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The Effect of Weave Structures and Treatments on the Wickability of Cotton Fabrics

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Abstract- *This paper examines the wicking behaviour of cotton fabric woven into eleven different weave structures, which were bleached, then treated with oxygen plasma gas and cross linking agent citric acid. The wicking behaviour of the different cotton fabrics has been studied by measuring the vertical wicking height as a function of time expressed as a wicking coefficient. The results showed that the atmospheric plasma treatment significantly improved the wickability of cotton fabrics. Washburn equation was found to follow in many cases as the square of wicking height had a high correlation with time. The coefficient of wickability was found to be higher in the warp diection that of weft.The increasing trend noticed in wickability among the weaves was not the same but was found to vary among treatments.*

KEY WORDS*: Cotton, Weave Structures, Plasma Treatment, Cross linking, Wickability, Wicking Coefficient.*

I. INTRODUCTION

Wettability is one of the most influencing parameter in the performance of textiles. Wetting is the displacement of a fiber-air interface with a fiber-liquid interface. Wicking is the spontaneous flow of a liquid in a porous substance, driven by capillary forces. Because capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system. Fiber wettability is therefore a prerequisite for the occurrence of wicking[1]. Wicking of yarns and fabrics reflect their efficacy of moisture absorption and breathability and hence affect the comfort properties. During sweating, a slow rate of moisture transfer through clothing may increase the humidity levels of the clothing suppressing the evaporation of sweat. The reduced cooling efficiency of sweat may increase discomfort and may cause skin diseases like eczema, resulting in heat stress. According to Patnaik et al.[2], the behaviour of fabrics while in contact with liquid is an important indicator of the comfort features of the textiles. Improvement of the fabric's ability to wick perspiration away from the skin will improve apparel qualities.

The free passage of perspiration is primary for the thermal comfort of the wearer. So fabrics worn close to the skin should assist for quick moisture release to the atmosphere (wicking of sweat)[3].Therefore the measurement of wicking in fabrics is of profound interest to garment manufacturers, physicists, textile technologists, chemists and civil engineers. A fabric that rapidly moves water away from the human body makes the wearer feel more comfortable by keeping him dry[4]. Cotton is the best fabric in terms of transportation of water. In order to study the heat and moisture comfort, Zhu et al.[5] used the wicking property of textiles as an important and effective tool. Recently much of research is carried out in the development of waterproof breathable clothing, which exhibit the ability to completey prevent the penetration of water droplets from one side, while being able to easily evaporate vapour and moisture on the other side [6]. In sportswear, wickability in terms of moisture transfer and quick dry behaviour is a very much desired property as it provides comfort to the wearer especially in hot climates. Thus to optimise the functionalities of comfort in sports clothing, Fangueiro et al.[7] investigated the wicking behaviour and quick drying capability of functional knitted fabrics. Wicking is also sometimes synonymously called imbibition. But when it occurs mainly due to capillary forces, it is called wicking. Imbibition is a measure of the liquid or water holding capacity of a textile material. It is also defined as the absorption of liquid in a porous media. The relation between wicking rate and time was studied by Washburn[8], who proposed the Lucas – Washburn equation. The equation is as follows:

$$h=k\sqrt{t} \qquad \text{----------------------- } \textbf{Eq.1}$$

where h is height of the liquid front (cm), t is the wicking time(s) and k is the slope coefficient($cms^{-1/2}$).

In the Lucas-Washburn equation, the slope coefficient is defined as:

$$k=\sqrt{\frac{\gamma r\cos\theta}{2\eta}} \qquad \text{----------------------- } \textbf{Eq. 2}$$

where γ is the surface tension (Nm^{-1}), r the capillary radius(m), θ the contact angle(^{0}) and η the dynamic viscosity(Pa s).Washburn[8] concluded that the relationship between the wicking length rate and the square root of wicking time is linear.

The capillary rise method is mostly used to measure wicking in fabrics. In vertical wicking the gravity influences the rise of liquid, so the wicking rate is higher initially than later. Also in vertical wicking, the rise occurs in a single dimension, hence causing differences in wicking behaviour along warp and weft directions[9]. Wicking generally takes place when a liquid travels along the surface of the fiber but is not absorbed into the fiber. But more so, in the absence of external forces, the transport of liquids in a porous media is driven by capillarity forces that arise from the wetting of the fabric surface[10]. Wicking depends on pore sizes of fibers and cross sections. Fabric constructions and weave structures affect wickability. Fabric structure includes wicking inside and outside the yarns, contact angle and surface modifications as a result of finishing treatments. Yarn twist and linear density can also affect wickability. Fabrics have complex structures which consist of two surfaces, one outer surface and another inner surface comprised of the inter-fiber/filament space, the inter-yarn space and the pore size distribution[11]. The pore structure of fabrics has a considerable influence on the wickability and water vapour permeability[12].

To further enhance the wickability of textile structures, an increasingly popular technology – plasma treatments is employed. The potential of plasma technology in the treatment of textiles is enormous. Some of the possible effects are improved hydrophilic properties, plasma induced hydrophobic properties, fiber surface cleaning etc.[13].Plasma modification has also been successful in improving wettability, adhesion promotion, surface energy improvement, printability and permeability of polymer surfaces[14].Surface treatment of textiles by plasma technology has evinced interest among researchers over the past two decades. As the advantages of the technique are diverse - it is rapid, environmental friendly, with low deposition temperature, is energy efficient while virtually producing no waste. Plasma technology is a green process as it’s a dry process, needs minimum chemicals and causes no downstream pollution[15]. Plasma treatment can induce charges in textile surface properties in terms of wettability. Borcia et al.[16] carried out plasma treatment on natural and synthetic woven fabrics. Significant improvement in wicking properties of the plasma treated samples was observed. The study[17] on the atmospheric pressure plasma treatment of polyester/cotton blended fabric has also shown significant improvement in the wicking height after plasma treatment. A detailed review of measuring wicking of yarns and fabrics was outlined by Subramaniam et al.[18] and is in important contribution in wicking. Wong et al.[9] and Bozaci et al.[19] have studied the effect of plasma treatment on the properties of linen and jute yarns respectively. They report an increase in the wickability following plasma treatment. However they have not quantified the effect of plasma treatment. In this study, wickability of the different woven structures of cotton was investigated subjecting the fabrics to plasma treatment and cross linking treatment, and reporting the increase in wickability as a wicking coefficient. Also, the validity of Washburn’s equation was checked.

II. EXPERIMENTAL PROCEDURE

2.1. Materials:100% Gray Cotton Doubled Yarns were selected.Properties of the yarns are presented in Table 1

Table 1. Yarn Properties

Specification	Cotton Fabric
Warp Count(Ne/Tex)	2/60’s
Weft Count(Ne/Tex)	2/60’s
Ends/cm	80
Picks/cm	72
Areal density(g/m^2)	130

2.2. Production of Weave Structures

Eleven fabrics of different weave structures comprising of a plain weave, a 2/2 twill weave, 3/1 twill weave, a 5 harness satin weave, a crepe weave, a buck-a-back weave, a granite weave, a dice weave, a honeycomb weave, a brighton honeycomb weave and an 8 harness satin weave. were produced.The fabrics were constructed from 100% gray cotton yarn. Doubled yarns were used along both warp and weft and were woven on an automatic loom. The fabrics differed only in weave structures and were identical in yarn and weave densities. Finishing conditions were also the same for all the samples.

2.3. Methods

2.3.1 Pre- Treatment

Enzymatic desizing, scouring and bleaching of the cotton fabric was carried out as one continuous process using a soft flow dyeing machine. After the final wash the pH of the fabric was kept neutral at 7 and Whiteness index between 70-80.

2.3.2 Cross-linking treatment

All the eleven bleached woven structures were given crease cross linking treatment using the poly carboxylic acid, citric acid at optimum process parameters, by treating with 7% concentration of citric acid at 160 degrees curing temperature and 3 minutes curing time.

2.4 Atmospheric Plasma Treatment

Bleached cotton fabrics of the different woven structures are subjected to atmospheric plasma treatment. In this study, a dielectric barrier discharge (DBD) atmospheric plasma device was used. The distance between the two aluminium electrodes is 7.5 cm. The reactor was a vacuum chamber equipped with vacuum pump, process gas sources and regulators. The gas used was oxygen which can modify the wettability of cotton. Five minutes was the selected timing for the treatment. The machine was set at 3000 volts 50m.amp. The initial pressure was maintained at $5x10^{-2}$m.bar. The bleached plain fabric was set at room temperature for 12 hours. The samples were fixed on the work holder. The machine was closed and the motor started which runs at 500 litres/min. The gas was passed through the fixed samples in the gas chamber and the plasma treatment, thus applied. Both the treatments were applied separately to the fabrics in order to investigate the effect of each treatment.

2.5. Vertical Wicking Test

Measurement of wicking properties is an important investigation especially for plasma treated sample as it increases their hydrophilicity. The wickability of the fabrics was measured using the vertical wicking tester(Figure1).The bleached, cross linked and plasma treated woven fabrics a total of thirty three, were subjected to vertical wicking using the vertical strip test method. Five samples of 12x1 inch dimension from each fabric was cut along the warp direction and marked with regular intervals, to measure the height of water travelled along the fabric. Then the fabric strip was suspended vertically on top. The screw below the beaker was adjusted and raised upward, and once the fabric comes in contact with the distilled water, height readings were recorded for every 1 min, 2min, 3min ....10 min respectively. The standard pin 53924 was followed in the tests.

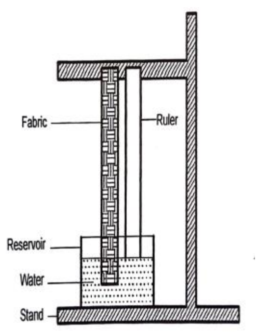

Figure 1 . Vertical Wicking Apparatus

III. RESULTS AND DISCUSSION

In order to validate the reproducibility of the experiment, the vertical wicking test was carried out ten times for each cotton sample. The results are presented in Table 2 and given graphically as h2=k(t). Graphs depict linearity which shows that the rise in wicking height is controlled by Lucas-Washburn equation and is expressed as a wicking coefficient. Table 2 presents data on wickability of fabrics comprising of eleven weaves and treatments with plasma and citric acid.

Table 2 . Linear regression of wicking data

Fabric No.	Weave type	Bleached				Plasma treated						PCA Treated					
		Warp		Weft		Warp			Weft			Warp			Weft		
		Slope of wicking rate cm^2/sec	R^2	Slope of wicking rate cm^2/sec	R^2	Slope of wicking rate cm^2/sec	Increase in wicking %	R^2	Slope of wicking rate cm^2/sec	Increase in wicking %	R^2	Slope of wicking rate cm^2/sec	Increase in wicking %	R^2	Slope of wicking rate cm^2/sec	Increase in wicking %	R^2
1	Plain	0.050	0.98	0.049	0.91	0.183	266	0.99	0.173	253	0.99	0.073	46	0.98	0.082	67	1.00
2	2/2 Twill	0.125	0.90	0.074	0.97	0.282	126	0.98	0.234	216	0.99	0.085	-32*	1.00	. 0594	-20*	0.99
3	3/1 Twill	0.134	0.94	0.091	0.95	0.272	103	0.97	0.225	147	0.98	0.061	-54*	1.00	0.079	-13*	1.00
4	4/1 Satin	0.103	0.96	0.066	0.99	0.199	93	1.00	0.189	186	0.99	0.071	-31*	1.00	0.056	-15*	0.99
5	Crepe	0.094	0.98	0.084	0.99	0.276	194	0.98	0.259	208	1.00	0.146	55	0.98	0.109	30	0.99
6	Huck-a-back	0.049	0.96	0.049	0.97	0.234	378	1.00	0.153	212	1.00	0.026	-47*	1.00	0.034	-30*	0.99
7	Granite	0.049	0.94	0.045	0.96	0.138	273	0.97	0.137	204	0.99	0.053	8	0.98	0.051	13	0.99
8	Dice	0.035	0.96	0.035	1.00	0.242	591	0.96	0.229	554	0.99	0.078	123	0.99	0.025	-29*	0.83
9	Honeycomb	0.155	0.96	0.131	0.97	0.219	41	0.92	0.180	37	0.98	0.028	-82*	0.99	0.023	-82*	1.00
10	Brighton honeycomb	0.055	0.92	0.052	0.92	0.165	200	0.99	0.189	263	1.00	0.078	42	0.95	0.037	-29*	1.00
11	7/1 Satin	0.084	0.93	0.033	0.87	0.169	101	0.95	0.200	506	1.00	0.105	25	0.98	0.040	21	0.95

*** - indicates drop in wickability**

3.1.1 Figure 2 shows the wicking height of plain weave along the warp direction as a function of wicking time. The relationship between wicking height and wicking time of bleached sample is linear (R^2=.0.961) and the slope of the curve yields the wicking rate, which in this case is 0.0448 cm^2/sec. Likewise linearity is observed in the case of plasma and citric acid treated sample, their R^2 values being 0.992 and 0.972 respectively.

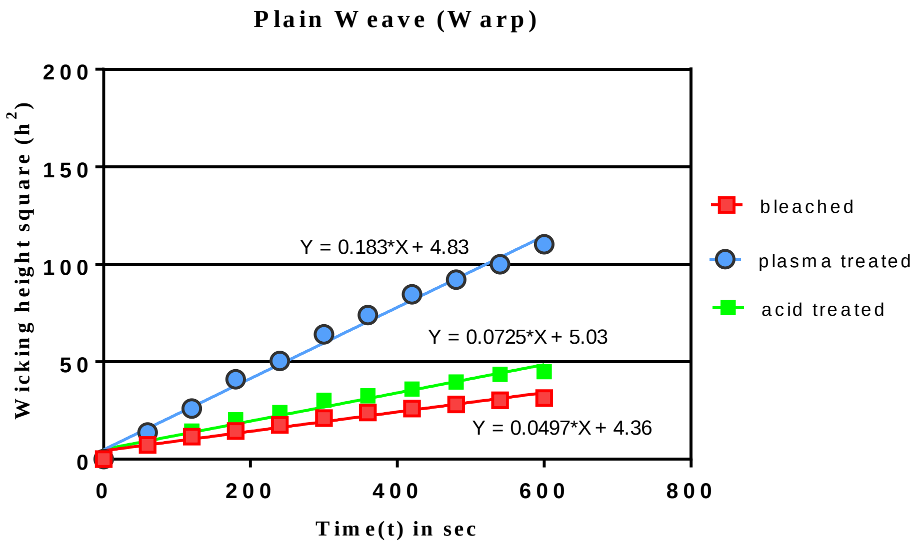

Figure 2 - Wicking in warp direction

3.1.2 Figure 3 shows the wicking height of plain weave along the weft direction as a function of wicking time. The relationship between wicking height and wicking time is linear (R2=.0.918) , as in almost all the cases, and the slope of the curve yields the wicking rate, which in this case is 0.0449 cm2/sec.

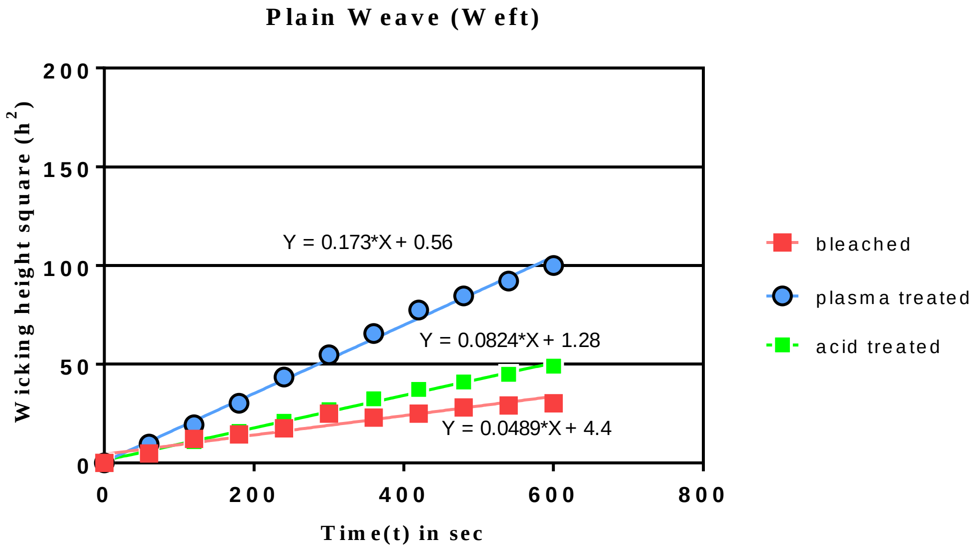

Figure 3 - Wicking in weft direction

3.2.1 Influence of Weaves

It is noticed that in the bleached state, honeycomb weave shows the highest slope indicating that the wickability is greater, clearly depicted by Figure 4. Dice weave exhibits the lowest slope. The percentage increase in wicking is found to be higher in warp way than in weft way.

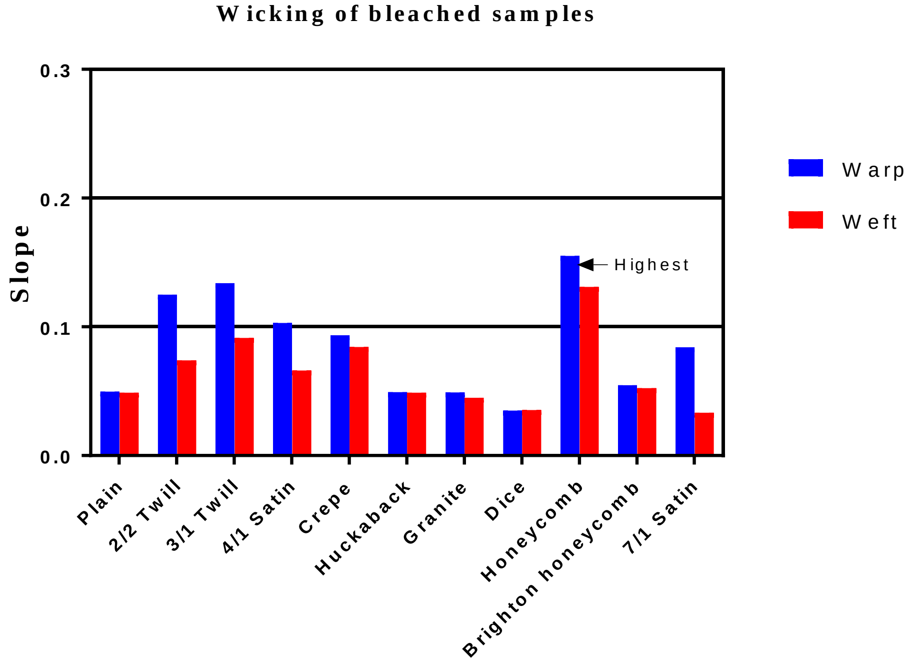

Figure 4 - Influence of Weaves

3.2.2 Figure 5 shows that in plasma treated samples, 2/2 twill shows the highest slope indicating that the wickability has significantly increased. Plasma treatment has improved the wickability remarkably, so to say that the improvement ranges between 41 to 591%. Granite weave exhibits the lowest slope in this case.

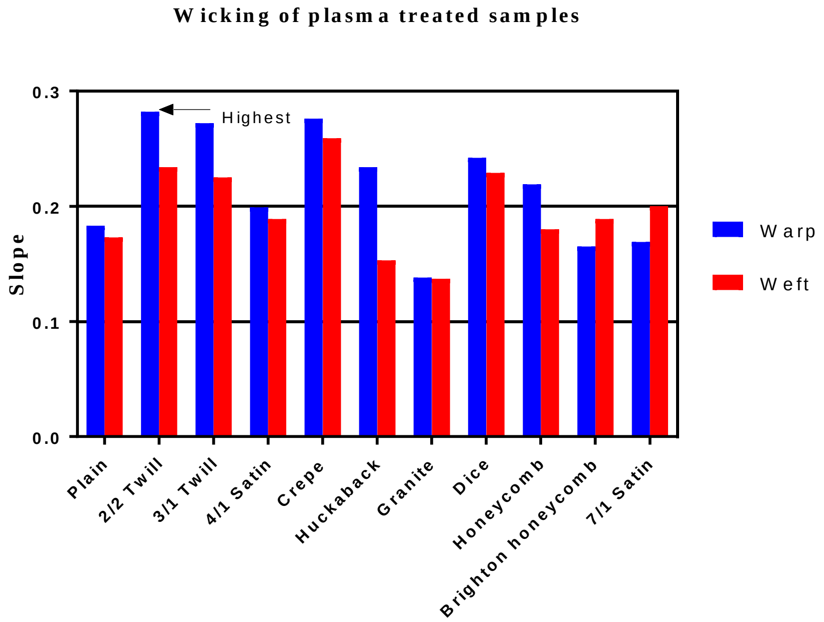

Figure 5 Influence of Weaves

3.2.3 Citric acid treated samples showed a small improvement in wickability, vis-à-vis bleached samples. It is clear from Figure 6 that in some cases a decrease in wickability of warp is observed. It has been reported that the moisture absorption of fabrics decreases following cross linking treatment. Crepe fabric shows the highest slope after being treated with citric acid. Following treatment, with citric acid it is noticed that wickability significantly decreases and in certain cases the drop is in negative as in the case of 2/2 twill, 3/1 twill, 4/1 satin etc.

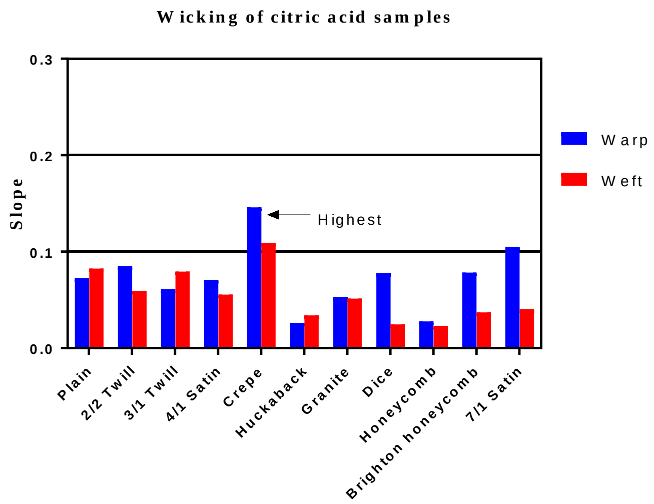

Figure 6 Influence of Weaves

3.3 Influence of Treatments

It is clear from Figure7a and 7b, that in almost all of the bleached and treated samples, the improvement in wicking was more in the warp direction than in the weft. It is remarkable to observe that almost in all of the cases, except a very few, the fabrics subjected to plasma had higher wickability. Crepe fabric showed a percent increase of 194 after plasma treatment in the warp, while it was 55 after citric acid treated. Plasma treatment had a profound influence on the wickability of cotton fabrics.

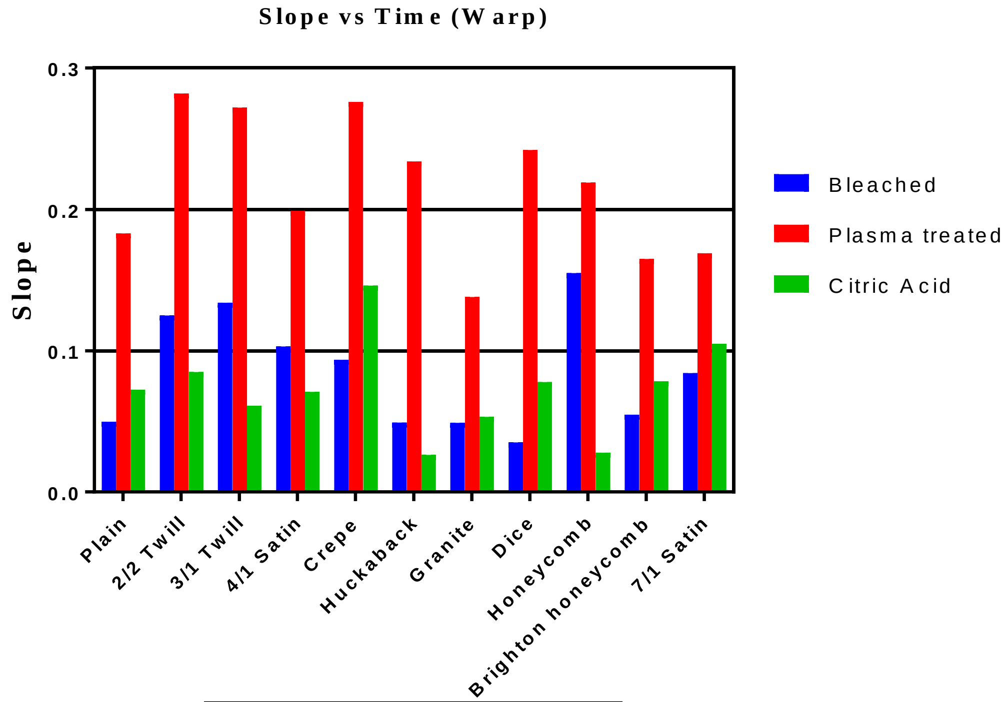

Figure 7a Influence of Treatments

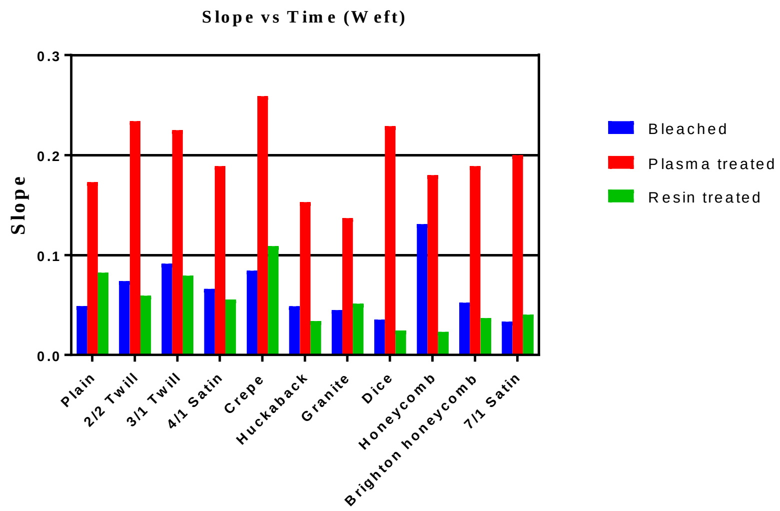

Figure 7b Influence of Treatments

IV. CONCLUSION

Wickability of fabrics is a vital factor in the physiological comfort of the wearer. Fabric structure parameters such as type of weave pattern, type of fiber content, fiber fineness and the type of treatments applied to the fabrics affect the wickability. The following conclusions have been drawn from the above study:
In the bleached state it is found that among the weaves studied honeycomb exhibits a significant increase in wickability in comparison to the other fabrics. Warp way wicking is found to be higher than that of weft way. The application of plasma treatment has led to a significant improvement in wickability, the values ranging remarkably. Weft way wickability also shows the same trend as in warp way. The application of cross linking treatment using citric acid has resulted in a drastic reduction in wickability and in some cases, it is found to have a negative drop, showing impart of water repellency. Some of the weaves which were found to be poor in wickability in bleached state, have shown improvement in wickability following plasma treatment. Data on wickability were found to follow Washburn's equation as the correlation coefficients between the square of the wicking height and time were found to be very high.

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