Heliyon 9 (2023) e13096

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Double air suctioned carding process: A method for achieving improved quality ring-spun carded yarn

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ARTICLE INFO

Keywords:
Cotton yarn
Ring spinning
Carded
Natural fiber
Process

ABSTRACT

This study aims to maximize yarn realization by minimizing hard waste generation. A new method has been evaluated in a conventional carding machine for this purpose by adding extra air suction units immediately above the doffer and in the brush roller above the stripping roller. Various yarn samples were spun using the double air suction carding (DASC) method and the traditional carding process, and the yarn quality parameters were compared. The results indicated that the DASC yarn had considerable technical improvements in all yarn characteristics (U%, CVm%, thick place, thin place, neps, hairiness) and mechanical properties (breaking strength and elongation). The number of classimat faults in the DASC yarn has also significantly decreased. Even though the DASC technique produced more droppings-1, it generated less pneumafil and hard waste, resulting in improved yarn realization. This research also examined cost analysis, advantages, and limitations. Overall, the findings indicate that the newly introduced DASC yarn has the potential to be a superior product in terms of both quality and cost.

1. Introduction

Among Natural fibers, cotton is the most consumed fiber in the world. It is widely used for various reasons, including comfort, superior spinning quality and luster. Cotton fiber consumption is estimated to be around 26.32 million metric tons in market year (MY) 2020–2021, and it is steadily expanding [1]. Since cotton yarn-based textiles are prevalent, several technologies and manufacturing procedures have been developed to preserve the cotton yarn's quality. Among various yarn production methods, ring spinning is the most adaptable, offering the broadest range of yarn counts [2]. John Thorp pioneered the ring-spinning process of yarn in 1832, and it still comes out on top in the spinning industry [3,4]. This technology produces over 70% of the total worldwide staple yarn [5].

Hairiness, unevenness, breaking strength, and elongation are all crucial features to look for in yarn quality. Yarn quality is primarily determined by the quality of the sliver. Short fiber content (SFC), trash content (TC), and micronaire value (MIC) are all vital fiber parameters for ensuring sliver quality. Short fibers have a higher bending rigidity during spinning, making it difficult to bend into yarn, resulting in hairiness. Yarn hairiness is defined as the extent to which a fiber protrudes from the main structure of a yarn [6,7]. Cotton dust is released into the atmosphere due to cotton fiber processing, together with any naturally existing items such as stems, leaves, bracts, and organic particles that may have formed on the cotton fibers during the growing or harvesting period [8]. Several cleaning procedures must be taken to guarantee yarn quality by eliminating these contaminants. Cotton bales are first subjected to a blow room,

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https://doi.org/10.1016/j.heliyon.2023.e13096
Received 11 July 2022; Received in revised form 13 January 2023; Accepted 16 January 2023

Table 1
Properties of raw material used to produce yarn.

Country Name	SCI	Moist	MIC	Mat	UHML (m)	UQL (m)	UI%	SFC (%)	Elg%	Strength (kg/tex)	Rd	+b
Brazil	145	6.2	4.01	0.86	0.302	0.312	82.85	8.7	5.8	0.0293	77.4	10.4
Burkina Faso	138	5.90	4.09	0.86	0.301	0.307	82.9	8.3	6.4	0.03	77.8	10.7

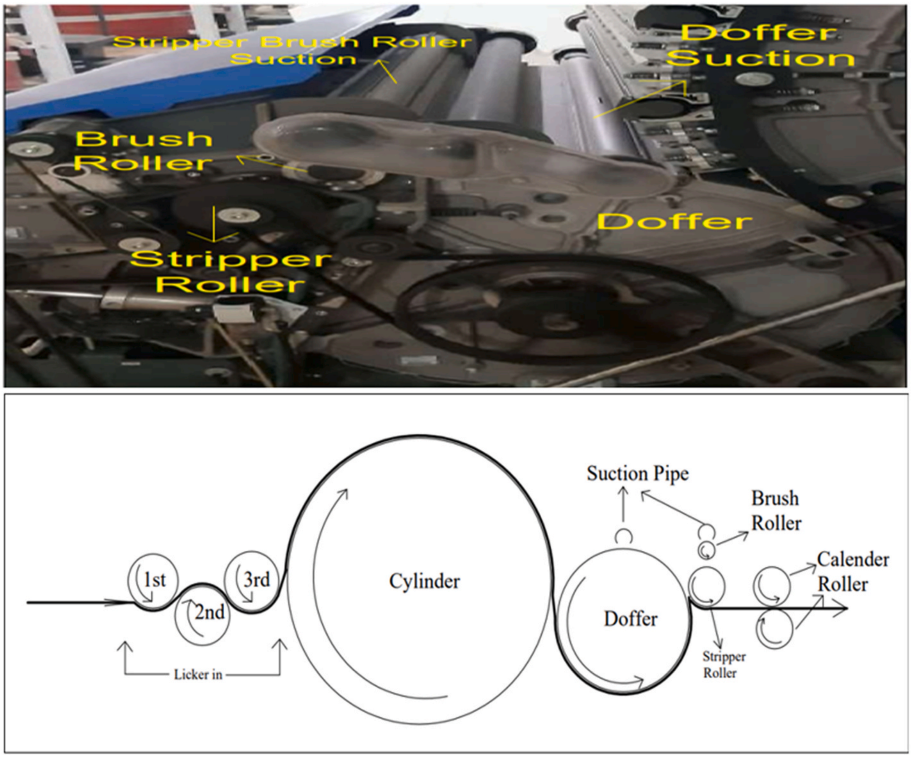

Fig. 1. Air suction arrangement on carding machine. [(a) Newly attached air suction unit in conventional carding machines, (b) simplified roller arrangements of rollers with newly attached air suction on carding machine].

where the fiber bales are opened up and cleaned by various equipment to remove these impurities. A pre-cleaning machine, for example, removes trash and dust, while a fine cleaner removes short fibers. Cotton fiber produces neps throughout these processes. The machine that is used to remove these neps, short fibers, trash, and make sliver at a time is card.

The heart of a spinning mill is referred to as the carding section [9]. Carding is one of the most significant textile technology processes to intermix loose fibers, eliminate impurities and short fibers, and straighten and align the remaining threads in a parallel pattern [10]. This process removes the majority of impurities, neps, short fibers, and other contaminants that escaped during the blow-room section [11]. As short fibers and dust are entrapped in neps, removing these dust and impurities is difficult until the fiber is in tuft or web form. Since the web is carried for sliver creation after doffing, carding is the last stage where the fiber can be found in its web form. Better quality sliver can be used to create better quality yarn. The quality of carded sliver is determined not only by trash and neps content but also by card web evenness (weight per unit area), fiber parallelization and fiber-to-fiber separation, and limiting short-term variability in sliver thickness [12]. The doffer receives the card web from the cylinder and feeds it to the stripper, ensuring that the web is fed evenly to the calendar rollers. The speed of the licker-in, cylinder, and doffer and the speed of the doffer comb should be enhanced to increase productivity. The doffer comb, however, is best used at a reduced speed. So, to cope with increasing output, several changes have been made, such as modifying one set of stripping rollers and a crush roll unit, or two sets of stripping rollers and a pair of crush roll units linked. Together the stripper comes with a brush that cleans the short fibers attached to the stripper wires and improves wire cleaning performance. When the wires on the cylinder, doffer, worker, and stripper are clean, the sliver evenness improves.

Various advances in cotton card quality have been noticed over the previous three decades [13]. Although many modifications to improve efficiency have been tried several times, such as roller moderation or adding extra rollers to carding machines, there are very few works where modifications to the existing suction system or attaching new suction systems to remove dust, trash, and other impurities have been found. Only one study found in the literature used an additional air suction system on the carding machine. In 2012, Mirzaei et al developed a new approach for reducing yarn hairiness which involved installing a simple and effective air suction

Table 2
Specification of the spare parts used in carding arrangement.

Name	Model	Part No.	Nos.
Suction pipe (Doffer)	T_4	997,100,151,013	1
Suction Pipe (Stripper)	T_{001830}	997,100,160,121	1
Connector	T_{005616}	977,100,590,180	1
Joiner (Connector + Pipe)	T_{001830}	977,100,160,120	2

Table 3
Different machinery and their set parameters used to perform the experimentation.

Machine	Parameter	Value	Machine	Parameter	Value
Blow Room (Trutzschler)	Blendomat	Take up depth: 5 mm	Finisher Draw Frame (TD-8, Trutzschler)	Hank	0.098 Ne
	Pre cleaner (CL-P)	Roller rpm: 680/690		Delivery Speed (m/min)	680
		Grid Bar Setting = 3°		Drafting system (4 over 3 rollers)	Front and back zone 40, 50 mm respectively
	Fine cleaner (CL-C3)	Roller rpm: 620, 1080, 1700 of 1st, 2nd and 3rd rollers respectively		Trumpet	3.5 mm
		Blade angle 10%,12%,14% 1st, 2nd and 3rd rollers respectively		Draft	8
Carding (TC-15)	Silver Grain/yards	85		Back Draft	1.32
	Delivery Hank	0.098 Ne	Simplex (FT-6D, Marzoli)	Del. Hank	0.60Ne
	Delivery Speed	263 m/min (95 kg/h)		TPI[a]/TM[a]	1.08/1.39
	Flat Speed	340 mm		Flyer speed	1100 rpm
	Cylinder Speed	560 mm		Spacer	Black (5.5 mm)
	Grid Bar Setting	1°		Drafting system (4 over 4 rollers)	Front, middle and back zone 44, 50, 64 respectively
Breaker Draw Frame (TD-8, Trutzschler)	Sliver (Grain/yds)	85		Break draft	1.33
	Del. Hank	0.098 Ne		Total draft	6.116
	Del. Speed (m/min)	650		DCP & TCP	83 & 57
	Doubling	08	Ring Frame (MP1N, Marzoli)	Count	14 Ne
	Drafting System (4 over 3 rollers)	Front zone = 40 mm Back zone = 50 mm		TPI	17.70
	Draft	8		Spindle speed	12,300 rpm
	Back Draft	1.35		Traveller No.	N-5 (Bracker)
	Trumpet size	3.8 mm		Drafting System (3 over 3 rollers)	Front zone = 44 mm Back zone = 60 mm
Waste Collector (BR-WC, Trutzler)	Suction Pressure (Pa)	1000	Winding Machine (Process Coner-2, Muratec)	Delivery Speed	1200 M/Min
	Total Nozzle	8		Winding tension	29.5 C N
	Total Suction box	5		Constant	0.290

[a] TPI = Twist per Inch, TM = Twist Multiplier, DCP = Draft Change Pinion, TCP = Twist Change Pinion.

system to the web detaching zone of a traditional carding between crush rollers and calendar rollers [14]. In this paper, two different air suction systems are attached, one right above the doffer for maximum efficacy because after doffing, the fiber no longer remains in its web form, and the other is on the stripping roller's brush.

In the fast-forwarding world, reducing waste is a major concern. It is essential to do cotton spinning because most of the production cost is from the cotton. The goal of this research was to increase yarn realization while limiting hard waste formation by adding extra air suction units right above the doffer and in the brush roller above the stripping roller. Several yarn samples were spun using the double air suction carding (DASC) method and the regular carding procedure, and the yarn quality parameters were examined. Finally, the study discussed the technical improvements in the DASC ring-spun yarn.

2. Materials and methods

2.1. Raw materials

100% cotton fibers from various origins are utilized to manufacture the required yarn samples. Fibers from two separate origins (Brazil and Burkina Faso) were combined to ensure the best possible product quality. Because of the cost, two varieties of cotton are used. The mixing cost of 100% Brazil cotton is 4.36 USD/Kg, while the mixing cost of Brazil and Burkina Faso cotton combined is 3.59 USD/Kg, and these mixed types of cotton can reach the required quality. The quality parameters of these two types of fibers, as evaluated by the High Volume Instrument (HVI) and the Advanced Fiber Information System (AFIS), are also shown in Table 1.

Table 4
Testing parameters with respective instruments list for the research work.

Name of the quality parameter	Testing instrument	Operation parameter	Associated ISO reference
Unevenness% (U%), Co-efficient of variation of mass (CVm%) of slivers	Uster evenness tester (UT-6)	Velocity 25 m/min, observing length 25 m.	These methods are based on capacitance measuring principles mentioned in the ISO 16549: 2004 [15]
Unevenness% (U%), Co-efficient of variation of mass (CVm%), Thick place, thin place, Neps and Hairiness (H) of ring yarn	Uster evenness tester (UT-6)	Velocity 400 m/min, observing length 400 m.	
Breaking strength and elongation% of ring yarn	Mesdan lab strength tester	Sample length 500 mm, clamp speed 1000 mm/min, and load cell ID/FS(kg) 3/12	The breaking strength (tenacity) and elongation at break have been documented in ISO 8939:1988 and ISO 2062: 2009 [16,17]
Wastage collection	Trutzschler waste collector	Suction pressure 1000 Pa	Air suction method.
Classimat Fault (Clearer Cuts)	Loepfe Zenith +	• Sample length 100 km. • Neps (N) - 3.8 • Diameter of short fault (DS) - 1.75 • Length of short fault (LS) - 1.7 • Diameter of Long fault (DL) - 1.18 • Length of Long (LL) - 26 • Diameter of thin fault (-D) - 14 • Length of thin fault (-L) - 26	The faults are measured according to ASTM D6197-99 (2005) standards.

2.2. Methods

The experimental work to complete this research work was carried out in a yarn spinning mill in Bangladesh. This work produces two types of carded yarn of 14Ne in both cases. The main difference between these two types of yarn is that one is produced in the general carding process, and the other is produced on a modified carding machine. Two additional suction systems are added above the doffer and brush roller that clean stripper in the typical carding machine to produce the modified DASC yarn. During the doffing action, the doffer picks up the web from the cylinder and passes it to the stripper. Since this procedure is continuous, some fiber tufts become clogged in the doffer wire, reducing the doffing operation and damaging the web. As a result, an extra suction system is attached to the doffer, which sucks up the loose fiber from the doffer wire and cleans it constantly without damaging the web. The same technique applies to stripper rollers. The brush cleans the stripper, and the suction cleans the brush roller to keep it running efficiently.

Fig. 1 shows these additional suction systems in carding arrangement. Specification of these additional arrangements are provided in Table 2. Produced yarn samples were tested on Uster evenness tester 6, and finally, an analysis of the quality of the two types of yarn were carried out. Microscopic view (Zoom: 2560×1922) of the yarn was taken using Digital Trinocular Stereo microscope with camera (Model: NZ 1703-M Camera Model: DC.5000-Pro)) from Netherlands.

2.3. Machinery and quality testing

2.3.1. Machinery

As the cylinder speed increases in carding machine, so will the production speed due to the increased feed in the doffer. Conversely, the higher speed has an impact on the sliver quality. Because more feed will reach the doffer, the brush roller that cleans it will be unable to clean the wires properly. As a result, fiber will linger on the doffer, resulting in less uniformity of the fiber fleece flowing from the cylinder. Furthermore, there is a strong possibility that the fibers on the doffer wire will be joined to the sliver and enhance hairiness. As a result, low-quality slivers will be formed, affecting the U%, CVm%, thick place, thin place, and neps. However, the additional suction mechanism keeps the doffer roller clean by enabling the doffer in uniformly collecting the fiber fleece from the cylinder. It will improve the sliver's quality, eventually improving the quality of the yarn. The machine parameters were not modified in this investigation; the parameters for the two procedures remained constant (See Table 3).

2.3.2. Quality testing

The instruments used to validate this experiment's results are listed below in Table 4. Associated parameters, along with their basic operation settings, are mentioned.

3. Results

3.1. Waste collection for two different processes

It is essential to calculate the amount of waste collection as it indicates the efficiency between the normal and modified processes.

Table 5
Analysis of waste collected in carding machine for normal and DASC processes.

Sample Number	Without Attachment	With Attachment	Total production (gm)	Total waste for normal yarn (%)	Total waste for DASC yarn (%)	Difference (%)
1.	887	907	10,000	8.16	8.34	0.20
2.	904	922.5				
3.	873	895.5				
4.	862	883.8				
5.	888.17	910.17				
6.	901	932				
Mean	885.86	908.50				

Table 6
Carded sliver report for conventional and DASC processes.

Sample Number	Normal Process				DASC Process			
	U%	CVm%	UQL(w) mm	SFC(w) %<12.5 mm	U%	CVm%	UQL(w) mm	SFC(w) %<12.5 mm
1	3.23	4.22	30.6	8.8	2.84	3.64	30.9	8.2
2	3.30	4.13	30.9	9.4	2.88	3.64	30.9	8.6
3	–	–	30.7	9.0	–	–	30.7	8.3
Mean	3.27	4.18	30.7	9.1	2.86	3.64	30.8	8.4

Table 7
Evenness test results for conventional and DASC ring-spun yarn.

Sample Number	Normal Process						DASC Process					
	U%	CVm %	Thin -50%/ Km	Thick+50%/ Km	Neps +200%/ Km	H	U%	CVm %	Thin −50%/ Km	Thick +50%/Km	Neps +200%/ Km	H
1	10.60	13.44	0	80	23	8.07	10.22	13.07	0	33	20	7.24
2	10.36	13.19	0	68	20	7.59	9.76	12.44	0	30	15	7.33
3	10.91	13.86	0	55	35	8.33	9.67	12.30	0	50	38	7.21
4	10.89	13.82	0	113	30	7.66	10.43	13.27	0	50	30	7.27
5	10.60	13.44	0	60	20	8.02	9.64	12.21	0	28	20	7.15
6	10.59	13.47	3	55	30	7.64	9.62	12.24	0	35	10	7.16
Mean	10.66	13.54	0.5	72	26	7.89	9.89	12.59	0	38	22	7.22

Table 5 shows the amount of waste collected in the normal carding and DASC processes. The total waste percentage (see Equation (1)) is calculated by using following formula.

$$Waste\ Percentage = \frac{Total\ Waste}{Total\ Feed} \times 100\% \tag{1}$$

Ring-spun yarn produced through DASC process generated a larger amount of waste (See Table 5). It can be seen that DASC process ring yarn produces 0.20% more waste, thus eliminating more impurities than the normal process ring yarn (paired *t*-test, $p \leq 0.05$, $n = 6$).

3.2. Analysis of carded sliver quality for two carding processes

Since the suction units were added in the carding stage, the quality data for this process has been collected and analyzed. Here mainly unevenness percentage (U%), coefficient of variation of mass (CVm%) and short fiber content (SFC%) of carded sliver were analyzed. Table 6 shows the USTER and AFIS report of carded sliver.

The normal process has a higher percentage of unevenness than the DASC process, which is 12.54% less uneven than the traditional. Moreover, the traditional yarn has a greater CVm% than the DASC yarn, which is deducted from Table 6. The regular process yarn has approximately a 14.84% higher coefficient of variation than the DASC yarn. The short fiber content of the DASC yarn is lower than that of the conventional yarn. From Table 6, it can be seen that the short fiber content of DASC yarn is roughly 7.69% lower than that of standard yarn.

3.3. Evenness report of produced sample ring-spun yarns

Quality parameters such as unevenness (U%), coefficient of variation of mass (CVm%), thick place, thin place, neps, and hairiness are measured to evaluate the yarn’s evenness. The results of evenness tests for both the ring-spun yarn conventional carding procedure

Table 8
Tensile test results for ring-spun yarn for conventional and DASC process.

Sample Number	Normal Process			DASC Process		
	Breaking Strength (cN/tex)	Elongation %	Tenacity [RKM]	Breaking Strength (cN/tex)	Elongation %	Tenacity [RKM]
1	14.75	7.86	15.045	20.21	9.30	20.606
2	15.09	7.98	15.383	23.30	9.00	23.759
3	15.61	8.64	15.914	23.54	10.08	23.998
Mean	15.15	8.16	15.447	22.35	9.46	22.788

Table 9
End Breakage percentage for conventional and DASC process ring-spun yarns.

Parameters	Sample No	Total Running Breakage	Breakage%/Hour/100 spindle	Percentage
Conventional Yarn	1	62	2.70	2.62
	2	60	2.54	
DASC Yarn	1	28	1.20	1.025
	2	19	0.85	

and the DASC method are shown in Table 7.

From Table 7, it can be seen that there are variations in the values of U%, CVm%, Thick place, Thin place, Neps, and Hairiness for the two varieties of ring-spun carded yarn. The DASC yarn has 7.22% less unevenness and a lower CVm% of 7.02% than ring-spun carded yarn manufactured using the traditional procedure.

The thick place and thin place ratios in the typical process ring-spun yarn are higher than in the DASC yarn, shown in Table 7. Normal process ring-spun carded yarn has higher thick places and thin places than DASC process ring-spun yarn by 89.47% and 50%, respectively.

The DASC yarn has lower neps and hairiness than the traditional process ring-spun yarn. Table 7 shows that the DASC process ring-spun yarn has 15.38% fewer neps and is 8.49% less hairy than normal process ring-spun carded yarn.

3.4. *Tensile report of produced sample ring-spun yarns*

The strength, tenacity, and elongation test results for both the regular carding procedure and the DASC method are shown in Table 8.

DASC process ring-spun yarn has a 47.51% higher breaking strength than conventional process ring-spun carded yarn, shown in Table 8.

Table 8 also shows that elongation is higher for the DASC process ring-spun yarn than for the normal process. The DASC process ring-spun yarn has a 15.93% higher elongation, as depicted in the table.

The tenacity of the DASC yarn is substantially higher, approximately 47.52% more than that of the conventional yarn, as seen in Table 8.

3.5. *End breakage and waste amount analysis*

Tables 9 and 10 show the number of end breakages and the amount of pneumafil for both yarn types consecutively. The end breakage rate (see Equation (2)) and pneumafil (see Equation (3)) are calculated using the following formula.

$$End\ Breakage\ Rate = \frac{Total\ Breakage \times 100 \times 60}{Total\ Spindle\ number \times Total\ time\ to\ doff} \times 100\% \tag{2}$$

$$Pneumafil\ Percentage = \frac{Weight\ of\ Pneumafil}{Weight\ of\ Production + Weight\ of\ Pneumafil} \times 100\% \tag{3}$$

Table 9 shows the end breakage percentages for both the normal and the DASC yarns, which is higher for the normal process. It can be deducted that the regular yarn has more than 1.5 folds higher amount of end breakages than the DASC yarn.

Table 10 shows that the pneumafil percentage is also higher for the normal process yarn. Approximately 67.07% higher pneumafil is produced for the normal yarn processing than the DASC yarn processing. Table 10 also depicts that the conventional yarn process produces almost 41.94% more hard waste than the DASC process. For DASC and conventional process, total wastage was 12.25% and 12.46% respectively, thus yarn realization was 1.69% higher for DASC process. This is because in DASC process, carding wastage increased only by 0.02% where hard waste reduced by 10.6% compared to normal process. Yarn realization is expressed as the ratio of output material to input material, that means higher the wastage, lower the yarn realization.

Table 10
Pneumafil and hard waste percentage for conventional and DASC process ring-spun yarns.

Parameters	Pneumafil						Hard Waste			
	Sample No	Production (kg)	Total Production	Pneumafil (kg)	Total Pneumafil (kg)	Pneumafil%	Sample No	Production (kg)	Hard Waste (kg)	Hard Waste (%)
Conventional Yarn	1	92	182.6	1.32	2.54	1.37	1	1250	11.14	0.88
	2	90.6		1.22						
DASC Yarn	1	90	179.3	0.860	1.481	0.82	1	2370	14.68	0.62
	2	89.3		0.621						

Table 11
Classimat fault for ring-spun yarn produced in conventional and DASC process.

Sample Number	Normal Process							DASC Process						
	Neps Cuts (N)	Short Cuts (S)	Long Cuts (L)	Thin Cuts (T)	Off Count (OC)	Short Off Count (SOF)	Total Cuts	Neps Cuts (N)	Short Cuts (S)	Long Cuts (L)	Thin Cuts (T)	Off Count (OC)	Short Off Count (SOF)	Total Cuts
1	0	74	25	0	0	0	99	10	195	12	3	0	0	212
2	2	64	16	1	0	0	80	12	220	20	4	0	0	256
3	0	56	15	0	2	0	71	09	215	18	2	0	0	240
4	1	59	20	0	0	0	80	05	191	17	2	0	0	234
5	0	57	34	0	0	0	91	4	209	13	4	0	0	230
Mean	0	62	22	0	0	0	86	8	206	16	3	0	0	233

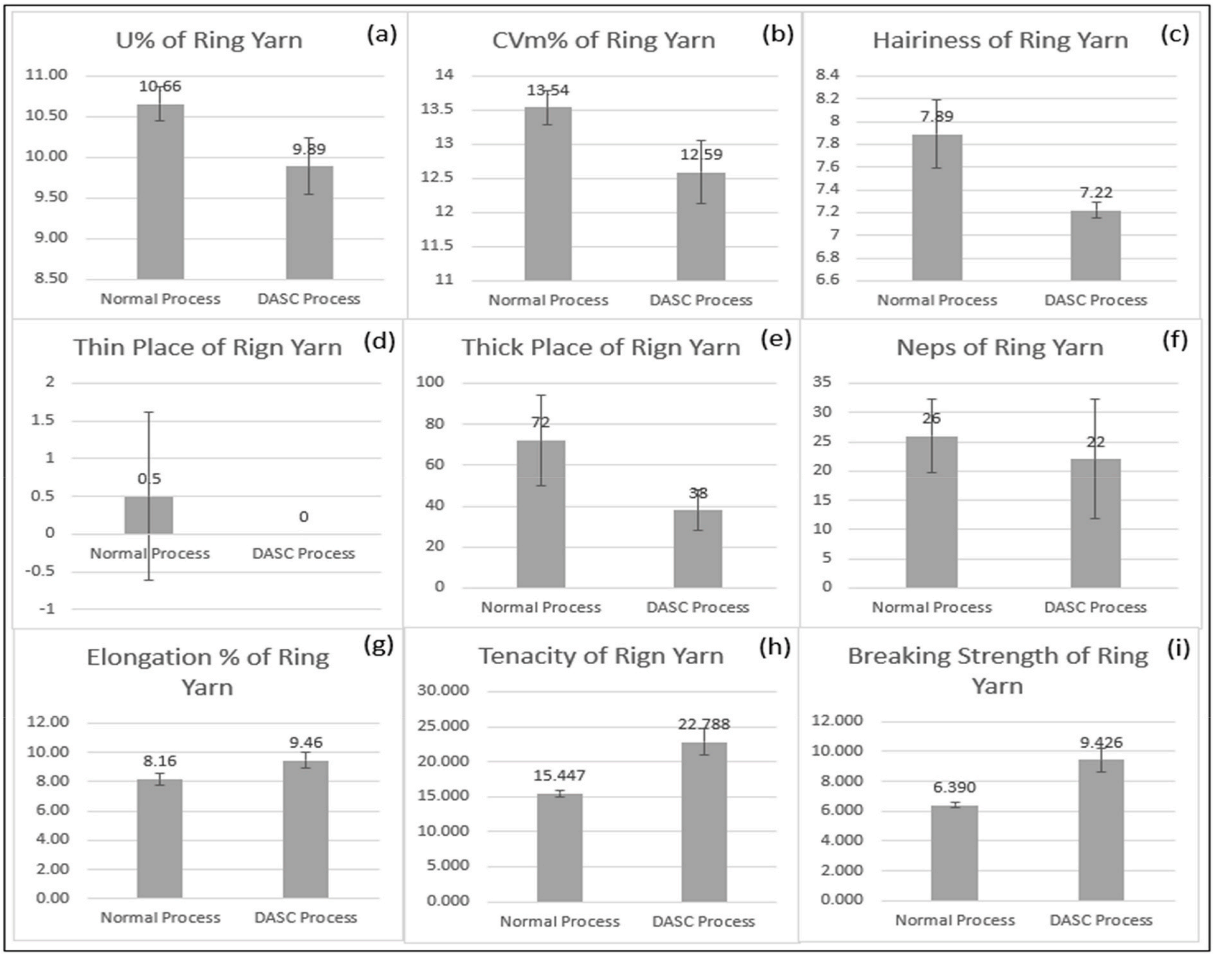

Fig. 2. Quality parameters for DASC process and conventional process ring-spun yarn. [(a) U% of ring-spun yarn. (b) CVm% of ring-spun yarn, (c) Hairiness of ring-spun yarn, (d) Thin place of ring-spun yarn, (e) Thick place of ring-spun yarn. (f) Neps of ring-spun yarn, (g) Elongation% of ring-spun yarn, (h) Tenacity of ring-spun yarn, (i) Breaking strength of ring-spun yarn].

3.6. *Classimat fault on different ring-spun yarns*

Classimat fault is a yarn analysis procedure that examines a wide range of defects. Table 11 shows the number of neps cuts, short cuts, long cuts, thin cuts, off counts, and short off counts found for DASC and typical yarns.

From Table 11, it is seen that normal yarn has 233 classimat faults, approximately 170% higher than DASC yarn, which has only 86 classimat faults. So, we prefer DASC yarn over traditional yarn since fewer defects ensure superior quality.

4. Discussions

The primary goal of this study was to eliminate non-useable hard waste by adding extra suction system to the carding machine. Carding is the essential spinning stage since it is where the sliver is developed. U%, CVm%, and Short Fiber Content (SFC)% are the main criteria to assure sliver quality. The results show that the DASC process sliver quality is better than the standard process quality (See Table 6). It happened because the suction system removed fiber tufts from the doffer and brush roller. As a result, more carding waste is collected during the procedure, as seen in the results section (See Table 5). The fiber tufts in the doffer and the stripper rollers are formed of short fibers and cotton seed coatings. As these components are eliminated, the sliver's quality improves [18].

The quality of card sliver is closely connected to the quality of yarn [19]. Yarn unevenness (U% and CVm%) is defined as the variance in yarn weight per unit length or variation in thickness [20]. The U percentages (see Fig. 2(a)) and CVm percentages (see Fig. 2(b)) of DASC yarn are somewhat higher than in the standard method. Spinners realize the significance of this minor improvement in fabric appearance [21].

Examining the surface morphology of yarns with microscopic view can show that DASC-process yarn has less hairiness. The microscopic images in Fig. 3 show a clear difference in the hairiness of two ring yarns made using the DASC and traditional processes.

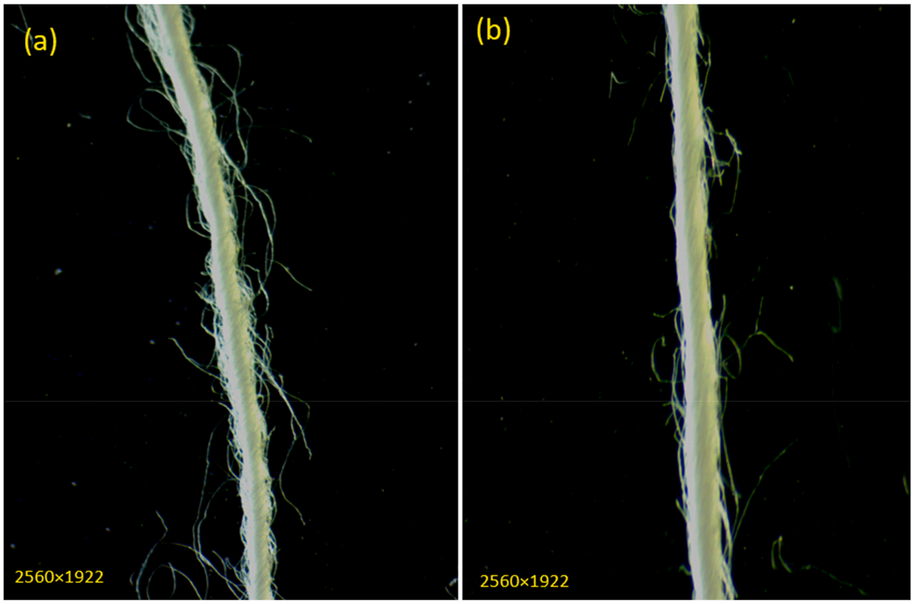

Fig. 3. Microscopic images of ring-spun cotton yarns produced in (a) conventional process (b) DASC process.

Table 12
Cost analysis of DASC process.

Investment cost per m/c (USD)	Total Machine (Pcs)	Total Invest (USD)	Increase in Dropping-1 (%)	Loss due to increase in waste per day (USD)	Reduction in hard waste %	Profit due to reduction in hard waste per day (USD)	Profit per day (USD)	Return of investment
1400	16	22,400	0.18% or 54 Kg	43.20	0.26% or 78 Kg	266.76	223.56	3.33 or 4 months

Fig. 3(b) shows that DASC-process ring yarn has a dense structure with highly parallel threads and is significantly less hairy. Such yarn will eliminate the singeing process and minimize dyestuff usage in the dying process [22].

Compared to the DASC method, ring yarn generated by the traditional approach, as illustrated in Fig. 3(a), has less parallel structure, and many fibers are organized in a disordered manner. Such protruding fibers give the yarn and products a rough feel and cause increased fly generation and a variety of downstream processing issues. Long protruding yarn hairs, for example, contribute to several breaks in weaving and fabric flaws such as stitches and floating [21]. Yarn imperfections such as thin places (see Fig. 2(d)), thick places (see Fig. 2(e)), and neps (see Fig. 2(f)) are reduced in the DASC process compared to the conventional procedure. Yarns with more irregularities, such as thick and thin places, and neps, might perform poorly in subsequent procedures, such as warping, sizing, weaving, and knitting. Imperfections can also significantly impact the aesthetic of a woven or knit fabric [23]. Moreover, the mechanical characteristics of the yarn in the DASC method are better than the usual procedure (see Fig. 2(g–i)). The tenacity of the yarn, in particular, is substantially higher in the DASC process. These properties are enhanced because tiny fibers are removed from the sliver, and longer fibers are now twisted together to produce the yarn. The yarn's tenacity significantly impacts the end breakage rate and the efficiency of the spinning, winding, weaving, sizing, and knitting operations [24]. Both types of yarn were spun at the same speed pattern, and it was observed that the DASC yarn had less end breakages (see Table 9).

The DASC method utilizes a $1400 expenditure per machine. The total investment for 16 machines would be $22,400. Despite the loss owing to higher dropping-1 waste, there would be a profit of $223.56 per day due to the attachments' decrease of unusable hard waste. As a result, the investment cost will be recovered within four months (see Table 12).

The study's main limitation was that air capacity, air pressure, and energy consumption could not be measured. Individual suction air capacity and pressure cannot be determined since the TC-15 carding machine only measures the central suction line. Since the two new attachments are connected to the existing main suction line without any additional compressor, energy usage cannot be determined. Since it was a centralized suction, energy usage could not be evaluated. As a result, energy costs cannot be included in the cost analysis.

5. Conclusions

Adding extra air suction units directly above the doffer and in the brush roller above the stripping roller formed a novel type of yarn in a standard carding machine, and the sliver and yarn quality parameters were examined. The sliver and yarn produced by the DASC process displayed significantly reduced U%, CVm%, and hairiness compared to those produced by the traditional carding process sliver and ring-spun yarn. The presence of thick places, thin places, and neps was also found in a reduced quantity, properties that are strongly connected to the appearance of a woven or knit fabric. Improved tensile characteristics, such as breaking strength, tenacity, and elongation, resulted from the additional air suction system. These improvements significantly increased the efficiency of the spinning, winding, weaving, sizing, and knitting processes and decreased the end breakage rate. Compared to yarn produced using the standard procedure, the production of hard waste was also reduced when manufacturing DASC yarn, which contributed to higher utilization of raw materials. Additionally, less hard waste leads to reduced production costs.

The double air suction system has several advantages, such as being simple to use as no additional manufacturing step is required. Therefore, no new procedure requires training the workforce. Improved tensile properties and quality parameters are ensured by this method. This method is more cost-effective than conventional since it guarantees improved yarn realization and fewer classimat faults.

Judging by the study's overall findings, the DASC procedure may produce superior yarn in terms of quality.

Author contribution statement

Towfik Aziz Kanon, Md. Atikul Islam: Conceived and designed the experiments; Performed the experiments.

Md. Ehsanur Rashid, Raihan Ul Haque: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Md. Rubel Khan: Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data included in article/supp. Material/referenced in article.

Declaration of interest's statement

The authors declare no competing interests.

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