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Effect of finishing on performance characteristics of woven and warp-knitted terry fabrics

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The influence of some finishing processes has been studied on the performance characteristics of woven and warp-knitted terry fabrics with open-end pile warp. Terry fabrics of similar structural parameters have been produced by weaving or warp knitting and then subjected to finishing processes which are commonly applied by the textile industry. Samples are extracted at different stages of the finishing processes. Water absorption behavior, structural parameters, and mechanical properties are evaluated and the results are compared by statistical analysis of the obtained data. It is observed that compared to greige terry fabrics, the finishing treatment increases basis weight and dimensional stability due to shrinkage occurred with relaxation, water absorption rate due to the removal of size and other hydrophobic substances, and elongation ratio because of the elimination of size film during pretreatment processing. Woven terry fabrics give higher strength values and warp-knitted terry fabrics show higher elongation.

Keywords: Finishing process, Mechanical properties, Terry towel, Warp-knitted fabric, Water absorption, Woven fabric

1 Introduction

A terry towel is described as “a textile product which is made with loop pile on one or both sides generally covering the entire surface or forming stripe, checks, or other patterns” according to ASTM D 123-03 standard terminology relating to textiles. Terry toweling is still known as ‘Turkish toweling’ or ‘Turkish terry’, as it was first woven in Bursa city of Turkey, probably as a result of a defective weaving[1]. Terry fabrics are produced by three systems of threads, namely ground warp, ground weft and pile warp. Here, the ground warp provides mechanical strength, while pile warp imparts water absorption properties[2] due to increased surface area[3].

Terry fabric can be produced by warp knitting as well as by weaving. Terry fabric formation by warp knitting technique is generally more economical than weaving technique due to its higher production rate. Synthetic fibres are generally used in ground threads in order to add strength and stability to the warp knitted structure[4]. In contrast to their cost-efficiency, very limited number of academic studies have been conducted on warp-knitted terry fabrics[4,5].

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Market requirements for terry towels include performance, fashion, style, color, pattern and hand[1]. None of these can be achieved without the help of finishing technologies and hence the importance of studies on the effects of finishing on the characteristics of terry towels is undeniable. The state-of-the-art of finishing terry fabrics includes desizing, scouring/bleaching, biopolishing, dyeing, softening and tumbling[2,6]. Among these finishing treatments, desizing treatment removes the size materials prior to subsequent finishing and dyeing processes[7], scouring removes impurities that impart hydrophobicity to cotton[8], bleaching increases whiteness level of the fabric and biopolishing removes loose fibre ends protruding from the fabric surface to enhance the handle[9]. Softening and tumbling processes aim at softer and fluffier touch for the terry fabric to appeal to the customer[1,2].

Several investigators attempted to study the effects of finishes on the characteristics of terry fabrics. Petrulyte and Baltakyte[10] observed wetting properties of terry fabrics made of bleached and unbleached 100% linen pile warps and found that the washing processes increased wetting rate, whereas towels with bleached linen pile warps showed faster wetting. They also investigated the effects of several finishing processes and pile loop height on basis weight, water absorption and thickness of terry towels[11] and reported that the greater the pile height the greater is the water absorption of towels. The authors also reported faster water absorption in terry towels that were subjected to more intensive finishing procedures[12].

There are very limited amount of research efforts devoted to knitted terry fabrics. In an early study, Anand and Smith[5] compared woven and warp-knitted terry fabrics in terms of several performance characteristics including tensile strength, tear strength and dimensional stability. They reported improved mechanical performance of woven terry fabric compared to the knitted one. Gericke *et al.*[4] investigated the strength loss due to laundering and tumble drying of warp knitted terry fabrics with polyester and nylon ground warps, and found superior durability of terry fabrics with polyester ground warps.

Prior to the current research, studies related to terry fabrics were mostly focused on woven terry fabrics, whereas knitted terry fabrics have been the subject of very limited research efforts. Furthermore, water absorption phenomenon of terry fabrics has been intensely investigated, leaving other performance characteristics relatively understudied. A survey of literature revealed that no comprehensive studies relating to the effects of finishing processes on the performance characteristics, including mechanical properties of woven and knitted terry fabrics, have been reported. Therefore, the present study has been aimed at investigating influence of some finishing processes on the performance characteristics of woven and warp-knitted terry fabric with open-end pile warp.

2 Materials and Methods

The construction details of woven and knitted terry fabrics are as follows:

Woven terry fabric

- Pile warp – open-end Ne 16/1 cotton
- Ground warp – open-end Ne 20/2 cotton
- Weft yarn – open-end Ne 16/1 cotton

Warp-knitted terry fabric

- Back side pile warp – open-end Ne 16/1 cotton
- Front side pile warp – open-end Ne 16/1 cotton
- Ground warp – 100 denier polyester (36 filaments)
- Weft yarn –100 denier polyester (36 filaments)

Woven terry fabrics were produced using weaving on Vamatex weaving looms by adjusting a thread density of 15 threads/cm and a reed density of 12 dents/cm. The woven fabrics were subjected to finishing processes, commonly applied by the textile industry of Denizli, Turkey. Knitted terry fabrics were produced using a Karl Mayer KS4 FBZ warp knitting machine with four guide bars. The machine parameters were: 10.5 wales per cm, 24 number of needles per inch (E), and 136 inches (D) machine width.

Pre-finishing and dyeing processes were carried out in a high-temperature (HT) machine. Samples were extracted at different stages of the finishing processes. Figure 1 presents the finishing steps when the samples were collected.

Samples were exposed to finishing procedures representative of those currently used in industrial practice. The greige fabric was desized in a high

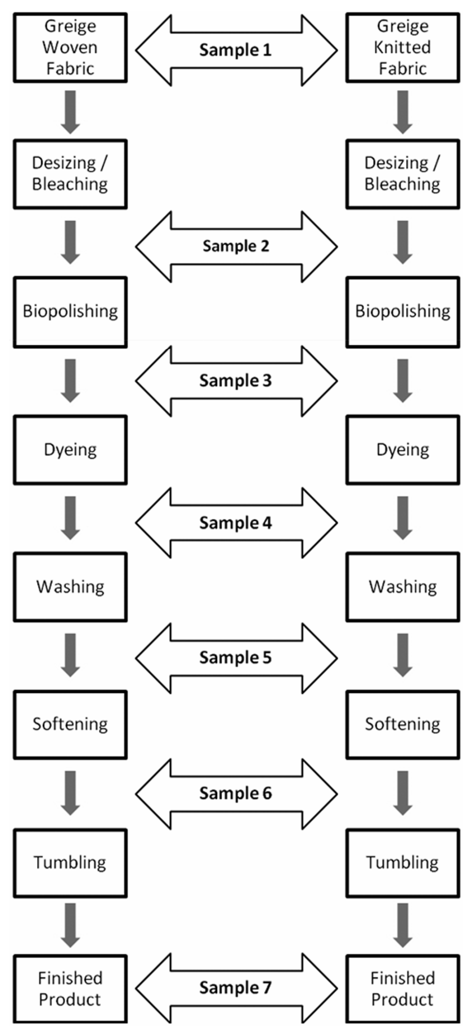

Fig. 1— Production steps and sample numbering

temperature machine prior to bleaching. Bleaching was carried out in presence of NaOH and H_2O_2 at 110°C for 20 min in the same machine. Following bleaching, the fabric was neutralized at 90°C for 10 min. The terry fabric was treated with enzymatic biopolishing agent Cellusoft Combi ® at 50°C for 60 min. Then, the fabric was dyed with reactive dyestuff in presence of salt and soda at 90°C. After dyeing, the fabric was neutralized, washed, and then treated with a softening agent at 40°C for 20 min. In the final step, the fabric was tumbled. The properties of sample terry fabrics are given in Tables 1-3.

2.1 Characterization

Fabric characteristics such as mass per unit area, tear strength, breaking strength, elongation, burst strength, water absorption, and dimensional shrinkage upon washing and drying were measured. Samples

Table 1—Effects of finishing processes on certain structural properties of the woven and warp-knitted terry fabric

Sample	Basis weight, g/m^2			Water absorption, s			Dimensional contraction after washing, %					
							Warp			Weft		
	μ	σ	Change %	μ	σ	Change %	μ	σ	Change %	μ	σ	Change %
						Woven fabric						
1	367	3.51	N/A	178	0.54	N/A	8.30	0.63	N/A	8.86	1.06	N/A
2	406	3.39	10.51	19	0.58	-89.14	1.12	0.64	-86.5	0.02	0.51	-99.8
3	406	2.97	0.10	7	0.55	-64.30	0.29	0.59	-74.5	-0.34	0.5	-1800.0
4	390	4.67	-4.13	5	0.52	-22.93	0.40	0.52	40.0	-0.50	0.54	47.1
5	390	4.16	0.21	4	0.46	-20.14	2.61	0.55	552.4	-0.67	0.59	34.0
6	408	5.13	4.41	4	0.54	-12.78	0.38	0.71	-85.4	-0.02	0.82	-97.0
7	396	4.69	-2.85	3	0.53	-29.67	2.25	0.36	490.6	-0.69	0.57	3350.0
						Weft-knitted fabric						
1	370	5.41	N/A	1022	159.16	N/A	5.10	0.67	N/A	1.56	0.54	N/A
2	464	4.93	25.16	12	1.86	-98.80	0.04	0.81	-99	-0.30	0.58	-119
3	460	11.74	-0.69	7	1.6	-40.54	-0.25	0.63	-725	-0.72	0.55	140
4	458	8.04	-0.56	4	0.19	-43.08	-0.32	0.88	28	-0.44	0.52	-39
5	438	10.46	-4.33	5	0.54	24.35	1.39	0.5	-534	-0.90	0.46	105
6	518	15.64	18.22	5	0.79	1.63	0.55	0.45	-60	-0.44	0.54	-51
7	440	6.84	-14.95	5	0.27	-6.32	1.22	0.49	122	-0.34	0.53	-23

Underlined figures indicate mean statistically significant differences.

Table 2— Effects of finishing processes on tensile properties of the woven and warp-knitted terry fabric

Sample	Tensile strength, N						Elongation at break — warp direction, %					
	Warp direction			Weft direction			Warp direction			Weft direction		
	μ	σ	Change %	μ	σ	Change %	μ	σ	Change %	μ	σ	Change %
						Woven fabric						
1	390	148.71	N/A	288	53.77	N/A	6.93	0.48	N/A	7.29	0.31	N/A
2	398	152.15	1.94	363	87.4	25.89	11.65	0.44	68.02	13.08	0.75	79.33
3	355	134.58	-10.79	326	77.72	-10.09	10.87	0.42	-6.65	12.95	0.53	-1.04
4	348	130.51	-2.01	310	78.97	-4.86	9.50	0.22	-12.62	12.35	0.59	-4.57
5	369	137.71	6.25	348	80.89	12.31	9.65	0.12	1.57	13.23	0.44	7.09
6	357	134.15	-3.38	366	97.28	4.96	11.39	0.22	18.08	13.14	0.81	-0.68
7	366	138.88	2.59	301	68.62	-17.69	9.92	0.50	-12.94	9.88	1.15	-24.79
						Weft-knitted fabric						
1	222	26.67	N/A	284	30.81	N/A	33.39	2.94	N/A	47.20	2.66	N/A
2	226	17.18	1.73	290	46.12	2.16	36.37	1.33	8.9	48.27	4.30	2.3
3	180	34.26	-20.29	242	30.67	-16.38	32.34	1.71	-11.1	45.40	2.80	-5.9
4	210	17.86	16.55	259	70.06	6.77	36.02	2.49	11.4	45.45	5.54	0.1
5	210	21.81	0.28	309	23.46	19.28	33.82	1.49	-6.1	50.14	1.55	10.3
6	181	17.04	-14.01	271	11.55	-12.34	36.70	2.01	8.5	45.43	1.28	-9.4
7	236	25.57	30.27	335	33.9	23.68	39.76	2.78	8.4	53.57	5.70	17.9

Underlined figures indicate mean statistically significant differences

Table 3—Effects of finishing processes on some mechanical properties of the woven and warp-knitted terry fabric

Sample	Burst strength, kPa			Tear strength, N					
				Warp direction			Weft direction		
	μ	σ	Change %	μ	σ	Change %	μ	σ	Change %
Woven fabric									
1	878	34.31	N/A	62	6.23	N/A	53	2.96	N/A
2	878	11.39	-0.03	65	5.91	4.50	45	4.23	-14.39
3	920	14.57	4.76	57	2.49	-12.33	44	2.7	-3.33
4	767	41.16	-16.65	57	1.85	0.09	39	2.78	-11.54
5	761	63.88	-0.71	56	1.32	-1.83	41	2.04	5.29
6	859	27.97	12.85	64	5.03	15.36	42	5.14	2.79
7	852	58.28	-0.83	62	6.23	-26.18	34	6.05	-18.89
Weft-knitted fabric									
1	600	11.49	N/A	25	1.98	N/A	28	1.79	N/A
2	642	26.58	6.98	28	1.28	14.49	30	1.36	7.93
3	678	30.22	5.54	25	1.18	-10.89	30	1.73	0.63
4	653	25.08	-3.62	28	1.61	11.87	32	2.14	4.95
5	626	36.42	-4.14	26	1.42	-6.10	32	1.48	-0.06
6	695	20.15	10.96	27	2.07	3.48	33	2.67	4.27
7	671	28.16	-3.45	26	1.52	-4.45	29	2.85	-10.69

Underlined figures indicate mean statistically significant differences.

were subjected to conditioning at 22°C and 65% RH for at least 24 h prior to characterization processes. Unless stated otherwise, tests were carried out using a set of 5 specimens from each sample prepared for determination of fabric properties.

Fabric mass per unit area was determined as per TS 251 method. Mass per unit area of woven fabrics was determined by weighing samples of 100 cm^2 area each to the precision of 0.001 g.

Tear strength of the fabrics was measured according to TS EN ISO 13937-2 method using samples of the size 50 mm × 200 mm. Measurements were conducted in both warp and weft directions using Tinius Olsen H10KT(R) tester equipped with QMat for Textiles(R) software. The crosshead speed was maintained at 100 mm/min and the gauge length was set at 100 mm.

Tensile strength and elongation-at-break values were measured according to TS EN ISO 13934-1 method using samples of the size 50 mm × 300 mm and then subjected to test in both warp and weft directions. The measurements were carried out using Tinius Olsen H10KT(R) Tester equipped with QMat for Textiles(R) software. The crosshead speed was maintained at 100 mm/min, the gauge length set at 200 mm and a pre-load of 5 N was applied during the measurements.

Bursting strength was measured according to TS EN ISO 13938-2 method using samples of the size 140 mm × 140 mm for measurement.

Tests for dimensional changes during washing and drying were conducted according to TS 5720 EN ISO 6330 method using samples of the size 500 mm × 500 mm. Washing was carried out at 40 ±3°C for 47 min in a wascator machine using detergent ECE without optical whitening agent. The loading weight was kept at 2000±100 g. The fabrics were dried by laying flat on the ground.

Water absorption of terry fabrics was determined according to TS 866 method using samples of the size 500 mm × 500 mm. According to the testing procedure, the fabric sample was placed horizontally on a cup of distilled water and the time taken for the sample to sink (i.e. to completely wet the fabric with water) was recorded with the help of a chronometer.

For the statistical analysis, the observed data were subjected to single-factor and two-factor replicated analysis of variance at α: 0.05 significance level.

3 Results and Discussion

3.1 Effect of Bleaching

The basis weight of both woven as well as warp knitted terry fabrics increases on bleaching as shown in Fig. 2(a) (p values = 1.07×10^{-7} and 2.5×10^{-9} respectively). This is presumed to be due to the shrinkage resulting from relaxation of the fabric from weaving or knitting tensions. Karahan *et al.*[3] also reported occurrence of shrinkage on application of wet treatment. As for the dimensional change after washing and drying, the greige fabric is found to contract by 8.30% and 8.86% respectively in the warp and the weft directions, whereas the bleached fabric is found to contract just by 1.2% only in the warp direction (Fig. 3). In the case of warp-knitted fabric, the greige fabric encounters a contraction of 5.10%

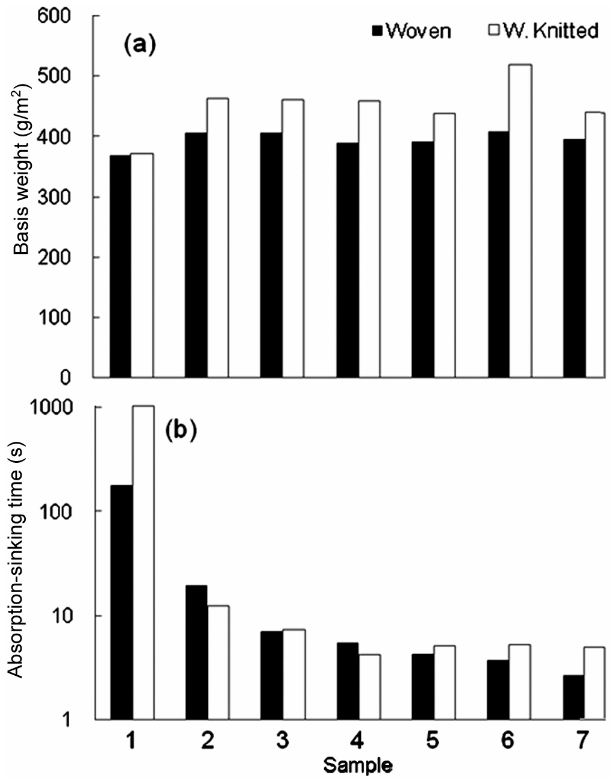

Fig. 2—Effect of finishing processes on (a) basis weight and (b) absorption rate (sinking time) of the woven and warp knitted terry fabrics

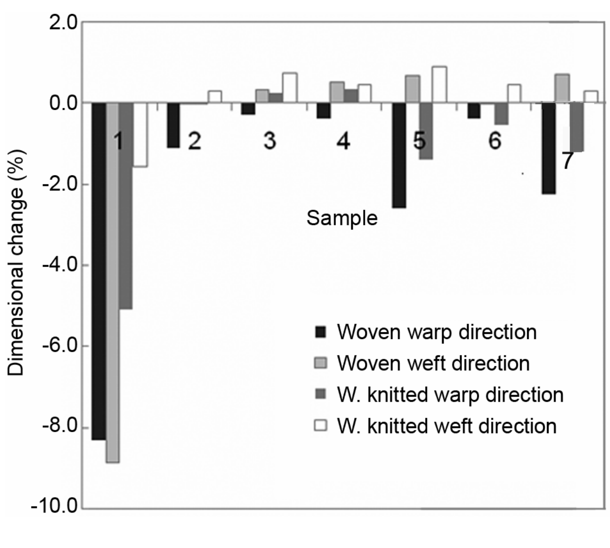

Fig. 3—Effect of finishing processes on the dimensional change of the woven and warp knitted terry fabrics after washing and drying

and 1.56% respectively in the warp and weft directions. The bleached fabric expands by 0.3% only in the warp direction, suggesting a relaxation of tensions during bleaching. The higher values observed in case of increase in the basis weight of the warp knitted fabric [Fig. 2(a)], might be attributed to the shrinkage of synthetic threads due to exposure to elevated temperatures.

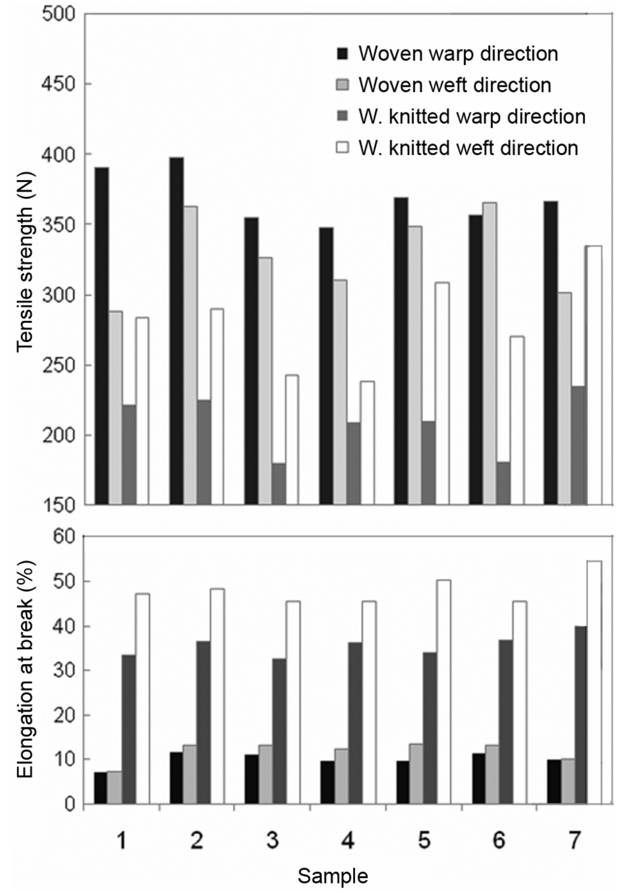

Fig. 4—Effect of finishing processes on the tensile strength and elongation-at-break values of the woven and knitted terry fabrics

As expected, the water absorption rate is found to be substantially higher for bleached fabric compared to that for the greige fabric. The supportive data are obtained by comparing the sinking time which drops from 178 s to 19 s ($p = 2.7\times10^{-7}$) for the woven fabric and from 1022 s to 12 s ($p = 5.97\times10^{-7}$) for the warp knitted fabric as depicted in Fig. 2(b). This may be attributed to the removal of size and other hydrophobic materials such as waxes from the surface of the threads. Kavitha and Selvakumar[13] also reported similar reduction in sinking time for cotton fabrics due to scouring.

Interestingly, the tensile strength of the woven fabric is found to increase upon bleaching, and the effect is more pronounced in the weft direction as compared to that in the greige fabric ($p = 0.002$) (Fig. 4). This may be due to the fact that the sizing material on the fabric results in a decrease in elongation and thus renders the greige fabric brittle.

The terry fabric get rid of this brittleness during desizing and bleaching process, and substantial increase in elongation-at-break is observed both in warp and weft directions as compared to greige fabric ($p = 1.69\times10^{-16}$) (Fig. 4). However, no statistically significant change in the tensile strength of warp knitted fabric is observed due to bleaching.

3.2 Effect of Biopolishing Process

Upon processing with the biopolishing agent, the woven pile fabric faced approximately 10% decrease in tensile strength in both warp and weft directions and 8% decrease in the elongation-at-break in warp direction (p values = 6.47×10^{-3} and 0.055 respectively). Similarly, a fall in tearing strength occurs especially in the warp direction (p=0.01), as shown in Fig. 5. In the case of warp-knitted fabric, 16 – 20% loss in tensile strength and 5-11% decrease in elongation-at-break values are observed (p values = 0.003 and 0.007 respectively). Also, the tearing strength in warp direction diminishes (p value = 0.01). The observed decrease in the tensile as well as tearing strengths is presumably due to the loss of strength and elasticity of cellulosic fibres brought about by the hydrolytic activity of enzymes. A similar decrease in strength and elasticity of cellulosic fibres due to enzymatic treatments is also reported by Yılmaz[14]. The loss of tenacity in cotton yarns upon enzymatic treatment is found by Tyagi *et al.*[15]. The biopolishing process results in an increase in water absorption rate as the sinking time of the fabric decreases from 19 s to 6 s in the case of woven fabric and from 12 s to 7 s in the case of warp-knitted fabric (p values = 2.09×10^{-5} and 0.002 respectively).

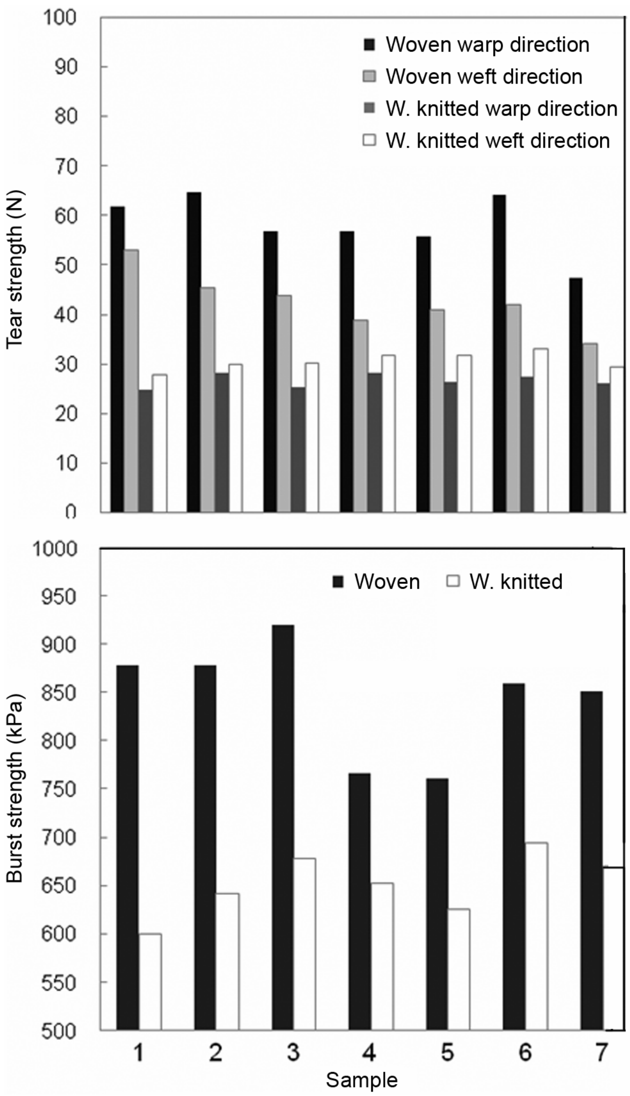

Fig. 5—Effect of finishing processes on the tear strength and burst strength of the woven and knitted terry fabrics

3.3 Effect of Dyeing and Neutralization

Dyeing and neutralization result in 4% decrease in the basis weight in woven fabric, whereas no statistically significant difference is marked for the warp-knitted pile fabric (p values = 1.4×10^{-4} and 0.69 respectively). The fabric samples extracted after dyeing and neutralization stage show contraction slightly in warp direction and lengthening slightly in the weft direction upon washing and drying, while no dimensional changes are observed for warp-knitted fabric.

While the dyeing and neutralization processes do not have a significant effect on the tensile strength of the woven fabric (p = 0,38), some decline in elongation behavior is noted ($p = 4.1\times10^{-5}$). In the case of the warp-knitted fabric no significant difference is observed in tensile strength and elongation-at-break values (p values = 0.47 and 0.20 respectively). The mentioned process results in a decrease in bursting strength of the woven terry fabric from 920 kPa to 767 kPa (Fig. 5), whereas no significant effect is observed for warp knitted fabric (p values = 5.04× 10-5 and 0.20 respectively). This finding is in agreement with the tensile strength and elongation analysis. There is some evidence that the process affects water absorption rate of the woven and warp-knitted fabric positively (p values = 0.09 and 0.002 respectively).

3.4 Effect of Washing after Dyeing and Neutralizing

The washing after dyeing and neutralization does not have a significant effect on the basis weight of the fabric (p=0.78). The washing process results in an increase in the tensile strength of the woven and warp-knitted fabric (p values = 0.009 and 0.04 respectively) and shows increase only in the elongation of the woven fabric (p=0.004). This might have been due to the increase in elasticity that comes with the removal of neutralization salts from the fabric structure during washing.

3.5 Effect of Softening

The treatment of the fabric with the softening agent results in 5% and 20% increase in the basis weight of the woven and warp knitted fabric in consecutive order (p values = 3.94×10^{-4}) and 1.26×10^{-5} respectively). The higher increase for the warp-knitted fabric might be due to greater contraction which comes with the higher flexibility of the knitting structure as compared to woven structure. The tear strength of the fabric increases especially in warp direction, accordingly p = 0.005. The bursting strength of the woven fabric increases from 761 kPa to 859 kPa (p = 0.01) and that of the warp-knitted fabric increases from 626 kPa to 695 kPa (p = 0.06), which occurs likely due to more uniform load distribution that comes with the softening of fabric threads.

3.6 Effect of Tumbling and Ram

The finishing process results in 3% decrease in basis weight of woven fabric (p = 0.006) and 15% decrease in warp-knitted fabric. This might be due to the dimensional adjustment of the fabric carried out during this process. A slight increase in water absorption has occurred, as indicated by the decrease in sinking time from 3.7 s to 2.6 s (p=0.02) for the woven fabric, while no significant difference is detected for the warp-knitted fabric.

3.7 Comparison of Woven and Warp-knitted Terry Fabrics

When the properties of woven and warp-knitted terry fabrics are compared, it is found that the woven fabrics have greater tensile, tear and bursting strength as compared to the knitted one. On the other hand, warp-knitted terry fabrics show higher values of elongation-at-break than that of the woven fabrics. These findings corroborate with the data reported by Anand and Smith[5]. While tensile and tear strengths of woven fabrics are higher in the warp direction as compared to those in the weft direction, of the same for warp-knitted fabrics are higher in weft direction.

Conclusion

Terry fabrics have been produced by weaving or warp knitting and subjected to finishing processes which are commonly applied by the textile industry. Samples have been withdrawn at different stages of the finishing processes for evaluation and comparison of water absorption behavior, structural parameters, and mechanical properties. Basis weight and dimensional stability of the terry fabrics are found to increase during finishing processes due to shrinkage which comes with relaxation. Water absorption rate increases with the removal of size and other hydrophobic substances. Elongation ratio increases during pretreatment because of the elimination of size film. Woven terry fabrics exhibit higher strength values, while warp-knitted terry fabrics show higher elongation rates.

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