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Effect of Fabric Weave and Weft Types on the Characteristics of Bamboo/Cotton Woven Fabrics

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Abstract
This paper presents a study of some physical and mechanical properties of bamboo, cotton and bamboo/cotton woven fabrics that are commonly used in the textile industry. 4 different weave type fabrics were produced under industrial conditions by using 100% bamboo of 36.90 tex as the weft yarn, three different mixes of bamboo/cotton and 100% cotton yarn. Unevenness, breaking strength-strain and number analyses were carried out on the weft and warp yarns. Tests of dimensional stability, air permeability, water absorption, abrasion resistance and bending rigidity were applied to the fabrics produced. The effect of the yarn and weave types on the physical and mechanical properties of the fabric were examined statistically. It was found that the weave type affects the physical and mechanical properties of the fabric more than the fiber mix and type in the weft yarn.

Key words: *bamboo/cotton, woven fabrics, weave type.*

Introduction

Bamboo is an antibacterial, relatively smooth fibre with low pilling and wrinkling, as well as high moisture-sweat absorption, due to the micro gaps in its profile [1 - 8].

Bamboo fabrics require less dyestuff than cotton fabrics in order to be dyed to the level desired, as they absorb the dyestuff better and faster and show the colour better [5].

Okubo *et al*. [9] examined the mechanical properties of bamboo fibre and reported that the resistance of bamboo fibre is equivalent to that of fibreglass. He *et al*. [10] examined the crystallite structure of bamboo fibre, compared it with ramie, linen and cotton fibres, and concluded that the crystallite size of bamboo fibre was close to that of ramie fibre, and larger than linen and cotton fibre. Lipp-Symonowicz *et al*. [11] compared bamboo fibres with viscose fibres and stated that bamboo fibres are in fact viscose fibres made from bamboo cellulose and bamboo fibres comparable to viscose fibres in their morphogical structure and properties. Karahan *et al*. [12] stated that natural bamboo fibre provided functional features to textile products due to its excellent moisture absorption, enabling fast evaporation, as well as its antibacterial properties. Natural bamboo fibre provides these functions without requiring any additional chemical or process, showing that the use of bamboo fibre will increase in the future. Godbole and Lakkard [13] examined the effects of water absorption on the mechanical properties of bamboo and stated that the breaking strength of bamboo decreased when left or boiled in pure water. Yakou and Sakamotu [14] examined the abrasion properties of bamboo using abrasive paper and reported that the abrasion resistance of the bamboo in the outer layer was less than that of the inner layers, depending on the friction surface. The firm Swicofil compared the performance properties of bamboo and cotton and reported that the dry and wet breaking resistance of bamboo was less than that of cotton; the proportions of the breaking strain, moisture gain and absorption were higher than those of cotton [3].

Erdumlu and Özipek [15] stated that bamboo yarn, with a high strain and moisture absorption capacity, had a higher level of shrinkage.

Dündar, Gün *et al*., and Chen *et al*. [16 - 18] studied bamboo woven fabrics. Dündar [16] found that the abrasion resistance of bamboo fabrics was higher than that of cotton fabrics. Gün *et al*. [17] examined the dimensional and physical properties of fabrics woven from 50/50 bamboo/cotton yarn in a type of single jersey fabric and mixed them with fabrics produced from a 50/50 viscose/cotton and 50/50 modal/cotton mixture. The researchers reported that the fabrics looked similar, their weight, thickness and air permeability were independent of the fibre type and the bamboo/cotton mix woven fabric showed less pilling. Chen *et al*. [18] found that the antibacterial characteristics of bamboo mixed fabrics were considerably higher than those of viscose/wood fibre mixed fabrics, which was because bamboo fibre absorbs water rapidly and evaporates it due to its structure, meaning that bacteria cannot live in such a dry environment.

Kawahito, Grineviciute *et al*., and Sarkar and Appidi [19 - 21] studied bamboo woven fabrics. Kawahito [19] produced ribbed woven textile fabrics from 100% bamboo and 100% cotton yarns. The results showed that the breaking resistance of the cotton fabrics were higher, their thickness greater, their water absorption faster and their drying properties better than those of bamboo fabrics. Grineviciute *et al*. [20] examined the handling properties of bamboo, cotton and cotton/bamboo mixed fabrics. The unbleached and finishing processes were carried out, and the findings stated that the fabrics gave the same results, and that the handle properties of the bamboo fabric were better than those of the cotton fabrics. Sarkar and Appidi [21] examined the protection provided by bamboo fabric against ultra violet light and their antimicrobial effects, concluding that the properties of the unbleached fabric that was not subjected to any process were weak and insufficient.

Table 1. Weft and warp yarns used.

Yarns	Linear tensity, tex	Fibre mixture rate, %	Yarn production technique
Weft	36.90	100 Bamboo	Ring system
		70/30 Bamboo/Cotton	
		60/40 Bamboo/Cotton	
		50/50 Bamboo/Cotton	
		100 Cotton	
Warp	36.90	100 Cotton	Open end system

Table 2. Properties of weft and warp yarns.

Measuring properties / Yarns	WARP	WEFT				
	100% Cotton	100% Bamboo	Bamboo/Cotton, %			100% Cotton
			70/30	60/40	50/50	
U, %	10.8	7.99	8.05	7.71	7.9	11.48
Thin places (-50%), km^{-1}	1.3	0	0	0	0	0.8
Thick places (+ 50%), km^{-1}	29.4	31.7	23.3	11.7	10.8	156.7
Neps (+ 280%), km^{-1}	3.1	12.5	25	6.7	10.8	55.8
Linear density, tex	36.66	37.21	36.87	37.35	38.81	37.26
CV%	0.82	1.71	0.44	0.29	0.52	2.28
Tenacity, cN/tex	14.95	15.20	11.50	12.89	12.76	20.00
Elongation at break, %	5.2	17.29	8.05	6.93	8.24	6.52

Table 3. Weight values of the fabrics produced.

Weave type	Weight, g/m^2				
	100% Bamboo	70/30% Bamboo/Cotton	60/40% Bamboo/Cotton	50/50% Bamboo/Cotton	100% Cotton
Plain	235.68	234.53	235.31	235.58	235.76
Panama	224.88	222.38	225.18	224.25	219.88
Twill	230.91	228.67	230.46	229.81	227.74
Satin	225.59	226.99	229.85	226.57	221.99

Table 4. Tests and standards used for fabrics.

Test	Standard
Textiles-domestic washing and drying procedures for textile testing	TS 5720 EN ISO 6330
Determination of water absorption of textile fabrics	DIN 53924
Textiles-determination of abrasion resistance of fabrics by the Martindale method - Part 2: Determination of specimen breakdown	TS EN ISO 12947-2
Textiles-determination of permeability of fabrics to air	TS 391 EN ISO 9237
Stiffness determination of Woven Textiles (This standard is used for determination of the bending rigidity of woven textiles with a flexometer)	TS 1409

There are relatively few studies examining the effect of using different amounts of bamboo fibre on the performance of textile fabrics. The purpose of this study was to examine the effects of different weave types and the proportion of bamboo fibre in the yarn on the dimensional stability, air permeability, water absorption, abrasion and bending rigidity of the textile fabric.

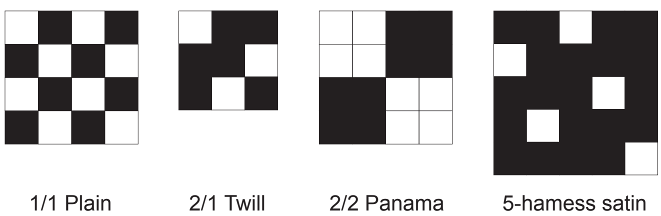

Figure 1. Weave types of the fabrics produced.

Material and methods

The bamboo used in the investigation was a kind of regenerated cellulose fibre produced from raw materials of bamboo pulp. Bamboo has been purchased in fibre form by the factory. Features of the weft and warp yarn types used in the study are given in ***Table 1***, the yarn properties are given in ***Table 2***, and the weight values of the fabrics produced are given in ***Table 3***. Unevenness tests of the weft yarns were carried out using an Uster Tester 5-S200, and breaking resistance and breaking strain tests were carried out in an Uster Tensorapid 3 device. The laboratory in which the experiments were carried out had a relative humidity of 65 ± 2% and temperature of 20 ± 2 °C. All the yarn and fabric samples were conditioned for 24 hours before the experiments were carried out [22].

Fabrics were woven using a Picanol Gamma flexible hooked weaving machine with a tightness of 18 weft/cm and 38 warp/cm in 4 different weave types (***Figure 1***).

Tests Applied to the Fabrics and Assessment

The tests applied to the fabrics and standards used are given in ***Table 4***.

The abrasion resistance of the fabrics was tested according to Standard TS EN ISO 12947-2 using a Martindale abrasion resistance test-device under 9 kPa mass pressure. Following the standard, the abrasion resistance of the fabrics was expressed in terms of the number of abrasion cycles (rotation) causing the breakdown of the sample fabrics.

The speed of water absorption was determined according to Standard DIN 53924, which measures the height of water level rise in fabrics. The fabrics were cut along the weft (250 mm length, 30 mm width), their bottoms were lowered vertically so as to make the bottom contact the water (15 mm from the bottom), and the water level rise (cm) was measured at 10, 30, 60 and 300 seconds.

The air permeability of the fabrics was measured using a Textest FX 3300 device under 200 Pa pressure according to the TS 391 EN ISO 9237 standard.

The bending rigidity of the fabrics was measured according to the TS 1409 standard, using a Shirley bending rigidity test device.

One-way analysis of variance (ANOVA) was applied to the test results (5% significance level). The analysis examined whether the weave and yarn types affected the properties of the fabrics. In this study the relationship between variables was evaluated by the ANOVA test. ANOVA was used for the statistical analysis because there was more than one independent variable. ANOVA was used to analyse the independent variables which interact among themselves, and how these interactions impacted the dependent variable [23].

Results and discussion

Dimensional stability

The dimensional stability results of the fabrics in the weft and warp directions are given in ***Figure 2***. In ***Figures 2 - 6***, label B is for Bamboo and C for Cotton.

The results of one-way ANOVA for the weft and warp directions are given in ***Table 5***.

When ***Figure 2*** is examined, it is observed that dimensional stability in the weft direction increases as the proportion of bamboo in the mix increases. In the fabrics woven with 100% bamboo and weft yarn containing bamboo, the dimensional stability is higher than in the 100% cotton fabric. Dimensional stability in the warp direction does not show a significant change when the proportion of bamboo in the mix increases. The weave type has an effect on dimensional stability in the weft and warp directions. It was observed that in the weave types where the weft yarns are free the dimensional stability is higher; conversely, the weft yarns were not free due to the connection they made with the warp yarns, and the dimensional stability is lower in the plain weave.

It can be seen in ***Table 5*** that the p value of the weft and weave type for dimensional stability in the weft and warp directions is smaller than 0.05. When the p value is greater than 0.05, the terms are not statistically significant for the model; however, they are statistically significant when this value is smaller than 0.05. In this case, both the fibre type and weave type have an effect on dimensional stability in the weft and warp directions at a significance level of 5%, and the effect of the weave type is greater (***Table 4***).

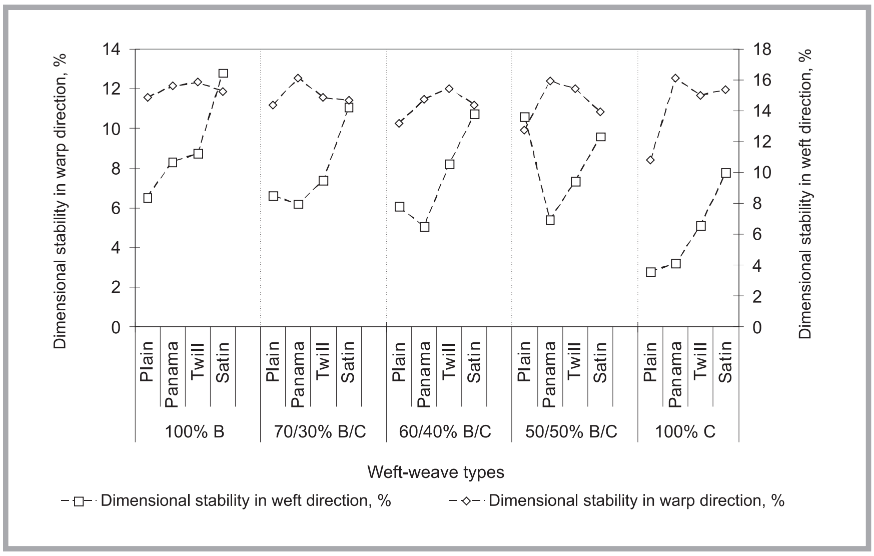

Figure 2. *Dimensional stability in the weft and warp directions for weft-weave types.*

Table 5. *ANOVA test and coefficient of determination (R^2) for dimensional stability in weft and warp directions.*

	Source	Sum of squares	DF	Mean square	F	Significant (p)	Effect, %
Weft	Model	115.83	7	16.55	45.27	< 0.0001	Significant
	Weft type	41.03	4	10.26	28.06	< 0.0001	33.88
	Weave type	75.22	3	25.07	68.60	< 0.0001	62.76
	R-Squared	0.966453					
Warp	Model	11.40	7	1.63	5.06	0.0110	Significant
	Weft type	3.24	4	0.81	2.52	0.1079	35.50
	Weave type	6.21	3	2.07	6.43	0.0106	42.47
	R-Squared	0.7797					

Water absorption

Water absorption results of the fabrics are shown in ***Figure 3***, and the ANOVA results are given in ***Table 6*** (see page 50).

It is seen from the significance results in ***Table 6*** that the weft and weave type had a highly significant effect ($p < 0.0001$) on the water level rise at 10, 30, 60 and 300 seconds, where the weave type had more effect on the water level increase than the weft type. As the duration in the water increased, and as the fabric reached water saturation, it was seen that the effect of the weft type decreased and the effect of the weave type increased.

It was observed that in Panama and satin weave types, in which the weft yarns are much more free, the water absorption level is higher (fast water absorption); conversely, the weft yarns were not free due to the connection they made with the warp yarns, and the rate of water absorption is slower in the plain weave and twill type fabrics.

In the fabrics woven with 100% bamboo and weft yarn containing bamboo, the water absorption is higher than in the cotton fabrics. Similar results were reported in some previous studies in literature [2, 3, 5]. However, other studies reported that the water absorption velocity of cotton fabrics is faster [18]. Karahan *et al* [12] stated that natural bamboo fibre has the perfect ability to absorb moisture.

Air permeability

The air permeability results of the fabrics are shown in ***Figure 4***, and the ANOVA results are given in ***Table 7*** (see page 50).

When ***Figure 4*** is examined, it is observed that air permeability is highest in the satin weave, in which the intersection (connection) numbers of weft and warp yarns are lowest; conversely, in the plain weave, in which the intersection number is the highest, the air permeability is the lowest. The results indicate that air permeability is higher in the fabrics woven with 100% bamboo and 70/30% bamboo weft yarn, and when the bamboo fibre content drops below 70%, the fibre proportion is not so effective. It is seen in ***Table 7*** that the effect of weave type on

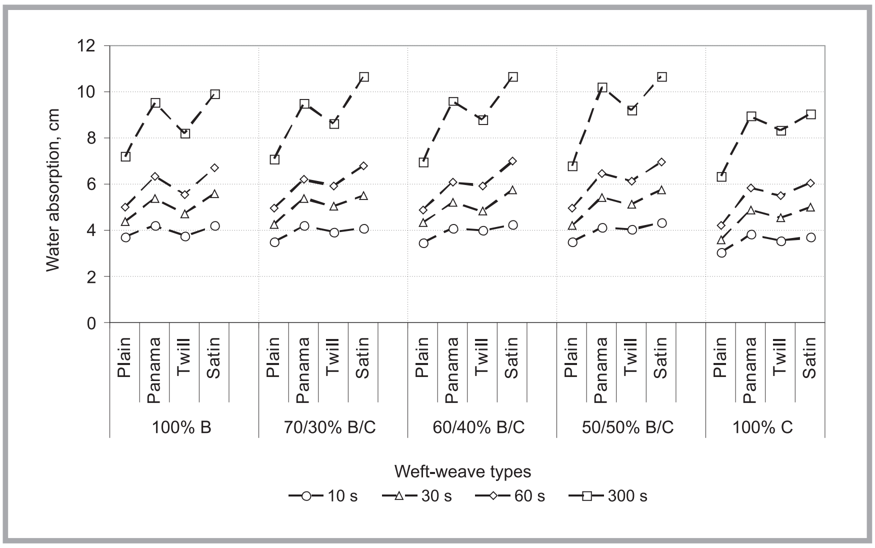

Figure 3. *Water absorption of fabrics at 10, 30, 60 and 300 seconds for weft-weave types.*

Table 6. *Anova test and coefficient of determination (R^2) for water absorption.*

Time, s	Source	Sum of squares	DF	Mean square	F	Significant (p)	Effect, %
10	Model	2.02784	7	0.289692	25.70281	< 0.0001	Significant
	Weft type	0.59887	4	0.149718	13.28362	0.0002	27.68579
	Weave type	1.42898	3	0.476325	42.26174	< 0.0001	66.06159
	R-Squared	0.937474					
30	Model	6.32502	7	0.903575	47.25193	< 0.0001	Significant
	Weft type	0.96797	4	0.241993	12.65486	0.0003	14.76803
	Weave type	5.35706	3	1.785685	93.38136	< 0.0001	81.73101
	R-Squared	0.96499					
60	Model	10.9385	7	1.562636	60.0783	< 0.0001	Significant
	Weft type	1.2512	4	0.3128	12.0261	0.0004	11.12121
	Weave type	9.6873	3	3.229085	124.1478	< 0.0001	86.10453
	R-Squared	0.972257					
300	Model	33.5263	7	4.789467	44.18294	< 0.0001	Significant
	Weft type	2.5988	4	0.649708	5.99357	0.0069	7.46210
	Weave type	30.9274	3	10.30915	95.10210	< 0.0001	88.80285
	R-Squared	0.962649					

air permeability is greater than that of the fibre proportion in the weft. It is observed in the plain weave and satin weave types, in which the number of connections between weft and warp yarns is high, that air permeability is lower than in the fabrics woven with satin and twill weave types. ***Figure 5*** shows SEM (Scanning electron microscope) images of the 100% Bamboo weft weave fabrics woven in the plain and satin weave types. The images clearly demonstrate the much greater number of connections between weft and warp yarns in the plain weave type compared with the satin weave type.

The results of the present study support the findings of previous studies, which reported that air permeability decreases as the weight increases [24]. However, in contrast to previous studies, it was observed in the present study that fibre type is not so effective with respect to air permeability (See ***Table*** *7*).

When ***Figure 4*** is examined, it is observed that air permeability decreases as the proportion of bamboo in the mix decreases. When ***Figure 4*** and ***Table 7*** are examined together, it is seen that the effect of the fibre proportion in the weft yarn is less than that of the weave type, and that the weave type affects air permeability to a great extent (98.69%). Gün *et al*. [16] compared fabrics produced from mixes of 50/50 bamboo/cotton, 50/50 viscose/cotton and 50/50 modal/cotton, and reported that air permeability is independent of fibre type.

Abrasion resistance

Abrasion resistance results of the fabrics are shown in ***Figure 6,*** and the ANOVA results are given in ***Table 8***.

As seen in the SEM images in ***Figure 7***, the amount of yarn in the fabric surface is higher in the twill weave type. In the Panama weave type, however, the yarns are kept tightly inside the weave, which indicates that the fabrics in the twill weave type show less abrasion resistance than those in the panama weave. Depending on the weave type used in the fabric, the abrasion resistance decreases as the hopping length increases [24].

It is observed that the effect of the weave type on abrasion resistance is higher than that of the fibre type; much more abrasion is seen in the twill and satin weave types, in which the hop-count is greater because of the floating yarns. It is seen that the abrasion resistance is higher in 100% cotton weft yarns and in the yarns with a higher proportion of cotton in the mixture. On the other hand, Dündar [16]

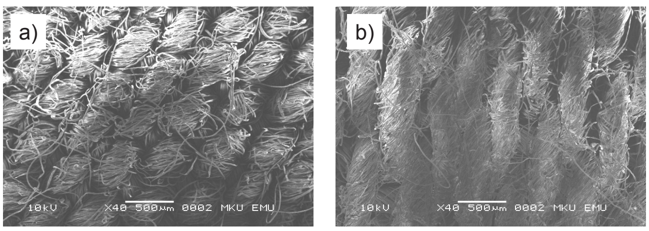

Figure 5. *SEM images of 100% bamboo weft weave fabrics; a) plain weave, b) satin).*

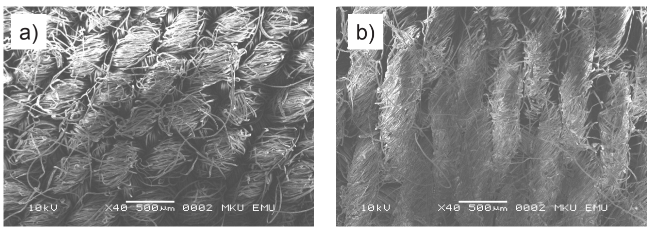

Figure 7. *SEM Images of 100% cotton weft weave fabrics; a) panama, b) twill.*

reported that the abrasion resistance of bamboo fabrics is greater than that of cotton fabrics.

Bending rigidity

The bending rigidity of the fabrics is shown in ***Figure 8***. The ANOVA results are given in ***Table 9***.

The fibre type and proportions of the mixes are effective in the bending characteristics of the fabric [24]. It is seen in ***Table 9*** that the weave type accounts for 79.33% of the bending rigidity and the weft type accounts for 15.99%; together, the weave type and weft type account for 95.72% of the variation in the model. It is seen that 100% bamboo weft yarn and plain weave fabrics have the highest bending rigidity (***Figure 8***).

General evaluation and results

When the physical and mechanic tests applied to the fabrics were examined, the following results were obtained;

- It was observed that both the fibre mixture proportion in the yarn and the weave type had an effect on washing shrinkage in the weft and warp directions, with the weave type having a greater influence on weft washing shrinkage.
- Statistical assessment of the water absorption characteristics showed that the fibre mix and weave type were highly significant ($p < 0.0001$), and that the weave type had more effect on the water rise levels than the proportions of the fibre mixture. It was also found that as the duration in the water increased and the fabric reached water saturation, the effect of the fibre type decreased and the effect of the weave type increased.
- It was seen that air permeability was highest in the satin fabric as satin fabrics have longer floats and fewer intersections. The number of intersections between weft and warp yarns was lowest in the satin fabric. Air permeability was lowest in the plain weave, in which the number of yarn intersections was highest. It was observed that air permeability was higher in the fabric woven with 100% bamboo and 70/30% bamboo weft yarn because the cross-section of the bamboo fibre is filled with various micro-gaps and micro-holes It was concluded that the weave type had a greater effect (98.69%) on air permeability than the

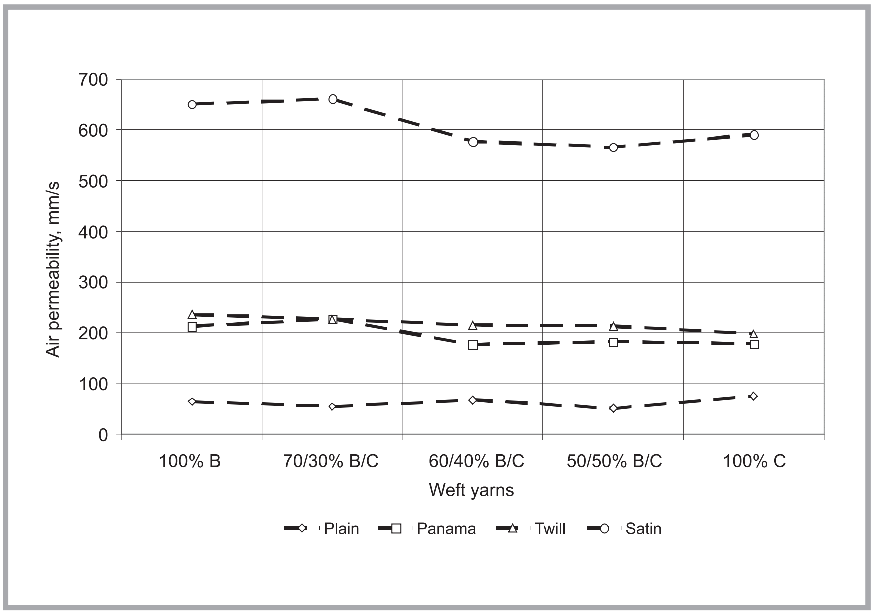

Figure 4. *Air permeability of fabrics according to weft-weave type.*

Table 7. *ANOVA test and coefficient of determination (R^2) for air permeability.*

Source	Sum of squares × 10^{-3}	DF	Mean square × 10^{-3}	F	Significant (p)	Effect, %
Model	837.6	7	119.7	271.38	< 0.0001	Significant
Weft type	5.731	4	1.432	3.25	0.0504	0.68
Weave type	831.9	3	277.3	628.89	< 0.0001	98.69
R-Squared	0.9937					

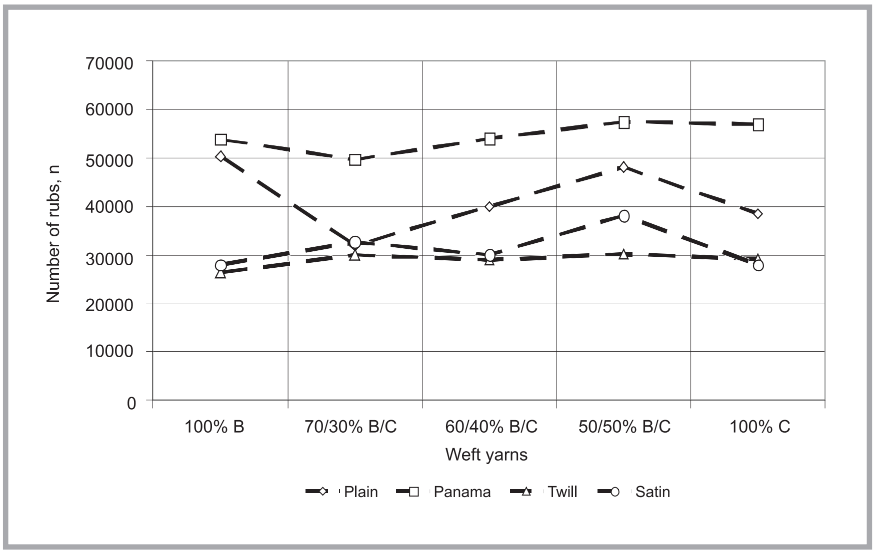

Figure 6. *Number of abrasion cycles required to cause the breakdown of the test specimen.*

Table 8. *ANOVA test and coefficient of determination (R^2) for abrasion resistance.*

Source	Sum of squares × 10^{-9}	DF	Mean square × 10^{-8}	F	Significant (p)	Effect, %
Model	2.021	7	2.887	55.78	< 0.0001	Significant
Weft type	*0.101*	4	*0.252*	*4.87*	0.0229	10.66
Weave type	*1.800*	3	*6.001*	*115.96*	< 0.0001	87.09
R-Squared	0.9775					

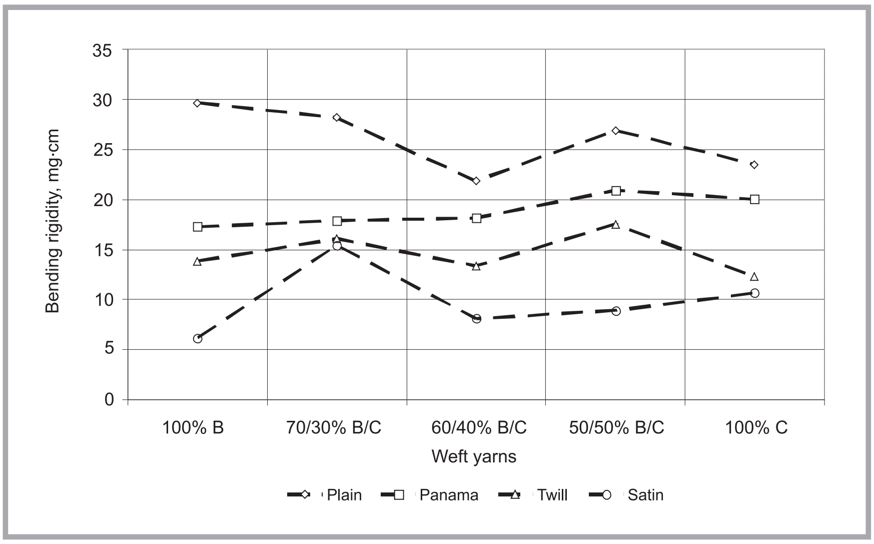

Figure 8. *Bending rigidity of fabrics according to weft and weave types.*

Table 9. *ANOVA test and coefficient of determination (R^2) for bending rigidity.*

Source	Sum of squares	DF	Mean square	F	Significant (p)	Effect, %
Model	633.0913	7	90.4416	31.94744	< 0.0001	Significant
Weft type	72.9729	4	18.2432	6.44421	0.0079	15.99
Weave type	527.3115	3	175.7705	62.08888	< 0.0001	79.73
R-Squared	0.9572					

proportion of bamboo fibre (0.68%) in the weft.

- It was concluded that the weave type had a greater effect on abrasion resistance than the fibre type; abrasion was higher in the twill and satin weave types, which had higher hop-counts due to the yarns floating on the surface of the fabric. Abrasion resistance was higher in 100% cotton weft yarns and in the yarns with a higher cotton proportion in the mixture.
- It was determined that the weave type accounted for 79.33% of the variability in bending rigidity and that the weft type accounted for 15.99%. Fabrics woven with 100% bamboo weft yarn in a plain weave had the highest bending rigidity.

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