EFFECT OF PILE YARN TYPE ON ABSORBENCY, STIFFNESS, AND ABRASION RESISTANCE OF BAMBOO/COTTON AND COTTON TERRY TOWELS

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Abstract. This study compared absorbency, stiffness, and abrasion resistance characteristics of bamboo/cotton and cotton terry towels. Bamboo/cotton terry towels were woven with bamboo pile yarn, which has been commonly used in textiles in recent years, whereas cotton terry towels were woven with cotton pile yarns. Desized woven terry towels without dye or any further finishing treatments were produced under industrial conditions. Effects of pile yarn type and pile height on physical and mechanical properties of fabrics were compared using analysis of variance. Design Expert 6.01 (Stat-Ease, Inc., Minneapolis, MN) was used for statistical analyses. It was found that abrasion of towels with bamboo pile yarn was higher than that of towels with cotton pile yarn at high abrasion cycles, whereas stiffness of bamboo/cotton towels was lower than that of cotton towels. Also, it was found that sinking time of terry towels with cotton pile yarn was longer than that of towels with bamboo pile yarn.

Keywords: Bamboo, cotton, terry towel, stiffness, absorbency, abrasion.

INTRODUCTION

Terry towel fabrics originated in Turkey and were first manufactured in hand weaving machines. This technique of weaving towels was further refined in European countries in the middle 19th century (Hobson 1990). A terry towel is described as a textile product with loop pile on one or both sides. There are three types of yarns used in terry towels, namely the ground warp yarn, the weft yarn, and the pile yarn. Quality of terry towel fabrics is determined by water retention; properties of pile warp, ground warp, and weft yarns; and pile height and strength (Anon 2007).

Terry towel fabrics should have high water absorption, good color fastness, and dimensional stability (Schramek 2009). Pile height has a significant effect on water retention capacity (Petrulyte and Naslenience 2010) and also water absorption levels of terry towel fabrics depending on fabric type and applied finishing procedure as well as the characteristics of the fabrics (Petrulyte and Baltakyte 2009). Previous research showed that water absorption occurred faster in towels that underwent a softening procedure (Petrulyte and Baltakyte 2008).

Yarn type is the most important factor for the dynamic water absorption property of a terry towel. One-ply yarns absorb water faster than two-ply yarns. Pile height and warp and weft density are not as effective on water absorption of terry towel fabrics as yarn type (Karahan 2007). Increased warp and weft density decreases water absorption percentage, whereas increased pile height increases water absorption percentage (Karahan and Eren 2006).

Recently, bamboo fiber began to be commonly used in terry towels. Because bamboo contains bamboo extract, a substance called Bamboo kun, it is difficult for disease-inducing organisms or insects to affect this plant. Therefore, bamboo is grown naturally without pesticides (Wallace 2005). Bamboo fiber is an environmentally friendly fiber. It is renewable and fast growing (Yueping et al 2010) and is a relatively smooth antibacterial fiber with low pilling and wrinkling with high moisture–sweat absorption and air permeability (Bambrotex 2007) because of micro-gaps in its profile (Gökdal 2007). Bamboo fiber

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is made from the starchy pulp of bamboo plants. In fact, bamboo fiber is a kind of regenerated cellulose fiber produced from raw materials of bamboo pulp. First, bamboo pulp is refined from bamboo through a process of hydrolysis alkalization and multiphase bleaching. Then bamboo pulp is processed into bamboo fiber. Repeated tests have proved it has strong durability, stability, and tenacity. The thinness and whiteness degree of bamboo fiber is similar to classic viscose (Bambrotex 2007).

Bamboo fabrics require less dyestuff than cotton fabrics to be dyed at the desired level. They absorb the dyestuff better and faster and show color better (Wallace 2005). Bamboo textile products have high demand in the market because of their antibacterial nature, biodegradable properties, high moisture absorption capacity, breathability, and fast drying behavior. Bamboo fiber ensures comfort in various applications (Majumdar et al 2011).

A review of the literature revealed that previous studies mainly concentrated on water absorption properties of cotton and linen terry towel fabrics and on comparison of cotton and bamboo yarns. There have not been enough studies on comparing cotton and bamboo/cotton towels and on the lifespan of terry towels. The objective of this study was to investigate water absorption and stiffness properties of bamboo and cotton terry towels and to indicate terry towel lifespan and durability with abrasion resistance tests. Effects of pile height and pile yarn type on water absorption, stiffness, and abrasion resistance were investigated.

MATERIALS AND METHODS

Bamboo fiber was purchased from a company in China and was converted into yarn and then fabric. Terry towel fabrics were manufactured in a three-weft system Vamatex hooked towel-weaving machine (Promatech Manufacturing & Trading Co., Bhilwaraat, India) with six different pile heights with constant densities of 17 weft/cm and 13 warp/cm. Desized woven terry towels without dyeing or any further finishing treatments were used for this study.

Breaking strength and elongation and determination of twist tests were performed on pile yarns according to TS (2010) and TS (2008a), respectively. The tests were performed on terry towel fabrics after the desizing process. Table 1 indicates yarn types used in the production of terry towels. Table 2 indicates breaking strength and elongation and twist values of cotton and bamboo pile yarns used in terry towels. Table 3 indicates pile height, pile/ground weight ratio, and mass values of terry towel fabrics. For pile heights, subindex references from 1 to 6 were used and the codes are presented in Table 3. These codes are also used in Figs 1-3. Terry towel samples were conditioned in standard atmospheric conditions for 24 h in accordance with TS (2008b). Mass loss caused by abrasion (%), stiffness, and sinking time were determined according to TS (2001) (9 kPa pressure), TS (1973), and TS (2007), respectively. Five samples were used for each test. Abrasion resistance of the fabrics was measured in a Martindale abrasion resistance device (SDL Atlas Ltd.) according to TS (2001) under 9 kPa mass pressure. The measurement was based on the principle of mass loss (%). Absorbency tests of the fabrics were calculated according to TS (2007). Five samples of $100 \pm 1 \times 100 \pm 1$ mm dimensions were cut, and one surface of the test sample was properly spread on the water surface. Then the chronometer was turned on. Time required for complete sinking of the test sample was recorded. The arithmetic mean of sinking times

Table 1. Yarn types used in terry towel production.

	Pile warp yarn	Ground warp yarn	Weft yarn
Cotton towel	100% cotton 36.87 tex Ring spun	100% cotton 29.5 × 2 tex Ring spun	100% cotton 36.87 tex Ring spun
Bamboo/cotton towel	100% bamboo 36.87 tex Ring spun	100% cotton 29.5 × 2 tex Ring spun	100% cotton 36.87 tex Ring spun

Table 2. Strength properties and twist numbers of pile yarns.

	Breaking strength (cN/tex)	Breaking elongation (%)	Twist per meter
100% cotton	16.55	5.25	582
100% bamboo	17.15	8.15	567

Table 3. Pile height, pile/ground weight ratio, and mass values of terry towel fabrics.

Terry towels fabric code	Pile height (mm)	Pile/ground weight ratio	Mass per unit area (g/m^2)
C_1	5.4	1.58	417.1
C_2	6.0	1.74	439.1
C_3	6.4	1.84	459.1
C_4	7.1	1.95	506.5
C_5	8.0	2.25	549.4
C_6	9.0	2.46	574.9
B_1	5.4	1.67	432.3
B_2	6.0	2.00	459.9
B_3	6.4	2.10	480.5
B_4	7.1	2.19	517.3
B_5	8.0	2.37	564.4
B_6	9.0	2.65	578.5

B, bamboo; C, cotton.

of test samples obtained from each series of five tests was calculated in seconds. Fabric stiffness was measured using a Shirley stiffness tester (Tonny International Co., Dongguan, Guangdong, China) according to TS (1973). The Shirley stiffness tester based on the cantilever principle was used to measure bending properties. The stiffness indicated the stiffness of terry towel fabrics. Stiffness is resistance to bending rigidity under its own weight. The arithmetic mean of stiffness of test samples was obtained from each series of five tests.

Analysis of variance (ANOVA) was used to analyze interactions among independent variables and how these interactions impact the dependent variable. Relationships among variables were evaluated with one-way and two-way ANOVA tests. One-way ANOVA produced data for a quantitative dependent variable by a single factor (independent) variable (Field 2005). Two-way ANOVA produced data for one dependent variable by two independent variables. One-way ANOVA was used for stiffness and sinking time characteristics, and two-way ANOVA was used for abrasion resistance property of terry towels. Experimental test results were used to formulate predictive equations for abrasion resistance, stiffness, and sinking time. ANOVA was performed

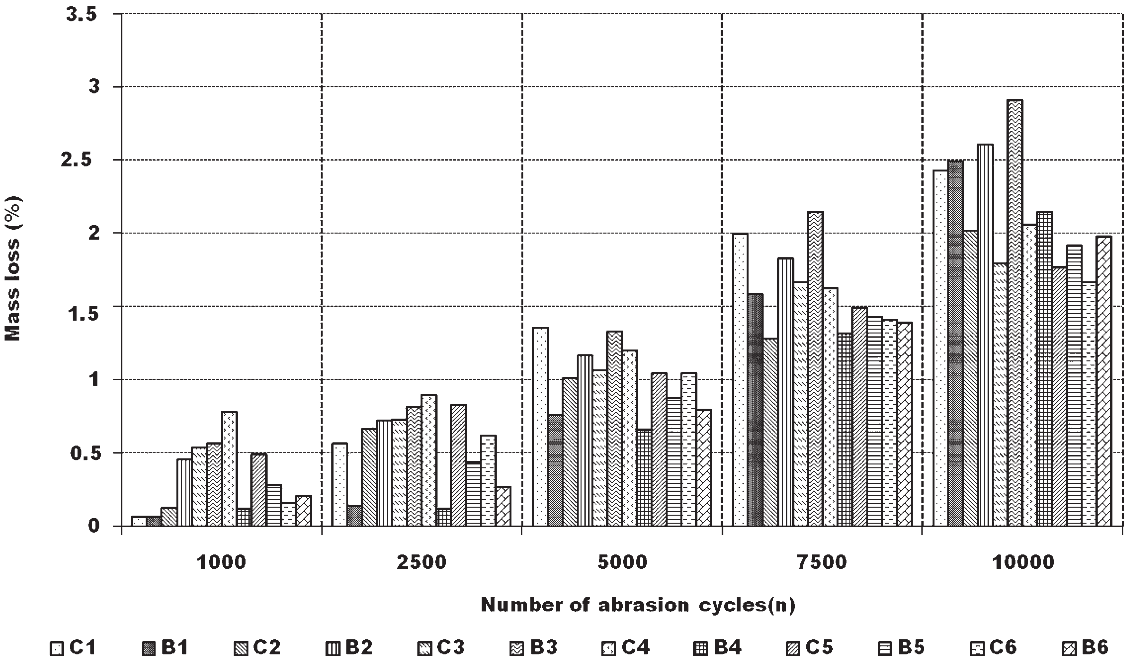

Figure 1. Mass loss of terry towel fabrics according to abrasion cycles (C, cotton; B, bamboo).

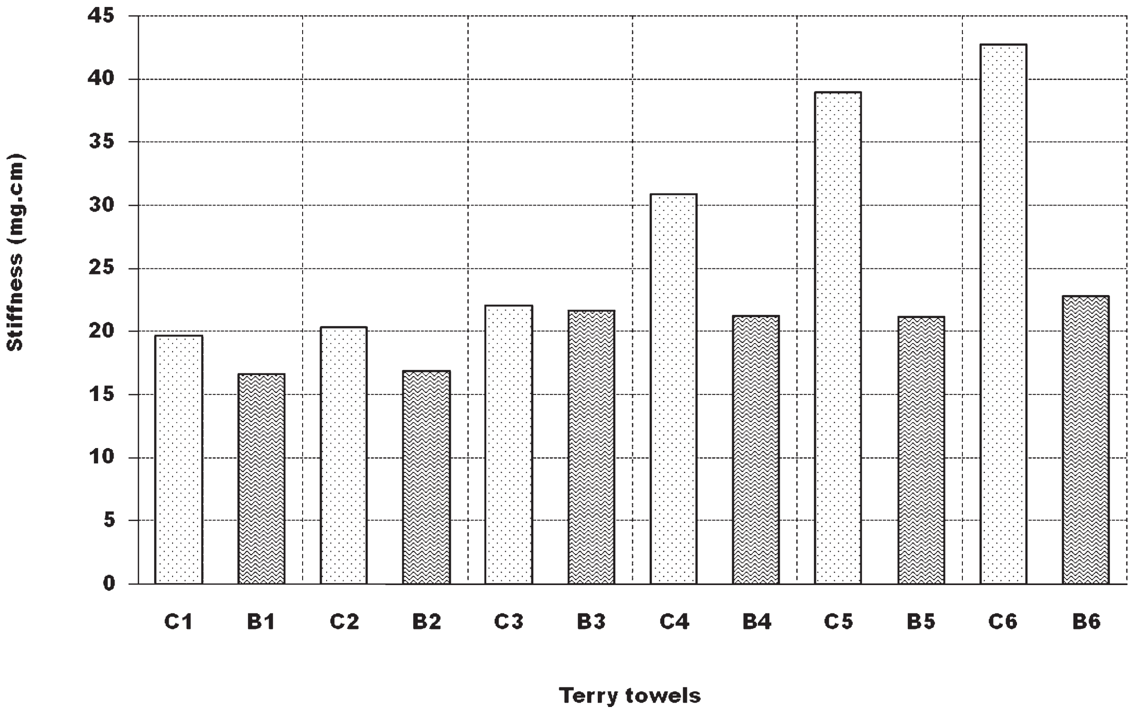

Figure 2. Stiffness of terry towels.

on the test results (at a significance level of 5%). Table 4 shows dependent and independent variables used in the mathematical equations.

RESULTS AND DISCUSSION

Test results and evaluations for abrasion resistance, stiffness, and absorbency properties are subsequently presented.

Abrasion Resistance Measurements

Abrasion resistance results of terry towel fabrics, calculated according to mass loss, are shown in Fig 1. ANOVA results are presented in Table 5. Figure 1 shows that abrasion level of terry towels manufactured with bamboo and cotton pile yarns of the same pile height did not follow a specific pattern. Analysis of mass loss (%) caused by abrasion after 10,000 cycles showed that the mass loss of bamboo pile towels was higher than that of cotton pile towels of the same pile height. It was observed that after 1000-7500 cycles, mass loss was sometimes higher in towels with cotton pile and sometimes in towels with bamboo pile. In this case, it can be stated that terry towels with bamboo pile displayed greater wear with long-term use. Mass loss of sample fabrics after 1000, 2500, 5000, and 7500 cycles was similar. Differences occurred after 10,000 cycles. The reason may be that bamboo yarn has fewer twists than cotton yarn, and fibers of bamboo yarn are exposed more easily during abrasion.

As a result of statistical analyses (Table 5), mathematical equations (Eqs 1 and 2) explaining the relationships between selected independent variables (abrasion cycle, pile yarn, and pile height) and the dependent variable mass loss caused by abrasion (%) were obtained. Coefficient of determination, R^2, of the model was 0.826. The model was statistically significant ($p < 0.001$). Independent variables explained 83% of abrasion resistance. Statistical analyses indicated that independent variables (P_H, A_N, $P_Y A_N$, $P_H A_N$) had

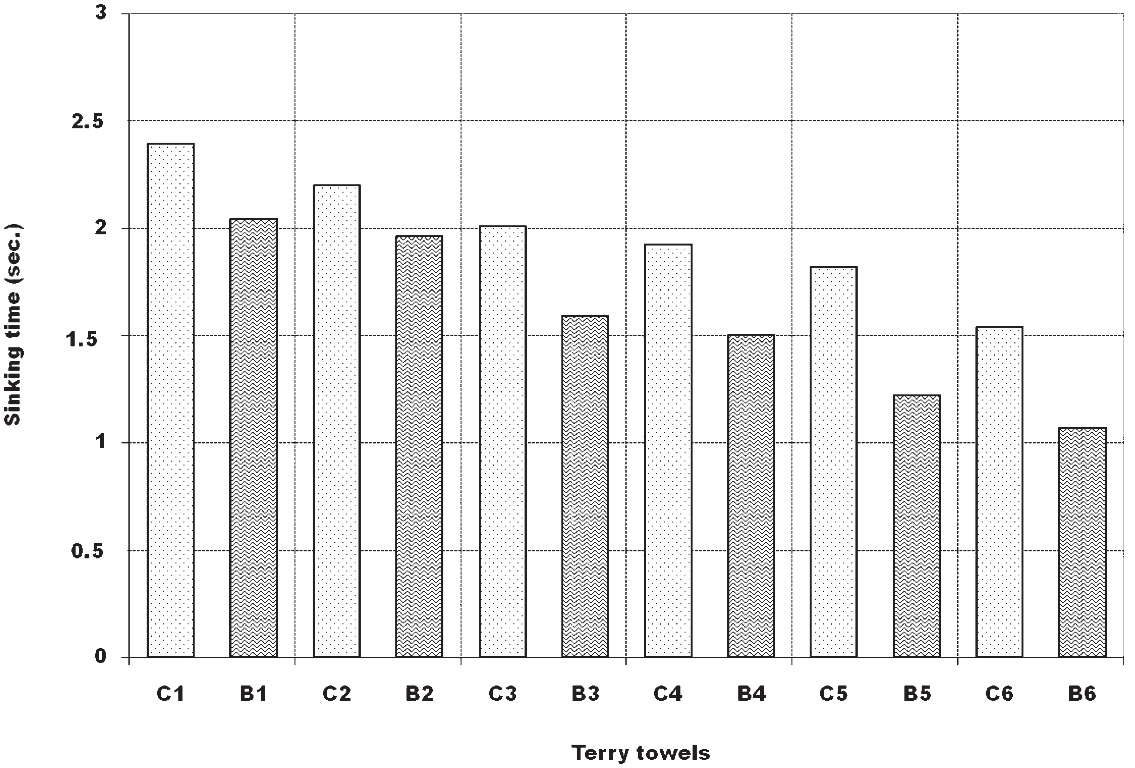

Figure 3. Sinking time of terry towels (C, cotton; B, bamboo).

significant effects on friction strength (for the significance level of a = 0.05) (Table 5).

$$A_{Rc} = -0.5327 + 0.1153 \times P_H + 0.0004 \times A_N - 3.2793E - 05 \times P_H \times A_N \quad (1)$$

$$A_{Rb} = -0.4065 + 0.0376 \times P_H + 0.0004 \times A_N - 2.2060E - 05 \times P_H \times A_N \quad (2)$$

where A_{Rc} is the abrasion resistance mass loss (%) equation of terry towels with cotton pile; A_{Rb} is the abrasion resistance mass loss (%) equation of terry towels with bamboo pile.

Table 4. Dependent and independent variables.

Dependent variables	Independent variables
Abrasion resistance (A_R)	Pile yarn (P_Y)
Sinking time (S_T)	Pile height (P_H)
Stiffness (S_R)	Number of abrasion cycles (A_N)

Determination of Stiffness (bending rigidity)

Stiff fabrics do not bend as easily as soft fabrics. Stiff fabrics have high resistance to bending. Results of terry towel fabric stiffness are shown in Fig 2. ANOVA results are shown in Table 6. Stiffness of 100% cotton terry towels was higher than that of bamboo/cotton terry towels of the

Table 5. Analysis of variance test for abrasion resistance.

Source	DF	F value	*p* value
Model	7	112.67	<0.0001
P_Y	1	1.237	0.2677
P_H	1	14.06	0.0002
A_N	1	657.98	<0.0001
P_Y P_H	1	0.22	0.6387
P_Y A_N	1	20.54	<0.0001
P_H A_N	1	19.83	<0.0001
P_Y P_H A_N	1	0.76	0.3849
R^2		0.826	
SD		0.317318	

DF, degrees of freedom; SD, standard deviation.

Table 6. Analysis of variance test for stiffness.

Source	DF	F value	p value
Model	3	62.54	<0.0001
P_Y	1	80.54	<0.0001
P_H	1	87.92	<0.0001
$P_Y P_H$	1	32.91	<0.0001
R^2		0.8279	
SD		3.677671	

DF, degrees of freedom; SD, standard deviation.

same pile height (Fig 2). Bamboo fiber is rounder and smoother than cotton fiber and has lower stiffness than cotton fibers. For this reason, bamboo pile terry towels are softer than cotton pile terry towels. As pile height decreased, towel stiffness decreased.

As a result of statistical analyses, Eqs 3 and 4 were obtained, which explain the relationship between selected independent variables pile yarn and pile height and the dependent variable stiffness. Coefficient of determination (R^2) of the model was 0.8279. The model was statistically significant ($p < 0.001$). Independent variables explained 83% of the variation in stiffness.

$$S_{Rc} = -10.3157 + 5.3802 \times P_H \qquad (3)$$

$$S_{Rb} = -10.7482 + 1.2957 \times P_H \qquad (4)$$

where S_{Rc} is stiffness of terry towels with cotton pile; S_{Rb} is stiffness of terry towels with bamboo pile.

Water Absorption Property

Results for terry towel sinking time are shown in Fig 3. ANOVA results are shown in Table 7. Figure 3 shows that sinking time of terry towels with cotton pile was longer than that of towels with bamboo pile. It was observed that as pile height of both towels increased, sinking time decreased. It was concluded that surface area to absorb water increased with increasing pile height and decreased sinking time. Results are consistent with a previous study (Koc and Zervent 2006). Absorbency of bamboo pile terry towels was higher than that of cotton pile terry towels. A cross-section of bamboo fiber shows many microgaps and microholes.

Table 7. Analysis of variance test for sinking time of terry towels.

Source	DF	F value	p value
Model	3	125.52	<0.0001
P_Y	1	160.04	<0.0001
P_H	1	274.34	<0.0001
$P_Y P_H$	1	10.91	0.0025
R^2		0.9285	
SD		0.094729	

DF, degrees of freedom; SD, standard deviation.

As a result of statistical analyses, Eqs 5 and 6 were obtained, which explain the relationship between selected independent variables pile yarn and pile height and the dependent variable sinking time. Coefficient of determination (R^2) of the model was 0.9285. The model was statistically significant ($p < 0.001$). Independent variables explained 93% of the variation in sinking time. Statistical analysis indicated that independent variables P_Y, $P_{H,}$ and P_YP_H had a significant effect on sinking time of towels (for a significance level of a = 0.05) (Table 6).

$$S_{Tc} = 3.4974 + 0.2173 \times P_H \qquad (5)$$

$$S_{Tb} = 3.8041 + 0.3255 \times P_H \qquad (6)$$

where S_{Tc} is sinking time of towels with cotton pile; S_{Tb} is sinking time of towels with bamboo pile.

CONCLUSION

In this study, effect of pile yarn type and pile height of terry woven fabrics on fabric performance properties was examined. The results listed subsequently were obtained from evaluation of physical and mechanical tests performed on the fabrics.

Abrasion resistance caused by mass loss was measured and compared between cotton and bamboo pile terry towels. Sometimes cotton and sometimes bamboo pile terry towels showed poor resistance to abrasion up to 10,000 cycles, but bamboo pile terry towels showed poor resistance to abrasion compared with cotton pile terry towels after 10,000 cycles. Future studies may focus on increasing abrasion cycles to determine if cotton or bamboo pile yarn provides more resistance to abrasion.

Stiffness of terry towels generally increased with an increase in pile height. Stiffness of bamboo pile terry towels was less than that of cotton pile terry towels. This shows that bamboo pile terry towels were softer than cotton pile terry towels.

Water absorption in terms of sinking time was greater in bamboo pile terry towels than in cotton pile terry towels. Pile height was proportional to sinking time. Sinking time for both kinds of terry towels decreased with increase of pile height.

Terry towels with bamboo pile yarns have superior properties with the exception of abrasion resistance compared with 100% cotton terry towels, but the price of bamboo fiber is nearly twice the price of cotton fiber. Terry towels produced from bamboo yarns probably will not replace cotton terry towels unless the price of bamboo fiber decreases.

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