# COMFORT AND HANDLE BEHAVIOUR OF LINEN-BLENDED FABRICS

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## *Abstract:*

*Few can dispute the tremendous values of linen, which is one of nature's greatest treasures. Linen is a longer-staple category, and as such the fibre is spun on a long-fibre spinning system. Due to the coarseness and stiffness of the fibre, linen fabrics are subjected to a strong bleaching action to reduce the stiffness of the fabric. Linen is also blended with other compatible natural and manmade fibres to achieve various structural and functional properties, and also to reduce costs. Fabrics produced from 100% linen and their blends with cotton and viscose have been studied for handle and comfort properties. Linen fabrics produce excellent aesthetic and drape properties. Linen fabrics are found to be tougher than cotton and other blends. However, linen offers the highest tensile resilience and the lowest friction coefficient under low stress-loading conditions. Linen fabric produces superior primary hand with respect to Fukurami and Shari. The total hand value (THV) of processed linen fabric is higher than that of cotton fabric as a summer wear. The blending of viscose and cotton improves the hand value of linen fabric.*

## *Key words:*

*chemical processing, comfort, handle, linen, low stress mechanical properties, toughness*

## 1. Introduction

Linen, which is a natural bast fibre, has unparalleled characteristicssuch as a feel of freshness and a magnificent brilliance. It is very hygienic and imparts an air of satisfaction and style to the wearer. The quality of linen produced is considerably influenced by the weather conditions during its growth[1]. With the trend of fashion towards natural, comfortable yet elegant fabrics, linen and linen-blended fabrics have gained prestige and increased in reputation. It is therefore necessary to raise awareness among users of the unmatched qualities of linen and its blends, to promote its production as well as its usage. In this context, the handle and comfort behaviour of linen and linen blended fabrics have been studied. For this purpose, the low stress mechanical properties[2-7] of linen and linen-blended fabrics have been studied to determine the total hand value (THV) and total appearance value (TAV) at both the grey and finished stages. Comfort is one of the most important aspects of all clothing [8]; many researchers have published extensively on clothing comfort [9-10]. However, the comfort characteristics of linen and its blends have hardly been discussed in literature. Therefore, in addition to fabric hand, the various transmission properties of linen fabrics are also studied.

## 2. Materials and Methods

### 2.1. Materials

The following fabric samples, with their fibre mix and product code, were used for this work.

Out of 12 samples, only L4 was prepared from the flax tow in a dry-spun system; all other fabrics were produced from line flax in wet system. The blends are all union fabrics, i.e. linen warp and cotton viscose weft.

**Table 1.** Details of fabric samples

| Code | Fibre mix | Fabric weight (gsm) | Spinning system |
|---|---|---|---|
| C | 100% Cotton | 100 | Wet |
| L1 | 100% Linen | 162 | Wet |
| L1 | 100% Linen (grey) | 162 | Wet |
| L2 | 100% Linen | 185 | Wet |
| L3 | 100% Linen | 220 | Wet |
| L4 | 100% Linen | 298 | Dry |
| LC1 | Linen: cotton (80:20) | 169 | Wet |
| LC2 | Linen: cotton (64:36) | 157 | Wet |
| LC3 | Linen: cotton (55:45) | 144 | Wet |
| LV1 | Linen: viscose (62:38) | 125 | Wet |
| LV2 | Linen: viscose (55:45) | 170 | Wet |
| LV3 | Linen: viscose (22:78) | 153 | Wet |

## 2.2. Sample preparation

As per the list given above, grey fabric samples were prepared in a mill under commercial production conditions. The grey fabrics were treated as stated below:

## 2.3. Process sequence

Grey fabric → Grey Singeing → Degumming → Bleaching → Drying → Mercerisation → Bleaching→ Dyeing → Finishing→ Drying

The fabrics were processed according to the above sequence with the standard process parameters used for commercial production.

## 2.4. Testing

*2.4.1. Fabric construction parameters*

Thread density was measured using a pick glass. Areal density in GSM (grams per square metre) was measured on an electronic balance. Yarn count was determined on a direct count balance.

*2.4.2. Measurement of fabrics' low stress mechanical properties*

The fabric's low stress mechanical properties, including tensile, shear, bending, compression, roughness and friction, were measured on a Kawabata fabric evaluation system (KESF) under the following testing conditions.

*2.4.2.1. Tensile and shear testing*

Tensile and shear testing were carried out on the KES-FB1. The testing parameters are given below.

| | |
|---|---|
| Sample size | 20 cm × 20 cm |
| Maximum tensile strain | 100% |
| Maximum shear strain | 8 deg. (7 mm) |
| Tensile strain rate | 0.2 mm/second |
| Shear strain rate | 0.417 mm/second |

*2.4.2.2. Testing bending behaviour*

Bending properties were studied on the KES-FB2 (pure bending tester). The testing parameters are given below.

| | |
|---|---|
| Sample size | 20 cm × 20 cm |
| Clamp interval | 1 cm |
| Rate of curvature | 0.5 cm/second |
| Maximum curvature | ±2.5 / cm |

*2.4.2.3. Testing compression properties*

Compression properties were tested on the KES-FB3 (compression tester). The testing parameters are given below.

| | |
|---|---|
| Sample size | 20 cm × 20 cm |
| Area of plunger | 2 $cm^2$ |
| Rate of compression | 1mm/50 seconds |
| Maximum compression load | 50 gf/cm |

*2.4.2.4. Testing surface properties*

Surface roughness and friction measurements were carried out on the KES-FB4. The testing parameters are given below.

| | |
|---|---|
| Sample size | 20 cm × 20 cm |
| Initial fabric tension | 40 g |
| Fabric speed | 1 mm / second |
| Maximum sweep | 3 cm |
| Vertical load on surface roughness detector | 10 g |
| Weight on surface friction detector | 20 g |

Nine readings in wrap and weft direction were taken for each sample. From the above tests, 16 low stress mechanical properties were evaluated as listed in Table 2. Finally, fabric hand value and appearance value were estimated, using the Kawabata system of equations.

**Table 2.** Fabric Mechanical Attributes

| *Test* | *Low-stress properties* | *Notation* | *Unit* |
|---|---|---|---|
| Tensile test | Extensibility | EM | None |
| | Linearity | LT | None |
| | Tensile energy | WT | gf $cm/cm^2$ |
| | Tensile resilience | RT | % |
| Shear test | Shear stiffness | G | gf cm/degree |
| | Hysteresis at $0.5^0$ shear angle | 2HG | gf/cm |
| | Hysteresis at $5^0$ shear angle | 2HG5 | gf/cm |
| Bending test | Bending rigidity | B | gf $cm^2/cm$ |
| | Hysteresis of bending moment | 2HB | gf cm/cm |
| Compression test | Linearity of compression thickness curve | LC | None |
| | Compressional energy | WC | gf $cm/cm^2$ |
| | Compressional resilence | RC | % |
| Surface characteristics | Coefficient of friction | MIU | None |
| | Mean deviation of MIU | MMD | None |
| | Geometrical roughness | SMD | $\mu m$ |
| Fabric construction | Weight/unit area | W | $mg/cm^2$ |
| | Fabric thickness | T | mm |

**Primary hand expressions and their meanings**

KOSHI : Stiffness/firmness
SHARI : Crispness
HARI : Anti-drape stiffness/hardness
FUKURAMI : Fullness/softness
NUMERI : Smoothness

*2.4.3. Measurement of fabric comfort properties*

In order to assess the comfort properties of various fabric samples, thermal conductivity, air permeability and moisture transmission behaviour were measured.

*2.4.3.1. Air permeability*

Air permeability was measured by the FX 3300 Textest air permeability tester. The rate of air flow through a known area of fabric was adjusted to secure a prescribed pressure differential between the two fabric surfaces in the test area; from this rate of flow, the air permeability of the fabric was determined.

Tests were carried out according to standard BS5636. This instrument measures air permeability with an accuracy level of ±3% of the displayed value. The testing parameters were as follows.

| | |
|---|---|
| Test area | 38 $cm^2$ |
| Test pressure | 200 pa |
| Unit of measurement | 1/m. sqr./second |

*2.4.3.2. Water transmission behaviour*

Water permeability was measured on an MVTR cell. In principle, the cell measures the humidity generated under controlled conditions as a function of time. This is based on the application of the gas permeability equation and the ideal gas law.

*2.4.3.3. Thermal resistance*

Thermal resistance or insulation was measured with the KES-FB5 (Thermolabo II). When a preheated hot plate (as a simulator of human skin) is placed on the fabric sample, a heat flux versus time curve is generated. Maximum (peak) heat flow (called Qmax) is measured in a fraction of a second after the hot plate contacts the fabric. The temperature of fabric is maintained at a constant value with the help of a water-circulating box. To measure constant thermal conductivity, the sample was kept between the heat source (a guarded hot plate) and the water box. Thermal conductivity was determined from the heat flow rate, and the temperature difference between heat source and sink after an equilibrium had been achieved.

Thermal insulation value is more useful from the point of view of actual wear conditions. A wind tunnel was employed to measure thermal insulation value,. The air was passed normally over the heat source plate when covered or not covered with fabric. The temperature of the heat source was maintained at near-body temperature. The heat flow rate, i.e. the power input to the heater to maintain the temperature, was noted in two cases (one without fabric, and the other with fabric placed over the heater plate). Next, the thermal insulation value was determined from these two power inputs.
The initial warm / cool feeling (Qmax) and thermal insulation value were measured. The dry contact method at an air velocity of 30 cm/second was used to measure the thermal insulation. The heat source temperature was maintained at 20$^{o}$C. Other testing parameters were kept as per standard.

## 3. Results and Discussion

### 3.1. Fabric dimensional properties

Fabric dimensional properties such as thread density, yarn number, areal density and thickness are given in Table 3.

The results show that high areal density is obtained either by using high thread density or coarse warp & weft yarns. By comparing the fabric thickness of similar fabric weights, it may be observed that the 100%-linen fabrics are usually thicker than cotton and blended fabrics. The increase of fabric weight generally shows a comparable increase in fabric thickness. On overall examination of the construction parameters of various fabrics, it may be observed that 100%-linen fabrics could be manufactured with comparatively low thread density, as compared to 100%-cotton and blended fabrics of similar areal density. This makes the weaving of linen fabric easier compared to cotton and other blended fabrics.

**Table 3.** Fabric dimensional properties

| Fabric code | GSM | Warp count (Ne) | Weft count (Ne) | EPI | PPI (mm) | Thickness |
|---|---|---|---|---|---|---|
| C | 100 | 60 | 60 | 100 | 72 | 0.56 |
| L1 | 162 | 40 | 40 | 37 | 37 | 0.78 |
| L2 | 185 | 40 | 40 | 67 | 49 | 0.78 |
| L3 | 220 | 25 | 25 | 49 | 41 | 0.76 |
| L4 | 298 | 8 | 8 | 21 | 17 | 1.40 |
| LC1 | 169 | 25 | 8 | 38 | 24 | 1.15 |
| LC2 | 157 | 18 | 25 | 41 | 37 | 0.64 |
| LC3 | 144 | 20 | 20 | 57 | 45 | 0.68 |
| LV1 | 125 | 25 | 25 | 39 | 40 | 0.68 |
| LV2 | 170 | 20 | 25 | 69 | 40 | 0.66 |
| LV3 | 153 | 20 | 20 | 68 | 49 | 0.65 |

## 3.1. Low stress mechanical properties

In order to evaluate the handle behaviour of various linen and linen blended fabrics, low stress mechanical properties such as tensile, bending, shear, compression and surface properties are measured on Kawabata system equipment. These parameters are entered into the Kawabata handle equation to calculation the primary head, the total head value (THV) and the total appearance value (THV)

### *3.2.1. Tensile*

The low stress tensile properties of various fabrics are given in Table 4. Properties such as linearity of load extension curve (LT),tensile energy (WT), tensile resilience (RT) and extensibility of the fabric (EM) are also shown in Fig. 1 (1a to 1k).

*Extensibility (EM)*

EM gives the tensile strain under strip biaxial extension. Extensibility has a good correlation with fabric handle. The higher the extensibility, the better is the fabric quality from the point of view of handle. A high EM value also signifies greater wearing comfort. It may be seen that 100%-cotton fabric gives moderate extensibility. Fabric extensibility generally increases with the increase of areal density. This implies that heavy fabrics might give better handle property, due to their higher extensibility at low stress deformation.

*Linearity (LT)*

The stress-strain curve is a straight line when LT=1. When LT is small, fabric extensibility in the initial strain range is high, and this gives comfort in wearing the cloth. Furthermore, the higher the linearity of load/elongation, the better is the handle property of the fabric. The 100%-cotton fabric and cotton-based linen-blended fabric barring LC1 show higher stress/strain linearity, followed by linen and linen based viscose blended fabric. The increase in the areal density does not affect linearity substantially in any type of fabric.

*Tensile energy (WT)*

WT indicates toughness, which reflects the mobility of the garment under deformation. If a fabric has a high toughness value, it should have a lower fabric handle value. It may be observed from the results that with the increase of the fabric areal density, the toughness per unit area increases. Increasing the cotton component in the linen fabric results in a decrease of the fabric toughness. The linen/cotton blended fabric gives the highest value for tensile energy, compared to 100% cotton and linen/viscose blended fabrics. No significant increase in tensile energy has been observed by increasing the viscose component in linen/viscose blended fabric. On overall examination, it may be seen that viscose-mixed fabrics give the lowest toughness value due to the inherent low modulus of the fibre, which would probably help in improving fabric handle. Cotton appears to have moderately high toughness, lying between linen and viscose fabrics. This may be because cotton, being smoother than linen, prevents the mobility of the component yarn, thus resulting in comparatively high toughness.

*Tensile resilience (RT)*

Resilience represents recovery from tensile deformation. The higher the tensile resilience of a fabric, the better is its fabric handle. In respect of resilience behaviour, the result shows that 100% bleached-linen fabrics give higher tensile resilience than 100%-cotton and all blended fabrics. The blending of cotton and viscose with linen fibre reduces the tensile resiliency significantly. In the case of linen/cotton blended fabrics, the increase of the cotton component decreases the tensile resiliency, whereas the increase of the viscose component in viscose-blended fabric increases the tensile resiliency.

It is interesting to note that although raw linen is the toughest fibre, with a high degree of crystallinity of its cellulose molecules, it gives high resiliency after bleaching, probably due to molecular relaxation. The degree of relaxation and the subsequent tensile resilience achieved by linen fabric is much more higher than viscose and cotton fabrics.

**Table 4.** Tensile properties

| Fabric code | EM | LT | WT | RT |
|---|---|---|---|---|
| C | 1.63 | 1.04 | 0.41 | 65.25 |
| L1 | 1.47 | 0.95 | 0.35 | 80.63 |
| L2 | 1.86 | 0.94 | 0.43 | 82.81 |
| L3 | 1.28 | 0.98 | 0.31 | 83.08 |
| L4 | 2.42 | 0.96 | 0.58 | 71.05 |
| LC1 | 2.39 | 0.92 | 0.55 | 56.10 |
| LC2 | 1.34 | 1.05 | 0.45 | 64.00 |
| LC3 | 1.85 | 1.03 | 0.38 | 63.00 |
| LV1 | 1.51 | 0.94 | 0.36 | 60.09 |
| LV2 | 1.33 | 0.86 | 0.28 | 70.41 |
| LV3 | 1.49 | 0.98 | 0.36 | 69.53 |

*3.2.2. Bending properties of the fabric*

Bending rigidity (B) is a measure of ease with which the fabric bends. The fabric's bending rigidity basically depends on the bending rigidity of constituent fibre yarns from which the fabric is manufactured, the fabric construction, and most importantly, the nature of the chemical treatment given to the fabric. The bending stiffness of the linen fabric is also influenced by the pectin content, the crystallinity of cellulose and the cross-sectional shape of the fibre, which is different from that of the cotton fibre. Because inter-yarn and intra-yarn friction play important roles in deciding the bending behaviour, this frictional restraint is mainly controlled by the type of chemical treatment given to the material. Bending at low stress is more important because it has a direct relationship and greater association with fabric handle. The higher the rigidity, the lower the fabric handle will be.

*Bending rigidity and hysteresis of bending movement*

The results for bending properties are shown in Table 5. It may be seen from the table that 100% cotton shows the lowest bending hysteresis. On the other hand, 100%-linen fabric gives the highest bending rigidity and hysteresis properties. The addition of the viscose and cotton component to linen reduces the bending rigidity; the reduction is almost proportional to the blend percentage. The reason for the high bending rigidity of linen fabric is the coarse linen fibres, whose diameter is much higher than viscose; this in turn increases the stiffness.

As is well-known, bending behaviour has a very good correlation with fabric handle, and as such low bending rigidity is one of the most desirable properties to achieve better handle property. Therefore, on the basis of the results obtained in this study, cotton fabric should give a superior Koshi (primary hand) value, followed by linen cotton, linen viscose and 100% linen fabric. In fact, the bending rigidity of linen is drastically reduced, and has come very close to that of other fabrics after bleaching, which has resulted in a substantial softening of the fabric.

*3.2.3. Shear properties*

The shear rigidity of a fabric depends on the mobility of cross threads at the intersection point, which again depends on weave, yarn diameter and the surface characteristics of both fibre and yarn. From the point of view of handle, the lower the shear rigidity, the better the fabric handle would be.

Shear rigidity (G) and hysteresis of shear force at 0.5 degree (2HG) and 5 degrees (2HG5) for various fabrics are shown in Table 5. 100%-cotton fabric and cotton-rich linen-blended fabrics give the highest shear rigidity and shear hysteresis properties. The 100%-linen fabrics give the lowest order of shear rigidity and shear hysteresis properties. In the case of blended fabrics, the addition of cotton and viscose fibre results in increases in shear resistance and shear hysteresis. This may be explained in the light of the characteristics of constituent fibres. Since linen fibre shows the lowest coefficient of friction compared to cotton and viscose, fabric made from it shows lower shear rigidity. Similarly, the increase of the cotton and viscose percentage in linen-blended fabrics exhibit a gradual increase in shear rigidity and shear hysteresis, due to the high coefficient of friction of these two fibres as compared to linen. This prevents the movement of yarn in the body of the fabric during the application of shear force. It is worth mentioning that the friction restraint plays an important role, particularly when deformation is taking place at low stress levels.

**Table 5.** Bending and shear properties

| **Fabric code** | **B** | **2HB** | **G** | **2HG** | **2HG5** |
|---|---|---|---|---|---|
| C | 0.034 | 0.031 | 0.672 | 1.153 | 2.286 |
| L1 | 0.285 | 0.144 | 0.227 | 0.060 | 0.209 |
| L2 | 0.195 | 0.069 | 0.252 | 0.118 | 0.389 |
| L3 | 0.355 | 0.162 | 0.354 | 0.245 | 1.075 |
| L4 | 0.679 | 0.390 | 0.284 | 0.158 | 0.429 |
| LC1 | 0.170 | 0.095 | 0.281 | 0.332 | 0.532 |
| LC2 | 0.157 | 0.075 | 0.613 | 0.983 | 2.483 |
| LC3 | 0.099 | 0.063 | 0.513 | 0.635 | 1.571 |
| LV1 | 1.58 | 0.116 | 0.246 | 0.156 | 0.325 |
| LV2 | 0.178 | 0.130 | 0.302 | 0.229 | 0.537 |
| LV3 | 0.068 | 0.050 | 0.330 | 0.257 | 0.636 |

*3.2.4. Surface characteristics*

The surface characteristics of a fabric influence the handle, comfort and aesthetic properties of the cloth made from it. MIU represents the coefficient of friction of the fabric surface; it is a function of the fibre properties, yarn structure, fabric geometry and finish applied to the fabric. MMD gives the mean deviation of MIU; in other words, it is the measure of variation of MIU. SMD represents the geometrical roughness of the fabric surface. The results for the surface characteristics are given in Table 6. Among all the fabrics evaluated for the surface properties, 100%-cotton fabric and cotton/linen-blended fabrics give comparatively low frictional properties compared to 100%-linen and linen-blended viscose fabrics. The geometrical roughness (SMD) for 100% cotton fabric is found to be the lowest, whereas linen and linen-blended fabric provide significantly higher geometrical roughness due to their highly crystalline linen component. The change in the cotton and viscose component in linen-blended fabrics do not cause any significant change in the surface characteristics of the processed fabrics. The minor variations in surface properties among different linen fabrics are mainly due to their differences in fabric construction particulars with respect to yarn diameter and twist. Since all the fabrics are made up of plain weave, no significant difference in surface characteristics are observed among the fabrics.

**Table 6.** Surface properties

| Fabric | MIU | MMD | SMD |
|---|---|---|---|
| C | 0.167 | 0.0182 | 6.24 |
| L1 | 0.183 | 0.0386 | 18.12 |
| L2 | 0.203 | 0.0412 | 10.97 |
| L3 | 0.166 | 0.0290 | 11.69 |
| L4 | 0.189 | 0.0236 | 17.08 |
| LC1 | 0.204 | 0.0292 | 11.17 |
| LC2 | 0.155 | 0.0188 | 10.39 |
| LC3 | 0.177 | 0.0407 | 11.05 |
| LV1 | 0.183 | 0.0226 | 13.22 |
| LV2 | 0.204 | 0.0321 | 12.05 |
| LV3 | 0.195 | 0.0300 | 10.76 |

*3.2.5. Compressional behaviour*

The compressibility of a fabric mainly depends on yarn packing density and yarn spacing in the fabric. Compressibility provides a feeling of bulkiness and spongy property in the fabric. Compressibility has some correlation with the thickness of the fabric; the higher the thickness, the higher the compressibility. The low stress compressional parameters such as LC, WC, RC, and T are related to the primary hand value (Fukurami or bulkiness) of the fabric. Physically these properties are analogous to the tensile parameters such as LT, WC & RC; RC gives the compressional resilience, WC is compressed energy and LC is the linearity of compression and fabric thickness, whereas T is the thickness of the fabric. The results of the compression properties are shown in Table 7.

It may be observed from the table that the compression resilience of 100% finished-cotton fabric is found to be less compared to those of 100% linen and linen-blended fabrics. However, the compressional energy is found to be lowest for linen/viscose blended fabrics. The compressional energy of 100%-linen fabric and linen-rich cotton-blended fabrics are higher than all other fabrics. It is interesting to note that no perceptible change in the linearity of the compression/thickness is obtained among the various fabrics considered in the study. However, it may be observed that generally compressional resilience has a direct bearing on the fabric areal density. The compressional energy at low stress deformation for linen/viscose-blended fabrics is found to be less compared to linen-cotton, 100%-linen and 100%-cotton fabrics.

**Table 7.** Compressional properties

| Fabric code | W | T | RC | WC | LC |
|---|---|---|---|---|---|
| C | 9.69 | 0.56 | 43.78 | 0.063 | 0.620 |
| L1 | 16.26 | 0.78 | 55.92 | 0.057 | 0.617 |
| L2 | 18.48 | 0.78 | 52.68 | 0.071 | 0.654 |
| L3 | 21.89 | 0.76 | 58.30 | 0.059 | 0.639 |
| L4 | 29.84 | 1.40 | 63.16 | 0.100 | 0.622 |
| LC1 | 16.91 | 1.15 | 52.66 | 0.086 | 0.538 |
| LC2 | 15.76 | 0.64 | 46.59 | 0.051 | 0.581 |
| LC3 | 14.46 | 0.68 | 51.08 | 0.048 | 0.665 |
| LV1 | 12.54 | 0.68 | 56.27 | 0.040 | 0.678 |
| LV2 | 17.02 | 0.66 | 51.57 | 0.046 | 0.625 |
| LV3 | 15.29 | 0.65 | 55.74 | 0.054 | 0.648 |

*3.2.6. Hand value of fabric*

Assuming that linen and linen blended fabrics are meant for summer shirt wear, the primary hand values such as Koshi, Hari, Shari, and Fukurami are estimated using the Kawabata system of regression equations for primary hand value evaluation. The results are shown in Table 8. The primary Fukurami value is mainly an indicative of softness, compressibility and surface smoothness. It may be observed that 100%-cotton, 100%-linen and linen-rich cotton fabrics give higher Fukurami values, indicating that these fabrics are soft, smooth and compressible. The result indicates that linen is probably more compatible with cotton than viscose. As far as Koshi is concerned, linen fabrics give higher hand values due to higher bending stiffness, because linen fabrics are coarser and tougher than cotton and viscose fibre. The Koshi value of dry-spun linen fabric is found to be the highest of all the fabric samples. 100% linen and linen blended fabrics give higher Shari values, mainly due to the lower stiffness of linen compared to 100% cotton and viscose blended fabrics. In the case of blended fabrics, the increase of the cotton component increases the Shari value, whereas an increase of the viscose component decreases the Shari value, due to the low bending stiffness of viscose fibre compared to linen fibre. Hari indicates bending hysteresis; a higher hysteresis increases the Hari value. This is also related to the surface properties, bending stiffness and shear rigidity. It may be seen that fabric weight has a direct bearing on the Hari value. In blended fabrics, with the increase of the cotton component, the Hari value increases due to the greater shear resistance. This can be attributed to the friction coefficient of cotton fibre being higher than that of linen fibre.

**Table 8.** Fabric hand and appearance values

| Fabric code | Primary hand values | | | | Total hand value (THV) | Total appearance value (TAV) |
|---|---|---|---|---|---|---|
| | Koshi | Shari | Fuku | Hari | | |
| C | 5.08 | 5.30 | 5.59 | 5.68 | 3.01 | 3.66 |
| L1 | 6.10 | 8.86 | 4.05 | 3.15 | 4.00 | 2.07 |
| L2 | 5.90 | 7.08 | 5.05 | 4.18 | 3.41 | 2.17 |
| L3 | 7.73 | 8.26 | 4.01 | 7.14 | 3.29 | 1.89 |
| L4 | 8.11 | 7.80 | 5.95 | 5.51 | 2.66 | 1.54 |
| LC1 | 5.66 | 6.03 | 7.00 | 3.76 | 2.64 | 2.00 |
| LC2 | 7.68 | 8.35 | 3.76 | 8.11 | 3.28 | 1.86 |
| LC3 | 6.48 | 7.84 | 4.37 | 6.41 | 3.46 | 1.44 |
| LV1 | 5.29 | 8.01 | 3.95 | 3.24 | 4.07 | 1.65 |
| LV2 | 6.06 | 7.52 | 4.16 | 4.31 | 3.72 | 1.94 |
| LV | 3 4.89 | 6.06 | 5.75 | 3.66 | 3.25 | 1.24 |

The total hand value (THV) of the fabric is estimated with the help of various primary hand values using the Kawabata system of equations. The result clearly shows that linen fabric gives higher handle property than a cotton fabric of similar construction and areal density. At the same time, it may be observed that linen fabric produced from the dry-spun system gives the lowest total hand value as compared to wet spun fabric. It is interesting to observe that blending cotton and viscose with linen further improves the THV of the fabrics. The increase of cotton percentage in linen/cotton-blended fabrics improves the fabric handle characteristics, whereas the increase of viscose fibre gradually decreases the fabric handle. These results clearly suggest that while blending both cotton and linen helps in the mutual sharing of properties for superior fabric handle, viscose should be added judiciously, in order to obtain the optimum handle value. The result also shows another important finding, namely that increasing the areal density decreases the fabric handle value for 100%-linen fabrics. This implies that linen fabrics of lower weight are more suitable than those of a higher weight from the point of view of the handle. This finding also suggests that linen fabrics can achieve high drapability, even with low fabric areal density, as compared to other fabrics.

The Total Appearance Value (TAV), as measured on the Kawabata system, shows that finished cotton fabric (bleached) gives the highest appearance value followed by 100%finished-linen fabrics. When linen is blended with cotton and viscose, the increase of the cotton and viscose component decreases the appearance value of the fabric. This is contrary to fabric handle value results. Blending helps in the sharing of the component fibre's mechanical properties to provide a higher resultant hand value, whereas it adversely affects the appearance value.

## 3.3. Fabric comfort

Among the three common comfort parameters such as psychological comfort, tactile comfort and thermal comfort, psychological comfort has no quantitative relationship with fabric properties; this is mainly related to the fashions prevailing in a particular society. Tactile comfort mainly depends upon mechanical properties and surface characteristics of fabric. Mechanical properties such as stretching, bending, shearing and compression at low stress levels predict the tactile comfort properties. However, thermal comfort is related to the fabric's transmission behaviours, namely thermal resistance, water vapour transmission and air permeability.

### *3.3.1. Air permeability*

The resistance of a fabric to the flow of air is a measure of the initial warm/cool feeling when the garment is worn. The higher the air flow value, the greater the intensity of the warm/cool feeling will be. The effect of air permeability on comfort properties is much greater when the speed of air is high, for example, in stormy weather conditions. The results of air permeability, in terms of the amount of air passing through a unit fabric area per unit time, are given in Table 9. The result shows that linen and linen-based blended fabrics permit more air to pass through, as compared to 100% cotton fabrics of similar areal density. The reason for the higher permeability in the case of linen and linen-blended fabrics can be attributed to the lower hairiness of these yarns, due to their longer fibre length as compared to cotton. It may also be due to the large diameter of the fibre, which results ?in/from the low packing density of the yarn. Linen fibres, being smoother, circular and coarser as compared to cotton fibres, also assist the easy passage of air through the yarn cross-section, which results in higher air permeability. The result shows that the air permeability decreases in the respective linen blended fabrics with the increase of the viscose component. The air permeability results reveal that the fabrics made from linen fibres are more suitable for summer dress material as compared to winter wear, provided the other comfort parameters of linen fabrics are made suitable to meet the requirements.

### *3.3.2. Thermal insulation*

The thermal insulation provided by a fabric depends on fibre type, fabric thickness, bulk density, fibre arrangement and the compressibility of the fabric structure. The mechanism of heat transfer involves dry heat transmission through conduction, convection and radiation. Latent heat transfer due to water vapour transport and liquid water transport also determines the thermal properties of the fabric. The thermal insulation properties of various fabrics measured on the Thermolabo (KES-FB5) are shown in Table 9. The result shows that the thermal insulation values for linen and linen blended fabrics are higher then those of cotton fabrics of identical fabric weight. It may be observed that in the case of blended fabrics, the thermal insulation decreases with the increase of cotton and viscose components, thereby showing demonstrating that linen has higher thermal insulation power than cotton and viscose fibres. On the basis of the thermal result, it may be concluded that linen fabrics can provide the desired protection to the human body against climatic fluctuations.

**Table 9.** Fabric comfort properties

| **Fabric code** | **Air passed (L/m2/sec.)** | **Mean amount of moisture (TIV)** | **(gm/sq. inch/24 hrs.)** |
|---|---|---|---|
| C | 1141 | 10.37 | 14.2 |
| L1 | 2408 | 15.23 | 15.4 |
| L2 | 657 | 12.84 | 16.0 |
| L3 | 712 | 11.81 | 16.8 |
| L4 | 2903 | 14.48 | 13.8 |
| LC1 | 2325 | 23.12 | 15.8 |
| LC2 | 773 | 14.59 | 15.2 |
| LC3 | 1795 | 12.57 | 14.2 |
| LV1 | 2220 | 14.68 | 14.0 |
| LV2 | 903 | 12.61 | 14.2 |
| LV3 | 994 | 11.62 | 14.3 |

### *3.3.3. Water permeability*

An ideal fabric should allow water vapour on skin (perspiration) to pass through its pores, irrespective of the fibre material's natural absorbency. If the water vapour cannot escape at a faster rate than it is released by the skin, the wearer feels uncomfortable. In order to assess the fabric's ability to permit moisture through it in a steady state, vapour transfer is measured with a MVTR cell. The results are shown in Table 9 in terms of the amount of vapour passed in grams per 24 hrs per square inch of fabric surface area. The result shows that 100%-linen fabric allows more moisture to pass, compared to cotton and blended fabrics of identical construction. This may be due to the fabric's high moisture absorbency and high porosity, as explained in the air permeability results. The result also shows that the heavy linen fabric restricts the passage of moisture due to its lack of porosity. Linen/viscose and linen/cotton-blended fabrics also permit only moderate moisture transmission. Increasing the cotton and viscose components has no significant effect on vapour transmission.

### 3.4. Effect of chemical processing on low stress mechanical properties and hand value of linen fabric

The effects of chemical treatment on various low stress mechanical properties and the hand value of linen fabric were studied, and the results are given in Table 10. The result shows that the extensibility and tensile energy of the fabric decrease, whereas the tensile resilience increases significantly, due to the chemical treatment such as bleaching, degumming, scouring etc. as per standard industrial practice. Both bending & shear rigidity and hysteresis values drastically decreased after the fabric was subjected to the above-mentioned chemical treatments. The reduction in bending and shear rigidity is due to the softening of fabric, and the reduction in fibre dimensions is caused by the scouring & degumming process. The surface characteristics with respect to both surface friction and surface roughness deteriorate marginally after the treatment. This is due to the swelling of individual fibres, resulting in high peaks and valleys on the surface of the fabrics. The chemical treatment of linen fabrics results in a substantial reduction in compressional energy, whereas the linearity of the compression thickness curve and compressional resilience improves significantly. The result also shows that both the thickness and areal density of the fabrics decreases marginally due to the removal of waxy substances during scouring and degumming.

**Table 10.** Effect of Chemical Treatment on Low Stress Mechanical properties of Linen Fabric

| FABRIC SAMPLE | TENSILE | | | | BENDING | | SHEAR | | | SURFACE | | | COMPRESSION | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EM | LT | WT | RT | B | 2HB | G | 2HG | 2HG5 | MIU | MMD | SMD | LC | WC | RC | T | W |
| **LINEN GREY** | | | | | | | | | | | | | | | | | |
| Mean | 2.86 | 0.940 | 6.73 | 46.89 | 0.492 | 0.517 | 1.29 | 1.70 | 4.79 | 0.174 | 0.0596 | 16.874 | 0.250 | 0.204 | 45.647 | 0.92 | 16.84 |
| STD | 0.07 | 0.012 | 0.14 | 1.53 | 0.043 | 0.031 | 0.03 | 0.02 | 0.14 | 0.006 | 0.0015 | 0.490 | 0.025 | 0.008 | 1.948 | 0.02 | 0.00 |
| CV% | 2.53 | 1.230 | 2.11 | 3.25 | 8.670 | 5.962 | 2.01 | 1.12 | 2.87 | 3.278 | 2.5017 | 2.904 | 10.008 | 10.008 | 4.267 | 2.16 | 0.00 |
| **LINEN FINISHED** | | | | | | | | | | | | | | | | | |
| Mean | 1.47 | 0.95 | 0.35 | 80.63 | 0.285 | 0.144 | 0.227 | 0.060 | 0.209 | 0.183 | 0.039 | 18.12 | 0.617 | 0.057 | 55.92 | 0.78 | 16.26 |
| STD | 0.13 | 0.03 | 0.04 | 1.27 | 0.020 | 0.014 | 0.007 | 0.010 | 0.0232 | 0.018 | 0.0033 | 1.59 | 0.029 | 0.002 | 2.10 | 0.00 | 0.00 |
| CV% | 8.53 | 3.56 | 11.40 | 1.58 | 7.172 | 9.556 | 3.134 | 16.552 | 11.213 | 9.998 | 8.6571 | 8.78 | 4.649 | 3.513 | 3.75 | 0.52 | 0.00 |

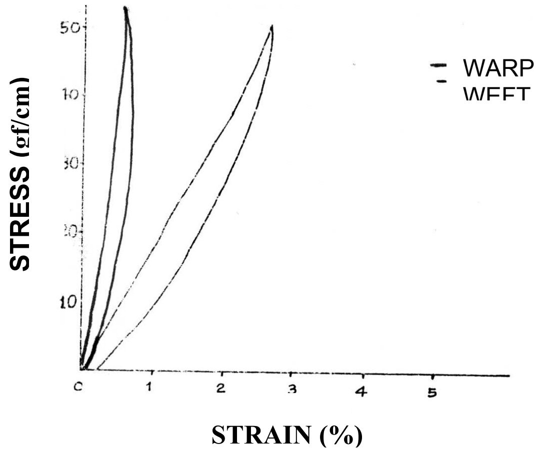
The primary hand, total hand and appearance value of 100% linen fabric before and after chemical processing are given in Table 11. As expected, the chemical treatment causes a substantial reduction in the Koshi and Shari values because of the reduction in bending rigidity, as described earlier. The Shari value shows a marginal fall, which is not statistically significant. This can be attributed to the fact that although the crispness decreases due to the chemical treatment, the surface smoothness is not significantly affected, for the obvious reason that the linen fabric's coefficient of friction is less. The primary hand value with respect to Hari (anti-drape stiffness) decreases substantially for the same reason as in case of bending.

Needless to say, the Total Hand Value and Total Appearance Value of linen fabric show tremendous improvements after wet processing according to the standard commercial methods. In fact, the result clearly reveals that the chemical treatment makes linen a high-quality fabric with regard to its handle and appearance.

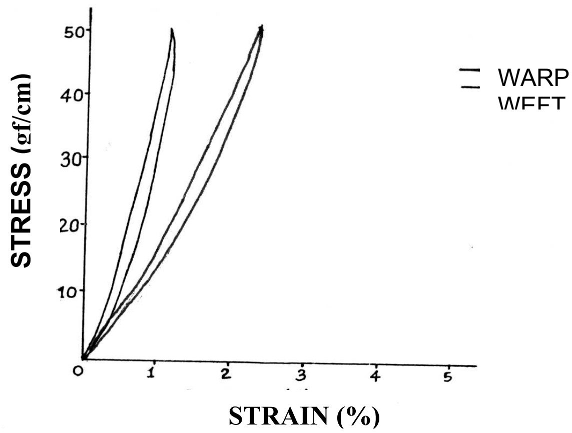
**Table 11.** Effect of Chemical Treatment on THV and TAV of Linen Fabric

| FABRIC SAMPLE | KOSHI | SHARI | FUKURAMI | HARI | THV | TAV |
|---|---|---|---|---|---|---|
| **LINEN GREY** | | | | | | |
| Mean | 10.36 | 9.69 | 1.53 | 13.15 | 0. 53 | 1.70 |
| STD | 0.03 | 0.08 | 0.08 | 0.45 | 0.29 | 0.09 |
| CV% | 3.14 | 0.80 | 5.28 | 3.40 | 55.26 | 5.29 |
| **LINEN FINISHED** | | | | | | |
| Mean | 6.10 | 8.86 | 4.05 | 3.15 | 4.00 | 2.07 |
| STD | 0.18 | 0.21 | 0.21 | 0.35 | 0.04 | 0.04 |
| CV% | 3.10 | 2.34 | 5.41 | 11.24 | 0.96 | 1.78 |

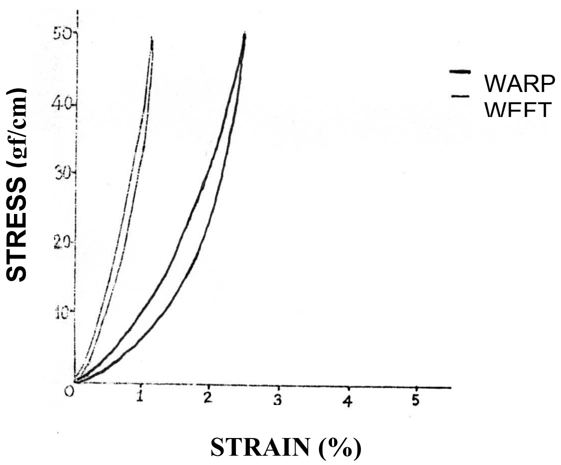
**1.A Tensile property of C**



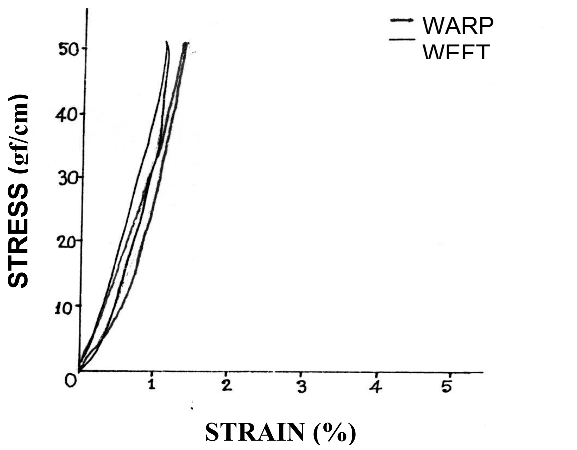

**1.B Tensile property of L1**



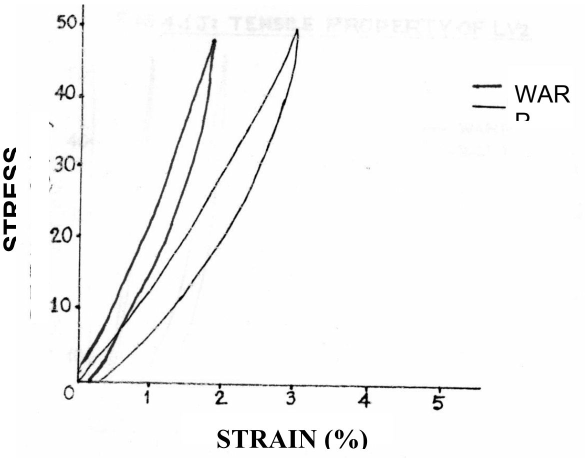

**1.C Tensile property of L2**



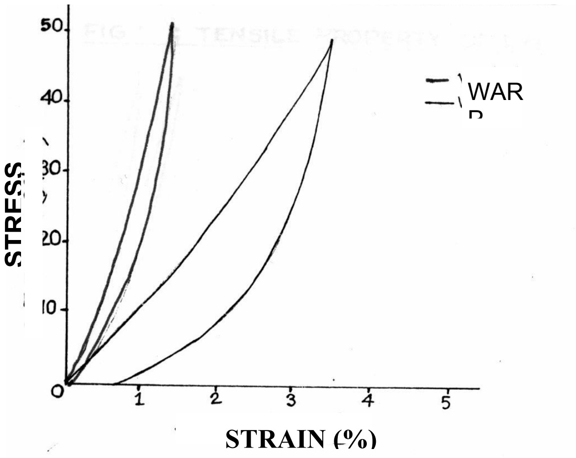

**1.D Tensile property of L3**



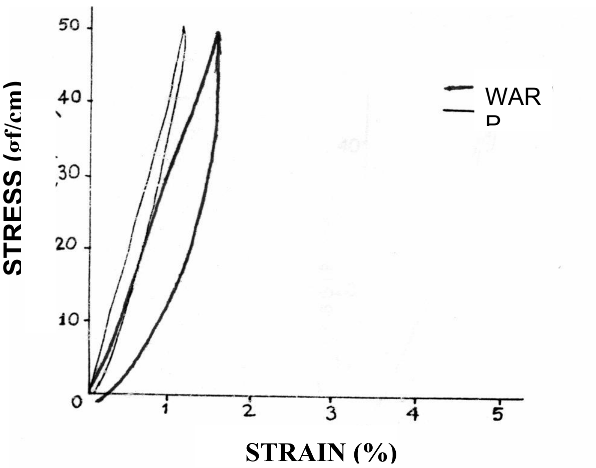
**1.E Tensile property of L4**



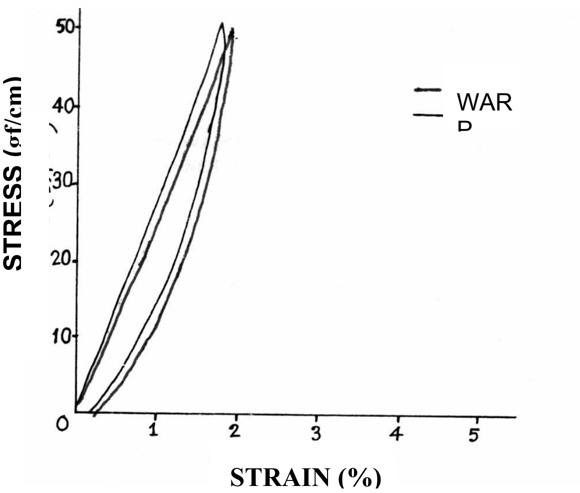

**1.F Tensile property of LC1**



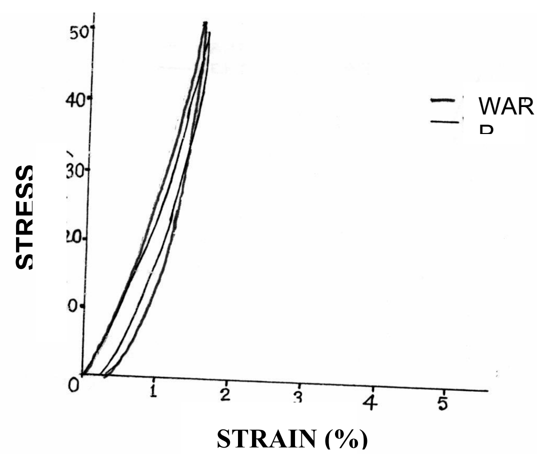

**1.G Tensile property of LC2**



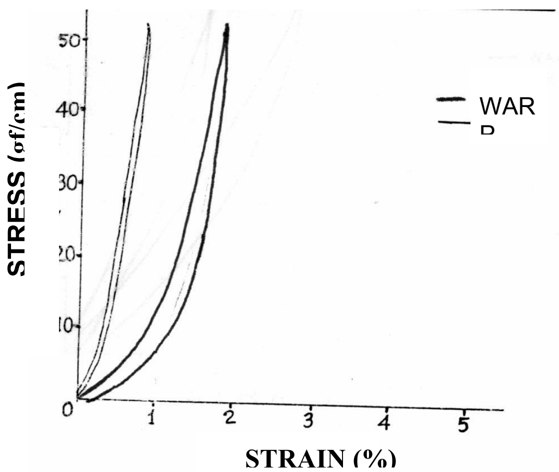

**1.H Tensile property of LC3**




**1.I Tensile property of LV1**




**1.J Tensile property of LV2**



**1.K Tensile property of LV3**

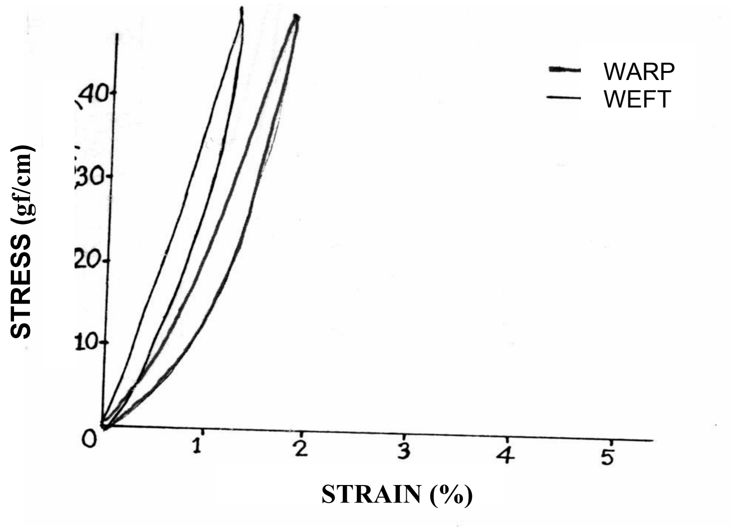



**Figure 1**

## Conclusion

At low stress deformation, bleached linen fabrics are more extensible than bleached cotton fabrics. Linen fabrics give comparatively higher toughness; the toughness is reduced by blending the fibre with viscose. 100%-linen fabrics offer the highest tensile resilience, bending rigidity and bending hysteresis. The addition of both cotton and viscose to linen helps to reduce its bending rigidity. 100%-linen fabrics give the lowest shear rigidity and shear hysteresis, as compared to 100% cotton and linen/cotton & linen/viscose blended fabrics. Cotton and cotton/linen blended fabrics give comparatively lower surface friction and surface roughness compared to 100%-linen fabrics. Compressional resilience for linen and linen-blended fabrics is found to be higher than that of cotton fabric. As regards primary hand values, 100% cotton, 100%-linen and linen-rich blended fabrics have higher Fukurami values, indicating that these fabrics are softer, smoother and compressible. Linen being the coarser and stiffer fibre produces fabrics with the highest Koshi value. Linen and linen-blended fabrics give higher Shari values, compared to 100%-cotton and cotton/viscose-blended fabrics. Hari has a strong association with fabric areal density. Cotton-rich blended fabrics have higher Hari values due to the high friction coefficient of cotton fibre. Linen fabrics give higher total hand value (THV) than cotton fabrics of similar construction and areal density, considering the fabrics are to be used for summer wear. Blending compatible fibres such as viscose and cotton further improves the hand value of linen-blended fabrics. As for hand, linen fabrics are more suitable within low weight ranges than when they are of heavy construction. Among all the fabrics included in the study, finished cotton fabrics have the highest total appearance value, followed by linen and linen-blended fabrics. 100%-linen and linen-blended fabrics are more permeable to air than cotton fabrics, which confirms the suitability of linen fabric for winter wear. Linen and linen-blended fabrics have higher thermal insulation values than cotton fabrics. Linen fabric has a higher moisture vapour transmission rate compared to cotton fabric, due to its higher affinity to moisture and its better air permeability. A substantial improvement in fabric primary hand, total hand and total appearance value can only be achieved after subjecting the linen fabric to the wet treatment process.

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