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Experimental Investigation of the Effect of Fabric Parameters on Static Water Absorption in Terry Fabrics

Abstract
We carried out an experimental investigation to determine the static water absorption properties of terry fabrics. We tested 216 terry fabric samples, woven using 6 warp densities, 4 weft densities, 3 pile height and 3 different yarn types. It is shown that terry fabrics produced with two-ply ring-carded yarn have the highest percent water absorption, and terry fabrics produced with two-ply open-end yarn have the lowest percent water absorption. It is also shown that an increase in warp and weft densities decreases the percentage water absorption of terry fabrics, and an increase in pile length increases it.

Key words: *terry fabric, terry fabric construction, water absorption, static water absorption.*

Introduction

Terry fabrics are produced by three yarn systems, weft, ground warp and pile warp yarns. The pile can be formed on one side or on both sides of a terry fabric by pile warp yarns. Pile structure has an important effect on the structure and usage properties of terry fabrics. Type of weft, ground warp and pile warp yarns, raw material used and pile structure are the main parameters that can be used to design a terry fabric for required usage properties.

Terry fabrics are characterised by their high water absorption ability. This feature is acquired by increasing the water absorbing surface of pile warp yarns. Cotton yarns are mainly used in producing terry fabrics due to their good water absorption properties. Although yarn material is the main parameter in determining water absorption properties of terry fabrics, terry fabric construction also has some effect on it. Therefore, it is important when designing terry fabrics to be aware of the effect of terry fabric constructional parameters and yarn properties on water absorption properties. The literature available on the water absorption properties of terry fabrics is limited. Frontczak-Wasiak & Snycerski investigated use properties of terry fabrics using ten different fabric samples [1]. Among other parameters of terry fabric, they tested its water sorption before and after washing. They concluded that the average relative (percent) water sorption after washing increased by over 10%, but this difference was not statistically significant, as the relative water sorption after washing decreased in some fabric samples while increasing in some others. Hardt reviewed the chemistry and properties of hydrophilic finishes that impart absorbency to a variety of fibres [2]. Basic notions of absorbency, mechanisms of water absorption and measurement and test methods of water absorption are covered in references [3 - 5]. No detailed study was found in the literature as to how terry fabric construction and the yarn types used may affect the water absorption properties of terry fabrics. This paper investigates the effect of terry fabric parameters on water absorption properties using 216 different terry fabric constructions woven for this purpose. No hydrophilic finishes were applied to terry fabric samples, and the static water absorption values were measured in the experiments.

Material and method

Material

The terry fabrics used in the experimental work were woven using cotton yarns. Three types of yarns were used in the production of terry fabrics. Table 1 shows the properties of weft, ground warp and pile warp yarns.

Six different warp densities, four different weft densities and three different pile lengths were used for the production of different terry fabric constructions. These are shown in Table 2.

The pile lengths of the terry fabrics are given in mm in Table 3. The terry fabrics were produced with six different warp densities at the same time, because a variable-density reed was used [6]. Therefore, terry fabrics with six different warp densities were woven for each weft density and pile warp yarn type with the same pile length.

Method

Method of producing terry fabrics

The terry fabrics used in the experiments were woven on a Nuova Pignone TPS 500 model rapier terry weaving machine with dobby, using the 3-picks principle. With the combination of six different warp densities, four different weft densities and three different pile heights, 72 different terry fabric constructions were obtained. As this was repeated for

Table 1. *Yarn types used in the production of terry fabrics.*

Pile warp yarn	Ground warp yarn	Weft yarn
29.5 tex (Ne20/1) twisted ring-spun carded cotton yarn, 760 turns/m	29.5×2 tex (Ne20/2) twisted ring-spun carded cotton yarn, 480 turns/m	36.9 tex (Ne16/1) ring-spun carded cotton yarn, 640 turns/m
29.5×2 tex (Ne20/2) twisted open-end cotton yarn, 216 turns/m	29.5×2 tex (Ne20/2) open-end cotton yarn, 480 turns/m	36.9 tex (Ne16/1) open-end cotton yarn
29.5×2 tex (Ne20/2) twisted ring-spun carded cotton yarn, 216 turns/m	29.5×2 tex (Ne20/2) twisted ring-spun carded cotton yarn, 480 turns/m	36.9 tex (Ne16/1) ring-spun carded cotton yarn, 640 turns/m

Table 2. *Warp density, weft density and pile lengths of terry fabrics.*

Parameter	Value
Ground warp density, ends/cm	10, 10.5, 11, 11.5, 12, 12.5
Pile warp density, ends/cm	10, 10.5, 11, 11.5, 12, 12.5
Weft density, picks/cm	16, 17.1, 18, 19.5
Pile types	low, medium, high

Table 3. Pile lengths of terry fabrics with three pile yarn types.

Weft density, picks/cm	Pile type	Pile length, mm		
		29.5 tex ring spun carded	29.5×2 tex OE	29.5×2 tex ring spun carded
16.0	low	7.3	6.6	6.8
	medium	10.8	8.6	9.3
	high	12.3	10.1	11.2
17.1	low	6.7	6.5	7.1
	medium	10.6	8.5	9.4
	high	12.0	9.4	11.0
18.0	low	6.6	6.3	6.6
	medium	10.5	8.5	9.3
	high	11.9	9.1	11.2
19.5	low	6.6	6.2	6.6
	medium	10.1	8.1	9.2
	high	11.8	10.2	11.2

three different pile yarn types (i.e. 29.5 tex ring-spun carded cotton yarn, 29.5×2 tex ring-spun carded cotton yarn and 29.5×2 tex OE yarn), a total of 216 different terry fabrics were produced for the experiments.

Before conducting the static water absorption measurements, all the terry fabric samples were subjected to pre-washing processes. However, no hydrophilic finishes were applied. Pre-washing was applied to all terry fabric samples to remove sizing substances, paraffin and oil remnants.

Measuring static water absorption

The static water absorption measurements were based on the Bureau Veritas Consumer Products Services BV S1008 internal test method. In order to measure the static water absorption according to this method, fabric samples were conditioned in laboratory conditions, and then cut into 10×10 cm dimensions and their weights measured. Following this, the fabric samples were kept for one minute in water at room temperature. After taking the fabric samples from the water, they were hung for three minute to remove the excess water on them. Then, the weight of wet fabric samples was measured. A Sortius precision electronic balance with the measurement precision of 1:10 000 g was used in the weight measurements.

the amount of water absorbed by the terry fabric samples was calculated by taking the difference between the wet and dry weights. The percentage of water absorption was calculated by the following formula.

$$W_a\,(\%) = \frac{m_w - m_d}{m_d} * 100 \quad [\%]$$

where:
W_a – the water absorption,
m_w – the fabric's wet weight,
m_d – the fabric's dry weight.

Table 4. Water absorption values in g for 29.5 tex ring-spun carded yarn.

Weft density, picks/cm	Pile type	Dry weights and absorption values, g	Warp density, ends/cm					
			10.0	10.5	11.0	11.5	12.0	12.5
16.0	low	Dry weight	2.72	2.80	2.98	3.01	3.10	3.19
		Absorption	11.66	11.72	12.38	12.44	10.95	11.34
	medium	Dry weight	3.37	3.41	3.63	3.71	3.87	3.97
		Absorption	16.14	15.80	17.53	17.23	15.06	15.82
	high	Dry weight	3.56	3.81	3.93	3.98	4.15	4.27
		Absorption	17.27	17.96	17.22	19.70	18.61	16.65
17.1	low	Dry weight	2.89	3.00	3.07	3.13	3.20	3.31
		Absorption	10.08	10.25	10.16	11.03	11.54	11.79
	medium	Dry weight	3.58	3.76	3.83	3.92	3.97	4.14
		Absorption	13.53	14.74	16.69	16.20	16.72	18.87
	high	Dry weight	3.87	3.99	4.09	4.19	4.32	4.49
		Absorption	18.69	18.22	19.45	19.32	18.29	16.60
18.0	low	Dry weight	2.93	2.99	3.07	3.23	3.36	3.50
		Absorption	9.54	10.44	11.21	10.99	13.21	12.34
	medium	Dry weight	3.71	3.78	3.87	4.12	4.29	4.46
		Absorption	13.22	14.60	13.27	16.21	15.84	16.49
	high	Dry weight	4.10	4.25	4.37	4.50	4.61	4.78
		Absorption	17.31	17.60	16.89	17..80	18.57	20.33
19.5	low	Dry weight	3.0	3.25	3.35	3.47	3.54	3.65
		Absorption	10.15	11.42	12.08	12.49	12.87	14.28
	medium	Dry weight	3.84	4.00	4.20	4.32	4.47	4.60
		Absorption	13.04	16.62	16.84	18.08	19.03	18.33
	high	Dry weight	4.17	4.36	4.49	4.76	4.87	5.05
		Absorption	17.02	19.20	18.21	17.01	19.63	19.14

Results and discussion

The water absorption properties of the terry fabrics were analysed with respect to warp density, weft density, pile length and the type of yarns used for producing them. The water absorption results are presented in grams as well as in percentages in the following six tables. Tables 4, 5 and 6 show water absorption values in gr for pile yarns of 29.5 tex cotton ring-spun carded yarn, 29.5×2 tex cotton ring-spun carded yarn and 29.5×2 tex open-end cotton yarn respectively. In all three tables, an increase in weft density, warp density or pile length causes some increase in water absorption in g. This is due to the increase in the dry terry fabric's sample weight. Three factor Anova statistical tests with a 95% confidence interval (α = 0.05) were applied to the static water absorption data in Table 4, 5 and 6. It was found that pile length had the most significant effect on static water absorption in all three tables. Warp and weft densities had less significant effect on static water absorption, compared to pile length. In Tables 4 and 6, the effect of warp density on static water absorption is more than weft density; in Table 5, weft density has more effect than warp density on static water absorption. Figures 1 to 3 show graphic representations of static water absorption with respect to dry sample weight for 29.5×2 tex ring-spun carded, 29.5 tex ring-spun carded and 29.5×2 tex open-end pile warp yarns respectively. The regression equations and correlation coefficients are given below each figure. 'x' represents the dry sample weight and 'y' represents water absorption in g. Correlation coefficients indicate a good match between the experimental data and linear curve for the data in all tables. For the same sample weight, the static water absorption is significantly higher with terry fabrics of 29.5×2 tex ring-spun carded pile warp yarn than those of 29.5 tex ring-spun carded and 29.5×2 tex open-end pile warp yarns. Terry fabrics woven with 29.5x2 tex open-end pile warp yarn have the lowest absolute static water absorption values. The slope of the regression equations (i.e. constant in front of 'x') increases as the pile warp yarn changes from 29.5×2 tex open-end to 29.5 tex ring carded and 29.5×2 tex ring carded yarn. This means that for the same change in terry fabric weight, the water absorption in gr increases most with the 29.5×2 tex ring-spun carded pile warp yarn, next with the 29.5 tex ring-spun carded pile warp yarn, and least with the 29.5×2 tex open-end pile warp yarn.

The weight of each terry fabric is adjusted for warp density, weft density and pile length along with yarn counts. For the same sample weight, lower pile length & higher weft and/or warp densities produce a denser terry fabric structure than do higher pile length & lower weft and/or warp densities. It can be seen from Tables 4, 5 & 6, and Figures 1, 2 and 3 that, for the same or very close sample weights, the static water absorption in grams is higher (with a higher pile length and lower weft and/or warp densities) than a lower pile length & higher weft and/or warp densities. This shows the effect of the terry fabric's construction on static water absorption. The effect of fabric construction on the static water absorption properties of terry fabrics can be better analysed by comparing the static percent water absorption values presented in Table 7, 8 and 9 for 29.5 tex ring-spun carded pile warp yarn, 29.5×2 tex ring-spun carded pile warp yarn and 29.5×2 tex open-end pile warp yarn respectively, as they represent the static water absorption values for unit dry sample weight (i.e. for 100 g sample weight). In all three tables, the percentage of water absorption decreases with increasing warp and weft densities as the terry fabric structure becomes denser, and it increases with the increase in pile length because of the increased pile warp yarn surface area.

The type of yarn has a more pronounced effect on the percentage of static water absorption than warp and weft densities

Table 5. *Water absorption values in g for 29.5×2 tex ring-spun carded yarn.*

Weft density, picks/cm	Pile type	Dry weights and absorption values, g	Warp density, ends/cm					
			10.0	10.5	11.0	11.5	12.0	12.5
16.0	low	Dry weight	3.43	3.52	3.76	3.83	3.98	4.14
		Absorption	19.64	20.14	21.22	21.59	21.30	22.13
	medium	Dry weight	4.31	4.40	4.51	4.73	4.87	5.0
		Absorption	26.58	26.32	27.40	28.51	29.23	29.38
	high	Dry weight	4.96	5.05	5.48	5.43	5.66	6.02
		Absorption	32.09	32.23	34.20	33.83	34.22	36.28
17.1	low	Dry weight	3.59	3.64	3.88	3.95	4.06	4.21
		Absorption	20.30	20.54	21.29	21.70	21.99	22.53
	medium	Dry weight	4.54	4.58	4.79	4.95	5.03	5.06
		Absorption	27.94	27.72	28.32	29.51	29.45	29.57
	high	Dry weight	5.18	5.31	5.60	5.72	6.08	6.19
		Absorption	33.01	33.40	33.33	33.82	35.76	36.30
18.0	low	Dry weight	3.80	3.90	4.0	4.15	4.25	4.40
		Absorption	21.11	20.79	21.59	22.13	22.60	23.30
	medium	Dry weight	4.75	4.87	5.08	5.19	5.37	5.49
		Absorption	29.07	29.03	31.48	30.36	32.72	32.45
	high	Dry weight	5.42	5.54	5.64	6.01	6.15	6.41
		Absorption	34.05	33.66	34.80	37.0	37.24	38.81
19.5	low	Dry weight	3.89	4.0	4.18	4.33	4.43	4.53
		Absorption	21.33	21.83	22.63	23.16	23.24	23.14
	medium	Dry weight	4.99	5.0	5.20	5.30	5.44	5.91
		Absorption	29.90	29.78	30.85	31.10	31.32	33.19
	high	Dry weight	5.97	6.10	6.30	6.35	6.47	6.49
		Absorption	37.12	36.57	38.10	38.36	38.42	36.83

Table 6. *Water absorption values in g for 29.5×2 tex open-end yarn.*

Weft density, picks/cm	Pile type	Dry weights and absorption values, g	Warp density, ends/cm					
			10.0	10.5	11.0	11.5	12.0	12.5
16.0	low	Dry weight	3.90	4.04	4.20	4.33	4.45	4.72
		Absorption	15.26	15.59	15.80	13.75	16.94	16.32
	medium	Dry weight	4.68	4.85	5.02	5.29	5.40	5.61
		Absorption	16.60	18.85	19.49	22.47	21.49	23.90
	high	Dry weight	5.02	5.20	5.42	5.61	5.74	5.92
		Absorption	18.21	18.78	19.72	20.05	20.82	22.54
17.1	low	Dry weight	4.18	4.24	4.32	4.43	4.57	4.73
		Absorption	14.47	16.63	17.40	15.99	15.95	16.70
	medium	Dry weight	4.95	5.08	5.40	5.53	5.69	5.86
		Absorption	19.18	20.71	20.13	20.80	20.08	21.65
	high	Dry weight	5.32	5.55	5.74	5.83	5.94	6.27
		Absorption	19.26	18.96	21.57	20.80	22.10	24.20
18.0	low	Dry weight	4.25	4.35	4.52	4.56	4.77	4.75
		Absorption	15.89	16.36	16.45	16.70	18.33	17.13
	medium	Dry weight	5.11	5.28	5.40	5.61	5.68	6.07
		Absorption	18.11	18.27	19.96	21.40	21.73	21.65
	high	Dry weight	5.49	5.76	6.08	6.25	6.35	6.44
		Absorption	19.71	20.71	20.08	21.28	20.37	21.81
19.5	low	Dry weight	4.35	4.50	4.65	4.84	4.93	5.19
		Absorption	17.0	17.89	17.39	17.11	18.61	19.31
	medium	Dry weight	5.48	5.68	5.80	5.98	6.19	6.30
		Absorption	21.10	19.78	23.09	22.74	21.39	23.37
	high	Dry weight	6.25	6.40	6.52	6.60	6.71	6.83
		Absorption	20.15	21.47	22.57	22.66	23.10	23.35

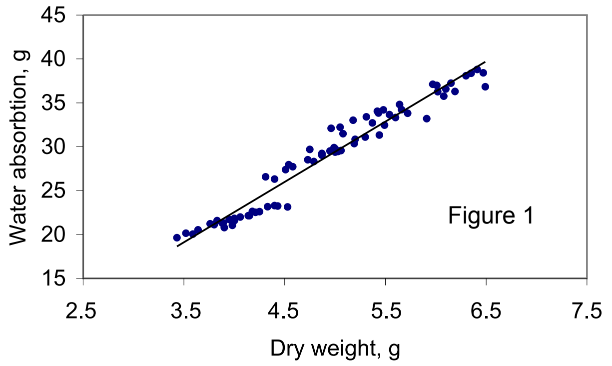

Figure 1. Static water absorption-dry weight relation for 29.5×2 tex ring-spun carded cotton pile warp yarn; y = 6.87x – 4.96 (Regression equation), r = 0.9766 (Correlation coefficient).

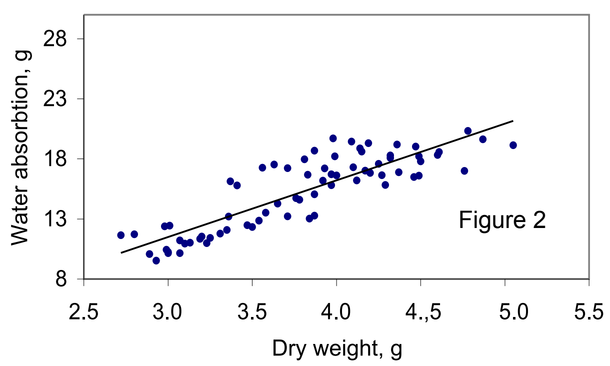

Figure 2. Static water absorption-dry weight relation for 29.5 tex ring-spun carded cotton pile warp yarn; y = 4.71x + – 2.63 (Regression equation), r = 0.8640 (Correlation coefficient).

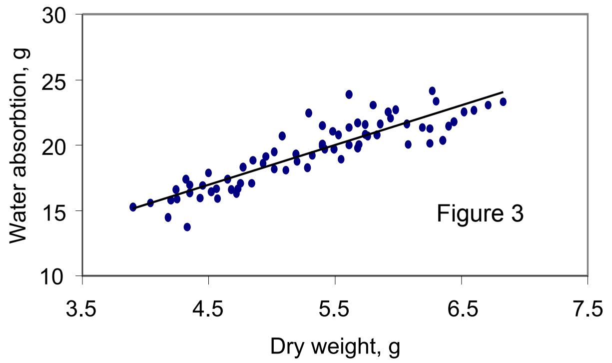

Figure 3. Static water absorption-dry weight relation for 29.5x2 tex open-end cotton pile warp yarn; y = 3.046x + + 3.26 (Regression equation), r = 0.8930 (Correlation coefficient).

and pile height. The percentage of water absorption is the lowest with open-end yarn, and the highest with the two-ply ring carded yarn. Terry fabrics produced with single-ply ring carded yarn have water absorption values between those of the two-ply carded ring yarn and the open-end yarn. In many cases, ring-spun yarns have a more compact structure than open-end yarns. Despite this, the higher twist values used in the production of open-end yarns are thought to make water penetration inside open-end yarns more difficult, and reduces the percentages of water absorption when compared to ring spun yarns. Two-ply ring-carded yarn has much higher water absorption values, because two-ply ring-spun yarns have more space for water penetration than single ring-spun yarns. This causes the percentage of water absorption to be significantly higher with two-ply ring-spun yarns than single-spun and two-ply open-end yarns. It is expected from these results that terry fabrics woven with single ply open-end yarns will have a lower percentage of water absorption than will two-ply open-end yarns.

The relation between the percentage of static water absorption and fabric construction was investigated by applying statistical tests to the data in Tables 7, 8 and 9. It was found when three factor Anova tests with a 95% confidence interval were applied to the data in Table 7 that pile length had the most significant effect on the percentages of static water absorption. This was followed by warp density and then weft density. In SNK (Student-Newman-Keuls) tests applied with a 95% confidence interval, the percentages of water absorption increased with the increase in pile length values. The percentage of water absorption values decreased from the maximum to minimum as warp density changes in the order of 10.5, 11.5, 11, 10, 12 and 12.5 ends/cm. The percentage of water absorption decreased with the weft density in the order of 16, 17.1, 19.5 and 18 picks/cm.

The same statistical tests were applied to the data in Tables 8 and 9. It was found for both tables that pile length had the most significant effect on the percentages of water absorption. The increasing values of pile length increased the water absorption values. In Table 8, the water absorption percentages decreased with warp density in the order of 10, 10.5, 11, 11.5, 12 and 12.5 ends/cm, and with weft density in the order of 16, 18, 17.1 and 19.5 picks/cm. In Table 9, the water absorption percentages decreased with warp density order of 11, 10.5, 12.5, 10, 12, 11.5 ends/cm, and with weft density in the order of 16, 17.1, 19.5 and 18 picks/cm.

Figures 4, 5, and 6 show the percentages of static water absorption change with respect to pile length, warp density and weft density respectively for three pile

Table 7. Percent water absorption values for 29.5 tex ring-spun carded yarn.

Weft density, picks/cm	Pile type	Warp density in the reed, ends/cm					
		10.0	10.5	11.0	11.5	12.0	12.5
16.0	low	428.7	418.6	415.4	413.3	353.2	355.5
	medium	478.9	463.3	482.9	464.4	389.2	398.5
	high	485.1	471.4	438.2	495.0	448.4	389.9
17.1	low	348.8	341.7	330.9	352.5	360.4	356.2
	medium	377.9	392.0	435.8	413.3	421.2	455.8
	high	482.9	456.6	475.6	461.4	423.4	369.7
18.0	low	325.6	349.2	365.2	340.3	393.2	352.6
	medium	356.3	386.2	342.9	393.5	369.2	369.7
	high	422.2	414.1	386.7	395.6	402.8	425.3
19.5	low	338.3	351.4	360.6	359.9	363.6	391.2
	medium	339.6	415.5	401.0	418.5	425.7	398.5
	high	408.2	440.4	405.6	357.4	382.5	379.0

Table 8. Percent water absorption values for 29.5×2 tex ring-spun carded yarn.

Weft density, picks/cm	Pile type	Warp density in the reed, ends/cm					
		10.0	10.5	11.0	11.5	12.0	12.5
16.0	low	572.6	572.2	564.4	563.7	535.2	534.5
	medium	616.7	598.2	607.5	602.8	600.2	587.6
	high	647.0	638.2	624.1	623.0	604.6	602.7
17.1	low	565.5	564.3	548.7	549.4	541.6	535.2
	medium	615.4	605.2	591.2	576.0	585.5	584.4
	high	637.3	629.0	595.2	591.3	588.2	586.4
18.0	low	555.5	533.1	539.8	533.3	531.8	529.6
	medium	612.0	596.1	619.7	585.0	609.3	591.1
	high	628.2	607.8	617.0	615.6	605.5	605.5
19.5	low	548.4	545.8	541.4	534.9	524.6	510.8
	medium	599.2	595.6	593.3	586.8	575.7	561.6
	high	621.8	599.5	604.8	604.1	593.8	567.5

Table 9. Percent water absorption values for 29.5×2 tex open-end yarn.

Weft density (picks/cm)	Pile type	Warp density in the reed, ends/cm					
		10.0	10.5	11.0	11.5	12.0	12.5
16.0	low	391.3	385.9	376.2	317.6	380.7	345.8
	medium	354.7	388.7	388.3	424.8	398.0	426.0
	high	362.8	361.2	363.8	357.4	362.7	380.0
17.1	low	346.2	392.2	402.8	391.0	349.0	353.0
	medium	387.5	407.7	372.8	378.2	352.9	369.5
	high	362.1	341.6	375.8	356.8	372.1	386.0
18.0	low	373.4	376.1	363.9	366.2	384.3	360.6
	medium	354.4	346.0	369.6	381.5	382.6	356.7
	high	359.0	359.6	330.3	340.5	320.8	338.7
19.5	low	400.0	397.6	374.0	353.5	377.5	372.1
	medium	385.0	348.2	398.1	380.3	345.6	371.0
	high	322.4	335.5	346.2	343.3	344.3	341.9

warp yarn types. The percentages of water absorption values in these figures are average values obtained from SNK tests. These figures show that pile warp yarn type has the most significant and decisive effect on the water absorption percentages of terry fabrics. Among the constructional parameters, pile length or pile height has a positive effect on percent water absorption. The effect of weft density and warp density is not as significant as of pile length. However, the percentage of water absorption is reduced in general by an increase in warp density and/or weft density as the fabric structure becomes denser.

Conclusions

The following conclusions can be drawn from the experimental work detailed above.

- The type of yarn used in the production of terry fabrics had the most significant effect on their static water absorption properties. Two-ply ring-spun yarn showed a higher water absorption value than two-ply open-end yarn and single-ply ring-spun yarn.
- The warp density, weft density and pile length of terry fabrics also had some effect on the water absorption properties. An increase in weft and/or warp density reduced the percentage of water absorption, and an increase in pile length increased that percentage. The effect of pile length on static water absorption was found to be more pronounced compared to warp and weft density.
- Static water absorption defines the amount of water which a terry fabric can absorb. It is an important property of any terry fabric. It is also important from the practical viewpoint how quickly a terry fabric absorbs water. This is determined by dynamic water absorption measurements. Research on the effect of terry fabric parameters on dynamic water absorption properties is in progress.

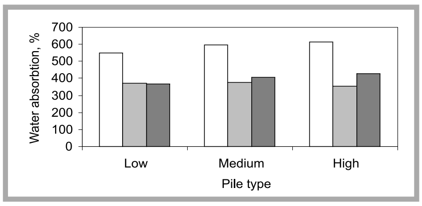

Figure 4. Percentages of water absorption values for three different pile types; □ *- 29.5x2 tex ring sp. car.,* ▨ *- 29.5x2 tex OE,* ■ *- 29.5 tex ring sp. car.*

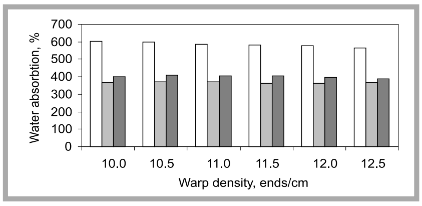

Figure 5. Percentages of water absorption versus warp density; □ *- 29.5x2 tex ring sp. car.,* ▨ *- 29.5x2 tex OE,* ■ *- 29.5 tex ring sp. car.*

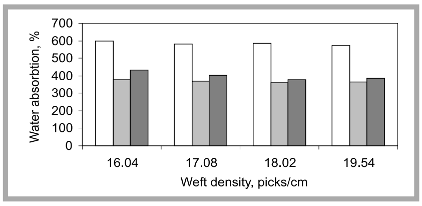

Figure 6. Percentages of water absorption versus weft density; □ *- 29.5x2 tex ring sp. car.,* ▨ *- 29.5x2 tex OE,* ■ *- 29.5 tex ring sp. car.*

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