Total Wear Comfort Index as an Objective Parameter for Characterization of Overall Wearability of Cotton Fabrics

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ABSTRACT
The state of physical comfort experienced by a wearer under a given environmental condition is greatly influenced by the tactile, thermal and moisture transport properties of the fabric. An in-depth study carried out to understand fabric handle and wear comfort in relation to fiber, yarn and fabric structural parameter is presented in this paper. The results obtained from this study provide an invaluable insight into engineering of required quality features into the cotton fabrics so as to provide optimum wear comfort. A comprehensive grading index incorporating the transport attributes (air permeability and moisture and thermal transport) of the fabric has been derived to grade end use efficiency of the fabric juxtaposing with fabric hand, which would finally decide the overall quality of the apparel fabric.

INTRODUCTION
Clothing comfort, being a fundamental and universal need for consumers, is defined as a pleasant state arising out of physiological, psychological and physical harmony between a human being and the environment[1]. The literature[2] generally classifies clothing comfort into three broad categories (a) aesthetic comfort (b) thermo-physiological comfort and (c) tactile comfort. Aesthetic appeal or psychological comfort is mainly based on subjective feelings and fashion trends that influence customer preferences. On the other hand, Thermo-physiological comfort relates to the ability of the fabric to maintain thermal equilibrium between the human body and the environment. Thermal, moisture and air resistance properties of the clothing material collectively contribute to the state of thermo-physiological comfort of the wearer. The tactile comfort is related to mechanical interaction between the clothing material and the human body and is an intrinsic and essential performance requirement in clothing. Although the fabric tactile properties have long being evaluated by a subjective method called fabric handle[3], it has been demonstrated in recent years that these are quantifiable in terms of physical measures. Most recently, major upsurge on research on friction of fabrics has taken place, as friction plays an important role on the hand of fabrics[4,5]. Hence, the Hand value together with the measured transport properties will determine the true quality of apparel fabrics.

No other fiber can give a better performance than cotton as far as the comfort requirements of fabrics are concerned. After experimenting with synthetics for over four decades there is a general agreement that there is no comparison with cotton as far as comfort is concerned, although better durability and aesthetic look might be achievable in the synthetics. Cotton, being a natural fiber, is inherently heterogeneous in it basic fiber properties. In particular, cotton is pre-sold to consumers on its comfort characteristics, in other words, moisture vapor transport[6]. Utilization of cotton fibers for diverse end uses and developing fabrics based on customer needs require a thorough understanding of the influence of fiber properties on the performance of end products. The volume of literature available today on aesthetic and comfort properties of cotton fabrics in relation to their yarn and fabric properties is grossly inadequate. The present work is indented to contribute to this area of textile science by way of providing an insight into the role played by fiber properties, yarn properties and fabric structure on the aesthetic and comfort of fabrics for different end uses. An attempt has been made to define a Total wear comfort index that could predict the overall clothing comfort performance for different end-uses and under different environmental conditions. Such a generalization could, possibly, make engineering of fabrics for specific end uses an objective science.

EXPERIMENTAL

Materials

The present study considered cotton fabrics of both plain and twill weave construction ranging in Grams per Square Meter (GSM) from 100 to 190 prepared using yarns that varied in count from 20/1 Ne to 50/1 Ne to 80/1 Ne spun using appropriate but two different twist levels for each count. Yarns of a given count were spun from cottons that varied in fiber attributes predominantly in fiber micronaire. Needless to mention that cottons from appropriate length groups were chosen to spin different counts. Only pure varieties of cotton were taken up for the study. The yarns and fabrics were prepared in a pilot plant on a laboratory scale. The greige fabrics were desized, scoured and bleached as per standard procedures. The schematic diagram showing the preparation of yarns and there from fabrics is presented in *Figure 1*.

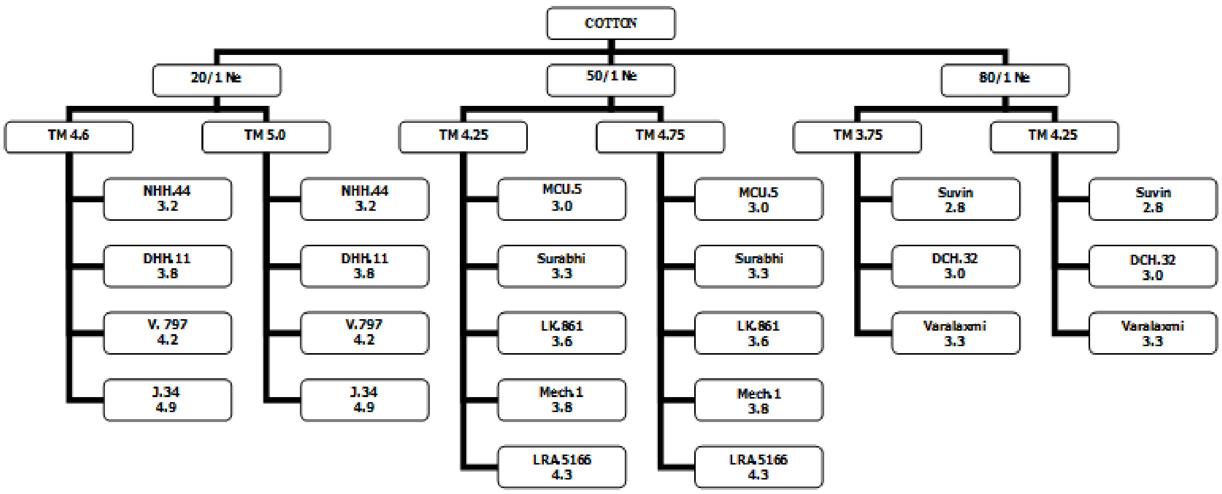

FIGURE 1. Scheme of sampling for preparation of yarn, Each of the above yarn samples is woven into plain and twill weave fabrics

Measurements

The fabrics of different grades obtained from the yarns described above were subjected to assessment of low stress mechanical properties using the entire set of Kawabata Evaluation System for fabrics (KES-FB). Both the Primary Hand Values (PHV) and Total Hand Value (THV) were obtained by using standard methods[7].

The transport property that is noted to be most sensitive to fabric structure is air permeability. This was measured by using Air Permeability tester KES-FB AP1[8]. The warm or cool feeling of a fabric, the thermal insulation and moisture transfer properties of the fabric were measured using Thermolabo II[9].

Derivation of an integrated index for wear comfort incorporating both tactile and thermo-physiological comfort parameters.

Sensory perceptions towards clothing, gathered from consumer surveys[10,11,13] across a number of countries by Li and by Byrne[12] suggests that the perception of comfort towards clothing has three major dimensions: thermal-wet, tactile and body- fit. Out of these three components, body-fit comfort is related to the garment design and only the first two components viz. thermal-wet and tactile are related to the fine structure and properties of the fabric. Hence, these two components are considered in the present study. Li has reported about a study in which the relative importance of different components of comfort for fabrics used for different end uses have been described. Analysis of the data obtained from the surveys and wear trials shows that the relative importance of these factors in consumer's perceived comfort was different under various combinations of physical activities and environmental conditions. The present study used the weighting factors reported by Li[14] to calculate the indices of comfort. Combining different parameters responsible for thermo-physiological and tactile comforts by conferring different weighting factors, a pair of indices of comfort have been defined viz. Thermo-Physiological Comfort Index (TPCI) and Total Wear Comfort Index (TWCI). These indices are expected to provide a practical way for assessing overall wear comfort. This argument does not underestimate the complex nature of comfort experienced by a wearer. However, it is fairly reasonable to obtain an index combining factors known to contribute to wear comfort for selecting a fabric for an anticipated end use.

The transport properties of fabrics are closely interrelated. Hence, we deceided to combine all transport properties of fabric; thermal insulation, air permeability and moisture permeability into a single factor namely Thermo-physiological Comfort Index (TPCI). After obtaining TPCI, Total Hand Value (THV), which is the index of tactile comfort, is incorporated into the first index to get a Total Wear Comfort Index (TWCI) after giving appropriate weighting factors to each parameter according to the findings of Li.

Before including the values of various transport related parameters and the THV into the index calculation, they were all normalized to a scale of 0-10 by applying suitable scaling factors. Normal ranges of values for different parameters included in the calculation have been either taken from literature or determined experimentally by measuring a wide range of fabrics.

Calculation of Comfort Indices

Winter Wear: In the case of winter wear fabrics, tactile and thermal-wet comforts are perceived to have equal importance. Winter fabrics should have high thermal resistance, at the same time they should be permeable to moisture owing to the fact that condensation of moisture in the fabric structure can lead to sudden lowering of thermal insulation. Increased movement of air through the fabric will reduce thermal insulation, hence, air permeability of the fabric should not be high.

Thermo-physiological Comfort Index for winter clothing ($TPCI_w$) is defined as:

$$TPCI_w = (TR*MTR*AR) \qquad (1)$$

TR - Thermal Resistance value (Tog)
AR - Air Resistance (KPa.s/m)
MTR - Moisture Transport Rate ($g/m^2.hr$)

As TPCI and THV are equally important for winter clothing, we can define Total Wear Comfort Index for winter clothing as:

$$TWCI_w = (TPCI)*0.5 + (THV)*0.5 \qquad (2)$$

Summer Wear: In the case of summer clothing, thermal-wet comfort was perceived to be more important followed by tactile comfort. Summer fabrics should be highly permeable to both air and moisture and at the same time, it should have low thermal resistance.

Hence Thermo-physiological Comfort Index for summer clothing ($TPCI_s$) is defined as:

$$TPCI_s = (MTR*AR)/TR \qquad (3)$$

As $TPCI_s$ is more important than THV for summer clothing, we can define Total Wear Comfort Index for summer clothing, by giving appropriate weighting factors to THV and $TPCI_s$, as:

$$TWCI_s = (TPCI)*0.7 + (THV)*0.3 \qquad (4)$$

RESULTS AND DISCUSSIONS

Influence of fiber micronaire value on low stress mechanical properties of yarns and fabrics:

Keeping all the yarn and fabric parameters the same and by only changing the fiber properties viz micronaire value, the changes brought about in the low stress mechanical properties of the yarns and fabrics were extensively studied. It was observed that (*Table I*), for any given yarn count, fabrics woven from yarns having finer fibers were observed to be easily stretchable when subjected to tensile deformation as can be observed from the values of tensile strain (EMT). This is also reflected in the higher values for tensile energy (WT). The tensile resiliency (RT), representing the recovery of the fabric from tensile deformation, was observed to increase with micronaire value of fibers. Fabrics made from coarser fibers were noted to be less extensible thereby improving their tensile resiliency.

The comfortable fitting of a woven fabric over a three dimensional surface is achieved mainly by a relative rotation of warp and weft threads, that takes place during shear deformation. Shear rigidity (G) which is a measure of the ease with which a fabric can be deformed in its own plane, was noted to be higher for fabrics made from finer fibers. Shear hysteresis (2HG), which is a measure of recovery from shear deformation, too showed an increase in fabrics made from finer fibers. This increase in G and 2HG may be due to the fact that for the same count, finer fibers in the yarn increases the yarn packing, resulting in an increase in the inter-fiber friction thereby ensuing greater resistance to relative movement of the yarns in the fabric.

As yarns are woven into fabric, flexibility remains one of the most important attribute of the fabric. Analysis of the bending properties showed that yarns and fabrics made up of finer fibers exhibited lower bending rigidity (*Figure 2*). In other words, yarns and fabrics stiffened with increase in coarseness (higher micronaire value) of the fibers.

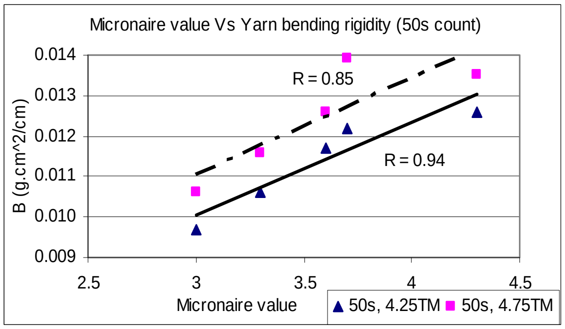

FIGURE 2. Fiber micronaire value vs yarn bending rigidity

The ratio of the coercive couple to the bending rigidity (Co/B) represents the curvature remaining in a yarn when the bending couple has been removed. Thus a smaller value of Co/B would imply better recovery. With increasing micronaire value of the fiber used, cotton fabrics showed a decrease in the ratio of coercive couple to bending rigidity Co/B and a better bending recovery. A lively fabric is expected to have low Co/B value. Therefore fabrics woven using finer fibers would be less lively and would not recover quickly from gentle crushing. Thus, fineness of single fibers stands out as an important factor contributing to yarn and fabric bending properties.

Fabric compression has been shown to depend on the pressure application which in turn influences the tactile perception of softness. The compressional energy (WC) for yarns and fabrics decreased with increase in fineness of the fibers used. Thus fabrics prepared from higher micronaire fibers would be softer in compression.

Resilience connotes the amount of strain energy present in a stressed system and is an important parameter influencing fabric hand. Without resiliency, a garment will soon distort, disfiguring the overall aesthetics. The resiliency of the yarns and fabrics (RC) improved with increase in fineness of the fibers.

Influence of yarn parameters on the low stress mechanical properties of fabrics and yarns

The yarn parameters that influence the aesthetic elegance, handle and comfort performance of the fabrics are mainly yarn twist and yarn count.

Influence of yarn count

Yarn count was observed to be an important parameter that affects the low stress tensile properties of fabrics. An increase in yarn coarseness resulted in increase in all the tensile properties of fabric namely tensile energy (WT), tensile resiliency (RT), linearity of load-extension curve (LT) and tensile strain (EMT). The low tensile resilience of fabrics made from finer yarns may have a contribution towards their low crease resistance.

Yarn count stands out as the single most important factor influencing shear properties of a fabric. Shearing in a fabric occurs due to the relative movement of the cross over yarns. Thus shear parameters mainly depend on the contact area at the yarn intersections in a fabric. This contact area between the yarns increases as the yarn becomes coarser and as a consequence, when a shearing deformative force is applied, the resistance torque also increases making it difficult to change the angle of crossing between the yarns at the cross over points. As the yarn becomes coarser, the fabric will become more rigid to shear. It is observed that the shear rigidity of fabrics made from 20/1 Ne count yarn is greater than those made from 80/1 Ne count yarn. The lower value of shear rigidity for the fabrics woven from 80/1 Ne count yarn suggests that these fabrics will adjust to three dimensional shape easily in response to shearing deformation force.

The same trend was observed for the shear hysteresis of fabric. Fabrics prepared from the coarser yarns (20/1 Ne count) had a higher shear hysteresis when compared to the fabrics woven from a finer yarn such as 80/1 Ne count. These results underline the influence of yarn count on the shear properties of fabric.

As the yarn becomes coarser, an increase is observed in the bending properties of yarn and fabrics. As coarser yarn have more number of fibers in their cross section compared to finer yarns, the inter fiber friction increased proportionately with decreasing yarn count thereby enhancing the resistance to bending. As a result, yarns that are denser and thicker are less flexible than their opposites. Bending hysteresis was also observed to be higher for fabrics woven from 20/1 Ne count yarns compared to that woven from 80/1 Ne count yarns.

The surface characteristics are one of the most important parameters contributing to the smoothness of the fabric. It was observed that only yarn and fabric construction parameters influence the surface features of the fabric. Geometrical roughness values (SMD) of a fabric was noted to depend on the count of the constituent yarns. As the yarn becomes coarser, the surface topology of the fabric will show large ups and downs when compared to a fabric made from finer yarns. This will result in a higher value for the geometrical roughness of the fabric. The deviation in the coefficient of friction (MMD) values of the fabric too showed an increase with increasing yarn coarseness, indicating that fabrics woven from coarser yarns have more uneven surface compared to those made from finer yarns. A compactly woven fabrics using finer yarns will thus considerably increase the smoothness of the fabric.

Influence of yarn twist

It was observed that changing only the yarn twist, keeping all other properties of the yarn and fabric the same, was able to bring about significant changes in the low stress mechanical properties of the fabric.

Tensile resilience (RT) was found to drop for fabrics made from higher twist yarns. This may be because with increasing yarn twist, fabrics were observed to have higher extension and that tensile resiliency is seen to have an inverse relationship with extension. This relationship was clearly discernable in fabrics made of coarser count yarns.

It was observed that for a given count, higher the twist multiplier, higher was the fabric extension. For example in the case of 20/1 Ne count yarn, fabric prepared from yarns of NHH cotton with twist multiplier of 4.6 and 5, showed an extension of 10.7% and 12.7% respectively. Yarns with higher twist have higher extension, possibly due to greater inclination of the fibers with respect to yarn axis. The fibers in the yarn tend to align itself parallel to the yarn axis upon stretching. This results in higher extension of these yarns and hence the fabric would also possess the same attribute. Thus an increase in fabric extension can be achieved by increasing the twist in yarn.

An increase in twist in the yarn also resulted in reduction in shear rigidity and shear hysteresis. As the twist increased, the yarns became more compact, reducing the contact area between yarns at the crossovers. This leads to lower friction between yarns at the intersections resulting in lower shear rigidity and shear hysteresis. This effect is more prominent in the fabrics woven from coarser count yarns, as there is greater reduction in the yarn diameter with increase in twist imparted to yarns.

Higher twist increases the compactness or packing of the yarns thereby restricting movement of fibers which will in turn increase the resistance to bending. Hence, an increase in twist will increase the fiber cohesion thereby increasing bending rigidity of the yarn which in turn will result in a higher bending rigidity for the fabric.

Compression properties are quite sensitive to twist levels in the yarn. An increase in twist resulted in reduction of both compressional energy (WC) and linearity in compression (LC) of the yarns. The greater the twist, the more restricted is the motion of the fibers against external pressure and hence less realignment and slippage of fibers resulting in decrease in WC and LC. High twist thus renders the yarn hard and wiry. Unlike yarns, fabrics woven from higher twisted yarns, showed an increase in WC. This is so because, a yarn of lower twist is softer and bulkier and when woven into fabric due to its bulkiness would increase the contact area between yarns. As a consequence, the inter-yarn frictional forces will increase which would in turn make the fabric more difficult to compress. At the same time, high twisted yarns are less bulky and when woven into fabric, will decrease inter-yarn frictional forces and as a result will be easier to compress.

Hence, the level of twist given to the yarn can be used as a factor for engineering the fabrics for desired qualities

Formability of fabrics

The measure of fabric "formability" is equal to the product of fabric bending rigidity and longitudinal fabric compressibility or extensibility. Fabrics made from coarse yarns (20/1 Ne count) shows a values greater than 5 while those made from finer yarns (80/1 Ne count) show a poor grading with formability values less than 2. Light weight fabrics would therefore be more difficult to tailor into garments of good appearance because they exhibit very limited longitudinal compressibility before fabric buckles or puckers (owing to high flexibility of thin light weight fabrics).

Handle values

When fabrics made from 20/1 Ne and 50/1 Ne count yarn were assessed as women's suiting, it was observed that fabrics, made from finer fibers, showed higher values for the primary hand values Numeri (smoothness) and Fukurami (fullness and softness), thereby improving the Total Hand Value.

Finer yarns (50/1 Ne count) in the fabric were seen to enhance the softness and smoothness (increased Numeri, Fukurami and Sofutosa), thereby giving a higher rating for these fabrics as women's suiting.

The Primary Hand Value and the Total Hand Value of the fabrics woven from 50/1 Ne and 80/1 Ne count yarn when assessed as Women's thin dress material also showed that fabrics woven from finer count yarn incorporating finer fibers have improved smoothness and softness values ensuring an enhanced Total Hand Value.

Higher twist in the yarn, increases fabric stiffness (Koshi) thereby bringing down both the Primary and Total hand values. The increase in Koshi with twist is more conspicuous for fabrics prepared from fibers having lower micronaire value.

It can thus be concluded that finer fibers when converted into yarns of finer count with optimum twist and then into fabric could provide improved hand or feel of the fabric when assessed as women's dress material.

Influence of weave on low stress mechanical properties

Change in weave from plain to twill was observed to bring about significant changes not only in the low stress mechanical properties of fabrics thereby influencing the Primary and Total hand values but also played a deciding role in transport behavior of fabrics such as air permeability, moisture permeability and thermal properties.

The loose structure of twill weave fabrics allows yarns and fibers to adjust and realign when deformation forces are applied, resulting in higher extensibility, lower tensile resiliency and lower bending rigidity. Tensile Energy (WT) values were noted to be lower for twill weave fabrics, which could be attributed to lower Tensile Linearity (LT) values, showing that these fabrics are easily deformable under low loads.

Fewer yarn cross overs in the twill weave fabrics compared to plain weave lead to lower inter yarn friction thereby bringing about significant reduction in shear rigidity, shear hysteresis and bending hysteresis (*Figure 3*).

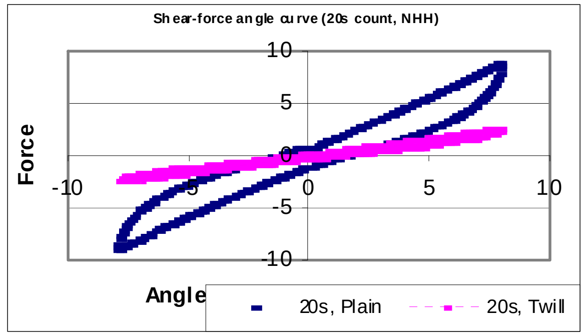

FIGURE 3: Shear curves for Plain and Twill weave fabrics

Another observation that could be made from the Electron Micrograph (*Figure 4 & 5*) is that due to the compactness of the plain weave, the yarns are more or less flattened, thus increasing the contact area between the warp and weft threads, thereby increasing shear rigidity.

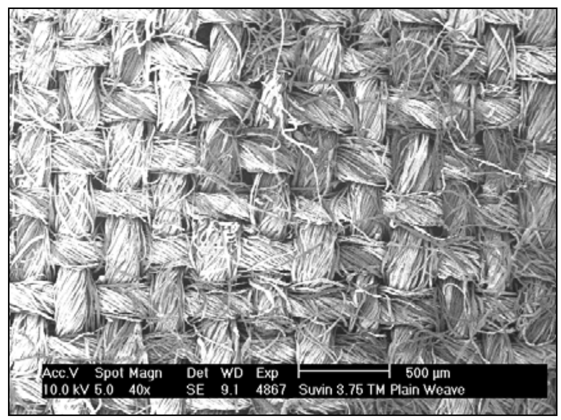

FIGURE 4 : Suvin Plain Weave

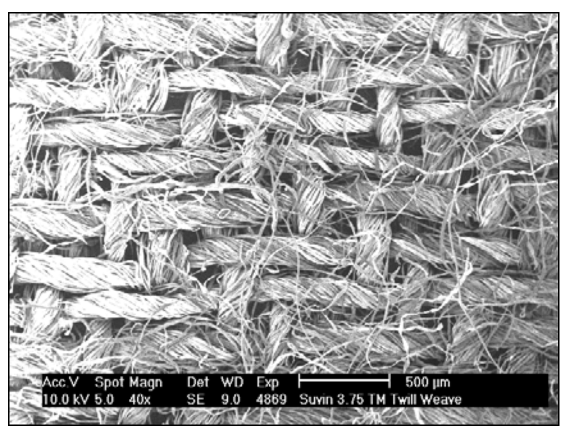

FIGURE 5 : Suvin Twill Weave

The reduction in surface parameters SMD and MMD for the twill weave fabrics can be attributed to fewer crossovers of the warp and weft yarns and also due to the presence of long floats resulting in less surface bumpiness. The surface roughness can thus be reduced by choosing weaves with longer surface floats.

Influence of weave on primary hand and total hand values

The change in the weave of the fabric from plain to twill brought about significant changes in the Primary and Total Hand Value when assessed for both women's suiting and women's thin dress material. Decrease in the fabric stiffness accompanied by enhanced smoothness and softness resulted in higher Total Hand Value for twill weave fabrics compared to plain weave fabrics.

Thermo-physiological comfort parameters

air permeability

A clear linear relationship was observed between air permeability and the fineness of cotton fibers used in making the fabric. The air permeability of fabrics woven from yarns having the same count and twist, had a negative correlation with fineness of the cotton used (*Figure 6*). This could be due to the fact that for a given count, yarns spun from finer fibers will have less intra-yarn space due to increased yarn packing. As all other yarn and fabric parameters are kept same, this decrease in intra-yarn spacing would result in reduced air permeability for fabrics woven from yarns having finer fibers.

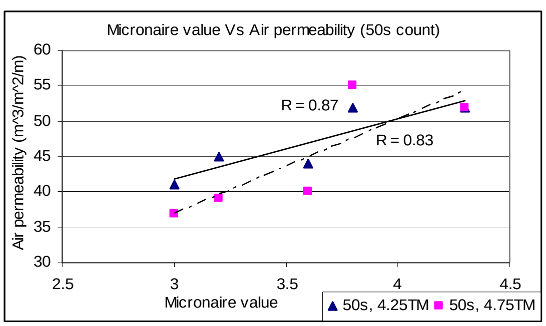

FIGURE 6: Influence of micronaire value on air permeability

Coarser yarns produce fabrics with more intra-yarn air spaces but with fewer inter-yarn air spaces resulting in lower air permeability.

Air permeability of fabrics made from yarns having higher levels of twist is observed to be higher. Higher twist leads to more compact yarns, thereby decreasing intra-yarn space at the same time increasing inter-yarn spacing within the fabric. In other words, the higher twist yarn produces a less dense fabric resulting in higher air permeability.

Thermal and moisture transport properties

Thermal and moisture transport properties of fabric, which are important from clothing point of view, are Thermal Insulation, Warm/Cool feeling and Moisture Permeability.

q_{max} or warm/cool feeling:

The sensation of warmth and coolness to touch when skin is brought into contact with a fabric is a transient heat conduction phenomenon and this contributes to the perception of comfort of the garment. The warm/cool feeling[11] is believed to be the result of the rapid transfer of heat flux from the skin to the fabric surface immediately after the fabric is placed in contact with the skin. This momentary flow of heat triggers the sub- cutanious warm and cool receptors and induces thermal sensations. The rate of heat flow, which reaches a peak value, (q_{max}) approximately 0.2 sec after contact with the fabric is related to the warm/cool feeling felt by the wearer.

It was observed (*Figure 7*) that the warm/cool sensation that results as the fabric contacts a skin surface is related to the surface contour of the fabric. The geometrical roughness and the variation in the coefficient of friction have a negative correlation with q_{max} . An increase in Geometrical roughness (SMD) and Variation in the Coefficient of friction (MMD) implies an increase in the roughness of the surface of the fabric. When the contact between skin simulating heat source and fabric is reduced by an irregular fabric surface contour, this will result in the lowering of q_{max} value. Fabric woven from 80/1 Ne count yarn have a smoother surface (lower value of MMD and SMD) and hence have higher q_{max}. The higher the q_{max} value (i.e. the greater the peak value of the momentary heat flow), the cooler will be the contact sensation.

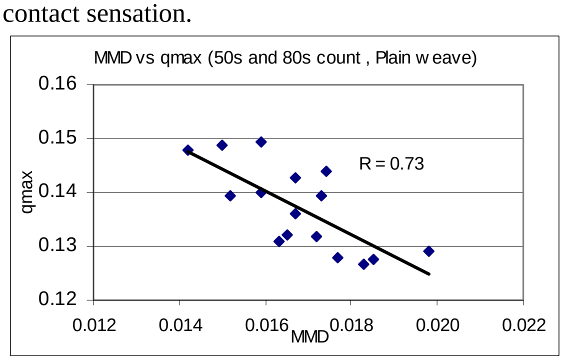

FIGURE 7: Influence of MMD on q_{max}

q_{max} value was observed to be lower for twill weave fabrics. This may be due to the slightly raised structure of these fabrics, which reduces the contact area between the skin simulating T box and fabric resulting in reduced q_{max} .

Thermal Resistance

The maintenance of thermal balance is probably the most important physical-comfort attribute of clothing. *Table II* gives the thermal transport data for the fabrics under study.

It is mainly the fabric construction parameters that were seen to influence the thermal properties of the fabric. Fabric warmth was noted to be largely a function of airspace and its distribution in the structure.

Thermal resistance showed a decrease with increase in air permeability. An increase in air permeability of the fabric means that more air will be able to penetrate through the fabric, which will enhance heat and vapor transfer from the guarded hot plate surface. Hence, a fabric with high air permeability implies a more open structure, which will give a cooler perception to the wearer in comparison to a less permeable one. In other words, lower air permeability thus implies a superior cover and hence improved fabric warmth.

Twill weave fabrics, by virtue of enhanced thickness, provided better thermal insulation comparable to plain weave fabrics. From the above discussions, it can be concluded that thermal resistance of a fabric is strongly dependant on the enclosed still air and this factor is in turn influenced by the fabric structure and air permeability.

Moisture Transport

The water-vapor permeability of clothing materials is noted to be a critical property of textiles which contribute to comfort under hot and cold weather conditions.

When fabrics made from yarns of a particular count and twist are considered, the data on moisture transfer rate showed that finer the fibers used for preparing the fabric, lower will be the moisture transport through the fabric. This may be due reduced air space in these fabrics made from finer fibers (*Figure 8*).

TABLE II : TRANSPORT PROPERTIES OF PLAIN & TWILL WEAVE FABRICS

Nominal count/TM	Cotton	Fabric Thickness (mm)		Air Permeability ($m^3/m^2/m$)		Thermal Resistance (Tog)		Moisture Transfer Rate ($g/m^2.hr$)	
				Plain	Twill	Plain	Twill	Plain	Twill
20/1 Ne, 4.6	NHH.44	0.70	0.91	24	49	1.46	1.41	2.98	3.31
	DHH.11	0.67	0.91	31	49	1.44	1.44	3.06	3.34
	J.34	0.71	0.91	36	53	1.46	1.47	3.01	3.37
	V.797	0.75	0.92	46	60	1.42	1.42	3.18	3.52
20/1 Ne, 5.0	NHH.44	0.69	0.91	28	52	1.45	1.40	3.01	3.38
	DHH.11	0.74	0.93	34	51	1.46	1.39	3.27	3.44
	J.34	0.73	0.93	46	57	1.41	1.39	3.18	3.48
	V.797	0.76	0.92	49	62	1.40	1.36	3.24	3.52
50/1 Ne, 4.25	MCU.5	0.45	0.63	41	63	1.35	1.36	3.29	3.54
	Surabhi	0.50	0.63	45	65	1.33	1.34	3.36	3.59
	LK.861	0.49	0.65	44	69	1.31	1.38	3.43	3.7
	Mech.1	0.48	0.64	52	70	1.31	1.35	3.52	3.79
	LRA.5166	0.52	0.68	52	71	1.29	1.41	3.72	3.93
50/1 Ne, 4.75	MCU.5	0.50	0.61	37	66	1.30	1.37	3.36	3.57
	Surabhi	0.51	0.63	39	67	1.31	1.36	3.34	3.53
	LK.861	0.51	0.64	40	72	1.29	1.35	3.48	3.78
	Mech.1	0.51	0.65	55	72	1.30	1.34	3.51	3.83
	LRA.5166	0.54	0.69	52	75	1.29	1.35	3.84	3.96
80/1 Ne, 3.75	Suvin	0.46	0.53	58	83	1.25	1.31	3.54	3.80
	DCH.32	0.45	0.57	57	85	1.24	1.33	3.48	3.90
	Varalaxmi	0.45	0.55	73	91	1.23	1.32	3.57	3.96
80/1 Ne, 4.25	Suvin	0.42	0.58	68	91	1.21	1.28	3.54	3.87
	DCH.32	0.41	0.55	77	95	1.26	1.30	3.63	4.02
	Varalaxmi	0.46	0.55	81	97	1.19	1.29	3.71	4.04

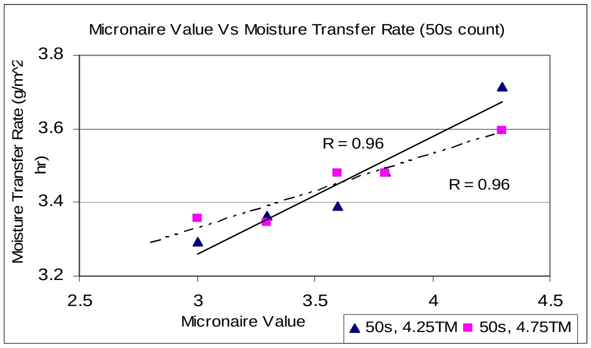

FIGURE 8: Effect of fiber micronaire on moisture transfer rate

It was observed from *Table II* that fabrics made from finer yarns were able to displace a greater amount of moisture in a given time. Finer yarns will produce a fabric with lower cover factor, thereby increasing the total air space within the fabric.

It is clear from *Figure 9*, that fabrics which allow easy flow of air through them will also be permeable to moisture. This result clearly indicates that water vapor transfer takes place through air spaces in the fabric.

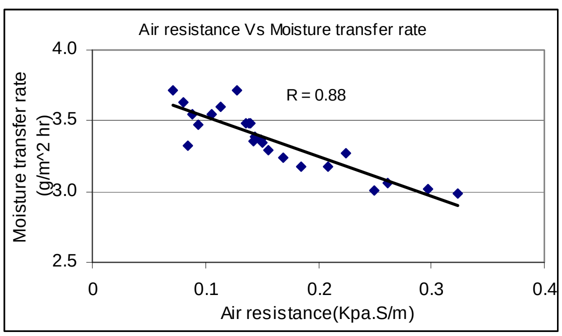

FIGURE 9: Relation between air resistance and moisture transfer rate

The movement of air, water vapor and heat depends on the air space within the fabric and hence would obviously depend to some extent on the fabric structure guided by the total air space and its distribution.

All the data obtained from objective measurements, viz. thermal resistance, moisture permeability and Total Hand Value, that influence fabric comfort property are used to derive a single index that will take into account both the tactile and thermo-physiological comfort of the fabric.

Integrated index for wear-comfort

Table III gives the Thermo-physiological Comfort Index (TPCI) and Total Wear Comfort Index (TWCI) for the fabrics under present study as both summer and winter wear and for different end uses viz. as Women's Suiting and as Women's Thin Dress Material.

TABLE III: TPCI AND TWCI VALUES FOR PLAIN WEAVE AND TWILL WEAVE FABRICS AS WOMEN'S SUITING

Nominal Count/TM	Cotton	Women's Suiting			
		Plain Weave		Twill Weave	
		$TPCI_w$	$TWCI_w$	$TPCI_w$	$TWCI_w$
20/1 Ne, 4.6	NHH.44	3.1	4.2	1.6	3.9
	DHH.11	2.6	3.7	1.6	3.7
	J.34	2.4	3.7	1.4	3.9
	V.797	2.1	3.5	1.2	3.6
20/1 Ne, 5	NHH.44	2.9	3.9	1.5	3.7
	DHH.11	2.4	3.4	1.5	3.6
	J.34	1.8	3.3	1.4	3.8
	V.797	1.7	3.3	1.2	3.6
50/1 Ne, 4.25	MCU.5	1.5	3.9	1.3	4.3
	Surabhi	1.5	3.6	1.1	4.2
	LK.861	1.4	3.7	1.1	4.3
	Mech.1	1.4	3.7	1.1	4.2
	LRA.5166	1.4	3.5	1.0	4.1
50/1 Ne, 4.75	MCU.5	1.4	3.6	1.0	4.0
	Surabhi	1.5	3.7	1.0	4.1
	LK.861	1.4	3.8	0.9	4.2
	Mech.1	1.2	3.6	0.8	3.9
	LRA.5166	1.2	3.6	0.8	3.9

From *Table III*, it is observed that fabrics made from low count yarns (20/1 Ne count) but using finer fibers (low micronaire value) gave highest value for Total Wear Comfort Index (TWCI) as women's suiting (winter wear) for plain weave fabrics. In the case of twill weave fabrics, fabrics woven from finer yarns (50/1 Ne count) gave better value for TWCI due to higher Total Hand Values for these fabrics. Another observation that could be made from Table III is that all the cotton fabrics showed comfort index to be less than 5, for winter wear, showing that these cotton fabrics are not ideal as winter wear fabrics.

The same was the case when finer fabrics (50/1 Ne and 80/1 Ne count) were evaluated for their Total Wear Comfort Index as women's thin dress for winter wear. The values of TWCI being less than 5, indicates that these fabrics are not suitable as winter wear fabrics, which is obviously true.

TABLE IV: TPCI AND TWCI VALUES OF FABRICS AS WOMEN'S THIN DRESS MATERIAL

Nominal Count/TM	Cotton	Thin Dress Material (Winter)				Thin Dress Material (Summer)			
		Plain Weave		Twill Weave		Plain Weave		Twill Weave	
		$TPCI_w$	$TWCI_w$	$TPCI_w$	$TWCI_w$	$TPCI_s$	$TWCI_s$	$TPCI_s$	$TWCI_s$
50/1 Ne, 4.25	MCU.5	1.5	4.2	1.3	3.3	3.1	6.2	4.4	5.0
	Surabhi	1.5	4.2	1.1	3.2	3.4	6.4	5.3	5.6
	LK.861	1.4	4.3	1.1	3.2	3.6	6.6	5.8	6.0
	Mech.1	1.4	4.2	1.1	3.2	3.8	6.7	6.1	6.2
	LRA.5166	1.4	4.1	1.0	3.0	4.5	7.1	7.1	6.8
50/1 Ne, 4.75	MCU.5	1.4	4.2	1.0	3.0	3.6	6.5	5.7	5.9
	Surabhi	1.5	4.1	1.0	3.0	3.5	6.4	5.7	5.9
	LK.861	1.3	4.2	0.9	3.1	4.0	6.9	6.7	6.7
	Mech.1	1.3	4.2	0.8	2.9	4.5	7.3	7.2	7.0
	LRA.5166	1.2	4.2	0.8	2.9	5.0	7.5	7.7	7.2
80/1 Ne, 3.75	Suvin	1.0	3.9	0.7	2.8	5.4	7.6	7.9	7.4
	DCH.32	0.9	3.8	0.6	2.5	6.0	7.9	8.2	7.6
	Varalaxmi	0.8	3.8	0.5	2.5	6.4	8.2	8.6	7.8
80/1 Ne, 4.25	Suvin	0.9	3.8	0.6	2.8	6.4	8.4	8.8	8.1
	DCH.32	0.8	3.8	0.6	2.6	7.3	9.0	9.3	8.4
	Varalaxmi	0.7	3.7	0.5	2.6	7.9	9.3	9.5	8.4

When considered as summer wear fabrics, both Plain and Twill weave gave higher values for $TWCI_s$ showing the suitability of these fabrics as summer wear. Fabrics woven from finer yarns (80/1 Ne count) gave higher value for $TWCI_s$, due to higher heat, moisture and air permeability of these fabrics compared to the ones woven from 50/1 Ne count yarns. When fabrics woven from 50/1 Ne count yarns or 80/1 Ne count yarns are considered separately, it was observed that fabrics prepared using coarser (high micronaire fibers) fibers gave the highest value for $TWCI_s$. This is because, these fabrics were permeable to air, heat and moisture, an important feature needed for summer wear fabrics

The use of very light fabric (80/1 Ne count fabric) would be ideal as a summer fabric as there will be more evaporation of sweat and loss of heat to the environment in addition to improved air permeability values, which is correctly predicted by the Total Wear Comfort Index.

Another observation was that all cotton fabrics under study showed TWCIw less than 5 showing the unsuitability of these fabrics as winter wear fabrics. When fabrics were considered for Women's suiting, Total Hand Value obtained from Kawabata system showed higher grading for fabrics woven from 50/1 Ne count yarn, by virtue of its higher smoothness and softness, compared to those from 20/1 Ne count yarn. However, the Thermo-physiological Comfort Index that grades the fabric on the basis of Thermo-physiological Comfort, showed higher value for fabrics woven from 20/1 Ne count yarn compared to those woven from 50/1 Ne count yarn due to higher thermal insulation value and moisture permeability. The combined Total Wear Comfort Index showed that fabrics woven from coarser count yarns were better suited as winter wear suiting fabric, which is obviously true.

Twill weave fabric showed better rating as a summer wear fabric, on the basis of $TWCI_s$. This is due to the improved transport properties of the twill weave fabrics making them ideal as summer wear fabrics.

CONCLUSIONS

The current study has gathered valuable information and some of the salient findings emanating from the study are outlined below.

It could be concluded that selecting either longer or finer fibers for preparing yarns and there from fabrics will help in realizing greater extensibility and higher tensile energy, of course at the expense of tensile recovery or resiliency. It could also be inferred that these fabrics would possess lower bending stiffness, lower compressional energy and lower bending recovery. Use of finer fibers for preparing fabrics will increase the recovery from compressional deformation thereby improving springiness of the fabric.

Yarn count is an important parameter that affects the mechanical properties of the yarns and fabrics made from them. Increase in yarn coarseness results in enhancement of all low stress mechanical parameters of the fabric.

Increase in yarn twist brings about an increase in bending rigidity, extensibility, compressional energy and the residual strain. At the same time shear rigidity and hysteresis and tensile resilience were found to decrease. Hence, the desired change in the fabric mechanical properties can be brought about by varying the yarn twist.

It can be summarized that finer fibers converted into yarns of finer count with optimum twist and then into fabrics, would improve the feel in terms of smoothness and softness and hence would provide a better overall grading (Total Hand Value) of the fabric when assessed for women's suiting and thin dress material.

The overall effect of change in the fabric structure on mechanical and surface properties of the fabric is quite prominent which in turn have influence on fabric handle and other comfort related properties of the fabric. Twill weave makes the fabric flexible for bending and shearing, improves extensibility and compressibility, reduces hysteresis effect and increases smoothness of the surface. The increase in smoothness, fullness and softness of twill weave fabrics in turn enhances the Total Hand Value of the fabric. Hence, fabric construction can be altered to offset the undesirable handle characteristics by selecting a weave that permits greater yarn mobility.

Air permeability showed a negative correlation with fineness of the cotton fibers and fabric cover. Increase in yarn twist, yarn fineness and more open structure of the fabric improved air permeability. It can thus be deciphered that air permeability will depend on the yarn or fabric structural parameters which will influence the shape and area of channels permitting airflow in fabrics. Thermal insulation or thermal resistance can be said to depend uniquely on factors that influence fabric thickness. The surface features of the fabric have a greater influence on warm/cool feeling than the fabric structure. A rough fabric surface reduces the area of contact appreciably, while a smoother surface increases the area of contact and the heat flow, thereby creating a cooler feeling. It was noted that Total Wear Comfort Index gives a better understanding of the suitability of a fabric for a given end use as it includes both thermo-physiological and tactile parameters combined into a single index.

The present study clearly showed that by an assessment of mechanical and transport properties that are necessary to get the best comfort levels, it is possible to engineer a fabric by appropriately selecting fiber, yarn and fabric constructional parameters based on their established relationships with different comfort parameters. The results obtained from this study can be used for modifying fabric features required at the garment level by appropriately choosing cotton fibers, setting spinning parameters and weave design.

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Table I. Low Stress Mechanical Properties of Fabrics

Nominal Count /TM	Cotton	Micro-naire Value	LT	WT $gfcm/cm^2$	RT (%)	EMT (%)	G gf/cm.deg	2HG gf/cm	2HG5 gf/cm	B gfcm/cm	2HB gfcm/cm	LC	WC $gf.cm/cm^2$	RC (%)	MIU	MMD	SMD (micron)	Formability
20/1 Ne / 4.6	NHH.44	3.2	0.632	16.8	42.4	10.7	0.91	1.86	3.00	0.050	0.045	0.294	0.21	51.4	0.191	0.033	7.71	5.1
	DHH.11	3.8	0.630	17.3	42.5	11.0	0.87	1.84	2.83	0.052	0.045	0.308	0.21	48.3	0.190	0.047	8.41	5.5
	J.34	4.2	0.630	15.6	42.7	9.9	0.76	1.59	2.52	0.056	0.042	0.307	0.24	46.0	0.193	0.036	7.83	5.3
	V.797	4.9	0.627	14.7	43.0	9.4	0.58	1.28	2.01	0.064	0.038	0.304	0.27	43.5	0.189	0.039	8.10	5.5
20/1 Ne / 5	NHH.44	3.2	0.585	18.1	41.2	12.7	0.82	1.76	2.72	0.051	0.042	0.311	0.22	49.9	0.190	0.04	7.67	6.7
	DHH.11	3.8	0.605	18.7	41.4	12.3	0.73	1.41	2.22	0.053	0.039	0.307	0.24	48.8	0.185	0.036	8.56	7.1
	J.34	4.2	0.637	16.4	41.6	10.3	0.70	1.47	2.37	0.058	0.047	0.294	0.24	47.4	0.192	0.040	7.70	5.6
	V.797	4.9	0.647	16.0	41.6	10.0	0.63	1.41	2.22	0.069	0.044	0.283	0.26	49.3	0.186	0.040	7.56	6.0
50/1 Ne / 4.25	MCU.5	3.0	0.610	14.0	38.8	9.2	0.49	0.96	1.40	0.020	0.013	0.32	0.15	63.9	0.188	0.015	4.71	2.1
	Surabhi	3.3	0.614	13.8	40.6	8.9	0.52	1.09	1.67	0.022	0.015	0.332	0.18	57.4	0.198	0.019	5.23	2.0
	LK.861	3.6	0.610	13.2	41.2	8.6	0.44	0.9	1.30	0.023	0.013	0.304	0.17	49.5	0.192	0.017	4.68	2.2
	Mech.1	3.8	0.629	13.0	42.2	8.2	0.45	0.93	1.41	0.026	0.015	0.311	0.18	49.5	0.190	0.017	4.71	2.1
	LRA.5166	4.3	0.631	12.8	42.6	8.1	0.41	0.83	1.18	0.027	0.015	0.321	0.21	47.0	0.194	0.020	5.55	2.4
50/1 Ne / 4.75	MCU.5	3.0	0.626	15.1	38.9	9.7	0.51	0.99	1.57	0.023	0.016	0.292	0.17	56.1	0.177	0.016	5.14	2.3
	Surabhi	3.3	0.628	14.7	38.6	9.3	0.49	1.06	1.55	0.024	0.015	0.298	0.18	52.8	0.187	0.017	5.13	2.3
	LK.861	3.6	0.621	14.9	39.7	9.6	0.47	0.98	1.41	0.026	0.015	0.316	0.2	49.8	0.189	0.016	5.30	2.6
	Mech.1	3.8	0.629	14.1	39.9	9.0	0.46	0.93	1.40	0.027	0.015	0.288	0.18	49.5	0.179	0.018	5.25	2.5
	LRA.5166	4.3	0.635	14.0	40.3	8.9	0.43	0.88	1.25	0.027	0.016	0.324	0.22	47.7	0.186	0.018	5.45	2.6
80/1 Ne /3.75	Suvin	2.8	0.604	11.1	38.2	7.3	0.31	0.67	0.86	0.015	0.011	0.242	0.16	68.4	0.182	0.015	4.03	1.3
	DCH.32	3.0	0.609	11.2	39.2	7.3	0.31	0.61	0.83	0.016	0.010	0.296	0.15	61.8	0.186	0.017	4.38	1.4
	Varalaxmi	3.3	0.607	11.3	39.4	7.5	0.29	0.54	0.72	0.016	0.010	0.303	0.19	53.9	0.182	0.015	4.28	1.6
80/1 Ne /4.25	Suvin	2.8	0.612	12.7	36.6	8.3	0.32	0.62	0.86	0.016	0.010	0.29	0.16	51.1	0.181	0.016	4.34	1.6
	DCH.32	3.0	0.616	12.7	37.1	7.9	0.32	0.64	0.89	0.016	0.012	0.331	0.17	48.9	0.185	0.017	4.76	1.5
	Varalaxmi	3.3	0.602	13.1	37.9	8.9	0.31	0.59	0.82	0.017	0.010	0.287	0.18	46.4	0.181	0.017	4.49	1.9