawaz et al. (2005) discussed the influence of splicing parameters on blended yarn characteristics and identified significant variations in terms of the properties of spliced yarn [9]. Hassen et al. (2008) examined the appearance and characteristics of cotton/ elastane spliced yarn and found that yarn count has a significant impact on the appearance and properties of spliced yarn [6]. Webb et al. (2009) investigated the impact of various variables on the appearance of yarn (spliced) utilizing the Taguchi analysis method and identified a significant impact on the appearance of yarn (spliced) [10].

Ünal et al. (2010) investigated the effects of splicing parameters, fibre and yarn properties on the tenacity and elongation of spliced yarns. In this study, artificial neural networks and response surface models were used to analyse spliced yarn tenacity and elongation as dependent variables. As independent variables, fibre properties together with the machine settings, such as opening air, splicing air, splicing time, yarn twist and yarn count, were chosen [11]. In the second part of their study, Ünal et al. (2010) investigated the retained spliced diameter as it relates to splicing parameters and fibre and yarn properties [12]. Ünal et al. attempted to identify optimum splicing settings to obtain maximum tenacity and elongation after the splicing of the yarns that have different fibre properties, yarn counts and yarn twists [13].

Webb et al. (2010) investigated the implementation of simulation and visualization methods in spliced yarn development and found that the model applies to spliced yarn to determine the required results [14]. Boubaker et al. (2010) tried to develop a model (descriptive) for the longitudinal construction of spliced yarns and found that this model helps determine yarn structure [15]. Jaouachi et al. (2010) discussed the assessment of spliced yarn performance utilizing fuzzy theory and found that fuzzy theory is more suited for prediction than regression theory [16]. Baykaldı et al. (2011) examined the effect of various parameters (specifications) on the quality of elastane/cotton blended spliced yarn and found a significant impact on spliced yarn properties [17]. Moqeet et al. (2013) discussed the influence of splicing specifications on spliced blended yarn (cotton/flax) and found that retained elongation, strength and appearance are affected by various parameters [18]. Uyanik (2019) attempted to identify the optimum splicing method for yarn count and fibre types, and found that a twin splicer is optimal for acrylic and cotton but not good for regenerated fibres (cellulose) [19].

Hossan et al. (2021) examined the splice strength of yarn manufactured from several types of cotton and found significant variations in characteristics between yarns [2]. Uyanık (2022) aimed to identify the optimum splicing method for cotton yarns and viscose yarns in terms of different yarn counts. For this purpose, three different methods – air splicing, wet splicing and twin splicing –were compared [20]. Ji & Wang (2023) attempted to develop a prediction model for spliced yarn and found that the model provides a basic formula for the relationship between splicing, fibre and yarn properties [21]. Hamdi et al. (2023) investigated the mechanical characteristics of elastic yarn (dual-core) splice and found that the preparation parameter has less of an impact than the joining parameter [22]. Fahmida et al. (2024) investigated the impact of mingling chambers (60z and 92z2 types made of copper) on yarn splice strength and appearance using air and wet splicing methods. Their study found that both the type of mingling chamber and the splicing medium significantly impact the quality of the yarn joint. The findings contribute to the understanding of how equipment configuration and process parameters impact splice performance, offering insights for optimizing yarn joining techniques in textile manufacturing [23]. Although there are some studies that have investigated the elongation, strength and appearance of spliced yarn based on fibre types and characteristics, yarn types, the linear density of yarn, the splicing method and the utilization of different theories and software, no works have been found where several parameters have been used within the same methods to join yarn ends through splicing. There is still a lack of information in literature regarding the investigation of spliced yarn performance based on various splicing variables within the same method of splicing. This study explored the comparative performance of different methods under several splicing parameters. The purpose was to systematically investigate how these parameters affect the key properties of the spliced yarn. In addition, most studies have been conducted on middle and fine yarns. However, this study was carried out using coarse yarn, which is commonly used in denim production.

2 Materials and methods

During this research, 100 tex cotton yarn (carded) was produced using a ring spinning machine to investigate the variables impacting spliced yarn characteristics.

1.1 Raw materials

For this study, 100% cotton (roller-gin Turkish cotton) was sourced from a local supplier to produce 100 tex yarns. The specifications of the cotton fibre are presented in Table 1. The cotton was tested using Uster HVI 1000 equipment. Ten test results were recorded, and the average result was taken for analysis.

Table 1: Properties of cotton fibre

SCI [a]	Mic [b] (μg/cm)	MI [c]	UHML [d] (mm)	UI [e] (%)	SFI [f]	Strength (cN/tex)	Elongation (%)	Moisture (%)	Trash count (g^{-1})	Trash area (%)
142.89	1.77	0.90	29.75	84.37	6.68	32.95	6.16	7.52	147.67	3.89

[a] Spinning consistency index, [b] Micronaire (1.77 μg/cm = 4.50 μg/inch), [c] Maturity index, [d] Upper half mean length, [e] Uniformity index, [f] Short fiber index

1.2 Spinning process

With this collected cotton fibre, carded yarn was manufactured using a traditional ring spinning machine. The parameters (specifications) of the production of several machines are presented in Table 2.

Table 2: Parameters of yarn production

Machine name	Brand name	Delivery material	Speed
Blowroom	Marzoli	card mat: 7.30 ktex	600 kg/h
Carding machine	Marzoli C601	sliver: 7.37 ktex	139 m/min
1st draw-frame	Rieter-SB D-50	1st sliver: 5.9 ktex	6 doubling: 750 m/min
2nd draw-frame	Rieter -RSB D-50	2nd sliver: 5.9 ktex	7 doubling: 750 m/min
Roving frame	Marzoli FTD-2	roving: 1.15 ktex	flyer speed: 1000 m^{-1}
Ring frame	Marzoli-MPTN-1	Count of yarn: 100 tex, TPI: 9.7 [a]	spindle speed: 6400 m^{-1}

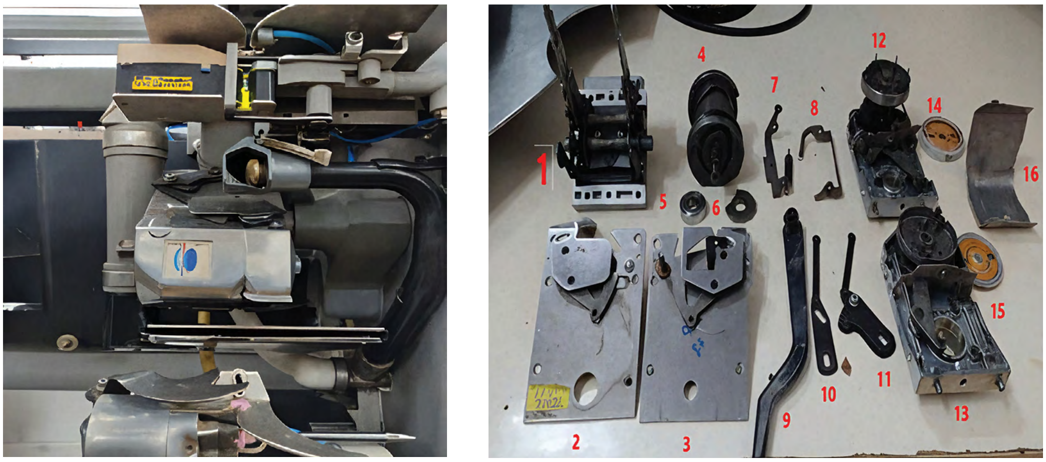
[a] turns per inch; 1 TPI = 0.3937 cm^{-1}

2.3 Winding process

After yarn production, the winding process was performed on a winding machine (SAVIO POLAR IDLS). During winding, three different splicing methods were employed to join broken yarn ends. These methods include mechanical (twin) splicing, pneumatic splicing without water and pneumatic splicing with water. Figures 1 and 2 show the mechanical splicer and pneumatic splicer, respectively.

2.4 Testing setup and specific process parameters

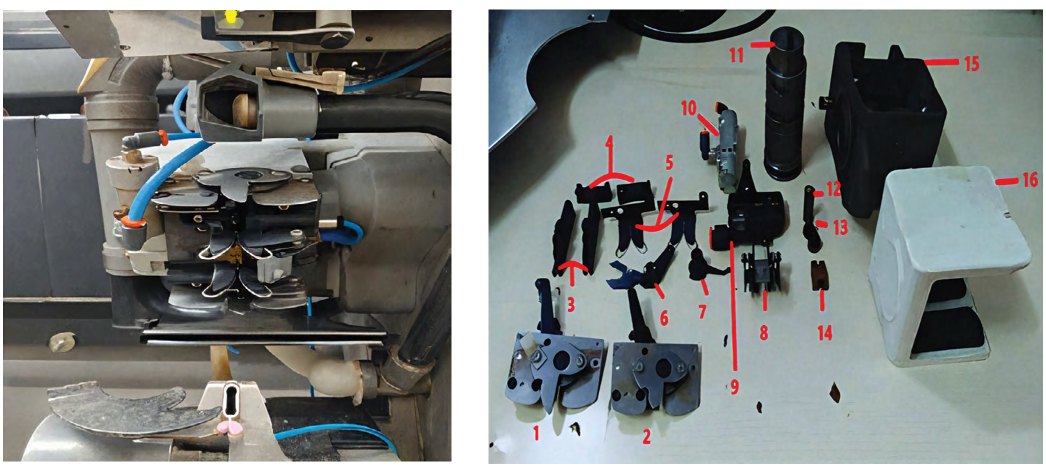
The specific process parameters, including untwisting time (U), re-twisting time (R), and drafting (D), which adjust the splice diameter, were investigated as process parameters for the mechanical method (Figure 1). The range of untwisting and re-twisting time is 1 to 7 (7 is the highest strength), while the range of drafting (which balances the diameter of the splice) is 0 to 4 (diameters decrease from four to zero). Also investigated were the duration of the blast (the ends preparation blast-T_1), overlap length (the end of the overlap-L), and the duration of the splicing blast (T_2) for the pneumatic methods (Figure 2). The range of the T_1 and T_2 is 1 to 12 (12 is the largest blast), and the range of the overlap length is 1 to 12 (12 is the maximum overlap). Based on previous studies and operational experience, the most commonly applied values were selected. In this context, T_1 was evaluated at two levels (2 and 3), L was evaluated at two levels (9 and 10) and T_2 was evaluated at three levels (6, 7 and 8) for pneumatic splicing with and without water, while U was evaluated at three levels (5, 6 and 7), D was evaluated at two levels (2 and 3) and R was evaluated at three levels (4, 5 and 6) for mechanical splicing. To reduce bias and improve the reliability of results, a structured randomization strategy was applied. The randomization process was designed using a random number generator via a Microsoft Excel function. Each experimental condition (i.e. a combination of T1, L and T2, water application for the pneumatic method, and U, D and R for the mechanical method) was first coded and listed. Random numbers were then assigned to each sample and the list was sorted based on these values to determine the testing order. This ensured that the sequence of experiments did not follow a systematic or ordered pattern that could influence the results. A total of thirty-six samples were produced based on various variables for the pneumatic method, which is presented in Table 3, and a total of ten samples were produced based on multiple variables for the mechanical method, which is presented in Table 4. The other parameters of the winding machine for all splicing techniques were the same, while the winding machine speed was 950 m/min and the air pressure was 6 bar for the pneumatic method.



a) b)

Figure 1: Mechanical splicer: a) splicer, b) splicer parts

Legend: 1 – yarn holding pliers, 2, 3 – cover, 4 – movement cam, 5 – bearing, 6 – flange, 7, 8 – fork opening device (collets), 9 – splice guide arm (lever), 10 – yarn breaking arm (lever), 11 – yarn tension adjustment (lever), 12, 13 – splice general body, 14, 15 – disc, 16 – dust prevention cover



a) b)

Figure 2: Pneumatic splicer: a) splicer, b) splicer parts

Legend: 1 – upper scissor group, 2 – lower scissor group, 3 – opener, 4 – opener scissor group, 5 – yarn guide, 6 – end lever, 7 – end retraction lever, 8 – chamber cover, 9 – valve, 10 – water tank, 11 – actuating cam, 12 – piston spring, 13 – splice piston rod, 14 – prism, 15 – body, 16 – carter

Table 3: Samples produced by the pneumatic method based on several variables

Serial no.	Sample code	Duration of blast, T_1 (ms)	Overlap length, L (mm)	Splicing blast, T_2 (ms)	Water application (1 or 2 times)
1	3-10-8	3	10	8	-
2	3-10-7	3	10	7	
3	3-10-6	3	10	6	
4	3-9-8	3	9	8	
5	3-9-7	3	9	7	
6	3-9-6	3	9	6	
7	2-10-8	2	10	8	
8	2-10-7	2	10	7	
9	2-10-6	2	10	6	
10	2-9-8	2	9	8	
11	2-9-7	2	9	7	
12	2-9-6	2	9	6	
13	3-10-8-W_1	3	10	8	1
14	3-10-7-W_1	3	10	7	
15	3-10-6-W_1	3	10	6	
16	3-9-8-W_1	3	9	8	
17	3-9-7-W_1	3	9	7	
18	3-9-6-W_1	3	9	6	
19	2-9-8-W_1	2	9	8	
20	2-9-7-W_1	2	9	7	
21	2-9-6-W_1	2	9	6	
22	2-10-8-W_1	2	10	8	
23	2-10-7-W_1	2	10	7	
24	2-10-6-W_1	2	10	6	
25	3-10-8-W_2	3	10	8	2
26	3-10-7-W_2	3	10	7	
27	3-10-6-W_2	3	10	6	
28	3-9-8-W_2	3	9	8	
29	3-9-7-W_2	3	9	7	
30	3-9-6-W_2	3	9	6	
31	2-9-8-W_2	2	9	8	
32	2-9-7-W_2	2	9	7	
33	2-9-6-W_2	2	9	6	
34	2-10-8-W_2	2	10	8	
35	2-10-7-W_2	2	10	7	
36	2-10-6-W_2	2	10	6	

Finally, the properties of manufactured yarns, such as strength and elongation, appearance, retained splice elongation (RSE) and retained splice strength (RSS), were investigated. The elongation at break and strength of yarns were tested using an Uster Tensorapid-3 according to the ISO 2062, DIN 53 834 and ASTM D-1578 standards. Ten test results were taken and the mean value was calculated for analysis. For visual analysis, photographs of every spliced place were taken after splicing. Testing conditions (temperature: 20 ± 2°C, relative humidity: 65 ± 2%) were continuously monitored and maintained using a controlled lab setup according to the ASTM D1776 standards. All yarns used were from the same production lot to ensure consistency in raw material properties.

The RSE and RSS were calculated using the following equations [17, 22, 24].

$$RSS = \frac{Spliced\ yarn\ strengt}{Strength\ of\ parent\ yarn} \times 100 \quad (1)$$

$$RSE = \frac{Spliced\ yarn\ elongation}{Elongation\ of\ parent\ yarn} \times 100 \quad (2)$$

For visual analysis, photographs of each spliced place were taken using an ultra-wide camera –13mm f/2.2 (Apple iPhone 14 Promax).

Table 4: Samples produced using the mechanical method based on several variables

Serial no.	Sample code	Untwisting time-U (milliseconds)	Drafting-D	Re-twisting time-R (milliseconds)
1	7-3-5	7	3	5
2	6-3-5	6	3	5
3	5-3-5	5	3	5
4	7-2-5	7	2	5
5	6-2-5	6	2	5
6	5-2-5	5	2	5
7	6-3-4	6	3	4
8	6-2-4	6	2	4
9	6-3-6	6	3	6
10	6-2-6	6	2	6

Furthermore, analysis of variance (one-way ANOVA) with a post-hoc test was applied as a statistical analysis to investigate the significant variation in terms of the characteristics of several yarns with SPSS 25.0 within the same splicing method and for different splicing methods. It was performed at a 95.0 percent confidence level or a 0.050 significance level, which shows that if the p-value is less than 0.05, the difference (properties) will be statistically significant [25–27].

3 Results and discussion

3.1 Results

The appearance of the yarns joined with the splicer is as important as their strength. For visual analysis, photographs of each spliced place were taken. When the photographs are examined, the hairiness of the yarns varies at the joints according to the selected process parameters and splicer. In the case of visual analysis, as shown in Figures 3 to 5, it can be generally observed that the splice appearance produced by the pneumatic method without the use of water exhibits a very hairy structure. This is primarily due to the incomplete twisting of fibres under the influence of pressurized air. When the pneumatic method is applied with water, the spliced yarns display a less hairy appearance than those produced without water. This improvement is attributed to the role of water in promoting fibre adhesion, thereby helping to prevent fibre separation from the yarn cross-section during the application of pressure.

Furthermore, spliced yarns prepared using the mechanical method exhibit the lowest hairiness among the three methods. With a mechanical (twin) splicer, the yarn ends are opened between two rotating disks, and then twist is given between the disks as it closely resembles the twisting process used in ring yarn spinning. The contact between the discs and the fibres ensures the effective re-twisting of the yarn ends. Moreover, there is no air pressure and thus the separation of short fibres is prevented. Similar results were also reported in earlier studies [19]. Conversely, when each splicing method was assessed independently, it was determined that the selected splice parameters did not result in a notable difference in splice appearance. This suggests that the splicing technique itself, rather than the specific parameters applied, played a determining role in the visual outcome of the splice.

The test results for strength, elongation at break, RSS and RSE are presented in Table 5. The strength of the parent yarn before splicing was 17.85 cN/tex with a CV of 6.2%, while the elongation at break of the parent yarn before splicing was 7.65% with a CV of 5.2%, taking into account ten measurements.

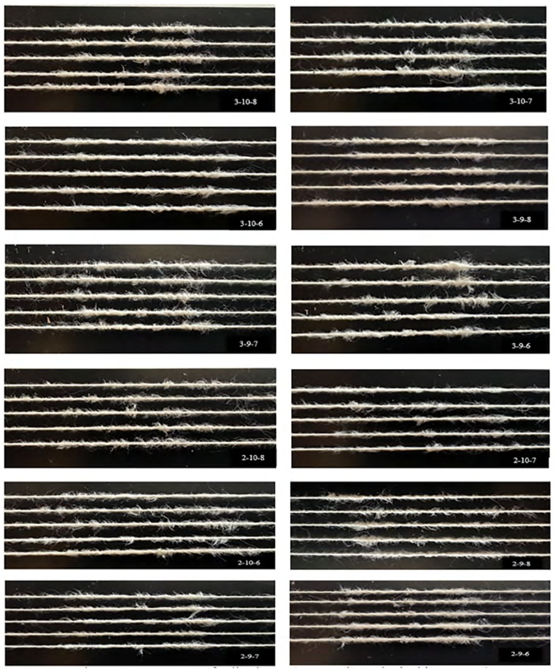


Figure 3: Appearance of spliced yarn-6x (pneumatic method without water)

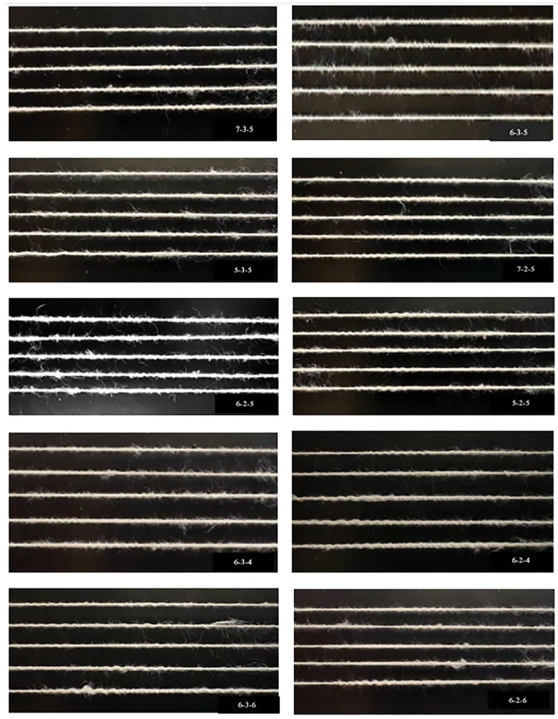


Figure 5: Appearance of spliced yarn-6x (mechanical method)

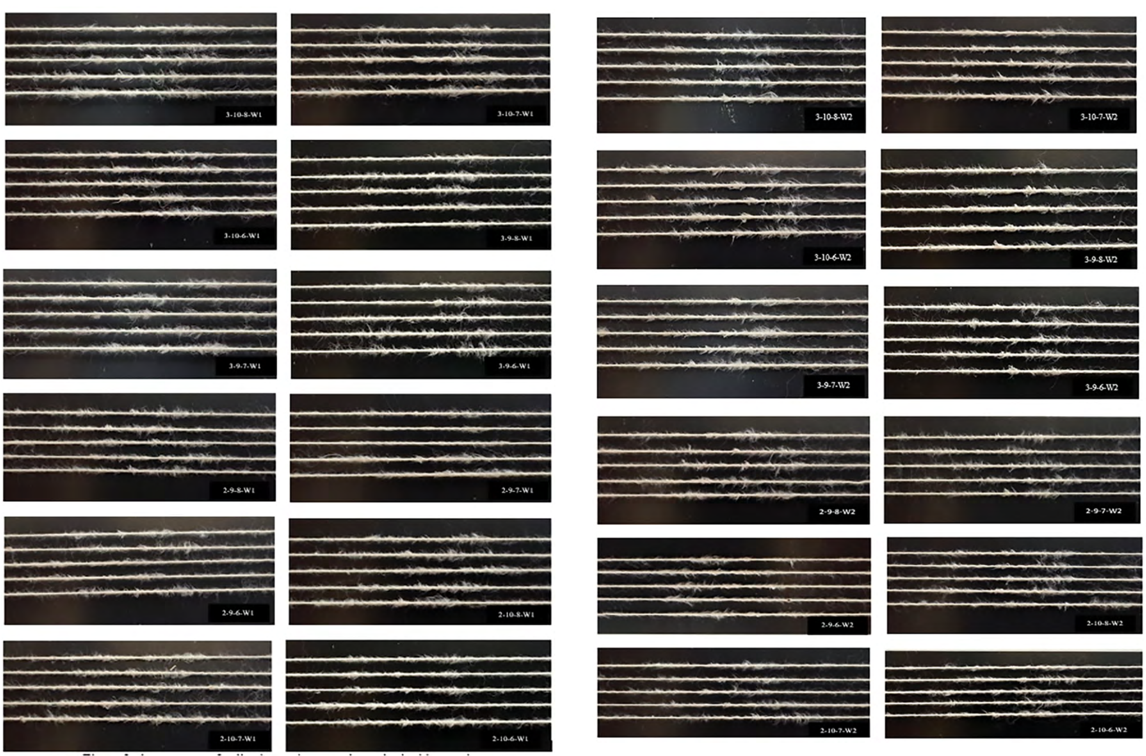


Figure 4: Appearance of spliced yarn-6x (pneumatic method with water)

Table 5: Test results of spliced yarn

Splicing method	Sample code	Elongation (%)	Strength (cN/tex)	RSE [a] (%)	RSS [b] (%)
Pneumatic splicing method without water	3-10-8	4.54	4.38	59.35	24.56
	3-10-7	4.82	4.12	63.01	23.08
	3-10-6	5.05	4.72	66.01	26.43
	2-10-8	5.18	7.41	67.71	41.54
	2-10-7	5.27	6.69	68.89	37.47
	2-10-6	5.41	7.45	**70.72**	**41.76**
	3-9-8	4.33	4.49	56.60	25.16
	3-9-7	5.17	5.33	67.58	29.83
	3-9-6	3.82	3.99	49.93	22.36
	2-9-8	5.18	5.10	67.71	28.57
	2-9-7	4.78	4.69	62.48	26.26
	2-9-6	4.09	3.71	53.46	20.77
Pneumatic splicing method with water	3-10-8-W_1	5.07	6.54	66.27	36.65
	3-10-7-W_1	4.97	6.34	64.97	35.49
	3-10-6-W_1	4.72	5.26	61.70	29.45
	3-9-8-W_1	5.16	6.79	67.45	38.02
	3-9-7-W_1	4.93	6.16	64.44	34.50
	3-9-6-W_1	4.53	5.83	59.22	32.64
	2-9-8-W_1	4.99	5.92	65.23	33.18
	2-9-7-W_1	4.82	5.32	63.01	29.78
	2-9-6-W_1	4.85	5.18	63.40	29.01
	2-10-8-W_1	5.45	6.49	71.24	36.37
	2-10-7-W_1	4.94	6.58	64.58	36.87
	2-10-6-W_1	4.71	5.08	61.57	28.46
	3-10-8-W_2	7	6.26	91.50	35.05
	3-10-7-W_2	4.85	5.93	63.40	33.24
	3-10-6-W_2	5.69	6.48	74.38	36.32
	3-9-8-W_2	5.44	6.85	71.11	38.35
	3-9-7-W_2	4.87	6.56	63.66	36.76
	3-9-6-W_2	5.03	6.61	65.75	37.03
	2-9-8-W_2	5.45	7.48	**71.24**	**41.92**
	2-9-7-W_2	5.22	7.02	68.24	39.34
	2-9-6-W_2	5.02	6.46	65.62	36.21
	2-10-8-W_2	4.78	5.84	62.48	32.69
	2-10-7-W_2	5.42	6.74	70.85	37.74
	2-10-6-W_2	4.79	5.35	62.61	30.00
Mechanical (twin) splicing method	**7-3-5**	6.06	11.72	**79.22**	**65.65**
	6-3-5	5.21	9.40	68.09	52.63
	5-3-5	4.95	8.97	64.68	50.27
	7-2-5	6.06	10.73	79.18	60.11
	6-2-5	5.41	10.83	70.73	60.66
	5-2-5	4.49	9.00	58.64	50.44
	6-3-4	5.30	10.60	69.29	59.39
	6-2-4	4.99	9.61	65.19	53.84
	6-3-6	4.87	9.77	63.69	54.72
	6-2-6	5.22	10.67	68.22	59.78

[a] Retained splice elongation; [b] Retained splice strength

3.2 Discussion of RSS and RSE

3.2.1 Evaluating RSS and RSE

RSS and RSE are the most important elements in investigating the properties of spliced yarn [22]. While T_1 changed from 3 to 2, RSS and RSE generally increased, as shown in Figure 6. On the other hand, as the T_2 value increased from 6 to 8, there was a general increase in RSS and RSE values. When the end preparation (blast duration-T_1) is short, the fibres are opened without being damaged. However, the long blast duration (T_2) for splicing ensures that the fibres intermingle well, creating a strong joint. In previous studies, it was found that splice strength improved with an increase in the joining air duration [6, 10].

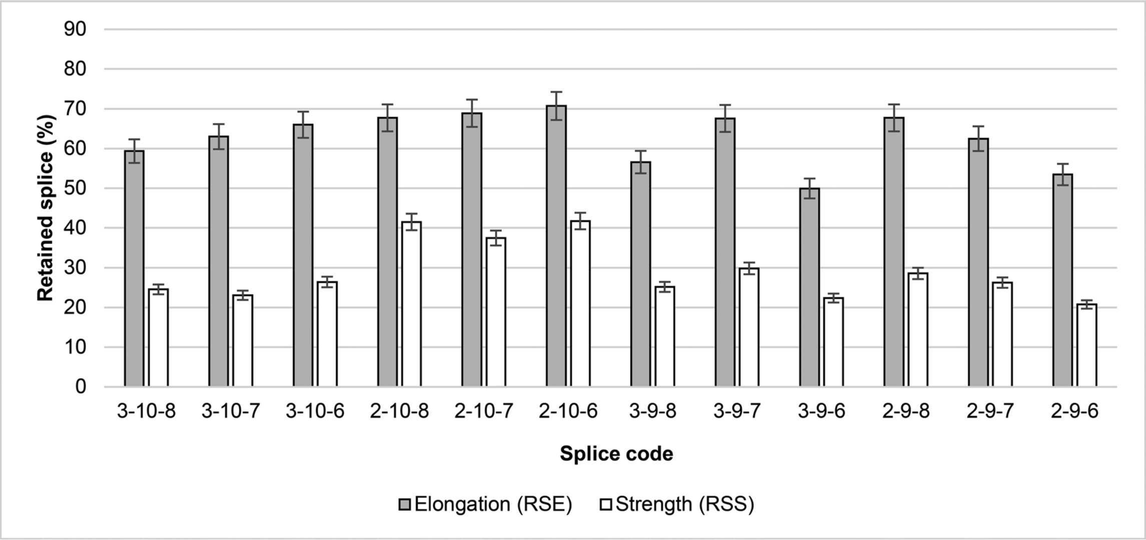


Figure 6: RSS and RSE of several yarns prepared using the pneumatic method without water

Increasing overlap length (L) from 9 to 10 generally increased RSS and RSE values. L refers to the length of the yarn ends that overlap before they are joined together. A high overlap length ensures a strong and durable splice. Similar results have been found in previous studies [7, 8].

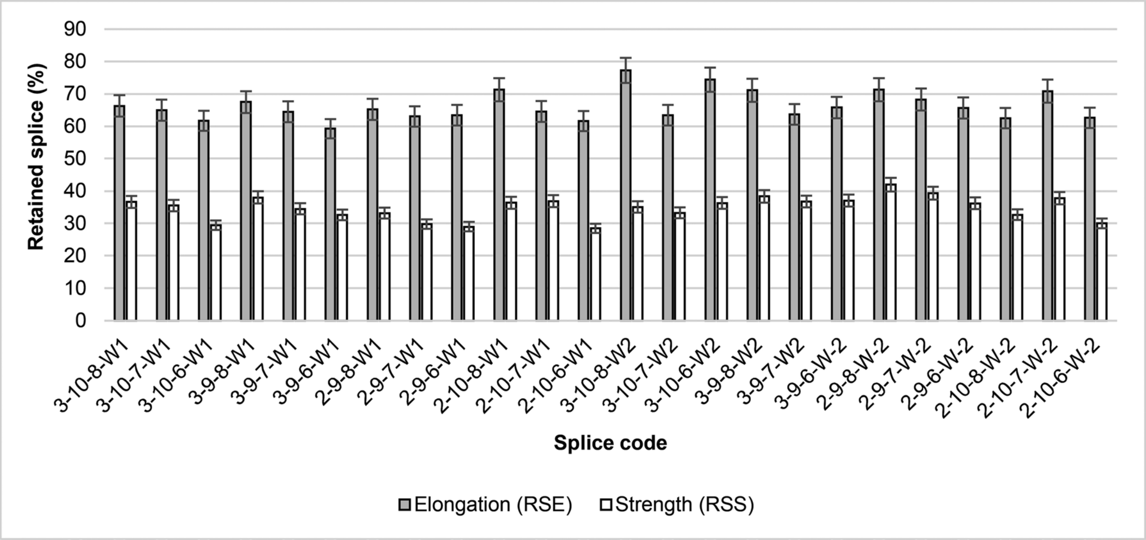


Figure 7: RSS and RSE of several yarns prepared using the pneumatic method with water

The results showed that applying water twice in the wet splicer generally improved the RSS and RSE values (Figure 7). The presence of water helps to improve the adhesion of fibres during the splicing process. Enhanced adhesion ensures that fibres remain well-integrated within the yarn structure [19].

Within the observed range, T_1 did not generally result in a significant change in RSS and RSE values; the variation in T_2 had a more pronounced effect. RSS and RSE were found to increase in most of the samples when T_2 was increased in the pneumatic splicing method with water. A previous study [22] emphasized that joining parameters are more impactful than preparation parameters. Similarly, in this study, T_2 was found to be more effective than T_1. Increasing overlap length (*L*) from 9 to 10 generally decreased RSS while increasing RSE values.

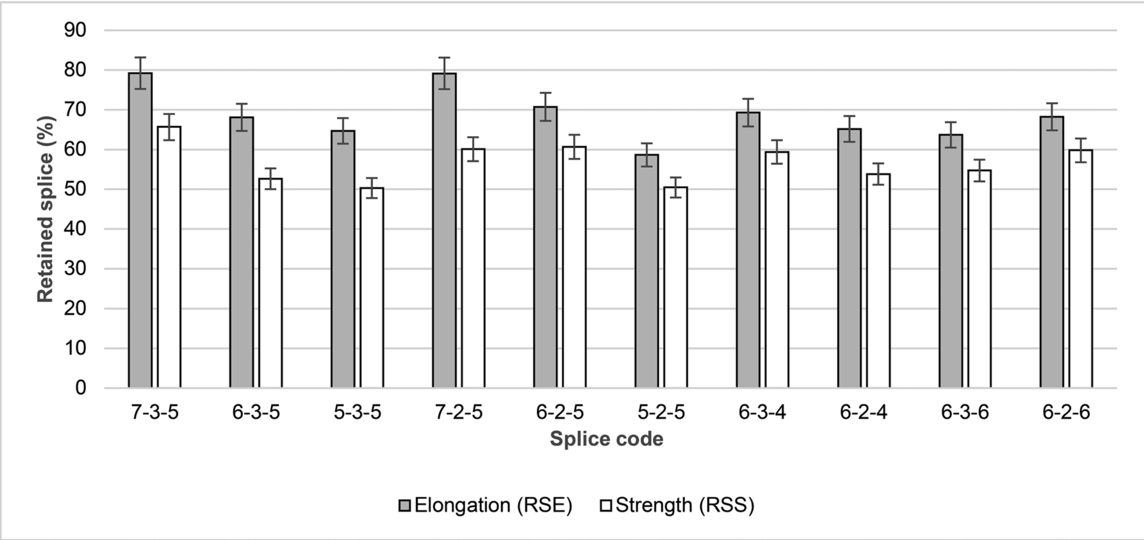


Figure 8: RSS and RSE of several yarns prepared using the mechanical (twin) method

In the mechanical method, increasing the U, D and R values generally increased the RSS and RSE values (Figure 8). Proper drafting (D) ensures that the diameter of the spliced section matches that of the original yarn, maintaining yarn consistency.

3.2.2 Comparison of splicing methods

For comparison purposes, the average RSS and RSE values across all variables were calculated for each method and are presented in Figure 9. It was found that the pneumatic method without water resulted in low RSS and RSE values. This is attributed to the incomplete twisting of fibres in coarse yarns, caused by the impact of pressurized air. In the case of the pneumatic method with water, the spliced yarns exhibited better results than the pneumatic method without water. This improvement is attributed to the presence of water, which enhances fibre adhesion and helps prevent fibre separation from the yarn cross-section under pressure, thereby resulting in higher RSE and RSS values. Spliced yarns produced using the mechanical method exhibited higher RSE and RSS values than the other two methods. This can be attributed to the lower likelihood of short fibre separation in the absence of air pressure and the ability of the twin discs to effectively twist the yarn ends through direct contact. Similar results have been found in previous studies [19, 20].

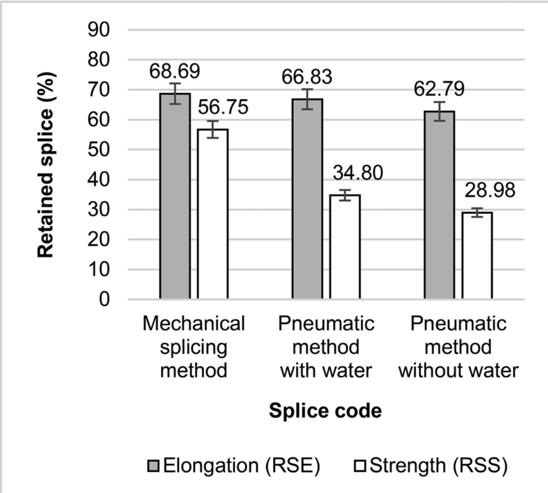


Figure 9: RSS and RSE of several yarns prepared by different methods

In the case of statistical analysis, the spliced yarn property (RSE or RSS) is the dependent variable, while the parameters (variables) of each splicing method are independent variables. For the homogeneity test (Levene's test), it was found the 'P' value of RSS and RSE was 0.084 and 0.079, both of which are greater than 0.05, which indicates the data are normally distributed. In the case of the post-hoc test, the Tukey test was performed. It was found that the "P" value of spliced yarn property (RSE or RSS) was less than 0.050 for one-way ANOVA and the post-hoc test, which indicates there is a significant variation in spliced yarn properties (RSE or RSS) prepared using different variables for each method, as presented in Tables 6 and 7.

Table 6: Statistical analysis for RSS and RSE (one-way ANOVA)

Method	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.
Pneumatic method without water	RSS	6399.766	10	581.799	24046.237	.000
Pneumatic method with water		6568.366	24	591.274	23016.254	.000
Mechanical (Twin) method		6101.153	12	562.362	21037.341	.000
Pneumatic method without water	RSE	5371.828	10	488.348	10226.374	.000
Pneumatic method with water		5534.153	24	490.258	10986.421	.000
Mechanical (Twin) method		5212.921	12	469.453	10101.289	.000

Table 7: Multiple comparison (post-hoc test)

Tukey HSD					
Dependent variable	(I) Method	(J) Method	Mean Difference (I-J)	Std. error	Sig.
RSS	Pneumatic method without water	Pneumatic method with water	4.04250	2.30192	.044
	Pneumatic method with water	Mechanical (Twin) method	1.86300	2.45058	.042
	Mechanical (Twin) method	Pneumatic method without water	5.90550	2.78776	.038
RSE	Pneumatic method without water	Pneumatic method with water	5.81250*	1.79894	.007
	Pneumatic method with water	Mechanical (Twin) method	21.9531*	1.91511	.000
	Mechanical (Twin) method	Pneumatic method without water	27.76567*	2.17862	.000

4 Conclusion

The splice structure is highly complex, especially when working with staple fibres. It is worth noting that understanding the intricacies of splice structures, particularly within the intricate context of yarn fibre structures, poses a formidable challenge.

The optimal values of splicing parameters are crucial for enhancing yarn performance. This study focused on the impact of different splicing variables on yarn properties using pneumatic and mechanical (twin) splicing methods. The performance of the spliced yarns was evaluated based on RSE and RSS by comparing them to the original yarn. Additionally, spliced yarn images were also taken. The key findings of the study are summarized below:

- The results showed that applying water twice in the wet splicer generally improved the RSS and RSE values for the pneumatic splicing method. As mentioned in previous studies, the presence of water reduces the likelihood of fibres separating from the yarn's cross-section. This is crucial when pressures are applied during the splicing process, as it maintains the integrity of the splice. The combination of water and air generates substantial torque within the air chamber, facilitating superior intermingling. Moreover, water acts as a lubricant, enhancing inter-fibre cohesion, further contributing to the overall quality of the splice [6, 19, 24].
- Similar to a previous study [19], the mechanical method yielded better results than the other two methods in terms of both RSS and RSE values, as well as yarn appearance.
- In the pneumatic method, optimal strength results were achieved when the blast duration was 2 ms, the overlap length was 10 mm and the splicing blast was 6 ms. On the other hand, no significant difference was observed between the splice appearances.
- In the pneumatic method with water, optimal strength results were achieved when the blast duration was 2 ms, the overlap length was 9 mm, the splicing blast was 8 ms and the water was applied twice. However, no notable difference was observed between the wet splice appearances.
- In the mechanical method, optimal strength results and better yarn appearance were achieved when the untwisting time was 7 ms, the drafting was 3 and the re-twisting time was 5 ms. However, no significant difference was observed between the wet splice appearances.
- The two main splice characteristics are appearance and strength. Although RSS is suitable for objective assessment, splice appearance is more difficult to assess. Specifically, a splice with an RSS exceeding 80% was considered acceptable for production purposes [22, 24]. An increase in yarn linear density causes a drop in the RSS because the splicer is designed for splicing fine yarns [6, 7]. In this study, a yarn count commonly used in denim (100 tex) was selected. It was observed that the RSS values were generally low due to the coarse nature of the yarn used in the study. Among the three methods, the mechanical splicer yielded the highest RSS value (65.65%). This study recommends the use of a mechanical splicer for coarse cotton yarns, both in terms of strength and splice appearance. Similar studies stated that the twin (mechanical) splicing mechanism is the most suitable for cotton fibres, with twin splicing being the best option for coarse yarns [19, 20].
- This research provides valuable insights into the optimization of splicing techniques to improve yarn performance in the spinning industry. By adjusting splicing variables, manufacturers can achieve improved yarn quality and durability, enhancing the overall quality and efficiency of the production process. This research focused on specific splicing parameters and methods for coarse cotton yarn. Further research could explore various fibre types and additional splicing techniques to validate and extend these outcomes.

Declaration of competing interest: No potential conflict of interest was reported by the authors.

Acknowledgment: We wish to express our appreciation to the employees of Bossa Ticaret ve Sanayi *İşletmeleri* T.A.Ş. for allowing us to carry out the entire experimental research in their facility.

Author contribution: All authors contributed equally.
Funding information: This research received no specific grant from any funding source.

Data availability statement: Since November 13, 2025, the research data have been available at https://doi.org/10.5281/zenodo.17599671.

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