

Comparison of the Effects of Different Cotton Fibre Wastes on Different Yarn Types

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Abstract

In order to make a contribution to the reduction of raw material costs, in the present study the effect of reused cotton fibres on the quality of conventional ring and OE-rotor yarns was investigated. In the yarn production, it three different waste fibres were taken from a cotton yarn production line and blended with primary cotton fibres at five different levels varying from 5% to 40%. In literature, studies have concentrated on the usage of recovered waste fibre in OE-rotor yarn production. However, to date there has been limited extensive and comparative research on the effect of recovered fibre quality on different yarn properties to determine the possibility of high-quality yarn production from reused fibres. In the study, we focused on the effect of different waste types as well as the amount of waste in the blends on the properties of different yarn types.

Key words: waste fibre, reused fibres, recycling, fibre blending, fibre cost.

Introduction

Today global competition in the textile industry forces yarn spinners to produce yarns with better quality and competitive prices. As in past times, the most important factor influencing yarn production costs is the raw material. In staple yarn production, it was reported that raw material costs constitute almost 50-70% of the total costs [1]. In addition to raw material prices, other costs such as energy and labour have risen [2]. In order to survive in the textile market against the effect of increasing production costs, the best way is to get the most out of the raw material. This case can be realised by benefiting from fibre properties with the optimisation of the spinning process and also by the reuse of textile wastes. As is known, several kinds of wastes of different form occur during textile processes. Today textile producers are interested in the reuse of textile wastes. The recycling of fibre wastes could be a challenge to reduce raw material costs and also to make a contribution to the efforts regarding environmental protection.

Many researchers have also concentrated on the usage of reused waste fibre in different products. Bruggeman [3] reported that recovered fibres can be reused for OE-rotor yarn spinning and recommended that the proportion of secondary raw material blended with primary material must be carefully studied. Wulforth [4] determined that recovered fibres up to 20% can be blended with primary raw material without noticeable changes in quality. Halimi et al. [2] evaluated the ratio effect of recovered fibre on the quality parameters of OE-rotor yarns,

and the results indicated that generated wastes contain about 50% good fibre and secondary raw material showed good cleanability. Therefore it was concluded that it can be blended in a proportion between 15 and 25% without even hardly noticeable changes in rotor yarn quality. In another work, Halimi et al. [5] studied the effect of percentage of fibres recovered from cotton wastes and it was determined that with a good choice of spinning parameters, waste usage up to 25% in the first passage of the drawing frame does not alter the uniformity and appearance of rotor yarn. Additionally it was found that yarn hairiness and the number of faults increase with higher waste fibre usage. Khan and Rahman [6] studied the effect of recycled waste type on OE-rotor yarn quality using response surface methodology. Results indicated that when pneumafil is used as recycled waste in mixing, yarn strength and elongation were improved whereas yarn imperfections and the end breakage rate decreased mostly in the range of 5-25%. It was reported that the negative impacts of rotor speed on yarn imperfections and end breakage can be minimised using 15% of pneumafil wastes in the mixing of blowroom.

In addition to the effect of the reused fibre amount on yarn quality, most authors have focused on the influence of production parameters on yarn properties. Particularly machine parameters of OE-rotor spinning have been mostly investigated. Duru and Babaarslan [7], in their works, produced seven different polyester/waste (cotton noil, recycled fibres, flat waste, etc.) rotor yarns at seven different opening roller speeds on a laboratory-type

OE-rotor spinning machine (Quickspin) and recommended higher opening roller speed such as 7000 rpm. Halimi et al. [5] indicated that yarn count, rotor parameters (diameter and form) and rotor speed have an effect as significant as the waste proportion. Hasani et al. [8] determined the optimum spinning conditions for rotor yarns for each ginning process waste proportion (65%, 50% and 35%). In another work, Khan et al. [9] showed that the blend ratio and rotor speed are the most influential factors for good quality yarn. Additionally they indicated that draw frame blending gives worse yarn strength values but better imperfection, irregularity and yarn elongation than the blowroom blending technique. A high cylinder speed was recommended in draw frame blending and during the blending of higher waste, while the spinning waste content did not provide the expected yarn strength.

In other works, Pınarlık and Şenol [10] prepared different fibre mixtures containing primary and recycled polyester and acrylic fibres, and determined that the tensile properties of OE-rotor yarns deteriorate as the reused fibre ratio increases. Contrary to Khan et al. [9], they indicated that blending in a blowroom gives better results than that of mixing on a draw frame. Celep and Yükksekaya [11] investigated the thermal comfort properties of blankets produced of primary and reused cotton, polyester and acrylic OE-rotor weft yarns. They determined that reused fibres provide good thermal comfort properties. Alan et al. [12] spun weft yarns from cotton and recycled cotton fibres, and reported that blankets produced from recycled fibres can be an alternative



Figure 1. a) mixer and b) band preparation machines.

to the originals due to lower production costs and acceptable tenacity properties.

The studies given above mainly focused on the reuse of recovered fibres in OE-rotor spinning and the effect of waste fibre on OE-rotor yarn properties. The blending of different waste fibre types with virgin cotton is a common phenomenon in rotor spinning to lower the production costs. However, to date, there has been no extensive survey comparing the quality of different yarn types produced from waste fibres to determine the possibility of high quality yarn production from reused fibres. Furthermore there are few papers published on the effect of recovered fibre quality on yarn properties. As is known, reused fibres have different cleanness and openness since they are taken from different machines. Therefore we believe that the effect of different waste types on different yarn qualities should be investigated. These kinds of studies could encourage manufacturers to treat the wastes. Therefore, in this study, it was aimed to produce con-

ventional ring and OE-rotor yarns with cotton secondary fibres and to analyse the properties of the yarns. In the yarn production, waste fibres from a cotton yarn production line and primary cotton fibres were blended with different waste fibres at various levels. In the research, the effect of different waste types as well as the amount of wastes in the blends on different yarn properties was studied. Additionally some of the yarn samples were selected and the pilling behaviour of knitted fabrics was studied to evaluate the fabric performance. The results of the study might help to determine the quality of the yarn blended secondary raw material with primary material and to give information about the potential of usage of waste fibres in the spinning industry.

Material and method

In order to investigate the effect of reused fibres on the quality of different yarn types, waste fibres were obtained from a cotton yarn spinning mill. Wastes were taken from preparation processes such as

blowroom and carding, as well as those sucked on the draw frame and on roving and conventional ring spinning machines. The reused fibres were named depending on the machines provided, such as blowroom wastes, card-flat wastes and pneumafil wastes. All wastes had a fibre form and they were directly used.

The wastes were blended with virgin cotton at five levels varying from 0 to 40%. Blends were prepared on a blowroom line and a conventional mixer was used. Virgin cotton was opened on a modern bale opener (Trützschler Blendomat BDT 019) and then on a conventional bale opener (Trützschler DX 385). Then virgin cotton and wastes were weighted depending on the blending ratio desired and afterwards put together in a mixer (Trützschler MCM8) (Figure 1.a). Following the mixer, the blends were processed on a Trützschler band preparation machine (Figure 1.b), which had been used for lap feeding to the card machines. At the end of the machine, fibre batt was wound on a lap tube, which was then transferred to the card machine [13]. In spinning mills, this machine is sometimes preferred to enhance the colour match in melange yarns and also to provide smaller amounts of products. In our study, primary and secondary used fibre blends were prepared in a fibre batt form, wound onto a bobbin and then fed to a Rieter C4 card machine. After carding, the blends were processed at the first and second passage on the drawing frame to improve the homogeneity of the blend. Slivers were processed on a Zinser Speed 5M roving machine.

This work is comprised of four parts. In the first part, fibre properties of blowroom, flat and pneumafil wastes were tested. In the second part, rovings with blowroom, flat and pneumafil wastes

Table 1. Setting of the machines.

Parameters		Parameters	
Mixer	Trützschler MCM8	Roving machine	Zinser Speed 5M
Band preparation machine	Trützschler	Total draft	6.8
Production speed, m/min	20	Roving no, tex	0.66
Card machine	Rieter C4 (1985)	Twist, tp m	46
Production speed, m/min	70	Production speed, m/min	15.2
Card band count, ktex	5	Ring spinning machine	Rieter G10
I. passage drawing machine	Trützschler TD 02	Yarn count, tex	37/1
Number of doubling	8	Total draft	20.5
Total draft	8	Ring diameter, mm	40
Speed, rpm	400	Type of ring	Conventional
Sliver count, ktex	5	Traveller	Bracker C1 LM udr
II. passage drawing machine	Trützschler TD 02	ISO No, mg/piece	63/1
Number of doubling	8	Twist, tpm	592
Total draft	8.7	α_{tex}	35.4
Sliver count, ktex	4.5	Production speed, m/min	21.9

Table 2. Spinning parameters for 37/1 tex OE-rotor yarns.

Parameters	
Sliver no, ktex	4.5
Twist, α_{tex}	35.4
Opening roller speed, rpm	9500
Rotor diameter, mm	50
Rotor speed, rpm	55000
Production speed, m/min	94.3

were used for conventional ring spun yarn production. 37/1 tex ring spun yarns were produced on a Rieter G10 conventional ring spinning machine. In the third part of the study, OE-rotor yarns of 37/1 tex were obtained from second passage slivers. In the last part, some of the yarn samples were selected and the pilling resistance of knitted fabrics were studied. The settings of the machines for 37/1 tex ring and OE-rotor spun yarns are shown in **Tables 1-2**.

Ten cops for ring yarns and five bobbins for OE-rotor yarns were produced for each experiment. The yarns were tested on an Uster Tester 3, Zweigle G566 and Uster Tensojet testers, and the cops and bobbins of each trial were fed in the same order to the testers. The sample length was 400 m for Uster Tester 3, 100 m for Zweigle G566 and 50 mm for Uster Tensojet. During the tensile tests, 100 breakings were done for each sample and the test speed was 200 m/min. The tests were carried out under standard atmospheric conditions and we conditioned samples for a minimum of 24 hours before the tests. All the tests were carried out on the same testers and the test results were analysed statistically with an SPSS 16.0 statistical program by the One-Way ANOVA test method for different blend ratios to determine any significant differences [14].

Yarn samples were knitted on a sample sock knitting machine (Lonati 462). Conventional ring and OE-rotor yarns with the highest waste fibre level (40%) were used for fabric production. Fabric productions were realized on the same knitting machine with the same loop density. The pilling behaviour of all fabrics was tested on a Nu-Martindale Abrasion Tester according to the TS EN ISO 12945-2 test method [15].

■ Results and discussion

Raw material properties

Prior to spinning, virgin and reused cotton fibre properties were determined by

Table 3. Fibre properties.

Properties	Virgin fibre	Blowroom wastes	Flat wastes	Pneumafil wastes
Fineness, Mic	4.34	4.22	3.53	4.39
Upper half mean length (UHML), mm	30.93	27.02	24.86	27.82
Uniformity index (UI)	84.9	77.7	72.8	72.9
Strength, g/tex	33.33	27.42	26.58	28.98
Elongation, %	7.94	8.1	8.1	5.8
Short fibre index (SFI), %	7.02	14.1	25.6	10.8

an HVI tester, the results of which are given in **Table 3**. **Table 4** presents a statistical summary of raw fibre properties.

As expected, primary cotton fibres had better fibre properties than those of the reused waste fibres. In particular, contrary to fibre elongation values, there were statistically significant differences in the fibre length, uniformity index,

strength and SFI values of virgin and each reused fibres (**Table 4**). On the other hand, when the waste fibre types were compared with each other, it was observed that pneumafil wastes had better values than the other wastes. The differences in all fibre properties of pneumafil and other wastes were statistically significant at the 5% level. As for blowroom and flat wastes, except SFI, the

Table 4. Anova test results for fibre properties. *Note:* * The mean difference is significant at the 0.05 level.

Raw material	Fineness, Mic	UHML, mm	UI	Strength, g/tex	Elongation, %	SFI, %
Virgin	Blowroom	0.073	0.000*	0.000*	0.172	0.000*
	Flat	0.000*	0.000*	0.000*	0.092	0.000*
	Pneumafil	0.359	0.000*	0.004*	0.000*	0.000*
Blowroom	Flat	0.000*	0.000*	0.000*	0.421	0.736
	Pneumafil	0.024*	0.031*	0.000*	0.000*	0.000*
Flat	Pneumafil	0.000*	0.000*	0.000*	0.000*	0.000*

Table 5. AFIS test results of II. passage slivers.

Waste, %	Short fibre amount, number	Neps, number/g	SCN, number/g
Blowroom	10	23.8	199
	20	25.7	281
	30	33.1	398
	40	31.7	545
Flat	10	23.9	254
	20	26.7	301
	30	34.4	450
Pneumafil	10	19.8	84
	20	23.4	99
	30	22.6	110

Table 6. Anova test results of II. passage slivers.

Waste, %	Raw material	Short fibre amount, number	Nepss, number/g	SCN, number/g
10	Pneumafil	Flat	0.025*	0.000*
		Blowroom	0.028	0.000*
	Blowroom	Flat	0.945	0.004*
20	Pneumafil	Flat	0.418	0.000*
		Blowroom	0.561	0.000*
	Blowroom	Flat	0.808	0.271
30	Pneumafil	Flat	0.005*	0.000*
		Blowroom	0.008*	0.000*
	Blowroom	Flat	0.660	0.028*

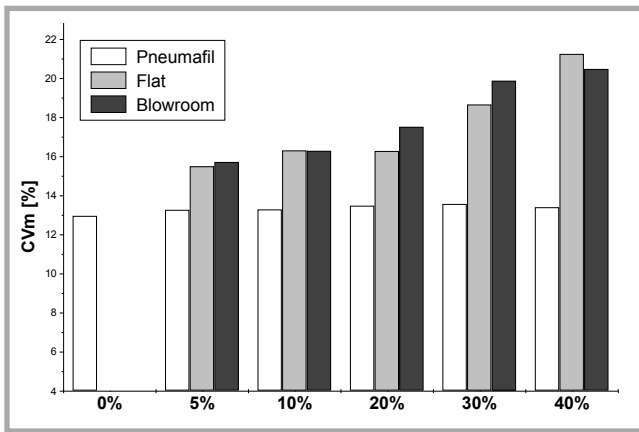


Figure 2. Yarn irregularity results.

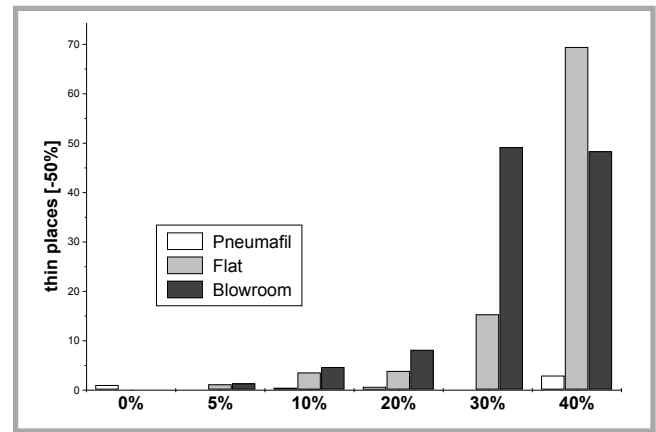


Figure 3. Thin place values.

blowroom waste fibres had better fibre properties in regard to length, strength, uniformity and strength values. Contrary to strength and elongation values, there were statistically significant differences in other fibre properties of blowroom and flat wastes. As a result, it was expected that the yarns blended with pneumafil waste fibres perform better, while those

containing flat fibres lead to worse values regarding yarn quality.

In the study, the fibre properties of II. passage slivers were tested on an AFIS tester (Table 5). Firstly the results were analysed for the waste type. Regarding short fibre, nepes and seed cotton (SCN) properties, pneumafil wastes had signif-

icantly lower values, while the slivers with flat waste fibres had considerably higher (Table 6). Therefore, as in fibre properties, the samples of pneumafil wastes provided better fibre properties than other samples. Particularly the differences in nepes and seed cotton nepes of the samples were significant and the samples containing pneumafil waste fibre blends had three times lower values than the other waste types. When the effect of the blend ratio was studied, it was observed that the values of short fibre, nepes and seed cotton nepes rose with the higher waste fibre proportion in the blends. Particularly the number of nepes and seed cotton nepes values considerably increased with the blend ratio.

Table 7. Anova test results for yarn irregularity values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
0	P	0.180	0	P	0.260	0	P	0.128
	F	0.000*		F	0.000*		F	0.000*
	B	0.000*		B	0.000*		B	0.000*
P	F	0.000*	P	F	0.000*	P	F	0.000*
	B	0.000*		B	0.000*		B	0.000*
F	B	0.251	F	B	0.940	F	B	0.000*
	30%	Sig.		40%	Sig.			
0	P	0.030*	0	P	0.193			
	F	0.000*		F	0.000*			
	B	0.000*		B	0.000*			
P	F	0.000*	P	F	0.000*			
	B	0.000*		B	0.000*			
F	B	0.000*	F	B	0.027*			

Effect of waste fibre usage on conventional ring spun yarn properties

In this part, the effect of different waste types and the amount of wastes in the blends on the properties of 37 tex conventional ring spun yarns was investigated.

Yarn irregularity

The results are shown in Figure 2. As expected, the ring spun yarns produced from virgin cotton fibres had lower irregularity values than those of yarns blended with three different waste fibres. As the proportion of waste fibres in the blends increased, yarn irregularity values got worse. However, in spite of its higher CVm values, there were not statistically significant differences between the results of the yarns produced from pneumafil and primary used cotton fibres (Table 7). Therefore the adding of pneumafil waste fibres into virgin cotton fibres up to 40% did not affect the yarn evenness significantly. On the other hand, the results

Table 8. Anova test results for thin place values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
0	P	0.227	0	P	0.587	0	P	0.769
	F	0.857		F	0.013*		F	0.091
	B	0.637		B	0.003*		B	0.000*
P	F	0.162	P	F	0.002*	P	F	0.048*
	B	0.084		B	0.001*		B	0.000*
F	B	0.774	F	B	0.316	F	B	0.010*
	30%	Sig.		40%	Sig.			
0	P	0.895	0	P	0.873			
	F	0.045*		F	0.000*			
	B	0.000*		B	0.000*			
P	F	0.059	P	F	0.000*			
	B	0.000*		B	0.002*			
F	B	0.000*	F	B	0.092			

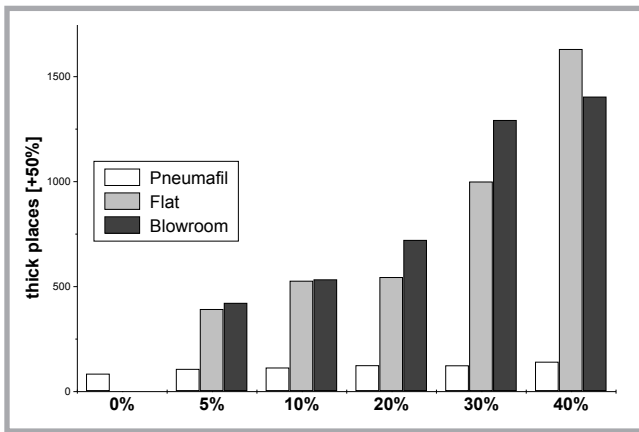


Figure 4. Thick place values.

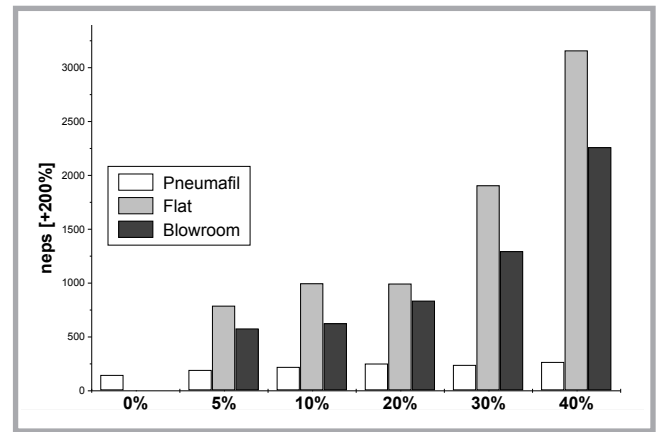


Figure 5. Nepss values.

of the yarns containing blowroom and flat waste fibres were statistically higher than those of the yarns produced from virgin cotton fibres and pneumafil blends. Moreover the yarns with blowroom and flat waste fibres had statistically similar yarn evenness below 20%. Nevertheless the irregularity of the yarns blended with blowroom waste fibres were the highest of all wastes, except 40%. As a result, the yarns with pneumafil waste fibres gave lower CVm values while the yarns blended with blowroom waste fibres generally led to higher values.

Yarn Imperfections

Yarn imperfection results are shown in Figures 3-5. As with yarn irregularity, the yarns produced from primary used fibres had lower thin-thick places and nepss values. Similar to yarn irregularity, the values of yarns obtained with virgin cotton and pneumafil waste fibres did not differ significantly and hence both yarns had similar yarn imperfections (Tables 8-10). In the case of blowroom and flat wastes, yarn faults were significantly higher, even at lower percentages, such as 5%. When the yarns produced from blowroom and flat waste fibres were compared, there were statistically significant differences at higher waste ratios than 10% (Tables 8-10). In general, the worst thin and thick places were in yarns with blowroom waste fibres, but the highest nepss were shown by yarns containing flat wastes. In all waste fibres, the best imperfection results were obtained with pneumafil waste fibres. Moreover a considerable increase in yarn imperfections was observed in blowroom and flat blends at 30% and 40%. As reported for rotor yarns by Halimi et al. [5], yarn faults increase with the waste fibre content in the blends.

Yarn hairiness

Uster H and Zweigle s3 hairiness results are given in Figures 6-7. When a general evaluation was made regarding all hairiness results, a similar tendency was observed, and the yarns with secondary used fibres had higher H and s3 hairiness values than those of the primary used fibres. According to Uster

H values, the usage of pneumafil waste fibres did not affect the yarn hairiness up to 30% (Table 11). In the case of s3 values, there were not statistically significant changes up to 40%. Therefore raw materials containing pneumafil waste fibres provided similar yarn hairiness to that of the virgin cotton fibres up to 30% (Table 12).

Table 9. Anova test results for thick place values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
0	P	0.510	0	P	0.615	0	P	0.510
	F	0.000*		F	0.000*		F	0.000*
	B	0.000*		B	0.000*		B	0.000*
P	F	0.000*	P	F	0.000*	P	F	0.000*
	B	0.000*		B	0.000*		B	0.000*
F	B	0.264	F	B	0.903	F	B	0.002*
	30%	Sig.		40%	Sig.			
0	P	0.442	0	P	0.394			
	F	0.000*		F	0.000*			
	B	0.000*		B	0.000*			
P	F	0.000*	P	F	0.000*			
	B	0.000*		B	0.000*			
F	B	0.000*	F	B	0.009*			

Table 10. Anova test results for nepss values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
0	P	0.156	0	P	0.439	0	P	0.003*
	F	0.000*		F	0.000*		F	0.000*
	B	0.000*		B	0.000*		B	0.000*
P	F	0.000*	P	F	0.000*	P	F	0.000*
	B	0.000*		B	0.000*		B	0.000*
F	B	0.000*	F	B	0.000*	F	B	0.000*
	30%	Sig.		40%	Sig.			
0	P	0.129	0	P	0.274			
	F	0.000*		F	0.000*			
	B	0.000*		B	0.000*			
P	F	0.000*	P	F	0.000*			
	B	0.000*		B	0.000*			
F	B	0.000*	F	B	0.000*			

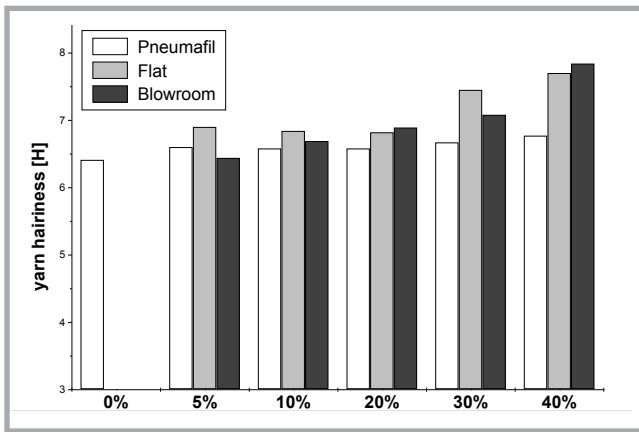


Figure 6. Yarn hairiness (H) results.

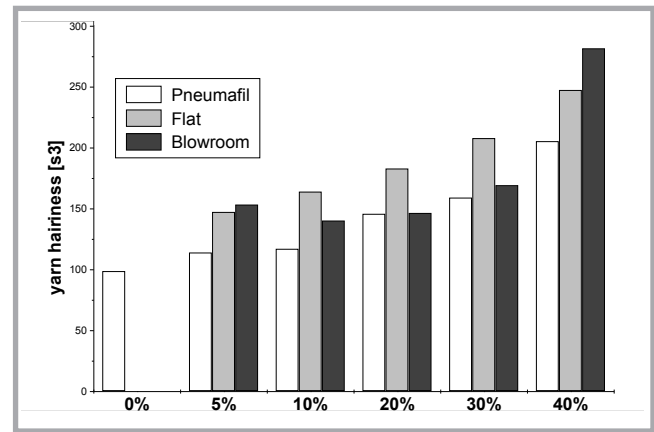


Figure 7. Yarn hairiness (s3) results.

As for blowroom and flat wastes, even 5% percent in the blends lead to producing hairier yarns. However, contrary to H hairiness results, it was found that the effect of blowroom waste fibres on s3 hairiness values only become statistically significant at a 40% blend ratio. Nonetheless the effect of flat wastes on yarn hairiness

was most distinct, and fibre usage caused a statistically significant increase in H and s3 hairiness values (Tables 11-12). when the waste types were compared, as for other results, pneumafil waste fibres produced less hairiness, while flat wastes, in general, caused hairier yarn production. Nevertheless ring spun yarns

got hairier, as in rotor yarns, whatever re-used fibre types were used [5].

Tensile properties

Yarn tenacity and elongation results are shown in Figures 8-9. As is seen, the yarns blended with waste fibres had lower tenacity and elongation values than those obtained with primary used cotton fibres. Whatever the waste fibre type was, the usage of waste fibre in yarn production led to a reduction in yarn tenacity and elongation values. Breaking tenacity and elongation values were the highest for pneumafil yarns, while they were the lowest for yarns with blowroom waste fibres. This case showed similarity to yarn irregularity, thin and thick place results, where the weakest points might lead to an increase in yarn breakages. The yarns containing pneumafil waste fibres had similarities to the virgin cotton fibres with respect to the breaking strength and elongation.

Upon examination of the effect of the blend ratio on tensile properties, the increasing content of waste fibres in the yarn structure caused a decrease in values for all waste fibre types. The reduction became more distinct at higher waste proportions than 20%, and additionally it was lower for the yarns with pneumafil waste fibres. Halimi et al. [5] also reported for OE-rotor yarns that the introduction of 15 and 25% waste fibre into cotton will not affect the tenacity, and hence our finding for ring spun yarns agreed with the literature. For blowroom waste fibres, the differences in tenacity values of blowroom waste and virgin cotton fibres reached about two times at the highest waste fibre proportion (40%). In the case of yarn elongation, the blend ratio was seen not to change the yarn elongation.

Table 11. Anova test results for Uster H yarn hairiness values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
0	P	0.107	0	P	0.197	0	P	0.106
	F	0.000*		F	0.012*		F	0.001*
	B	0.770		B	0.044*		B	0.000*
P	F	0.017*	P	F	0.155	P	F	0.092
	B	0.153		B	0.494		B	0.024*
F	B	0.000*	F	B	0.382	F	B	0.551
	30%	Sig.		40%	Sig.			
0	P	0.043*	0	P	0.013*			
	F	0.000*		F	0.000*			
	B	0.000*		B	0.000*			
P	F	0.000*	P	F	0.000*			
	B	0.002*		B	0.000*			
F	B	0.003*	F	B	0.398			

Table 12. Anova test results for Zweigle s3 yarn hairiness values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
0	P	0.465	0	P	0.770	0	P	0.611
	F	0.024*		F	0.036*		F	0.004*
	B	0.023*		B	0.098		B	0.234
P	F	0.108	P	F	0.064	P	F	0.014*
	B	0.090		B	0.171		B	0.434
F	B	0.791	F	B	0.492	F	B	0.189
	30%	Sig.		40%	Sig.			
0	P	0.083	0	P	0.003*			
	F	0.001*		F	0.000*			
	B	0.083		B	0.000*			
P	F	0.067	P	F	0.201			
	B	0.743		B	0.015*			
F	B	0.228	F	B	0.341			

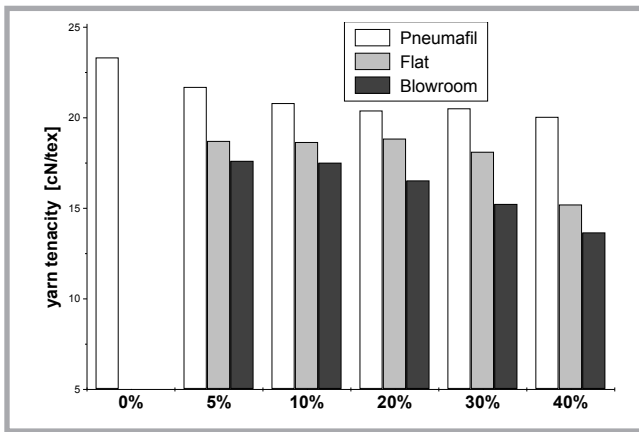


Figure 8. Yarn tenacity results.

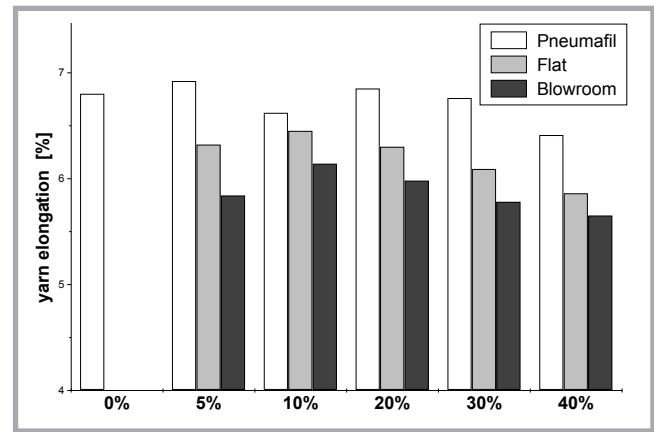


Figure 9. Yarn elongation results.

Effect of different waste fibre types on different yarn properties

In this part, pneumafil, blowroom and flat wastes were used for the production of OE-rotor spun yarns up to 50%, and the properties of the yarns were compared to those of conventional ring spun yarns to determine the effect of different wastes on yarn quality.

Yarn irregularity

Figure 10 shows the irregularity results of conventional ring and OE-rotor spun yarns. Like ring spun yarns, OE-rotor yarns produced from flat and blowroom wastes had higher CVm values, while the blends containing pneumafil wastes had lower. Therefore the yarns of pneumafil waste blends were more even, while other wastes led to considerably uneven yarns. Contrary to ring spun yarns, the differences between the results of pneumafil and other wastes were not more apparent in OE-rotor yarns. The differences at 40% waste levels of pneumafil and flat wastes were about 59% for ring spun yarns, while it was about 4.5% for rotor yarns. When a similar evaluation was made for pneumafil and blowroom wastes, the difference determined was 53% for ring and 1.5% for rotor yarns, respectively. According to the statistical analysis results of OE-rotor yarns, there were not always significant differences between the values of pneumafil and other wastes. Moreover slightly higher CVm values of blowroom waste blends were not found to be statistically significant from pneumafil fibre mixtures (Table 13). Therefore we concluded that the effect of waste fibre usage on the unevenness of ring spun yarns was higher in comparison to rotor yarns.

On the other hand, in ring spun yarns, the blends with blowroom wastes mostly led

to the highest CVm values. However, in OE-rotor yarns, it was a different case, where the blends containing flat wastes led to more uneven yarns than those of the pneumafil and blowroom wastes.

As expected, the test results revealed that the mass variation of all yarn types increased with higher reused fibre percentages. For ring spun yarns, yarn irregularity values worsened by about 1% when the pneumafil fibre waste ratio was increased from 5% to 40%. This case was about 37% and 30% for flat and blowroom waste fibres, respectively, while it was about 16, 10 and 12% in rotor yarns for the three waste types.

Yarn Imperfections

Yarn imperfection results are shown in Figures 11-13. When the thin and thick place values were analysed, a similar case was observed determined from yarn irregularity results. Pneumafil waste blends gave fewer faults while flat wastes produced higher values at all mixture rates. The differences in thin and thick values of pneumafil and flat waste blends were mostly statistically significant (Tables 14-15). However, the slightly higher thin and thick place faults of blowroom waste mixtures were not found to be statistically more important than those of the pneumafil wastes. Hence, as with pneumafil waste blends, blowroom

Figure 10. Yarn irregularity results.

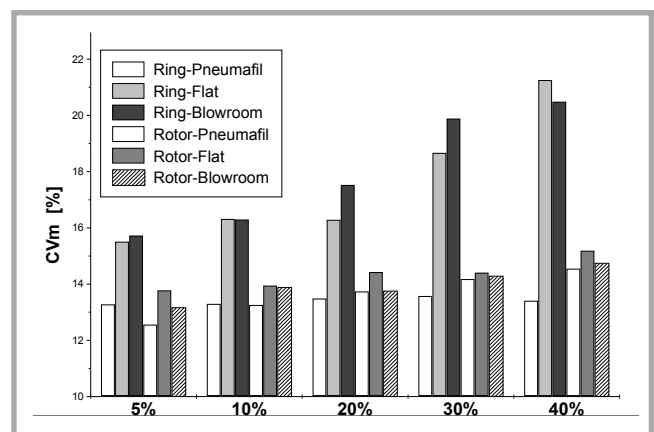


Table 13. Anova test results for OE-rotor yarn irregularity values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
P	F	0.000*	P	F	0.003*	P	F	0.000*
	B	0.063		B	0.022*		B	0.336
F	B	0.017*	F	B	0.281	F	B	0.000*
	30%	Sig.		40%	Sig.			
P	F	0.002*	P	F	0.000*			
	B	0.075		B	0.012*			
F	B	0.063	F	B	0.003*			

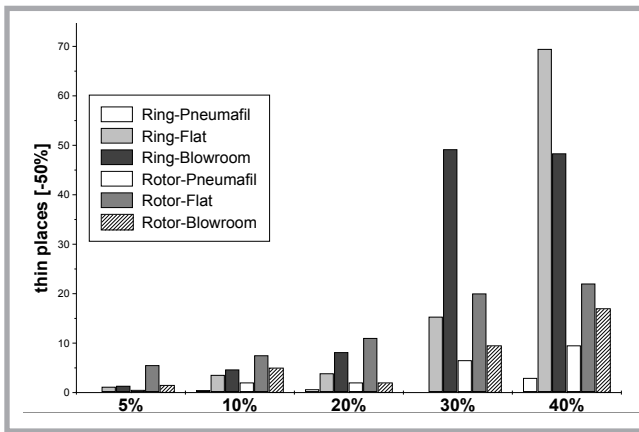


Figure 11. Thin place values.

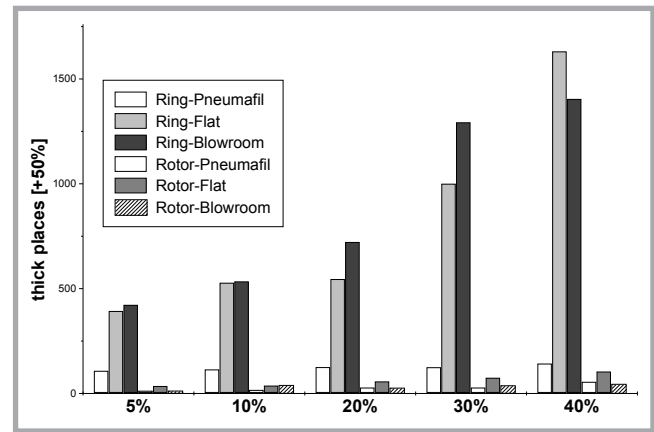


Figure 12. Thick place values.

wastes gave lower values than those of the flat wastes.

On the other hand, unlike rotor spun yarns, in general the highest thin and thick place faults were obtained with blowroom blends in ring spun yarns.

Therefore the results of thin and thick places did not coincide in ring and rotor yarns.

Nepps results of OE-rotor yarns showed some similarity to thin and thick place faults (Figure 13). In general, the yarns

produced from pneumafil waste mixtures had lower nepps values and the blends with flat wastes caused higher nepps values. This result was in agreement with the finding of ring spun yarns. Unlike yarn irregularity and thin-thick places, there were statistically significant differences between pneumafil and other waste blends (Table 16). Additionally the differences between flat and blowroom wastes were also statistically significant. Moreover, as reported by Halimi et al. [5], the number of faults increased with higher waste fibre usage.

Table 14. Anova test results for OE-rotor thin place values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
P	F	0.014*	P	F	0.022*	P	F	0.006*
	B	10.00		B	0.128		B	10.00
F	B	0.014*	F	B	0.001*	F	B	0.006*
	30%	Sig.		40%	Sig.			
P	F	0.232	P	F	0.006*			
	B	0.417		B	0.308			
F	B	0.058	F	B	0.001*			

Table 15. Anova test results for OE-rotor thick place values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
P	F	0.000*	P	F	0.115	P	F	0.000*
	B	10.00		B	0.055		B	0.933
F	B	0.000*	F	B	0.678	F	B	0.000*
	30%	Sig.		40%	Sig.			
P	F	0.103	P	F	0.000*			
	B	0.653		B	0.167			
F	B	0.217	F	B	0.000*			

Table 16. Anova test results for OE-rotor nepps values. Note: * The mean difference is significant at the 0.05 level.

	5%	Sig.		10%	Sig.		20%	Sig.
P	F	0.000*	P	F	0.000*	P	F	0.000*
	B	0.001*		B	0.011*		B	0.002*
F	B	0.000*	F	B	0.000*	F	B	0.000*
	30%	Sig.		40%	Sig.			
P	F	0.000*	P	F	0.000*			
	B	0.002*		B	0.000*			
F	B	0.000*	F	B	0.033*			

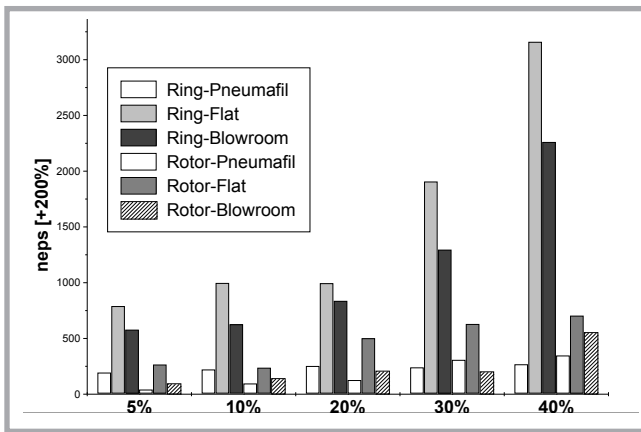


Figure 13. Neps values.

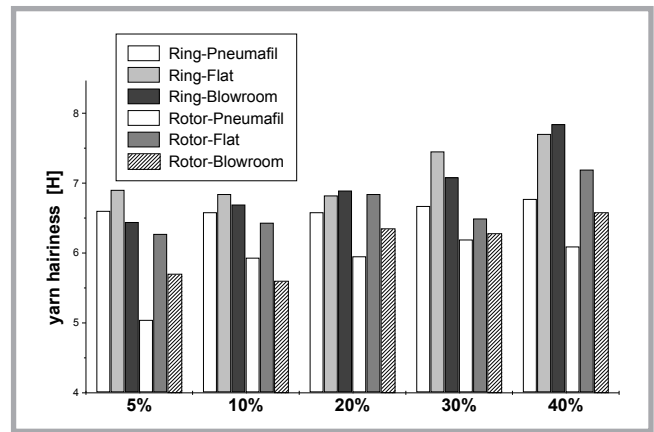


Figure 14. Yarn hairiness (H) results.

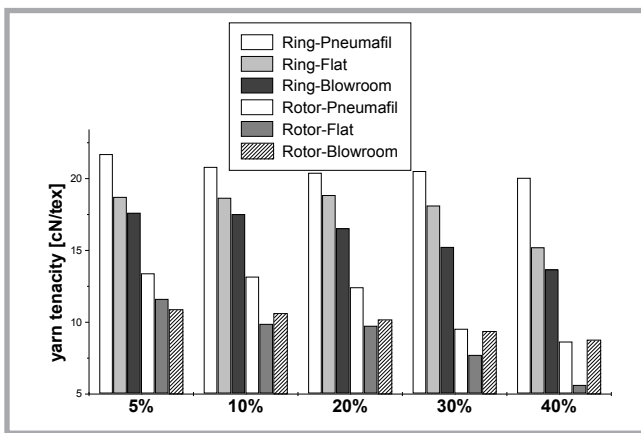


Figure 15. Yarn tenacity results.

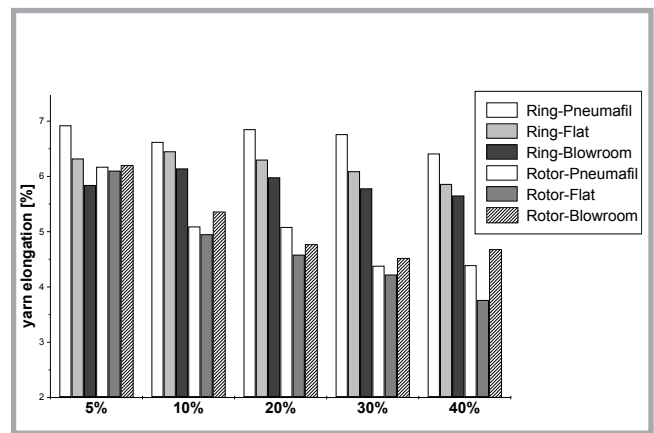


Figure 16. Yarn elongation results.

ring spun yarns and 21, 15 and 15% in rotor yarns with rising contents of the pneumafil, flat and blowroom wastes from 5% to 40%. As indicated, both yarns were influenced at a similar level with the usage of waste fibre in the blend.

Tensile properties

Yarn tenacity and elongation results are shown in Figures 15-16. As seen in Figure 15, the OE-rotor yarns obtained from pneumafil waste blends had the highest tenacity values, while the yarns produced from flat wastes had the lowest. An interesting feature was observed in the tenacity results and usage of flat wastes in that it led to the weakest yarns in comparison to other waste types. The values of blowroom waste blends were expected to be lower than the for pneumafil and then flat wastes in the case of ring spun yarns. However, in OE-rotor yarn, blowroom waste blends gave better tenacity values than flat waste fibres.

As the waste fibre amount increased in the raw material, tenacity values de-

creased. In particular, the yarns produced from flat waste blends got considerably weaker, and there was even a three times higher difference between the values of the lowest (5%) and highest (40%) waste fibre level.

As expected, yarn elongation was the lowest in OE-rotor yarns obtained with flat waste blends, and the yarns containing pneumafil waste fibre had the highest (Figure 16). Contrary to ring spun yarns, in rotor yarns, the yarns of blowroom waste fibre blends had mostly higher

elongation values than those of the flat waste fibres, which is an interesting .

As shown by Pınarlık and Şenol [10], the tensile properties of OE-rotor yarns deteriorated as the reused fibre ratio increased. Yarn tenacity values decreased by 8, 9 and 22% in ring spun yarns when the pneumafil, flat and blowroom waste contents were increased from 5% to 40%. For rotor yarns, this was about 36, 52 and 20%. As for yarn elongation, the introduction of these waste fibres into the cotton decreased the elongation val-

Table 17. Anova test results for Uster H hairiness values of OE-rotor yarns. Note: * The mean difference is significant at the 0.05 level.

		5%	Sig.			10%	Sig.			20%	Sig.
P	F		0.000*	P	F		0.000*	P	F		0.000*
	B		0.000*		B		0.000*		B		0.000*
F	B		0.000*	F	B		0.000*	F	B		0.000*
		30%	Sig.			40%	Sig.				
P	F		0.000*	P	F		0.000*				
	B		0.015*		B		0.000*				
F	B		0.000*	F	B		0.000*				

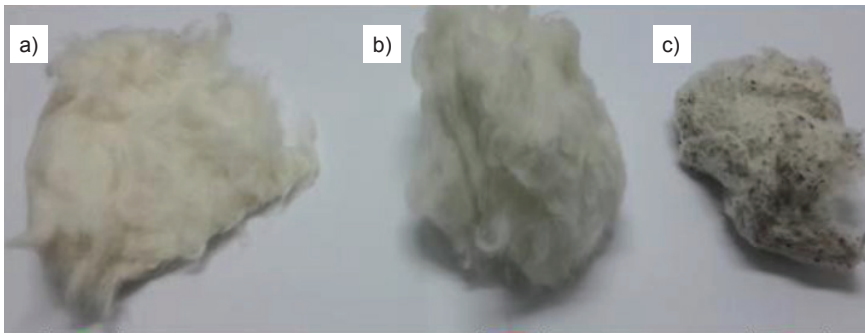


Figure 17. Waste fibres: a) pneumafil waste, b) flat waste, c) blowroom waste.

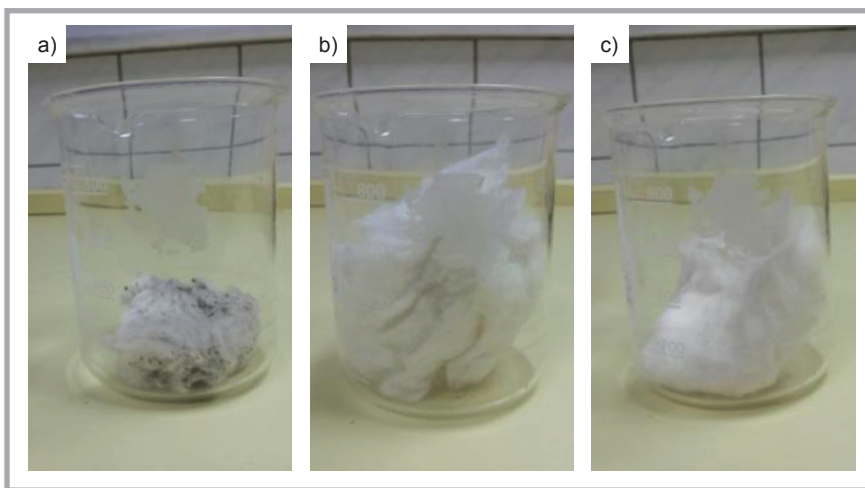


Figure 18. Waste fibres in a glass bowl: a) pneumafil waste, b) flat waste, c) blowroom waste.

ues by 7, 7 and 3% in ring spun yarns and 29, 38 and 25% in rotor yarns. As is seen, the reduction was higher in rotor yarns compared with ring spun yarns, and hence the most influenced properties were the yarn tenacity and elongation in rotor yarns with waste fibre usage in the blend.

Comments on the results of conventional ring and OE-rotor yarns

Over the years, several researchers have studied the effect of fibre properties on yarn quality [16-19]. In addition, numerous works indicated that the impurities in cotton fibres affect the yarn quality negatively due to disrupting the spinning process. Particularly the presence of seed coat fragments (SCF) and other contaminants such as dust and nepes were reported as increasing yarn evenness and faults, particularly thick places and nepes, but reducing the tenacity and elongation [19-26].

From these findings, it was thought that the lower the upper half mean length, the higher the short fibre index, and nepes

values of waste fibres might be one of the reasons for higher yarn irregularity, faults and hairiness, while lower fibre length and tensile properties and higher contaminants of the waste fibres might reduce the tensile properties of the yarns together with higher yarn faults.

As stated above, pneumafil waste fibres had better fibre properties, and in this case comparable quality parameters with those of virgin cotton fibres in conventional ring and OE-rotor spun yarns were achieved. As for blowroom and flat waste fibres, yarn properties changed depending on waste and yarn types. In both yarn types, flat waste fibres generally caused the highest nepes faults. Our finding is in agreement with the literature [27], where seed coat fragments might be the main cause for higher nepes results. Flat waste fibres had the highest number of contaminants, and they were twisted and transferred to the yarns. In addition to higher contaminants, lower upper fibre length and a higher number of short fibres of flat wastes caused higher hairiness values in both yarn types.

On the other hand, in all yarn properties, the worst values were expected from flat waste fibre blends due to their worse fibre properties. Contrary to expectations, in ring spun yarns, those produced from blowroom waste fibre blends lead to worse yarn properties, except yarn hairiness. Despite its higher fibre tenacity and elongation values, blowroom waste fibre blends interestingly lead to lower tensile properties compared with flat waste fibre blends. It was believed that one of the reasons might be an insufficient fibre opening level. As is known, the function of opening is separating the fibre clumps into smaller ones, which primarily enhances the effective cleaning and blending of the fibres. In literature, Ishtiaque et al. [28-29] also indicated that the optimum degree of opening on a blowroom line improves the yarn tenacity and total imperfections. Additionally, in ring spinning, roller drafting could not open the fibres individually nor remove SCN and other contaminants like nepes and trash. However, in OE-rotor spinning, fibre tufts are separated into individual fibres by the opening roller, which gives the opportunity to eject the trash and nepes from the yarn formation. From these findings, it was thought that fibre openness was mainly responsible for the results of ring spun yarns, and insufficient openness of blowroom waste fibres might reduce the cleaning and blending of the fibres. In order to check the effect of fibre openness on yarn properties, a simple test was done. In literature, fibre tuft size is given in g or g/cm^3 and therefore we followed a similar course in the study [27, 30]. Some fibre samples were taken from each waste fibre, and then weighted and fixed to the same fibre weight (4.5 g). As seen in **Figure 17**, flat and pneumafil waste fibres (C) were observed to be more bulky, while blowroom waste fibres (A) had a compact form. The fibres were closed and the fibre tuft was denser than the other waste fibres. Lord [30] stated that the specific volume of the fibre mass changes considerably as the material is opened. The height of the fibre tufts was measured by a ruler, and the values were 2.5 cm for blowroom waste, 7.0 cm for flat waste and 4.0 cm for pneumafil waste fibre. Additionally the waste fibres were put into a glass bowl and the height of the fibres was measured to evaluate the fibre openness only. As seen in **Figure 18**, the heights were 200-400 mL for blowroom waste, 800 mL for flat waste and 600 mL for pneumafil waste. According to our observations, the insufficient opening

level of blowroom waste fibres resulted in insufficient cleanness and more uneven, faulty and weaker yarn production.

In rotor spun yarns, contrary to the case of conventional ring yarns, flat fibre blends lead to the worst yarn properties. As stated above, flat waste fibres had the lowest length, strength and elongation values, and its worse properties might be one of reasons for higher hairiness and lower tenacity and elongation values of the yarns. Additionally flat wastes had higher contaminants, which affected the rotor yarn production negatively. As is known, rotor yarn spinning is sensitive to fibre cleanness, but a more critical factor in OE-rotor spinning is the build-up of impurities in the rotor groove, as they block the twist flow into the fibre ribbon. The result is a constant decrease in tensile properties and an increase in irregularity [27]. Contrary to ring spinning, higher strength and elongation values of blowroom waste fibres might enhance the stronger yarns more than in the case of flat wastes after fibre separation by the opening roller in rotor spinning. Consequently, due to individual fibre separation, fibre properties become more effective for rotor yarn quality rather than for fibre openness. Moreover, as stated above, it was observed that pneumafil and blowroom waste fibre blends did not differ from each other regarding CVM, thin and thick places, and the OE-rotor machine might tolerate the differences in fibre properties of both waste fibres.

Pilling resistance of the fabrics

Table 18 displays the differences in pilling rates of the knitted fabrics produced from conventional ring and OE-rotor yarns with 40% pneumafil, flat and blowroom waste fibres.

The fabrics knitted from pneumafil waste fibre blends had more pill-resistance than the other fabrics obtained from blowroom and flat waste blends. However, flat and then blowroom waste fibre blends gave the lowest pilling resistant degree. Therefore, pneumafil fibre blends showed more enhanced resistance to pilling while other waste fibre blends displayed worse resistance. Hairy and uneven waste fibre blend yarns might be the main reason for the higher pilling behaviour of the fabrics. On the other hand, as is seen, the pilling of the fabrics reached the lowest grade (severe pilling) before 7000 cycles, indicating that waste fibre usage affected the pilling behaviour of the fabrics sig-

Table 18. Pilling resistance results.

Fabric types 125		Cycles					
		500	1000	1500	2000	3000	
Ring yarn	Pneumafil	4-5	4	3-4	3	2-3	2
	Flat	4	3-4	3	2-3	2	1-2
	Blowroom	3-4	3	2-3	2	1-2	1
OE-rotor yarn	Pneumafil	4-5	4	3	2-3	2	2
	Flat	4	3-4	2-3	2	1-2	1
	Blowroom	3-4	3	2	1-2	1-2	1

nificantly. Furthermore there was not an apparent difference between the fabrics of conventional ring and OE-rotor yarn blends. As is reported above, the hairiness of ring and rotor yarns were affected by the waste fibre usage similarly.

Conclusions

In this study, the effect of different waste fibre types on the quality of different yarn types was investigated. The conclusions derived from all parts of the study were as follows:

- In conventional ring spun yarns, the blending of pneumafil waste fibres with virgin cotton fibres up to a certain level (below 40%) could provide comparable quality values to those of virgin cotton fibres. On the other hand, the blends with blowroom waste fibres led to the highest yarn unevenness, thin and thick places and the lowest tensile properties, while flat waste fibre blends gave rise to the highest neps and hairiness values.
- In OE-rotor yarns, as for ring spun yarns, the blends containing pneumafil wastes enhanced yarn properties better, while the blends with flat wastes caused the worst yarn quality values.
- Whatever yarn types were produced, the usage of flat waste fibres significantly deteriorated neps and hairiness properties of the yarns. However, other yarn properties changed depending on the yarn type due to different processes in yarn production.
- As expected, waste fibre usage in spinning deteriorated the yarn quality whatever yarn types were produced. When the pneumafil, flat and blowroom waste percentage was raised from 5% to 40%, yarn irregularity values increased up to 37% in ring spun yarns and 16% in rotor yarns. Hairiness of the yarns increased by about 21-22% for ring and rotor yarns, while yarn tenacity values decreased by 22% in ring yarns and 52% in rotor yarns. As for yarn elongation, the introduction of the

waste fibres into virgin cotton reduced elongation values by 7% in ring spun yarns and 38% in rotor yarns.

- With the usage of waste fibre, the most deteriorated yarn properties were yarn unevenness in conventional ring spun yarns and tensile properties in rotor yarns. In general, the hairiness of both yarns was influenced at a similar level, due to waste fibres in the blend.
- For ring spun yarns, fibre openness was the most crucial factor for yarn irregularity, thin and thick places and tensile properties, while impurities such as short fibres, neps and seed cotton neps in the raw material affected neps and yarn hairiness values significantly. As for rotor yarns, the contaminants and fibre quality were the most effective parameters for yarn quality.
- When the pilling resistance of the knitted fabrics (40% waste fibre blends) were compared, it was determined that pneumafil fibre blends increased the resistance to pilling, while for other waste fibre blends it was worse. The pilling of the fabrics knitted from waste fibre blend yarns reached to the lowest grade (severe pilling) before 7000 cycles, and hence the effect of waste fibre usage on fabric pilling behaviour was found to be significant.

At the end of the study, it was suggested that the designing of processing steps and machinery according to the waste fibre type decreases raw material costs in the production of yarns with comparable quality values from fibre wastes.

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