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Comfort properties of non-conventional light weight worsted suiting fabrics

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Mechanical and thermal comfort aspects of fabrics produced from some non-conventional blends and light weight constructions have been examined. Single yarn woven worsted suiting fabrics show better physical as well as physiological comfort-related properties. Among various natural fibre based worsted suiting fabrics, the linen blend proves to be most suitable with respect to mechanical comfort. Wool and wool:silk blends provide very good transmission properties. Fabrics produced from single worsted yarns are found to be superior to those of the equivalent 2-ply yarns as regards to both mechanical and thermal comforts.

Keywords: Air permeability, Fabric handle, Thermal insulation, Water vapour permeability, Worsted suitings
IPC Code: Int. Cl.[8] D03D

1 Introduction

Consumers are now much more quality conscious than ever before. The market is solely dependent on customers' choice. Textile materials and applications have experienced a dramatic transformation in the last few decades.[1] Apparel fabrics are rejected much ahead of their life time only because they lose their aesthetic appeal or functionality. Functionality is determined by the ability of the textile material or more specifically the apparels to meet the needs of the consumer. Comfort has totally replaced the durability as far as the selection of garments/fabrics is concerned.[2,3]

Current trends show a shift from heavy weight fabrics towards light weight high quality fabrics. Also, there is a definite shift towards the use of natural fibre based apparel fabrics. Suiting fabrics are now preferred in the range of 130-220 gsm in contrast to conventional 250-350 gsm. Efforts are being made to produce such fabrics by using non-conventional blends of natural fibre based fine worsted yarns and light weight fabric construction. While developing such new fibre-mix and light construction, the primary attributes of ideal fabric[4,5] are expected to change, because basic fibre characteristics and fabric construction parameters substantially influence fabric properties and performance. It is essential to understand the physical and physiological interrelationship between the new cloth and human body. Both mechanical comfort and thermal comfort characteristics of the fabric need to be investigated. It is therefore important to examine the change in mechanical properties of fabric and final hand value including various transmission behaviour with change in fibre-mix. The present work was, therefore, aimed at studying both mechanical and thermal comfort aspects of fabrics produced from some non-conventional blends and light weight constructions.

2 Materials and Methods

2.1 Materials

Worsted suiting fabrics with a wide range of areal densities were manufactured from various non-conventional natural fibre blends like wool:silk, wool:tassar, wool:linen, wool:cotton and silk:linen, at different proportions. Pure wool, pure silk and a few synthetic fibre blended samples were also prepared for comparison purpose. The list of fabric samples developed along with their constructional details are given in Table 1. Fabric samples with identical blend percentage and areal densities were also produced using single and 2-ply yarns separately to examine the advantage of production of light weight fabrics with single yarn.

2.2 Methods

2.2.1 Evaluation of Fibre Properties

The fibre tensile properties were evaluated on Instron tensile tester as per ASTM D 3822-01.

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Table 1 — Constructional parameters of fabric samples

Sl No.	Blend	Blend ratio	Warp count Nm	Weft count Nm	EPI	PPI	Fabric weight gsm
1	Wool	—	1/40	1/40	70	60	122
2			2/78	1/40	70	60	127
3			2/50	2/50	64	54	166
4	Silk	—	1/20	1/20	60	48	181
5			1/12	1/12	48	32	282
6	Wool:Tassar (W:T)	80:20	1/48	1/48	82	68	122
7		80:20	2/100	1/48	82	68	126
8		70:30	1/48	1/48	82	68	126
9		70:30	2/100	1/48	82	68	133
10		60:40	1/48	1/48	82	68	124
11		60:40	2/100	1/48	82	68	128
12	Wool:Silk (W:S)	70:30	1/48	1/48	78	60	127
13		70:30	2/100	1/48	78	60	124
14		70:30	1/48	1/48	84	64	135
15		70:30	2/100	1/48	84	64	134
16		50:50	2/56	2/56	42	56	163
17	Wool:Linen (W:L)	70:30	2/48	1/24	68	54	221
18	Wool:Cotton (W:C)	65:35	1/20	1/20	54	64	191
19	Silk:Linen (S:L)	80:20	2/60	2/60	70	52	162
20	Wool: PET (W:PET)	50:50	2/38	2/38	56	48	177
21	Wool:Nylon (W:N)	80:20	2/22	2/22	38	36	311
22	Wool:Acrylic (W:A)	32:68	2/52	2/52	60	52	155

Kawabata evaluation system KES FB2 bending tester was used to measure the bending rigidity of fibres. Paper windows of 10 cm length and 1 cm width were prepared for this purpose. Ten fibres per window were used to test bending rigidity with a maximum curvature of 2.5 cm^{-1}.

Fibre diameter was measured using projectina microscope and denier by taking weight of a known length of fibres using a digital balance.

2.2.2 Evaluation of Yarn Properties

Yarn bending rigidity was measured on the Kawabata pure bending tester (KES FB2). Yarn samples were prepared into windows of 20 cm length and then tested on the instrument using 20 yarn samples per window, 20 cm window length and 1 cm window width (test length of yarn). The maximum yarn curvature was 1 cm^{-1}.

Similarly, the yarn compressibility was tested on KES FB3 compression tester. Windows were prepared with 2 cm × 2 cm dimensions and 10 number of yarns per window. The maximum pressure of 50 cN/cm^2 was maintained.

2.2.3 Evaluation of Fabric Handle by KES

The Kawabata evaluation system was used to measure fabric hand value. The system comprises four modules for testing the fabric low-stress mechanical properties, such as tensile, shear, bending, compression and friction. Total 16 sub-parameters were obtained from the instrumental measurements. The primary hand values pertaining to specific comfort aspects of the fabric were calculated by the software.[6,7] Then the total hand value was determined for winter as well as summer applications separately using Kawabata equation, as given below:

$$\mathrm{THV} = C_0 + \sum_{i=1}^{16} [\, C_{1i}\,(X_i - m_{1i})/\sigma_{1i} + C_{2i}\,(X_i - m_{2i})/\sigma_{2i}]$$

where C_0, C_{1i} and C_{2i} are the coefficients/constants for the i^{th} parameter; X_i , the mechanical property of the i^{th} variable term; m_{1i} & σ_{1i}, the population mean and standard deviation; and m_{2i} & σ_{2i}, the square mean and standard deviation.

2.2.4 Evaluation of Transmission Properties of Fabrics

Air permeability of all the fabric samples was measured on Textest FX 3300 tester. The instrument measures the volume of air passing through the fabric per unit area per unit time.[8,9] The air pressure maintained was 100 Pa, diameter of sample under test was 2.54 cm and the test area was 5.08 cm^2.

The thermal insulation was evaluated on KES as well as Alambeta thermal tester. The Kawabata evaluation system (KES FB7) was used to measure the resistance to heat flow or thermal insulation value.[9,10] The sample dimension maintained was 20 cm × 20 cm. Dry contact method was involved in this test with air velocity of 30 cm/s.

The relative water vapour permeability was evaluated on the Alambeta Permetest equipment[11] using the following relationship:

Relative water vapour permeability $P_{wv} = \frac{q_1}{q_0}$

$$= \frac{\text{Heat lost when fabric is placed on the measuring head}}{\text{Heat lost from bare measuring head}}$$

Therefore, $P_{wv} = \frac{u_1}{u_0}$

where u_1 is the output voltage when fabric is placed on the measuring head; and u_0, the output voltage from bare measuring head. The sample dimensions were 10 cm × 10 cm and minimum sample thickness required was 0.5 mm.

3 Results and Discussion

3.1 Fibre Properties

All the fibres used for the preparation of various blends were evaluated for their dimensional and physical properties in order to understand their role in fabric mechanical and comfort properties. The results are given in Table 2.

It may be observed from the table that linen is the stiffest among all the fibres followed by tassar, silk, cotton and wool. Linen is also least extensible and having very high initial modulus, whereas wool is highly extensible with lowest initial modulus.

3.2 Handle Properties of Non-conventional Worsted Fabrics

All fabric samples were evaluated for their handle using KES. The total hand value (THV) was calculated for summer and winter applications separately. In all the fabric samples, a lower total hand value results because of the poor finishing treatment under laboratory conditions only. However, still better handle can be expected upon proper finishing under actual industrial conditions. It is observed that most of the fabrics give better THV for winter applications as compared to summer. This may be due to the fact that the majority component in almost all fabrics is wool fibre, having excellent properties for winter application. This property in wool is inherent due to crimp and the scaly surface structure of the fibres. However, some of the fabrics show suitability for summer applications as well when blended with tassar or cotton. Cotton is well known for its suitability in summer. However, tassar fibre in combination with wool is sometimes suitable as a summer suit because it has a higher stiffness/rigidity and it improves the crispness of the fabric. The results clearly depict that wool:silk blends are not suitable for summer applications. It was thus felt necessary to compare the different wool and wool blended fabrics for their best suitability in winter or summer applications individually.

3.2.1 Effect of Fibre Properties on Handle of Worsted Fabrics

The fibre properties decide the suitability of a fabric for winter or summer suit based on their low-stress mechanical properties. Fig. 1 clearly depicts that 100% wool fabrics are most suitable for winter applications because of the smoothness, softness and fullness developed due to the crimp in the fibres. Wool:tassar blended fabrics are suitable for winter when tassar percentage is low but as the percentage of tassar fibre in the blend increases, its suitability for summer is developed. This is because of the comparatively higher bending rigidity of tassar which develops crispness and anti-drape properties in the fabric required for summer applications. Synthetic blends have a higher bulk and related fullness needed

Table 2 — Fibre properties

Fibre	Average diameter µm	Average fibre denier	Average bending rigidity cN.cm^2/tex^2	Average initial modulus cN/den	Average extensibility %	Average tenacity cN/den
Wool	20.0	2.7	0.00020	55.23	29.36	1.61
Silk	12.5	1.6	0.00065	86.10	20.54	4.41
Tassar	22.5	3.0	0.00075	91.02	16.86	5.36
Linen	21.5	3.5	0.00105	201.39	2.48	6.12
Cotton	13.5	1.5	0.00056	88.82	7.3	5.42
Silk comber noil	13.0	1.6	0.00052	74.05	18.96	4.14

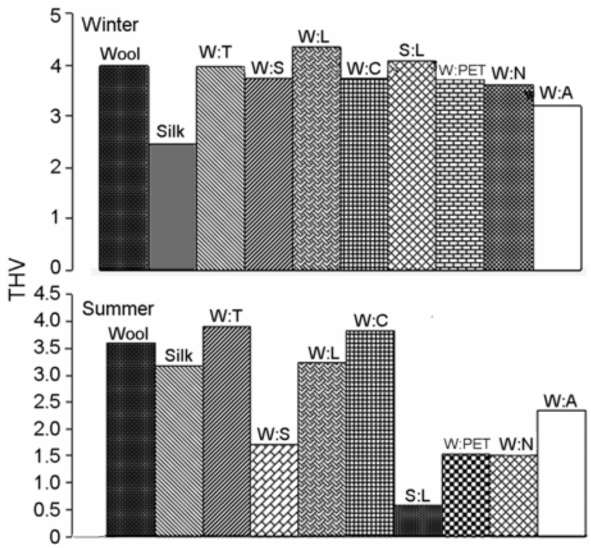

Fig. 1 — Total hand value (THV) for different worsted blends

for winter applications because of the crimp which can be artificially induced as per requirement by processes like texturing.

3.2.2 Application of Worsted Fabrics

The total hand values were analyzed with respect to winter and summer applications for different blends so as to decide the best composition. It is observed from Fig. 1 that some of the worsted blends attain a THV of 4 or higher which is the standard for the ideal fabric as defined by Hand Evaluation and Standardization Committee (HESC), whereas most other blends are marginally trying to touch that threshold value. Thus, it can be inferred that the worsted blends, in general, have an excellent handle for winter use. The wool:linen blended sample shows a maximum winter THV of 4.34. This can be attributed to the bulk of the fabric which is too high and a higher compressibility is responsible for higher THV. However, a THV of above 4 is also found in silk:linen blend which is comparatively lighter in weight. Thus, it is understood that linen in combination with wool or silk is suitable for winter. This property of linen blends can be attributed to the fact that linen is much coarser a fibre in comparison to wool or silk. Thus, due to fibre migration in ring spinning, the linen fibres come to the surface of the yarn generating hairiness in it. This yarn when woven into fabric gives bulkiness or sponginess and a higher compressibility leading to higher winter THV. Wool fabric and a wool:tassar blend have every possibility

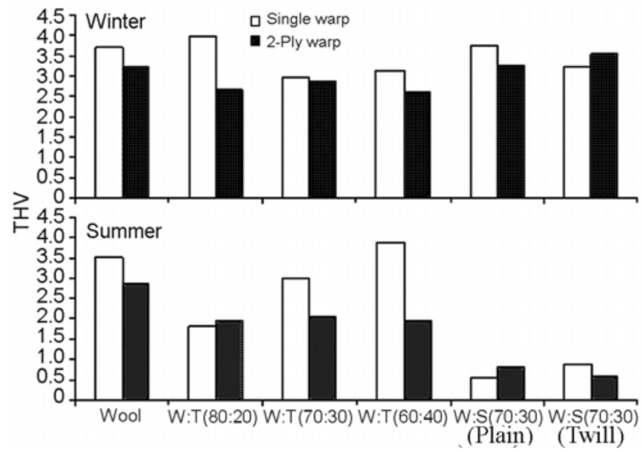

Fig. 2 — THV for single and 2-ply yarn woven worsted fabrics

to cross the ideal fabric threshold limit. In pure wool fabric again the bulk is the deciding factor, whereas in wool:tassar, a better handle is observed only in 80:20 blend where the property is again dominated by the wool component and tassar seems to have a negligible importance. Wool:silk and wool:cotton blends also give good handle when a larger proportion of wool is taken in the composition. Among the synthetic blends of wool, wool:PET gives better results due to the fact that polyester fibres are more uniform and finer in denier to give better blending intimacy with wool. Again the total hand values were analyzed with respect to summer application for different blends.

When a comparison is made between different blends for their summer applications, a wool:tassar blend gives best result. This fact is described by a high bending rigidity of tassar fibres as discussed earlier. Again it is observed that the summer suitability of wool:tassar fabrics is improved with decreasing areal density. This can be attributed to the softness and smoothness arising from light weight fabrics. Wool:cotton shows a comparable THV for summer application because of the cotton component in the blend. A very light weight wool fabric may be suited for summer use as is observed for a 100% wool composition. However, it may be inferred that the worsted fabrics, in general, are not very suitable for summer application.

3.2.3 Handle of Single and 2-Ply Yarn Fabrics

The total hand values were compared for single yarn woven worsted fabrics with double yarn woven fabrics with respect to winter and summer use. Figure 2 shows that in almost all cases, the single warp yarn woven fabric gives better hand value as compared to the 2-ply warp woven fabrics. This can be attributed to the fact that a single yarn shows low bending rigidity as compared to equivalent 2-ply yarn. This results in low bending rigidity of single yarn woven fabric. Thus, the fabric becomes smoother to feel. On the contrary, the 2-ply yarn becomes stiff and rigid because of twist during doubling. The fabric woven with 2-ply warp has a higher stiffness/rigidity giving a harsh feel. This trend is observed in all samples, irrespective of blend composition. The last sample of wool:silk blend shows an opposite effect and it may be due to blend irregularity arising from wide variation in fineness of wool and silk fibres.

Hand values for summer application were also compared for single warp woven fabrics with equivalent 2-ply warp woven fabrics. It can be observed from Fig. 2 that single yarn woven fabrics still prove to be more suitable in summer as compared to 2-ply warp woven fabrics in most cases. This is because the stiffness and softness attributes are common for winter as well as summer applications as defined by HESC. However, in 80:20 wool:tassar blend there is a slight deviation which may be due to blend irregularity because the tassar fibre percentage is too low as compared to wool fibre percentage. As the proportion of tassar is increased, the trend becomes as usual. Another very interesting observation is that as the tassar fibre proportion increases from 20% to 30% and then to 40%, the single yarn woven fabric becomes more and more suitable for summer use. This may be attributed to the tassar fibre bending rigidity which increases the crispness of the fabric essential for summer use. Also, as the areal density is decreased, an improvement in summer handle is resulted because of the smoothness and crispness. Moreover, a better blend uniformity is responsible for better properties. The 2-ply warp woven fabric shows almost same handle irrespective of blend proportion as the plying effect is predominant over the fibre properties. The wool:silk sample again shows some deviation and it may be due to wide variation in fibre fineness.

3.2.4 Effect of Yarn Properties on Handle of Single and 2-Ply Yarn Fabrics

To investigate the yarn properties which affect the handle of fabrics, a comparison was made between single and equivalent 2-ply yarns with respect to bending rigidity and compressibility. A comparison of bending rigidity between single and equivalent 2-ply yarns is shown in Fig. 3.

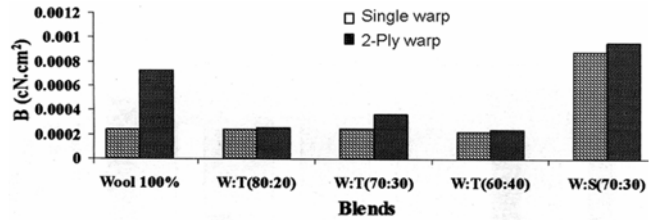

Fig. 3 — Bending rigidity (B) of single and equivalent 2-ply yarns

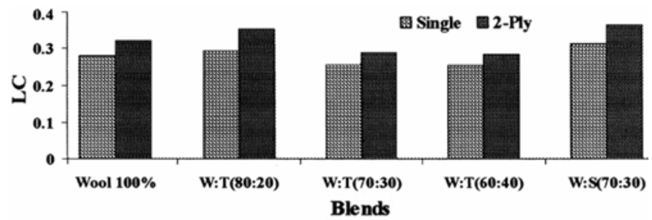

Fig. 4 — Compressibility (LC) of single and equivalent 2-ply yarns

It is clearly observed that the single yarn bending rigidity is less than equivalent 2-ply yarns. This may be attributed to the higher packing density of 2-ply yarns arising from the twisting operation during doubling. A lower bending rigidity is responsible for smoothness and softness of the fabrics, resulting in better handle. Wool:silk blend shows an exceptionally high bending rigidity due to the compactness of yarn because of a strong adhesion of silk fibres with wool.

Figure 4 shows that the single yarns have a lower linearity of compression (LC) compared to 2-ply yarns. LC is analogous to the compressional rigidity. Thus, a lower LC value indicates easier compressibility relating to softness and fullness of fabric. This is responsible for better winter as well as summer hand value of single yarn woven fabrics compared to 2-ply yarn woven fabrics.

3.3 Air Permeability of Worsted Fabrics

Air permeability is another very important aspect relating to the transmission properties of apparel fabrics. The air permeability of different worsted suiting fabrics was studied to ascertain their physiological comfort. It is observed from the results of air permeability test that basically the volume of air passing through the fabric is inversely related to the areal density or the cover of the fabric. However, the construction and the composition of the fabric have a role to play in this regard.

3.3.1 Effect of Fibre Properties on Air Permeability of Worsted Fabrics

A comparative account of air permeability for worsted fabrics of different compositions is given in Fig. 5.

Wool and wool:tassar blended fabrics of loose constructions favour air passage through them because of the high fibre crimp in the former case and the openness of yarn structure arising from high bending rigidity of fibres in the later. Silk does not give positive results because it has very high cohesivity as well as adhesivity, thereby making the yarns and also the fabric construction compact. Linen blended fabrics also restrict air passage because of excessive hairiness on the yarn surface which actually closes the interstices of yarns, thereby increasing fabric cover. Wool:silk fabrics show moderate permeability to air because the yarn openness is compromised by blending with silk. Wool:cotton shows maximum air permeability because of breathing nature of cotton due to the convolutions present in the fibres. Among the synthetic blends, it is again fabric cover and areal density which restrict air permeability. Wool:PET and wool:acrylic blends show better permeability than wool:nylon due to lower areal density.

3.3.2 Air Permeability of Single and 2-Ply Yarn Fabrics

Fabric constructional parameters, like yarn count, thread density and weave, are very crucial to determine the transmission behaviour of the fabric. However, in the present study only the warp yarn count has been changed keeping other parameters constant.

It is clear from Fig. 6 that the single yarn woven fabrics show higher air permeability compared to those woven from equivalent 2-ply warp having nearly equal areal density. This can be attributed to the relatively low packing density in case of single yarns. The plied yarns become more compact because of twisting the component yarns together. The 100% wool yarn invariably gives higher air permeability due to bulkiness caused by fibre crimp in both single as well as plied yarns. Thus, the difference also is not very significant when 2-ply yarn is replaced with single yarn. However, a significant difference can be observed in case of wool:tassar blends. A single yarn with higher number of fibres in the cross-section has more porosity as compared to a double yarn of equivalent linear density where the number of fibres in each component is reduced to about half and packing density is higher because of higher twist. All these are responsible for reducing porosity of the yarn and the fabric woven there from. The higher bending rigidity of tassar fibre causes more open spaces in the yarn structure. Wool:silk fabrics, though follow similar trends, do not yield very encouraging differences. This is because of the compactness of yarns caused by stickiness of silk fibres. Stickiness is basically due to the presence of sericin and a comparatively fine denier (12.5 in contrast to 20.0 of wool) of silk fibres. Finer fibres have a large specific surface area (total surface area/area of cross-section), causing more interaction/cohesion among fibres in yarn cross-section and increasing compactness.

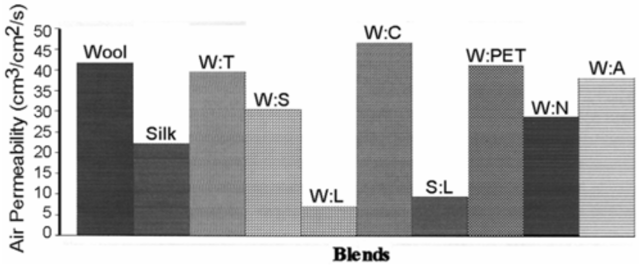

Fig. 5 — Air permeability of different worsted blends

3.4 Thermal Insulation Property of Worsted Fabrics

Worsted and woollen fabrics are well known for their excellent thermal properties. The crimp of wool and scaly structure of fibre which cause porosity in the wool blended yarns and fabrics are responsible for this. The fabric samples developed were evaluated for their thermal properties using KES and Alambeta equipments.

3.4.1 Effect of Fibre Properties on Thermal Insulation of Worsted Fabrics

The thermal insulation property was studied for all the blends of wool so as to analyze the effect of fibre composition on insulation behaviour. The results are shown in Fig. 7.

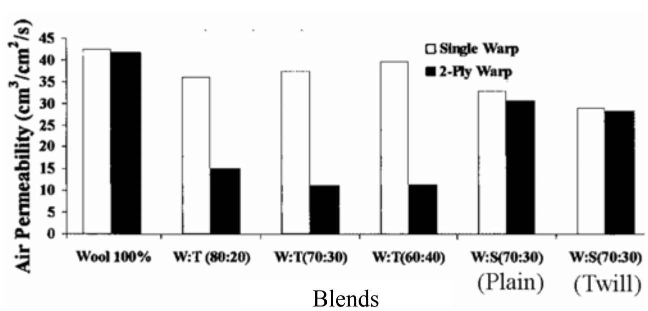

Fig. 6 — Air permeability of single and 2-ply yarn woven worsted fabrics

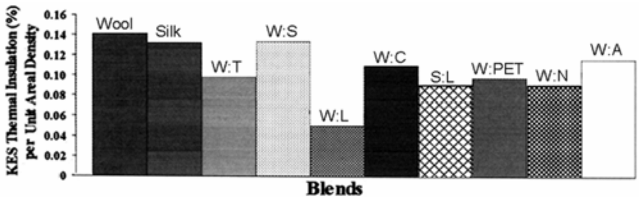

Fig. 7 — Thermal insulation per unit areal density for different worsted blends

The thermal insulation property of worsted fabrics is largely dependent on the areal density. That is why the values are normalized by dividing with the respective areal densities. However, the fibre properties like crimp and fineness have a lot to do with thermal properties. The wool and wool blends normally have a good insulation value due to presence of scales on wool fibre surface as well as the crimp in fibre. These are responsible for entrapping air pockets on the fibre which act as insulators for heat. Wool fabrics show the best thermal insulation behaviour. This is purely attributed to wool fibre crimp creating openness or porosity in the yarn structure as well as the micro air pores in the scaly structure of individual fibres. Silk and silk blends also give good insulation and hence are suitable in winter and not in summer. This behaviour of spun staple silk yarn is attributed to the porous structure developed from crimp of fibre once again. Wool:tassar and wool:cotton fabrics show moderate insulation behaviour due to presence of the other component which is comparatively less crimped and less insulating. Wool in combination with linen gives low insulation value due to less porosity in the yarns and fabric developed by the more rigid and high modulus linen fibres. Among the synthetic blends of wool, an acrylic blended fabric proves to be thermally most insulating whereas other two blends have moderate insulation property. The crimp plays a major role in deciding insulation property and it can be very well regulated in case of synthetic fibres.

3.4.2 Thermal Insulation of Single and 2-Ply Yarn Fabrics

The thermal insulation property was compared between single yarn woven fabrics and the fabrics woven from equivalent 2-ply yarn in the warp. The results of thermal insulation are shown in Fig. 8.

It is observed that the single yarn woven fabrics have an exceptionally higher thermal insulation compared to their counterparts, i.e. equivalent 2-ply warp woven fabrics. In certain cases the former has an insulation more than twice to that of the later. This

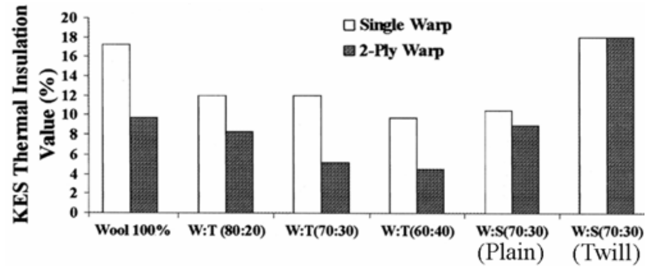

Fig. 8 — Thermal insulation of single and 2-ply warp woven worsted fabrics

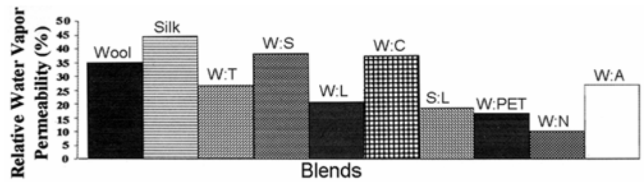

Fig. 9 — Effect of blend composition on relative water vapour permeability

difference is very well attributed to the porosity in single yarns and compactness of double yarns due to extra twist. The only exception to this trend is a wool:silk blend which shows equal values for both fabrics. Again the values for two different pairs of wool:silk blends are widely varying. This difference might have arisen from blending irregularity as the deniers of wool and silk fibres are widely different.

3.5 Water Vapour Permeability of Worsted Fabrics

Moisture and water vapour transmission are another very important parameters governing the physiological comfort of apparel fabrics. They play a major role in deciding to what extent the wearer feels comfortable in a sweating or similar condition. The relative water vapour permeability of all samples was tested on Alambeta permetest instrument. The results of water vapour permeability are analyzed to examine the effect of fibre composition and fabric construction.

3.5.1 Effect of Fibre Properties on Relative Water Vapour Permeability

Water vapour permeability is again influenced by the fabric thickness and weight. However, the fabric properties are basically influenced by the fibre composition. A comparative account is given in Fig. 9.

Water vapour permeability is a surface phenomenon of the fibres. The relative water vapour permeability is maximum in case of silk fabrics

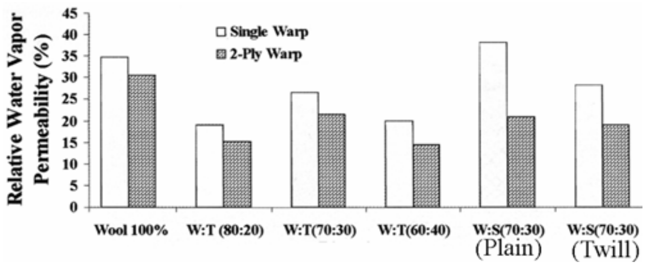

Fig. 10 — Relative water vapour permeability of single and 2-ply warp woven worsted fabrics

because of fineness of fibre. Silk and silk blended fabrics show higher water vapour transmission due to extra fine denier of silk providing more surface area available for adsorption and diffusion of moisture. Combination of wool with cotton shows good result because of relatively better hygroscopicity of cotton. Wool and its combinations with protein fibres like silk also show higher vapour transmission due to fineness of fibre and related higher specific surface area. Linen by its inherent nature is highly crystalline and thus prevents vapour transmission. Synthetic blends as usual show low permittivity. Fibre properties like bending rigidity and modulus play a major role in deciding the openness of structure responsible for water vapour transmission. Wool fabrics have a considerable permeability due to crimp related openness of structure and hygroscopic nature of wool fibre itself.

3.5.2 Relative Water Vapour Permeability of Single and 2-Ply Yarn Fabrics

The relative water vapour permeability of single and 2-ply warp yarn woven worsted fabrics has been compared and the results are shown in Fig. 10.

All single yarn woven fabrics show higher water vapour transmission compared to 2-ply warp woven worsted fabrics. This is due to the open and porous yarn structure of single yarn woven fabrics which allow better adsorption and transmission of moisture/water vapour through them.

4 Conclusions

Physical and physiological comforts are two important quality aspects of the ideal fabric. Worsted suiting fabrics, in general, show excellent comfort properties. Among the natural fibre blends of wool, the linen blend proves to be most suitable with respect to mechanical comfort. However, it does not prove so well with respect to transmission behaviour relating to the human physiological comfort. Pure wool or blends of wool with silk/tassar are very good in transmitting air or water vapour through them. Thermal insulation per unit areal density is best achieved in 100% wool fabrics. Wool:cotton proves very good for air permeability and is suitable as a summer suit. It is observed that as the areal density of wool:tassar fabric decreases, the handle for summer application is improved. Thus, the natural blends individually have their uniqueness in property and end-use applications. Single yarn woven fabrics prove to be superior to equivalent 2-ply warp woven fabrics with regards to both mechanical and thermal comfort. However, to make them weavable, a suitable warp preparation technique has to be adopted.

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