A Comparative Analysis of Towels Produced From Twisted and Twistless Cotton Pile Yarns in Terms of Absorptive Capacity and Flexural Rigidity

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ABSTRACT

The study compares cotton towels produced from twisted and twistless cotton pile yarn. The towels were manufactured with different weft density, different weft yarn counts, and different pile heights. The water absorptive capacity, absorbency time and flexural rigidity properties of twisted pile towels were compared with those of twistless pile towels. The test results were evaluated using statistical analysis. Effects of twisted and twistless pile yarn, pile height, weft density, and weft yarn count on absorptive capacity, absorbency time, and flexural rigidity of fabrics were examined using analysis of variance (ANOVA). The results indicate that the towels woven with twistless pile yarns have greater absorptive capacity, longer absorbency time, and lower flexural rigidity than towels woven with twisted pile yarns.

INTRODUCTION

Towels are woven with three different yarns: weft, warp, and pile [1]. Pile heights and pile yarn features of towel fabrics have a significant role in their absorptive characteristics [2].

The absorptive capacity of towel fabrics depends on pile height [3-5], weft -warp density [3,5], and the yarn type used [5]. An increase in the pile height of fabrics results in an increase in static absorption rate [4]. However, pile height and weft–warp density have less effect than yarn type on water absorption [3]. An increase in weft and warp density causes a decrease in water absorption rate. In addition, increased weft and warp density has less effect than pile height on absorptive capacity [5]. An increase in pile height reduces the absorbency time of towel fabrics High absorptive rates can be achieved by increasing the surface area of pile yarns, and using fewer twisted cotton yarns as warp yarns [6-8]. Murphy and Macormac [9] reported that there is no effect of fabric weight on absorption rate. The absorption rate, absorbency time, and absorptive capacity of twistless towels are greater than those of twisted towels which has resulted in an increased demand for towels produced with twistless pile yarn [10].

The present study focused on cotton towels, because cotton pile yarn is commonly used in towels intended to provide rapid water absorption. Although the literature includes many studies examining cotton towels produced with twisted pile yarn, few studies have examined the use twistless pile yarn. This study compares towels produced from twisted and twistless pile yarn with different weft density, weft yarn count, and pile heights, in terms of water absorption capacity, absorbency time, and flexural rigidity.

MATERIAL AND METHOD

Material

The twistless pile yarns used in the present study were produced via the twilo twistless yarn production method. The adhesive used to bind the staple fibers in the yarn was PVA (polyviniyl alcohol) fibers. The PVA was later removed after the fabric was woven [11].

15 kinds of towels were produced using twisted and twistless pile yarns, with different pile heights, different weft density, different weft yarn count, with fixed warp yarn count, and warp yarn density. The fabrics were woven using a Picanol Gamma gripper weaving machine in accordance with industrial conditions. Woven towel fabrics were dyed with reactive dye in the same conditions. *Table I* shows the properties of yarns used to produce the towels, *Table II* shows some physical properties of towel fabrics, and *Figure 1* shows the ground pattern used for towel fabrics.

TABLE I. Properties of yarns used in the production of terry towels.

	Weft yarn	Pile warp yarn	Ground warp yarn
Towels with twisted pile yarn (Weft density=13-15 weft/cm)	100% Cotton 42.6 tex Ring spun	100% Cotton 36.87 tex Ring spun	100% cotton 29.5×2 tex Ring spun
Towels with twisted pile yarn (Weft density=24-27 weft/cm)	100% Cotton 34.7 tex Ring spun		
Towels with twistless pile yarn (Weft density=13-15 weft/cm)	100% Cotton 42.6 tex Ring spun	100% Cotton+PVA 36.87 tex Twilo	100% cotton 29.5 ×2 tex Ring spun
Towels with twistless pile yarn (Weft density=24-27 weft/cm)	100% Cotton 34.7 tex Ring spun		

TABLE II. Physical properties of fabrics.

Fabric Code*	Weft yarn, Tex	Weft density, weft/cm	Pile height, mm	Weight, g/m^2
T_1	42.6	14	32.60	294.01
T_2	34.7	25	32.37	338.20
T_3	42.6	13	50.30	367.92
T_4	34.7	25	54.35	441.52
T_5	42.6	14	74.73	480.98
T_6	34.7	26	71.03	514.58
T_7	42.6	14	84.57	540.21
T_8	34.7	25	89.87	617.75
ZT_1	42.6	14	32.27	298.11
ZT_2	42.6	14	40.40	378.76
ZT_3	34.7	27	52.08	423.85
ZT_4	42.6	14	72.00	482.70
ZT_5	34.7	27	74.40	521.74
ZT_6	42.6	15	87.03	550.65
ZT_7	34.7	26	82.73	590.12

*T= Towels with twisted pile yarn
ZT=Towels with twistless pile yarn

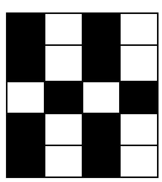

FIGURE 1. Ground pattern of towels.

Method

Towel fabrics were conditioned according to TS EN ISO 139 (2008) [12] standards, and their performance was assessed according to TS 1409 (1973) [13], TS EN 14697 (2007) [14] and ASTM D1117-80 (2009) [15].

Flexural Rigidity

Flexural rigidity is the resistance of products against bending. The feeling of toughness when touched indicates high flexural rigidity of textile products. The TS 1409 standard was applied for flexural rigidity of towel fabrics. Flexural rigidity value was derived from a rectangle-cut cloth, one side of which is defined as horizontal, from its horizontal state under its own weight [13].

Absorbency Time

Water absorbency time is the time required to completely wet a towel placed on the surface of water [14]. The TS EN 14697 standard was used to test absorbency of towel fabrics; five experimental sample were cut in (100 ± 1) mm × (100 ± 1) mm sizes, one side of each sample was spread on the water surface, and the time elapsed to thoroughly saturate the sample was recorded with a stopwatch. The arithmetic mean of absorbency times obtained from five experiments was calculated [14].

Water Absorptive Capacity

Absorptive capacity is the ratio of water held by the specimen to the weight of the dry specimen [15]. The absorptive capacities of towel fabrics were determined in accordance with standard ASTM D 1117, Samples were cut to 76 mm × 76 mm size, weighed, and then loosely placed in a cylindrical wire basket. The cylindrical wire basket was lowered into distilled water at temperature 20°C from a height of 25 mm. After the wire basket was completely submerged, samples were drained for 10 seconds and then re-weighed. The water absorptive capacities of the towel fabrics were calculated using Eq. (1) [15].

A is the sample weight before immersion (g), B is the sample weight after immersion (g) in Eq. (1).

$$Water\ absorptive\ capacity(\%) = \frac{(B-A)}{A} X100 \tag{1}$$

Statistical Analysis

ANOVA (Analysis of variance) was used to determine whether independent variables are effective on the dependent variables. Experimental test results were used to formulate predictive equations for flexural rigidity, absorbency time, and water absorptive capacity. The 0.05 level of significance was used in the statistical analysis. The experimental data were analyzed by using Design Expert 6.0.1 statistical software.

The descriptions of statistical terms used in *Table V-VII*, are given in *Table III. Table IV* illustrates the dependent and independent variables used in regression equations and the symbols used to represent the dependent and independent variables.

TABLE III.The definitions of statistical terms.

Term	Definition
p-value	It is the probability that the results of the study being due to only chance. If the p value is less than 0.05,the results are said to be statistically significant, conversely results are said to be not statistically significant when the p value is greater than 0.05[16].The results that the p values are greater than 0.05, are removed from the regression model.
R-squared	It is a statistical measurement of the strength of the correlation between the variables and ranges from 0 to 1. R^2 value close to 0 means, there is no correlation between the variables, in other words the independent variable does not predict the dependent variable. R^2 value close to 1 means, there is strong correlation between the variables, in other words the independent variable does help to predict the dependent variable [17].
Standard deviation	Standard deviation is the square root of the variance, is the average squared distance from the mean, and provides a measure of the standard distance from the mean[18].
F-Value	The term F value that is a statistics is given in F-tables for different probability levels. If the F-value calculated in the ANOVA is greater than the value in the F- tables, the independent factor or interactions expected to be significance at that probability or confidence limit [19].

TABLE IV. Dependent and Independent variables.

Dependent Variables	Independent variable	Variable Type
Flexural rigidity Absorbency time Water absorptive capacity	Pile yarn type(P_Y)	Categorical
	Pile height (P_H)	Numeric
	Weft yarn count (W_{Yc})	Numeric
	Weft density (W_{Yd})	Numeric

RESULTS AND DISCUSSION

Flexural Rigidity

Figure 2 illustrates the flexural rigidities of twisted and twistless terry towels. As seen in *Figure 2*, an increase in pile height in twisted and twistless towels, woven with the same weft yarn number and weft density, and different pile heights, results in an increase in flexural rigidity. The flexural rigidity of twistless towel fabrics with the same weft density, weft yarn number, and similar pile height values is lower than that of twisted towels. The flexural rigidity of both twisted and twistless towels increase as their weft density increase (*Figure 2*). *Table V* provides ANOVA test results for flexural rigidity.

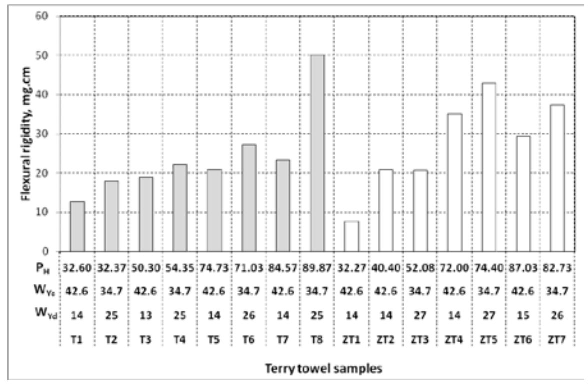

FIGURE 2. Flexural rigidity test results; P_H= pile height (mm), W_{Yc} = weft yarn count (tex), W_{Yd}= weft density (weft/cm), T= towels with twisted pile yarn, ZT=towels with twistless pile yarn.

TABLE V. Flexural rigidity (ANOVA).

Variance Source	F value	P-value (Significance)
Model	76.582	< 0.0001
P_Y	45.715	< 0.0001
P_H	314.883	< 0.0001
W_{Yc}	37.752	< 0.0001
W_{Yd}	31.510	< 0.0001
$P_Y * P_H$	41.861	< 0.0001
$P_H * W_{Yd}$	33.585	< 0.0001
R-Squared	0.935	
Standard deviation	3.29	

*at a level of 0.05 significance

As seen in *Table V*, the determination coefficient of the model is 0.935, indicating that the independent variables used to create the model of flexural rigidity can explain 94% of the observed variance. The coefficient of variable is highly statistically significant ($p < 0.0001$). The R^2 of 0.935 for flexural rigidity was considered relatively high. This indicates that there was a good agreement between the experimental value of flexural rigidity and the predicted one from this model.

Model F-value of the flexural rigidity of 76.582 implies that the model is significant, and there is only 0.01% chance Model F- value this large could occur due to noise. All independent variables and pile yarn type–pile height and pile height–weft density significantly affects flexural rigidity ($p < 0.0001$).

Model F-value of the flexural rigidity of 76.582 implies that the model is significant, and there is only 0.01% chance that a Model F- value this large could occur due to noise. Regression equations were created for towel fabrics with twisted and twistless pile yarns in order to predict flexural rigidity of the final product before weaving. These equations enable calculation of flexural rigidity before weaving, based on pile height, weft yarn count, and weft density factors.

Eq. (2) is the final regression equation of flexural rigidity (F_{R1}) in terms of actual values for towel fabrics woven with twisted pile yarn, and Eq. (3) is the final regression equation of flexural rigidity (F_{R2}) in terms of actual values for towel fabrics woven with twistless pile yarn.

$$F_{R1} = 576.702 - 0.163P_H - 10.748W_{Yc} - 8.239W_{Yd} + 0.0282P_H W_{Yd} \quad (2)$$

$$F_{R2} = 562.399 + 0.262P_H - 11.048W_{Yc} - 8.239W_{Yd} + 0.0282P_H W_{Yd} \quad (3)$$

Absorbency Time

An increase in weft density of towel fabrics with twisted piles reduces absorptive capacity, and an increase in weft density of towel fabrics with twistless pile yarns increases the absorbency time. Absorbency time of towels produced with twistless pile yarns is longer than that of towels with twisted pile yarn. *Table VI* shows ANOVA results for absorbency time.

An increase in pile heights of towels with twisted and twistless pile yarns with same weft density results in an increase in their absorbency time. However, this situation is not observed in towels with pile heights of more than 8 mm (*Figure 3*). However, several studies within the literature report that an increase in pile heights in towels with twisted piles decreases their absorbency time [6, 7]. The fact that the absorbency time of towels produced with twistless pile yarns is greater than those with twisted pile yarns may result from the greater surface area of twistless pile yarns due to their bulk, and therefore their ability to absorb water. It is also reported that towels with twistless yarns are softer and bulker, and are therefore preferred for absorption [10].

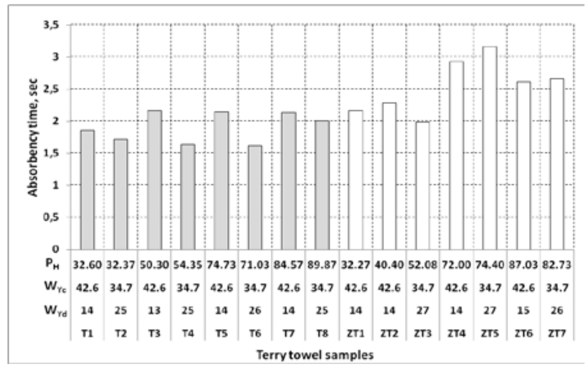

FIGURE 3. Water absorbency time; P_H= pile height (mm), W_{Yc} = weft yarn count (tex), W_{Yd}= weft density (weft/cm), T= towels with twisted pile yarn, ZT=towels with twistless pile yarn.

TABLE VI. Absorbency time (ANOVA).

Variance Source	F value	P-value (Significance)
Model	19.830	< 0.0001
P_Y	45.816	< 0.0001
P_H	34.502	< 0.0001
W_{Yc}	4.492	0.0461
W_{Yd}	6.238	0.0209
P_Y * P_H	9.161	0.0064
R-Squared	0.825	
Standard deviation	0.19	

*at a level of 0.05 significance

From *Table VI*, the model with a determination coefficient of 0.825 is statistically significant ($p < 0.0001$). The R^2 of 0.825 for absorbency time was considered relatively high. This indicates that there was a good agreement between the experimental value of absorbency time and the predicted one from this model. Model F-value of the absorbency time of 19.83 implies that the model is significant, and there is only 0.01% chance that a Model F- value this large could occur due to noise. Pile yarn type and pile height have a highly statistically significant affect on absorbency time ($p < 0.0001$). Weft yarn count and weft density significantly affect absorbency time ($p < 0.05$). There are significant interactions between pile yarn type and pile height ($p<0.05$). Regression equations were created for towel fabrics with twisted and twistless pile yarns in order to predict absorbency time, thereby permitting absorbency time to be predicted before weaving, based on pile height, weft yarn count, and weft density factors.

Eq. (4) is the final regression equation of absorbency time (T_{A1}) in terms of actual values for towel fabrics woven with twisted pile yarn, and Eq. (5) is the final regression equation of absorbency time (T_{A2}) in terms of actual values for towel fabrics woven with twistless pile yarn.

$$T_{A1} = 15.335 + 0.0056P_H - 0.255W_{Yc} - 0.201W_{Yd} \quad (4)$$

$$T_{A2} = 15.306 + 0.0169P_H - 0.255W_{Yc} - 0.201W_{Yd} \quad (5)$$

Water Absorptive Capacity

An increase in pile height of towels with twisted and twistless pile yarns produced with the same weft density produces an increase in their absorptive capacity. This result is consistent with information in the literature on twisted towels [4].

Towels produced with twistless pile yarns have greater water absorptive capacity (*Figure 4*), because twistless pile yarns have more surface area to absorb water due to their bulk. The literature reports that the twistless towels have greater water absorptive capacity. As the weft density of towel fabrics increases, their water absorptive capacity decreases; towels produced with twistless pile yarns were found to have greater water absorptive capacity than those produced with twisted pile yarns [10].

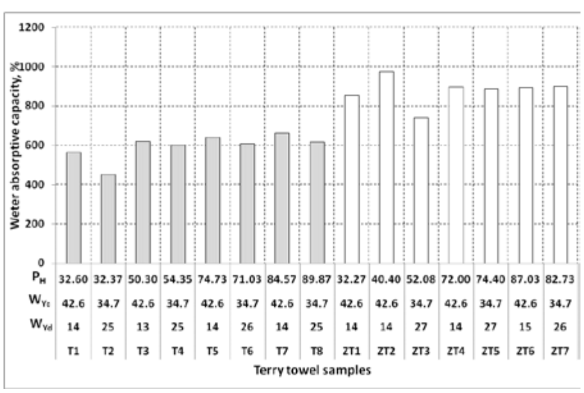

FIGURE 4. Water absorptive capacity of terry towel fabrics; P_H= pile height (mm), W_{Yc} = weft yarn count (tex), W_{Yd}= weft density (weft/cm), T= towels with twisted pile yarn, ZT=towels with twistless pile yarn.

Table VII shows ANOVA results for water absorptive capacity.

TABLE VII. Water absorptive capacity (ANOVA).

Variance Source	F value	P-value (Significance)
Model	121.549	< 0.0001
P_Y	354.838	< 0.0001
P_H	68.170	< 0.0001
W_{Yc}	1.944	0.1681
W_{Yd}	3.518	0.0653
P_Y * P_H	7.717	0.0072
P_H * W_{Yc}	9.032	0.0038
P_H * W_{Yd}	10.754	0.0017
R-Squared	0.931	
Standard deviation	43.12	

*at a level of 0.05 significance

Table VII shows that the determination coefficient of the model is 0.931, and the model is statistically significant ($p < 0.0001$). Pile yarn types and pile heights have a highly statistically significant affect water absorptive capacity ($p < 0.0001$). The R^2 of 0.931 for water absorptive capacity was considered relatively high. This indicates that there was a good agreement between the experimental value of water absorptive capacity and the predicted one from this model.

Model F-value of the water absorptive capacity of 121.549 implies that the model is significant, and there is only 0.01% chance Model F- value this large could occur due to noise. Weft density and weft yarn count do not significantly affect absorptive capacity on their own. Because the p values of those greater than 0.05; however, the interactions between pile yarn–pile height, pile height–weft density and pile height–weft yarn count significantly affect absorptive capacity ($p \leq 0.005$).

Eq. (6) is the final regression equation of water absorptive capacity (C_{A1}) in terms of actual values for towel fabrics woven with twisted pile yarn, and Eq. (7) is the final regression equation of water absorptive capacity (C_{A2}) in terms of actual values for towel fabrics woven with twistless pile yarn.

$$C_{A1} = 11468.52 - 157.207P_H - 205.465W_{Yc} - 157.966W_{Yd} + 2.991P_H W_{Yc} + 2.254P_H W_{Yd} \quad (6)$$

$$C_{A2} = 11868.06 - 159.211P_H - 205.465W_{Yc} - 157.966W_{Yd} + 2.991P_H W_{Yc} + 2.254P_H W_{Yd} \quad (7)$$

An increase in weft density of towel fabrics was found to reduce their water absorptive capacity. This finding is consistent with the literature [4] and the water absorptive capacities of towels produced with twistless pile yarns were found to be higher than for towels produced with twisted pile yarns. This result is also consistent with the literature [10].

CONCLUSION

The results indicate that:

- An increase in weft density negatively affects the water absorptive capacity of towels, and increases flexural rigidity.
- As pile height increases, water absorptive capacity and flexural rigidity increase, and absorbency time decreases.
- The flexural rigidity of towels produced with twistless pile yarns is lower than those produced with twisted pile yarns.
- The water absorptive performance and softness of twistless towels are better than those of towels with twisted pile yarns.
- As a result of this study, it was possible to predict the water absorptive capacity, water absorption time, and flexural rigidity of terry towels, before the production of the terry towels by using obtained regression equations.

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