EFFECT OF WASHING AND DRYING PROGRAMS ON LOW STRESS MECHANICAL PROPERTIES OF WEFT-KNITTED FABRICS

By

M. RAMKUMAR
Reg.No.71203502010

Of

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BONAFIDE CERTIFICATE

Certified that this project report titled "**EFFECT OF WASHING AND DRYING PROGRAMS ON LOW STRESS MECHANICAL PROPERTIES OF WEFT-KNITTED FABRICS**" is the bonafide work of **Mr.M.RAMKUMAR** who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

V. Kr 10/6/05

Dr. V.Krishnakumar
Asst. Professor
(Supervisor)

16/6/05

Prof.Dr.V.Natarajan
Professor & Head

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This Project report has been submitted by

NAME : M. RAMKUMAR

Regd. No. : 71203502010

For the viva-voce examination held on 25-06-2005

ABSTRACT

Over the years, the subjective assessment of fabric hand has played a key role in fabric quality evaluation. However, on account of its highly complex nature and lack of quick response coupled with the ever increasing diversity of fabrics and clothing, it has come under close scrutiny in recent times. Kawabata's analytical model of fabric hand based on its relationship with basic mechanical properties of the fabric has been helpful in overcoming the above difficulties. In fact, the objective evaluation of fabric hand is now widely employed for specifying quality and performance requirements of fabrics. The low stress mechanical properties, before and after washing, of weft knitted single jersey cotton fabric have been measured using Kawabata Evaluation System with a view to investigate the effects of washing and drying programs of the two types of widely used modern domestic washing machines namely the top-loading agitator type machine and the front-loading horizontal drum type machine. It is only to be expected that these textile properties will have been altered due to the mechanical and thermal stresses which the fabric has been subjected to during washing and drying. In fact, the statistical analysis of the test results has revealed that the process of washing has influenced the compressional, surface, tensile, shear and bending properties in the order of decreasing significance. To have an overall view of the effect of the changes in these properties on the fabric hand and to understand the relative contributions of the individual properties towards the fabric hand, an appropriate set of Kawabata Transformation Equations has been used to arrive at the primary hand values of the fabric. Of the four primary hand values, FUKURAMI, (fullness and softness) and SHARI (crispness) have shown perceptible changes which can be attributed to washing whereas KOSHI (stiffness) and HARI (anti-drape stiffness) have been relatively uninfluenced. Incidentally, despite the fairly different mechanisms of washing employed in the two machines, their effects on the low stress mechanical properties as well as the primary hand values of the fabric have been reasonably similar.

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CHAPTER 1

INTRODUCTION

Fabric hand which represents the comfort and aesthetic characteristics of the fabric plays an important role in fabric quality evaluation. Traditionally fabric hand has been subjectively assessed by expert judges and therefore has always been the subject of much discussion by fabric finishers and garment makers.

Prof. Sueo Kawabata was the first to demonstrate that the subjective comfort and aesthetic characteristics of a textile fabric could be quantified in terms of physical measures called low stress mechanical properties. The basic concept underlying the objective fabric evaluation technology is that necessary and sufficient instrumental measurements should be made on the fabrics for the specification and control of the quality, tailorability and ultimate performance of the fabric.

Low stress mechanical properties, as their name implies, refer to the properties of a textile fabric measured with the application of low levels of forces to simulate the real-life situations in which the fabric, as a part of a garment, will be put to use.

Since the washing action of a modern washing machine on the fabric can be considered as gentle (which is more so in the case of knitted fabrics due to the choice of an appropriate washing program), investigation of the low stress mechanical properties to understand the effects of washing and drying is certainly appropriate and well justified

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Ever since the advent of Kawabata Evaluation System introducing the concept of low stress mechanical properties of a textile fabric, the objective evaluation of fabric hand has taken precedence over the subjective assessment of the same by expert judges. The research works in this field have generally revolved around the following themes.

- Factors which influence the low stress mechanical properties of a fabric.
- Optimization of low stress mechanical properties to suit a particular end use of the fabric.
- Degree of correlation between subjective assessment and objective evaluation of fabric hand in various situations.

2.2 FACTORS INFLUENCING LOW STRESS MECHANICAL PROPERTIES

2.2.1 Effect of Knit Structure

Mee–Sung Choi and Susan Ashdown (2001) investigated the mechanical and hand properties of weft –knit cotton fabrics with the following six structures with same stitch density.

1) 1x1 rib
2) half–cardigan rib
3) half–milano rib
4) single pique

5) interlock
6) cross miss interlock

Their study reveals that

- 1x1 rib and interlock samples, constructed using knit stitches have excellent tensile elongation and have the ability to absorb external stresses. Single pique and cross miss interlock samples which have tuck and miss stitches in the course direction cannot absorb external stresses.

- Compression values do not show any consistent and significant difference among the different knit structures.

- 1x1 rib fabric tends to be the least stiff and the smoothest surfaced of all six structures. The cross miss interlock is the stiffest. The cross miss interlock and the single pique tend to be fuller and softer.

2.2.2 Effect of Knit Density or Stitch Density

According to Mee-Sung Choi and Susan Ashdown (2001), Knit density (wales/cm x courses/cm) has a significant influence on low stress mechanical properties of weft-knit fabrics.

- Tensile properties (strength, elengation) increase with knit density.
- Bending properties (bending rigidity and hysteresis of bending moment) increase with knit density.
- Compression properties generally decrease with knit density.
- Surface properties such as softness and smoothness generally increase with knit density.
- The fabrics tend to be stiffer, rougher surfaced and less full and soft as the knit density increases.

2.2.3 Effect of Blend Proportion in P/C Knit Fabrics

The research work of H.N. Yoon et al (1984] on 'Improved Comfort Polyster' arrived at the following conclusions.

As the percentage of cotton increases in the P/C blend,

- tensile elengation increases for the same applied load.
- resistance to compression increases.
- both static and kinematic fabric to fabric frictional coefficients increase.
- Kinematic fabric to rubber frictional coefficient decreases.

2.2.4 Effect of Washing and Drying

P.J.Weedall et al (1994) subjected 6 samples of white P/C cotton fabric (67/33 blend, 90 g/m^2) to 0, 1, 5, 10, 20, 30 wash and wear cycles as follows.

The wash cycle consisted in washing the samples under a constant load in a domestic washing machine.

The wear cycle consisted of tumbling the samples along with a denim fabric in a domestic tumble dryer for 30 minutes at room temperature.

The following are the conclusions:

- most of the mechanical properties showed only a small change with increase in number of washing cycles.
- The only exceptions were the shear properties and surface properties.
- Shear rigidity decreased considerably with increase in number of wash / wear cycles.
- Surface geometrical roughness increased noticeably with increase in number of wash / wear cycles.

2.2.5 Effect of Dry Cleaning and Steam Pressing

R.C. Dhingra et al (1989) studied the effect of dry cleaning and steam pressing on wool and wool blend fabrics. The findings are

- noticeable increase in tensile extensibility (15%).
- negligible change in tensile resilience (less than 5%)
- considerable decrease in shear rigidity and hysteresis of shear (10-15%)
- Slight decrease in bending parameters.
- fabric thickness increased considerably (30-45%).
- Compressional energy increased very considerably (50-90%).
- Surface parameters showed little change.

2.2.6 Effect of Finishing

R.H. Gong and S.K. Mukhopadhyay (1993) investigated the low stress mechanical properties of caustic-reduced polyester fabrics and liquid ammonia treated cotton fabrics.

Liquid ammonia treatment of cotton fabrics resulted in

- increase in tensile resilience
- increase in shear stiffness
- much lower bending hysteresis
- negligible change in bending rigidity
- little change in surface properties.

Caustic reduction treatment of polyester fabrics resulted in

- increase in tensile resilience.
- decrease in shear stiffness and hysteresis.
- lower bending stiffness.
- lower surface roughness.
- higher surface friction coefficient.

2.2.7 Effect of Fibre Distribution within Yarn

P.Radhakrishnaiah and A.P.S. Sawhney (1996) investigated low stress mechanical properties of P/C yarns with random fibre disposition and in core-sheath construction (cotton covered polyester yarn).

Preferential positioning of polyester fibres in the yarn core resulted in

- decrease in bending rigidity
- decrease in compressive resilience
- decrease in tensile elongation.

This indicates that the core-sheath yarn is softer and more flexible and is difficult to stretch under low load conditions.

2.2.8 Effect of Fibre Content of the Fabric

R.K. Datta, A.M. Shah and N.C. Patel (1996) measured the low stress mechanical properties of seven groups of fabrics with the fibre content cotton, P/C, P/V, normal polyester, caustic reduced polyester, microdenier polyester and silk. The conclusions of their work are

- Microdenier polyesten fabrics have high flexibility with soft feel, fullness and excellent drapability. They resemble silk in fullness.
- Cotton, P/C, P/V fabrics have modest flexibility with soft feel and modest fullness and poor drapability.
- Normal polyester fabrics are the least silk-like.
- Caustic reduced polyester fabrics have better fullness, flexibility, softness and drapability compared to silk.
- Bending hysteresis is as important as bending stiffness in influencing fabric handle.

2.2.9 Effect of Blend Proportion of Acrylic-Viscose Fibres in Interlock Fabric.

I.C. Sharma, A. Mukhopadhyay and B.P. Dash (2001) studied the low stress mechanical properties of interlock knitted fabrics with respect to the blend proportion of acrylic-vicose fibres. They used acrylic-viscose blended yarns of four different blend proportions (40-60, 50-50, 65-35, 75-25) for knitting the interlock fabric. The following conclusions were arrived at.

- Tensile parameters (EM, WT & RT) increase with the increase in acrylic content.
- Bending parameters (B, 2HB) increase whereas the shear parametes (G, 2HG and 2HG5) decrease with increase in acrylic content.
- In acrylic-rich blended fabrics, compressional energy (WC) is higher but compressinal resiliency (RC) is lower
- The coefficient of friction (MIU) and geometrical roughness (SMD) are higher for acrylic-rich fabric.

2.2.10 Effect of Blend Proportion in P/C Woven Fabric

The low-stress mechanical properties of specially engineered cotton and polyester blended fabrics differing in ends and picks, yarn count (both warp and weft) and cloth cover have been measured with KES-FB system at CIRCOT, Mumbai. By the use of suitable regression equations, the low-stress mechanical properties are converted into primary hand values and total hand values.

The following are the conclusions:

- With increase in polyester content, the primary hand values like fullness and anti-drape stiffness decreased. For optimal realization of hand values, a polyester content of 60-80% is desirable.
- Optimum improvement in handle properties is achieved when the heat-setting of polyester fabric is carried out in the range of 140°C-160°C for a short duration of 1-2 minutes.

- Light and medium weight cotton fabrics showed relatively good rating in the KES-FB system.

2.3 Optimal Combinations of Low-Stress Mechanical Properties for Men's Suiting Materials.

With a view to arrive at the optimal combinations of low-stress mechanical and surface properties of men's summer/winter suiting materials, R.Postle and R.C. Dhingra (1989) analysed the properties of over 200 suiting materials. Optimization of handle of medium/heavy and light/medium weight fabrics corresponding to winter and summer suiting led to the following conclusions.

- Parameters to be maximized are fabric extensibility, compressional resilience and smoothness.
- Parameters to be minimized are shear hysteresis, residual shear strain, bending rigidity, surface coefficient of friction and surface geometrical roughness.
- The optimal mechanical properties result in the production of soft, smooth, extensible and flexible fabrics for men's suiting materials.

2.4 Fabric Low Stress Mechanical Properties and Drapability

K.R. Sharma and B.K. Behera (2004) investigated the dependence of the drape of the fabric on bending stiffness and shear stiffness. Two groups of fabrics (100% wool, 55/45 poyester-wool) were considered with weight/unit area as the parameter. The end product considered was men's jacket. The investigation revealed the following.

- Drape coefficient has strong correlation with bending properties, good correlation with shear properties and average to weak correlation with tensile properties.
- Compression Properties are not at all related to drape coefficient

2.5 Tactile sensory Assessment of Fabric Hand

Geitel Winaker and J. Kim (1980) studied the tactile sensory assessment of selected fabrics (cotton and polyester) with stiffness, roughness and thickness as variables representing the bending, frictional and compressional deformation that occur in handling a fabric. The experimental results were analysed using ANOVA.

9 adjective pairs were developed for describing the three physical properties.

TABLE 2.1

ADJECTIVE PAIRS FOR FABRIC PHYSICAL PROPERTIES

Adjective Pair	Physical Property
Limp - crisp	Bending
Scratchy - silky	Frictional
Fine - coarse	Frictional
Light - heavy	Area density
Smooth - rough	Frictional
Thin - thick	Compressional
Firm - sleazy	Bending
Hard - soft	Compressional
Flexible - stiff	Bending

The following were the conclusions arrived at.

- All four main effects (Fibre content, stiffness, roughness and thickness) significantly affected the sensory responses of the judges with respect to the nine adjective pairs.

- ANOVA result shows six two-way interactions, four three-way interactions and one four-way interaction. However there were relatively fewer two-way interaction effects among the nine adjective pairs considered.

CHAPTER 3

RESEARCH OBJECTIVE

To investigate the effect of washing and drying on the low stress mechanical properties of weft knitted fabrics.

- The fabric under investigation is single jersey cotton fabric.
- Both types of modern domestic washing machines are to be used.
    - top-loading, agitator type washing machine
    - front-loading, horizontal drum type washing machine
- All the sixteen low stress mechanical properties of the fabric are to be investigated.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 TEST PLAN

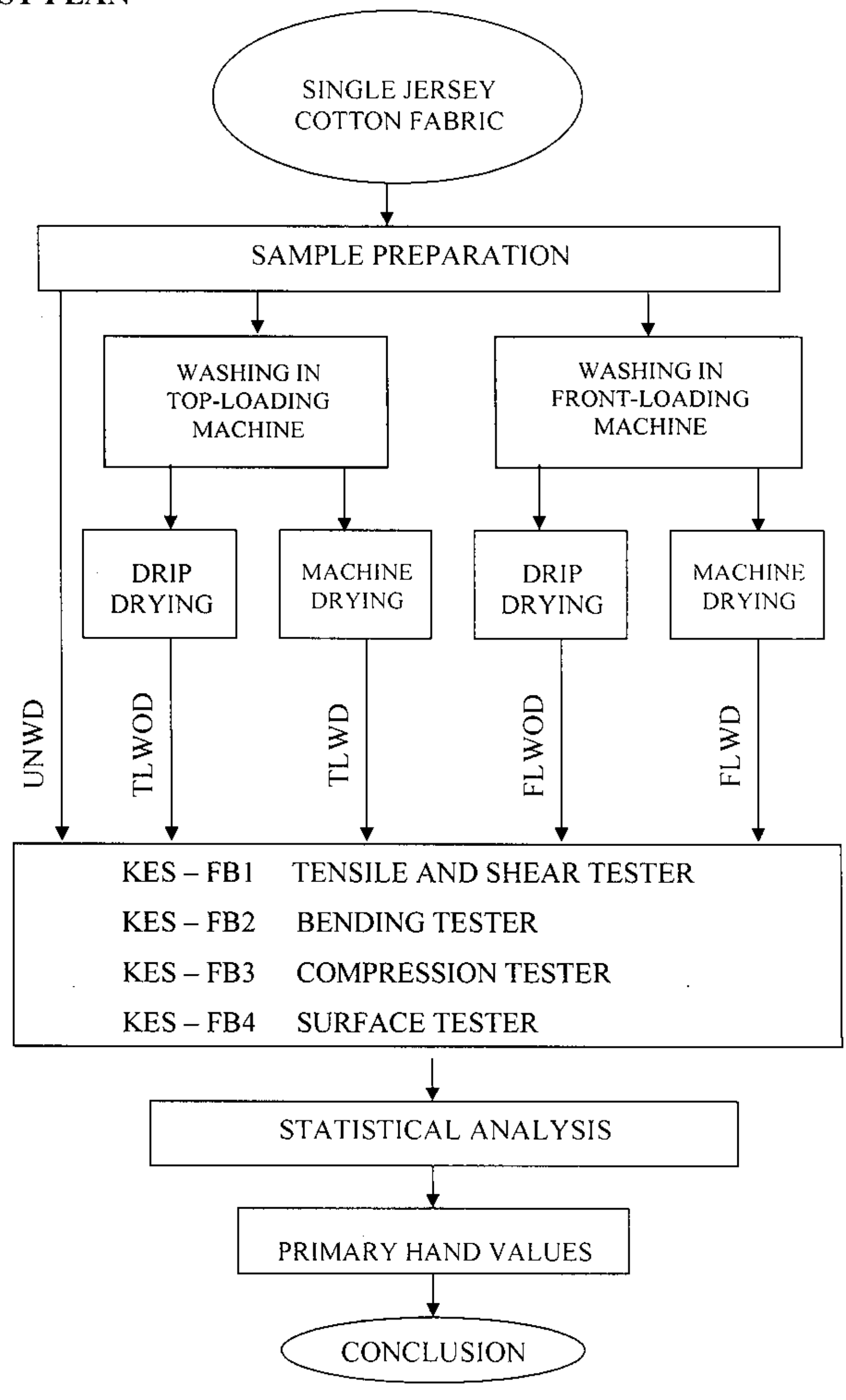

FIGURE 4.1 TEST PLAN

4.2 FABRIC PRODUCTION

4.2.1 Yarn Parameters

For producing the single jersey fabric meant for the project work, 30s carded cotton hosiery yarn with following yarn parameters has been used.

Count Variation (%)	1.5
Yarn Unevenness (U%)	11.68
Imperfection / Km	500
Yarn Twist (TM)	3.75
Yarn Hairiness Index	5.68
Yarn CSP	2350
Yarn Appearance Grade	B
Yarn friction Coefficient	0.14

4.2.2 Knitting Machine Specifications

Machine	Single jersey weft knitting machine
Make	KNITMAC, Tirupur
Type	SB
Diameter	16 inches
Gauge	20
No. of feeders	22
rpm	24
total needles	996 Type 102 52
Total sinkers	996 Type 38 23
Direction of knitting	counter clockwise

4.2.3 Fabric Construction Details

Cpi	42
Wpi	29
Loop length	0.12 inch
GSM	122

4.3 WASHING AND DRYING

4.3.1 Washing Machines

The two washing machines used in this work are

- ✓ LG fully automatic washing machine (front loading horizontal drum type).
  MODEL : WD 8001 C1

- ✓ WHIRLPOOL Semi-automatic washing machine (top loading agitator type).
  MODEL : H 68

The technical specifications of these machines are furnished in table 4.1.

4.3.2 Mechanism of Washing

The principle on which washing is based is the flexing of fabrics in washing machine with currents of that solution being used to carry the dirt away from the fabric. The washing machines generally use two major methods to bring about washing. Please refer figures 4.2 and 4.3.

(a) Agitation : This type of washing takes place in a top-loading machine with a vertically positioned agitator in the centre. The agitator is provided with blades or fins. The movement of the agitator causes currents in the water within the tub which gently forces water through the clothes.

(b) Tumbling : This type of washing takes place in a front-loading machine in which washing takes place in a horizontally placed drum which is perforated and which revolves in a partially filled tub of water. There is no agitator. With each revolution of wash basket, the clothes are carried near the top by a series of baffles and are dropped into the wash water.

The basic difference in the mechanisms of washing of the two types of washing machines can be stated as follows.

The clothes move through the water in a front-loading machine whereas the water moves through the clothes in a top-loading machine.

TABLE 4.1

TECHNICAL SPECIFICATIONS OF WASHING MACHINES

Top-loading Agitator type Washing Machine

WHIRL POOL SEMI-AUTOMATIC Model S 68

Power Supply	240V-AC, 50Hz, 5A		
Input Power	Wash motor 340W; Spin motor 150W		
Water Level	High 65L	Medium 55L	Low 40L
Water pressure	0.15-1kg/cm2		
Capacity Wash	6.8kg dry cloth		
Washing Rate	12±1 spm		
Heater power	1500W		

Front-loading Horizontal Drum Type Washing Machine

LG FULLY AUTOMATIC MODEL WD – 8001 C1

Capacity (dry fabric) (kg.)	5.0
Power requirement	220-230 v, 50 Hz.
Motor power (W)	300
Heater Power (W)	1900
Washing Speed (rpm)	50
Spin speed (rpm)	800

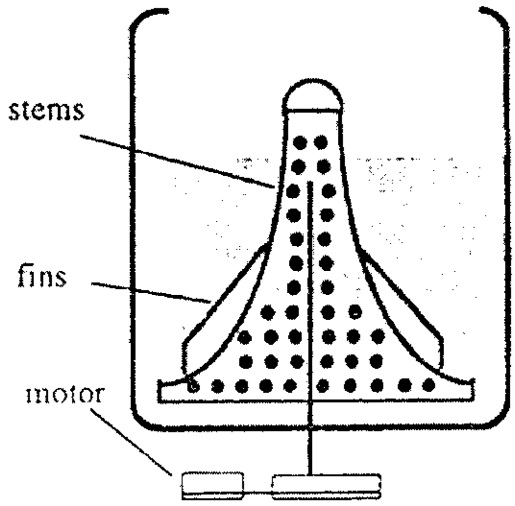

FIGURE 4.2 WASHING USING AGITATION

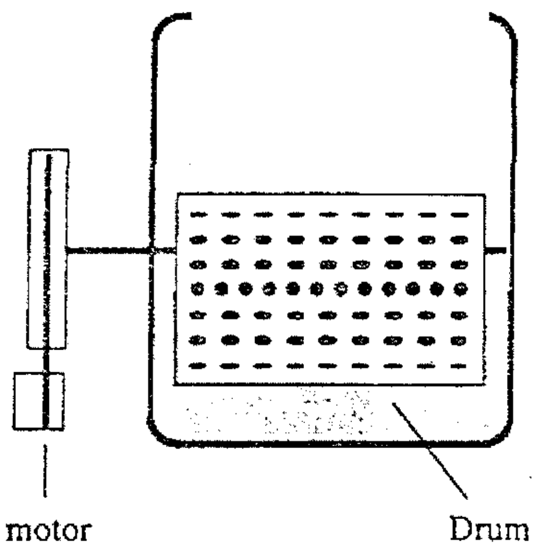

FIGURE 4.3 WASHING USING TUMBLING

4.3.3 Mechanism of Drying

Spin Drying

Air of relatively low temperature is circulated at high velocity through the clothes. Air from the room enters the dryer through the openings at the rear. It passes over the source of heat and then enters the cylinder at the right front side. After the air has passed through the clothes, it is drawn from the cylinder at the left with the help of the low pressure area created by the blower. Finally the air leaves the dryer through an exhaust lint trap at the rear. The advantage of this type of dryer is that the temperature and the humidity of the exhaust air are relatively low to cause any change in the ambient conditions. Spin drying is employed in top-loading washing machines.

Tumble Drying

Tumble drying is based on the principle that by increasing the temperature of the air, its ability to hold moisture is increased. Tumble dryers incorporate a source of heat, a fan or blower and a cylinder, housed in a cabinet. Air is brought into the dryer, heated and blown through the clothes as they tumble about in the cylinder. The warm air picks up the moisture and the moisture-laden air is then blown out of the machine. This type of dryer is used in front-loading washing machine.

4.3.4 Washing Procedure

The following guidelines enlisted in AATCC test method 135-1995 for automatic home laundering of woven and knit fabrics have been adopted.

❖ Sample size	:	38 cm X 38 cm
❖ Sample conditioning	:	Before each and every washing cycle, the samples are to be preconditioned for a period of not less than 4 hours at a temperature of 21±1°C and at a humidity of 65±2%.
❖ Washing cycle	:	each washing cycle consists of one main wash, three rinses and one spin operations.
❖ Temperature of wash water	:	40 °C.
❖ Addition of ballast	:	adequate ballast is to be added to the samples during washing so that the total wash load is 5 kg. This is to be done to simulate the actual washing conditions.
❖ Number of washing cycles	:	10 ; (too low a number of washing cycles lead to inconsistent test results while too high a number of washing cycles lead to saturation of expected changes in the mechanical properties of the fabric.)
❖ Time interval between Successive washing cycles	:	24 hours.

4.4 KAWABATA EVALUATION SYSTEM

This system has been developed to relate objective measurements of the important properties of fabric to subjective evaluation of fabric hand.

Kawabata considered the following mechanical, surface and physical properties to be important from the point of view of fabric hand.

- Tensile
- Bending
- Shearing
- Compressional
- Surface
- Weight and thickness

In each of the above, certain characteristic values were identified to represent the property and to establish the inter-relationship between fabric handle and these properties.

A total of 16 Characteristic Values (Parameters) were identified by Kawabata. They are furnished in table 4.2.

For the measurement of above parameters, four instruments are available. (Photo copies are included in the appendices 12 and 13). These instruments are versatile and allow data regarding deformation and recovery for each mechanical property to be obtained. The unique feature of these instruments is their ability to measure fabric mechanical properties at small stresses with high sensitivity. A brief description of the KES-FB Testers and the testing procedure follows.

TABLE 4.2

THE SIXTEEN PARAMETERS DESCRIBING THE FABRIC PROPERTIES

Parameter Group	**Description**			**Unit**
Tensile	1.	LT	Linearity of load-extension curve	-
	2.	WT	Tensile energy	gf.cm/cm^2
	3.	RT	Tensile resilience	%
Shear	4.	G	Shear rigidity	gf/cm.degree
	5.	2HG	Hysteresis of shear force at 0.5 degree shear angle	gf/cm
	6.	2HG5	Hysteresis of shear force at 5 degree shear angle	gf/cm
Bending	7.	B	Bending rigidity	gf.cm^2/cm
	8.	2HB	Hystersis of bending moment	gf.cm/cm
Compression	9.	LC	Linearity of compression-thickness curve	-
	10.	WC	Compressional energy	gf.cm./cm^2
	11.	RC	Compressional resilience	%
Surface	12.	MIU	Coefficient of friction	-
	13.	MMD	Mean deviation of MIU	-
	14.	SMD	Geometrical roughness	micron(μm)
Fabric Construction	15.	W	Fabric weight per unit area	mg/cm^2
	16.	T	Fabric Thickness	mm

4.4.1 KES – FBI (Tensile And Shear Tester)

Shear test is done before tensile test because tensile deformation is more than shear deformation.

4.4.1.1 Shear Test

Instrument Settings

Rate of shearing	:	0.417 mm / s
Max shear angle	:	± 8°
Tension on sample	:	10 g f / cm^2
sample size (l x w)	:	5 cm x 20 cm

Procedure

The sample is clamped between two jaws with the effective test area of 5cm x 20cm.

The sample is subjected to a constant tension of 10 g f / cm^2 by means of a weight attached to the drum on which one of the jaws is mounted.

The drum is allowed to rotate freely by disengaging the clutch. This has to be done to maintain constant tension on the sample.

The shear deformation is applied at a constant rate to a preset shear angle.

Then the recovery cycle is automatically started.

The shear force is measured by a transducer connected to the jaw (which is moved sideways to apply the shear deformation).

The shear strain is detected by a potentiometer.

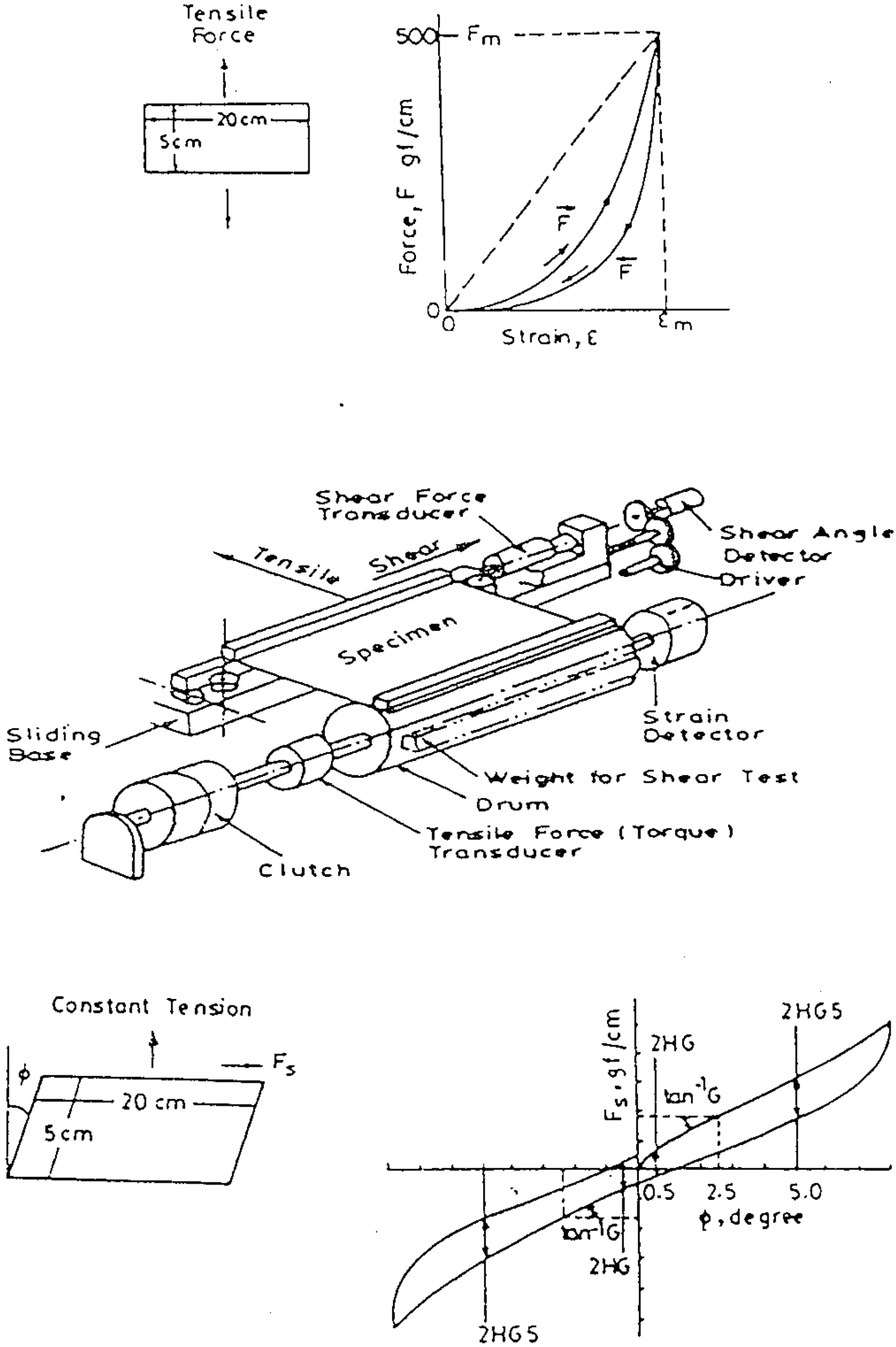

FIGURE 4.4. TENSILE AND SHEAR TESTS USING KES-FB1

Shear characteristic values

A graph is drawn with shear strain along the x axis and shear force along the y axis. The following shear characteristic values are obtained from the graph. which is known as shear hysteresis curve.

(1) G (Shear rigidity)

(2) 2HG (Hysteresis of shear force at 0.5 degree shear angle)

(3) 2HG5 (Hysteresis of shear force at 5 degree shear angle)

(i) G = Slope between 0.5^0 and 2.5^0 shear angle
Unit: N/m degree (or) g f / cm. degree

(ii) 2HG = hysteresis of shear force at 0.5^0 shear angle
Unit: N/m (or) g f / cm

(iii) 2HG5 = hysteresis of shear force at 5^0 shear angle
Unit: N/m (or) gf / cm

4.4.1.2 Tensile test

The clutch is engaged to arrest the free rotation of the drum.

Fabric is extended at a constant strain rate by moving the other jaw assembly until a preset load is reached.

Then the recovery cycle is started automatically.

A Torque detector connected to the drum is used to detect the tensile force in the fabric.

Instrument settings

Rate of extension : 0.02 mm/s
Max. tensile force : 500 gf/cm
Sample size (L x W) : 5cm x 20cm

Tensile characteristic values

A graph drawn between tensile strain and tensile force is called "tensile hysteresis curve".

(i) Linearity of load – extension curve (LT)

$$LT = \frac{\int_0^{\varepsilon_m} \overrightarrow{F}\, d\varepsilon}{0.5 F_m \varepsilon_m}$$

unit: no unit.

(ii) Tensile Energy (WT)

$$WT = \int_o^{\varepsilon_m} \overleftarrow{F}\, d\varepsilon$$

unit: N/m or gf.cm/cm^2

(iii) Tensile Resilience (RT)

$$RT = \frac{\int_o^{\varepsilon_m} \overrightarrow{F}\, d\varepsilon}{\int_o^{\varepsilon_m} \overleftarrow{F}\, d\varepsilon} x100$$

unit: %.

4.4.2 KES – FB2 (Bending Tester)

A fixed jaw holds one edge of the 2-20cm wide sample. The movable jaw at a distance of 1cm holds the other edge of the sample.

The movable jaw follows a fixed orbit by turning its head.

The fabric curvature increases at a constant rate till the required curvature is reached.

A sensor attached to the fixed jaw detects the bending moment of the sample.

The relationship between the bending moment and the curvature is obtained between the set curvature limits.

Instrument Settings

Rate of bending	:	0.5 cm^{-1}/s
Maximum curvature	:	2.5 cm^{-1}
Sample size (L x W)	:	2-20 cm x 1cm

Bending characteristic values

(i) Bending Rigidity (B)	=	Slope between 0.5 and 1.5cm^{-1} curvature Unit: 10^{-4} N/m ($gfcm^2/cm$)
(ii) Hysteresis of bending moment (2HB)	=	Hysteresis at 1cm^{-1} curvature. Unit: 10^{-2} N (g f.cm /cm)

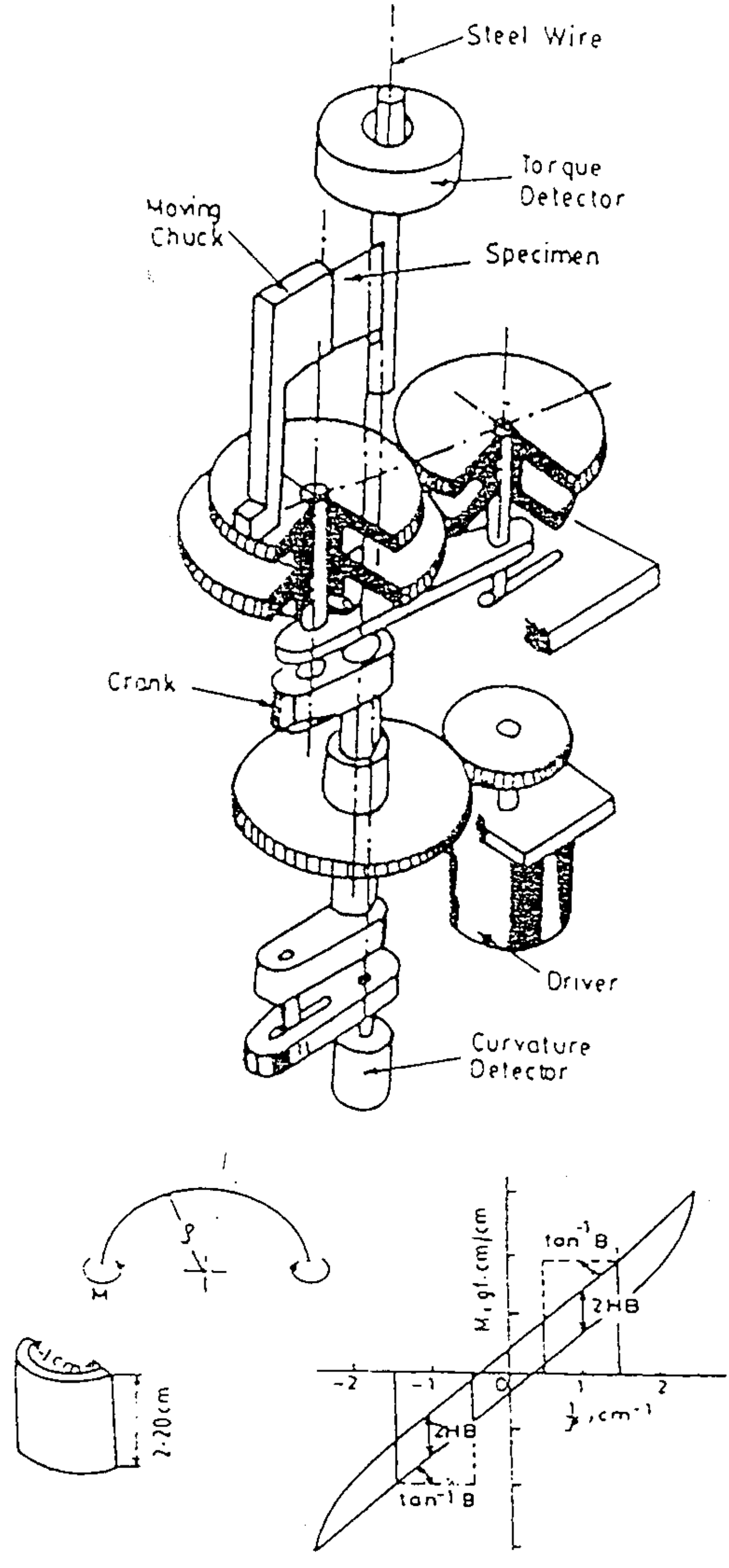

FIGURE 4.5. BENDING TESTS USING KES-FB2

4.4.3 KES –FB3 (Compression Tester)

This tester gives a cyclic compressive deformation to a fabric within the predetermined maximum load of compression.

Fabric sample is placed on the bottom plate of the instrument.
A plunger of area $2cm^2$ is used to compress the sample at a constant rate.

Fabric is compressed till a preset pressure is reached.

Then the recovery cycle is carried out at the same constant rate.

Instrument Settings

Rate of compression	:	0.02 mm / s
Maximum force	:	$50gf / cm^2$
Area compressed	:	$2\ cm^2$

Compressional characteristic values (parameters)

There are calculated from the compression hysteresis curve as follows.

(i) Linearity of compression – thickness curve (LC)

$$LC = \frac{\int_{Tm}^{To} \vec{P}\, dT}{0.5(T_m - T_o)P_m}$$

Unit: no unit

(ii) Compressional energy (WC)

$$WC = \int_{T_m}^{T_o} \vec{P}\, dT$$

unit: N/m or ($gf.cm/cm^2$)

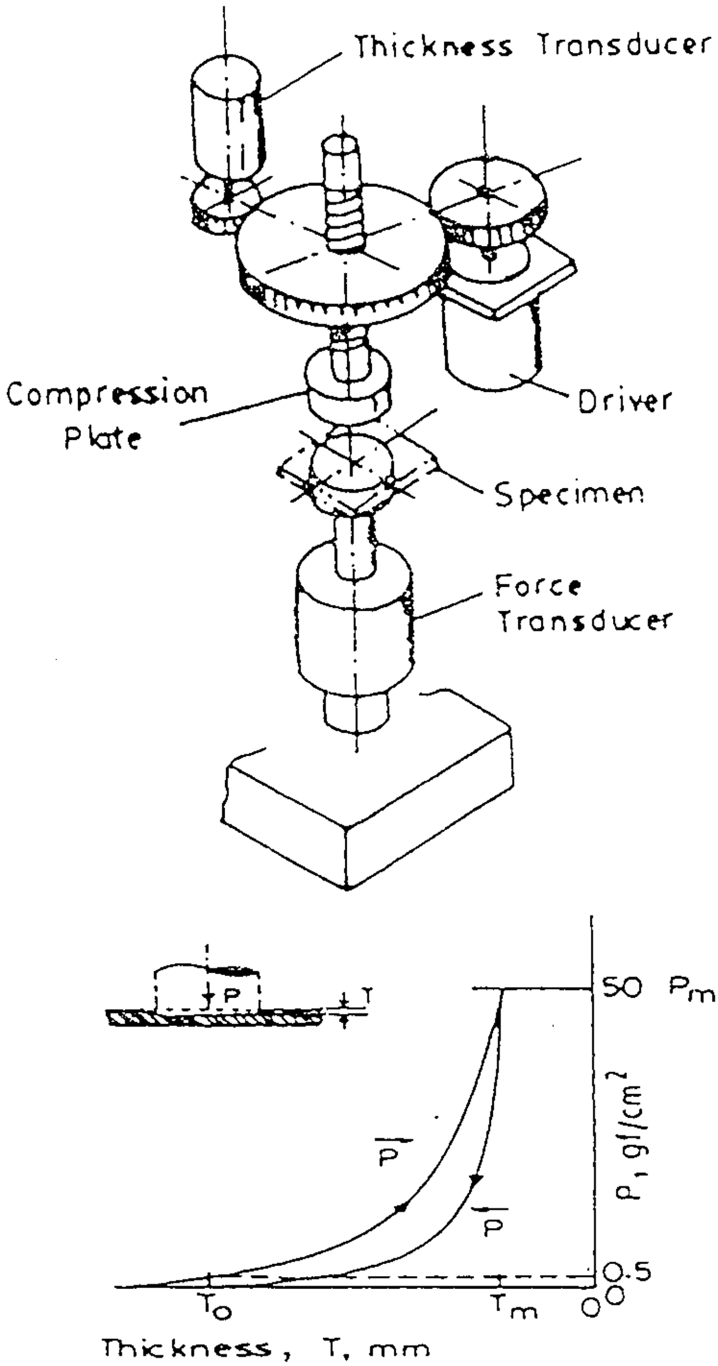

FIGURE 4.6. COMPRESSIBILITY TEST USING KES-FB3

(iii) Compressional resilience (RC)

$$RC = \frac{\int_{T_m}^{T_o} \overrightarrow{P}\, dT}{\int_{T_m}^{T_o} \overleftarrow{P}\, dT} x100$$

unit: %

4.4.4 KES – FB4 (Surface Tester)

This tester is used to determine the coefficient of friction, its variation and the surface roughness of the fabric.

One end of the sample is fixed on the winding drum. The other end of the sample is held by a weight to apply a constant tension on the fabric.

The winding drum turns to displace the fabric at a constant speed by 2-3cm on a horizontal, smooth steel plate.

Two specially designed sensors measure surface friction and roughness.

The sensor of surface roughness in made by a steel piano wire of 0.5 mm dia. It is bent as a staple pin and lowered on the fabric with a top load of 10gf.

Surface friction is measured by using 10 such pins bonded together and placed on the surface of the fabric with 50 gf compressional load.

Instrument settings

Rate of traverse	:	1mm / s
Tension in sample	:	20gf / cm
Normal force, friction	:	50gf / c,
Normal force, roughness	:	10gf / cm
distance moved	:	3 cm

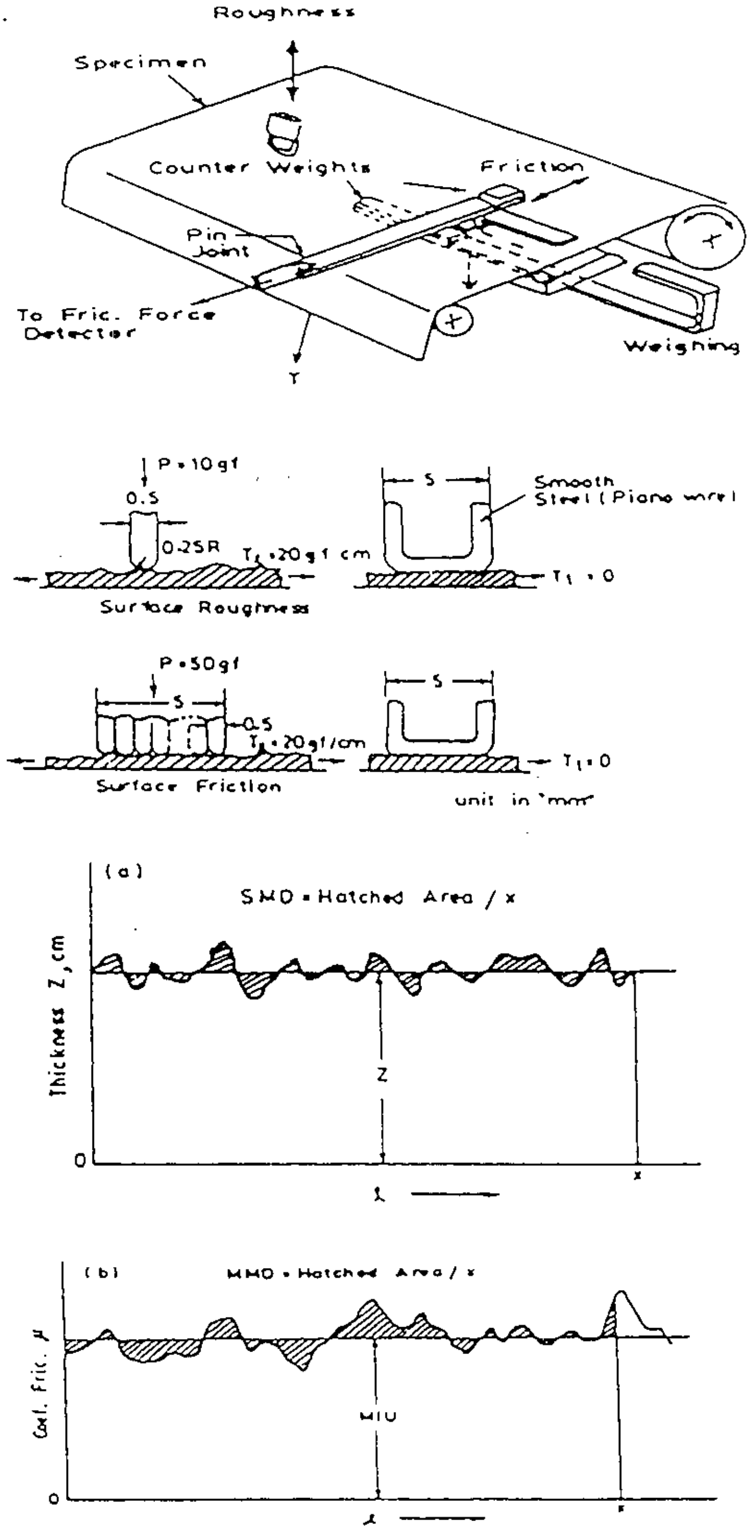

FIGURE 4.7. SURFACE CHARACTERISTICS TEST USING KES-FB4

Surface Characteristic Values

(i) Coefficient of friction, (MIU)

$$\text{MIU, } \bar{\mu} = \frac{1}{X} \int_0^x \mu \, dl$$

unit : no unit

(ii) mean deviation of coefficient of friction

$$\text{MMD} = \frac{1}{X} \int_0^x / \mu - \bar{\mu} \; / dl$$

(iii) Geometrical roughness : (SMD)

$$\text{SMD} = \frac{1}{X} \int_0^x / Z - \bar{Z} \; / dl$$

Frictional coefficient (μ) is defined as the ratio of frictional force (F) and the normal pressure (N) by which the contactor is pressed on the fabric surface.

The (μ) value fluctuates during the sweep of the fabric surface. The mean value of coefficient of friction, MIU and its mean deviation (MMD) are calculated from the following data.

$$\text{MMD} = \frac{HatchedArea}{X}$$

The data of the vertical displacement (z) of the surface roughness contactor from the standard position helps us to calculate the mean deviation of surface contour (SMD)

$$\text{SMD} = \frac{HatchedArea}{X}$$

4.5 TESTING WITH KES – FB TESTERS :

The following are the notations of the five fabric samples to be tested.

1. UNWD : unwashed sample
2. TLWD : sample washed in top-loading machine and dried using the dryer available in the machine.
3. TLWOD : sample washed in top-loading machine and dried by drip drying. The dryer in the machine is not used.
4. FLWD :sample washed in front-loading machine and dried in the machine itself.
5. FLWOD : sample washed in front-loading machine but not dried in the machine and dried by drip drying.

The low stress mechanical properties of the above five fabric samples have been evaluated by the KES-F testers available at CIRCOT, Mumbai. A total of four readings (two taken in the course direction and two taken in the wale direction) are furnished per sample for each of the sixteen low stress mechanical properties.

The test results obtained from CIRCOT, Mumbai are furnished in the Appendices 1, 2 and 3.

The cloth samples are furnished at the end of this project report.

CHAPTER – 5

RESULTS AND DISCUSSION

5.1 STATISTICAL ANALYSIS

For each low stress mechanical proeprty, 't' Test for difference in sample means is carried out for the following six pairs of samples.

1. UNWD Vs TLWOD
2. UNWD Vs FLWOD
3. TLWOD Vs TLWD
4. FLWOD Vs FLWD
5. UNWD Vs TLWD
6. UNWD Vs FLWD

to draw conclusions on

1. Effect of washing in TL machine.
2. Effect of washing in FL machine
3. Effect of drying in TL machine
4. Effect of drying in FL machine
5. Combined effect of washing and drying in TL machine.
6. Combined effect of washing and drying in FL machine.

The result of 't' Test are furnished in Table 5.1

A model 't' Test calculation for the parameter WT is available in Appendix 4.

TABLE 5.1
RESULTS OF 't' TESTS

		Effect Of Washing		Effect of Drying		Combined Effect	
		TL	FL	TL	FL	TL	FL
Tensile	LT		✓✓				✓✓
	WT				✓	✓	✓
	RT	XX	XX			XX	XX
Bending	B						
	2 HB	X	X			XX	
Shear	G	✓	✓✓				
	2 HG			X			
	2HG5	✓	✓				✓
	LC					✓	✓
Compression	WC				X		XX
	RC	X	X	✓	✓		
Surface	MIU	✓	X	X	✓✓		
	MMD						
	SMD	X	XX	X		XX	XX

✓ Increase significant at 5 % level

✓✓ Increase significant at 1 % level

X Decrease significant at 5 % level

XX Decrease significant at 1 % level

TL Top –loading washing machine

FL Front – loading washing machine

The following inferences can straightaway be drawn from the results of 't' Test.

- With the lone exception of LT, washing in both TL and FL machines has influenced the same 7 properties. Among these 7 properties, the influence is similar in respect of 6 properties with the only exception of MIU. So we can safely arrive at the conclusion that washing actions of both the machines are comparable and quite similar.

- Drying in both the machines has affected so few properties that it is difficult to make any comparison.

- Between the washing and the drying actions, it is clearly the washing action which has left its mark on the low stress mechanical properties.

- Compared to the unwashed sample (UNWD), the washed samples (TLWOD and FLWOD) are expected to be fuller and softer on account of decrease in RC, SMD and RT values and less crisp on account of increase in G value and decrease in RC, RT and SMD values.

5.1.1 Tensile Properties

1. LT (Linearity of Load Extension Curve)

The test results are shown graphically in figure 5.1

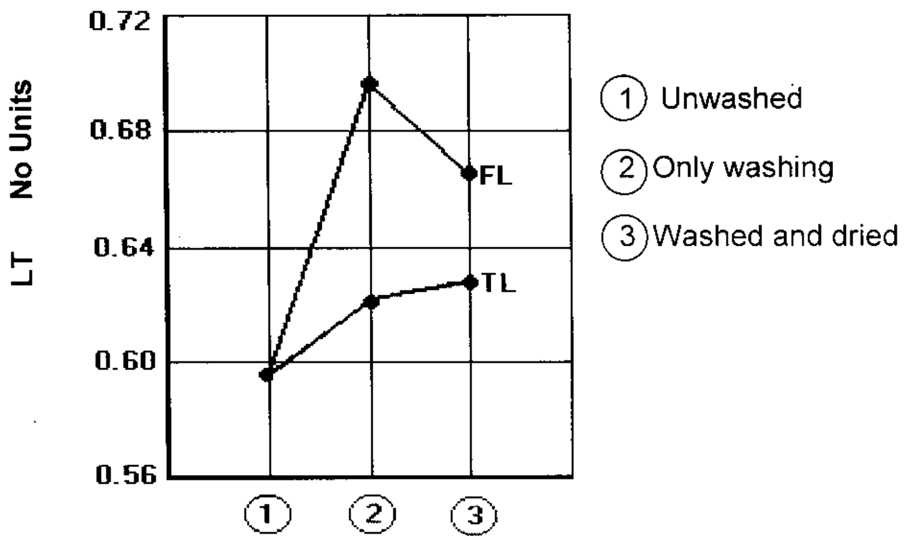

FIGURE 5.1 LT (LINEARITY OF LOAD EXTENSION CURVE)

RESULTS OF 't' TEST

Effect of washing	:	Significant increase at 1% level in FL m/c. increase not significant in TL m/c
Effect of drying	:	not significant
Combined effect	:	significant increase at 1% level in FL m/c only.

Inference :

Increase in LT results in decrease of fullness and softness.

2. WT (Tensile Energy)

The test results are shown graphically in figure 5.2

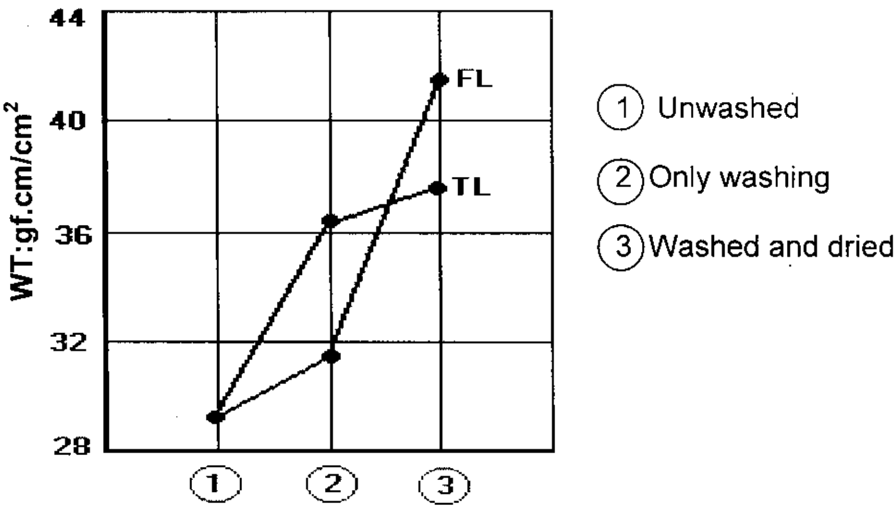

Figure 5.2 WT (Tensile Energy)

RESULTS OF 't' TEST

Effect of washing	:	increase in WT in both m/cs but not significant.
Effect of drying	:	further increase in WT, negligible in TL m/c but significant at 5% level in FL m/c
Combined effect	:	increase in WT both m/c significant at 5% level

Inference :

Increase in WT results in decrease of stiffness

3. RT (Tensile Resilience)

The test results are shown graphically in figure 5.3

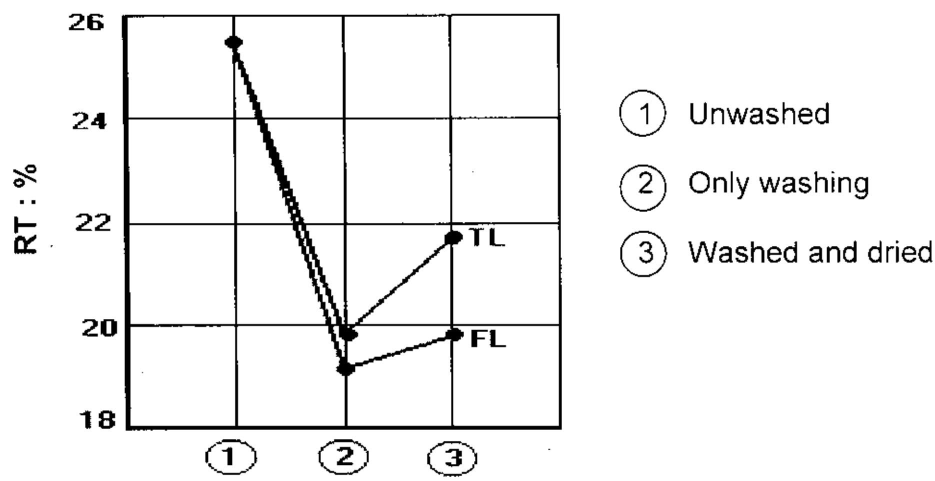

Figure 5.3 RT (Tensile Resilience)

RESULTS OF 't' TEST

Effect of washing	:	decrease in RT, significant at 1% level in both TL & FL m/c
Effect of drying	:	not significant
Combined effect	:	decrease in RT significant at 1% level for both TL & FL m/c.

Inference:

Decrease in RT results in

(i) increase of crispness

(ii) decrease of fullness and softness

5.1.2 SHEAR PROPERTIES

1. G (Shear Stiffness)

The test results are shown graphically in figure 5.4

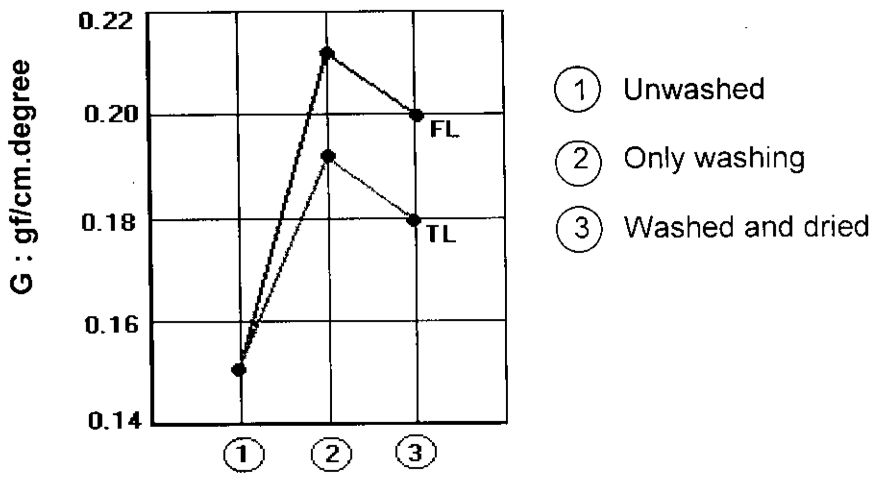

FIGURE 5.4 G (SHEAR STIFFNESS)

RESULTS OF 't' TEST

Effect of washing	:	increase in G, significant at 1% level in case of FL m/c and significant at 5% level in case of TL m/c
Effect of drying	:	decrease of G in both m/c but not at significant levels.
Combined effect	:	increase of G in both m/c but not at significant levels due to opposite effects of washing and drying

Inference :

Increase in G results in decrease of crispness

2. 2HG (Hysteresis of Shear Force at 0.5^0 Shear angle)

The test results are shown graphically in figure 5.5

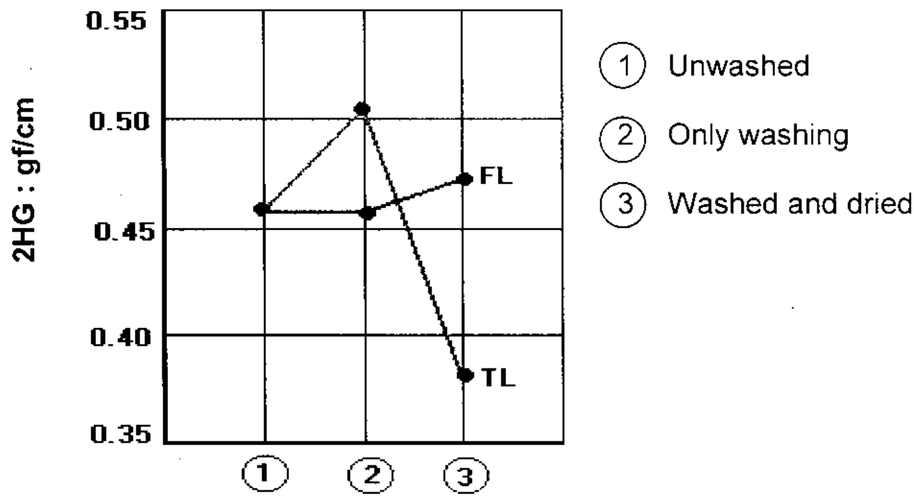

Figure 5.5 2HG (Hysteresis of Shear Force at 0.5^0 Shear angle)

RESULTS OF 't' TEST

Effect of washing : not significant

Effect of drying : spin drying in TL m/c results indecrease of 2HG value, significant at 5% level; no change in FL m/c

Combined effect : not significant

Inference :

No significant change in fabric hand due to this property.

3. 2HG5 (Hysteresis of Shear Force at 5^0 Shear angle)

The test results are shown graphically in figure 5.6

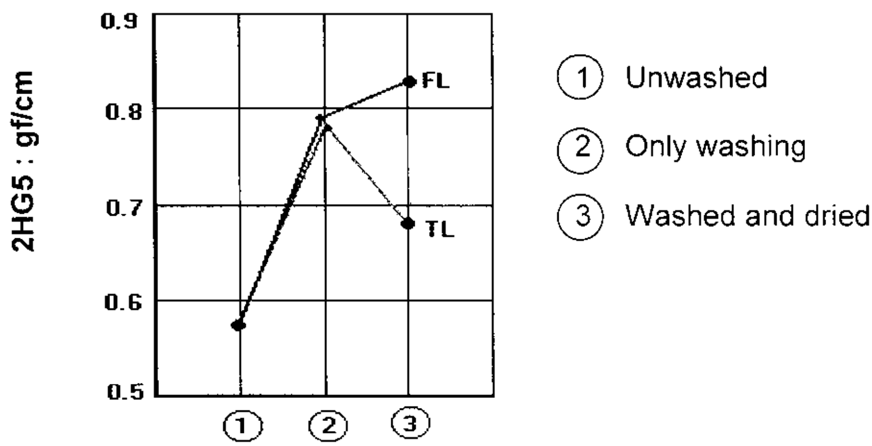

Figure 5.6 2HG5 (Hysteresis of Shear Force at 5^0 Shear angle)

RESULTS OF 't' TEST

Effect of washing	:	increase in both m/c, significant at 5% level
Effect of drying	:	decrease in TL m/c but increase in FL m/c, both not significant
Combined effect	:	significant increase at 5% level in FL m/c only.

Inference :

The influence of this property is minimal on fabric hand and so no marked change in fabric hand is expected.

5.1.3 BENDING PROPERTIES

1. B (Bending Stiffness)

The test results are shown graphically in figure 5.7

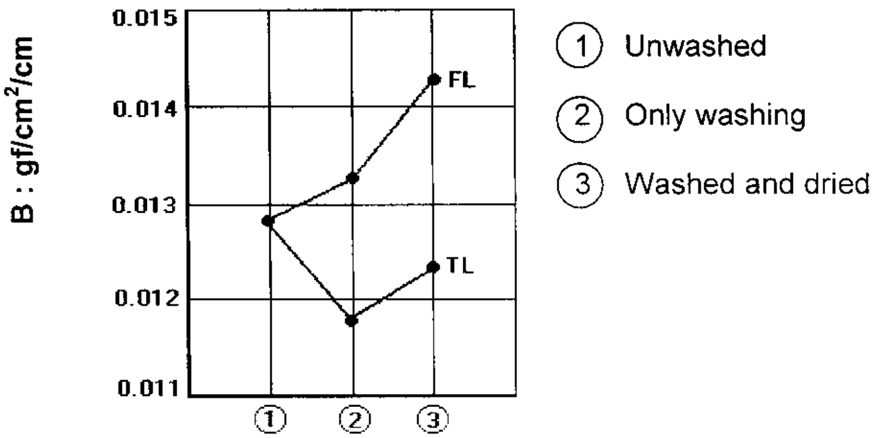

FIGURE 5.7 B (BENDING STIFFNESS)

RESULTS OF 't' TEST

Washing and Drying in both TL and FL machines do not have any significant effect on this parameter.

Inference :

Increase / Decrease of B results in increased / decreased stiffness

2. 2HB (Hysteresis of Bending Moment)

The test results are shown graphically in figure 5.8

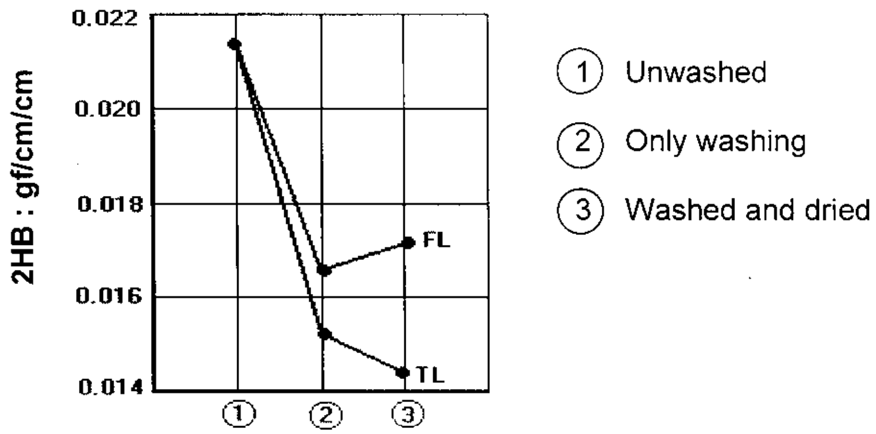

FIGURE 5.8 2HB (HYSTERESIS OF BENDING MOMENT)

RESULTS OF 't' TEST

Effect of washing : decrease of 2HB value, significant at 5% level in both TL and FL machines.

Effect of drying : no significant effect.Slight further decrease in TL m/c. Slight increase in FL m/c.

Combined effect : decrease of 2HB value, significant at 1% level in TL m/c. In case of FL m/c, the decrease in 2HB value is not significant.

Inference :

Decrease of 2HB value results in increased stiffness.

5.1.4 COMPRESSION PROPERTIES

1. LC (Linearity of Compression – Thickness curve)

The test results are shown graphically in figure 5.9

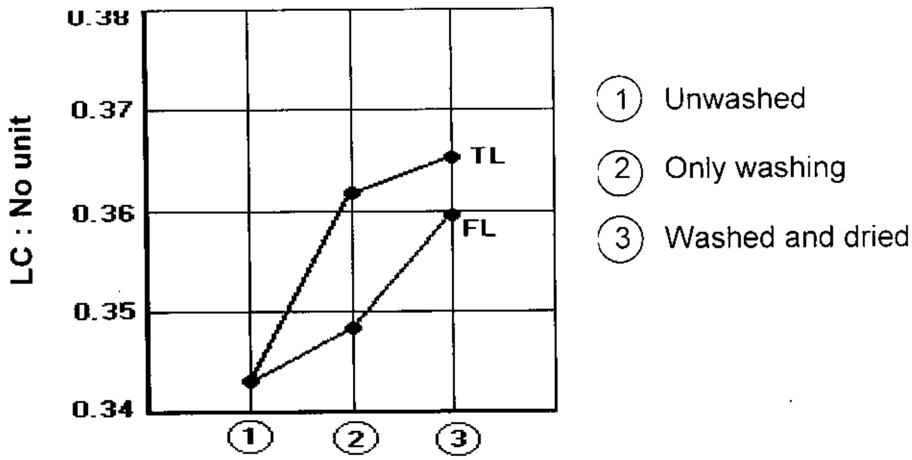

FIGURE 5.9 LC (LINEARITY OF COMPRESSION – THICKNESS CURVE)

RESULTS OF 't' TEST

Effect of washing	:	increase in both TL and FL machines but not at significant levels.
Effect of drying	:	further increase in both m/c but not at significant levels.
Combined effect	:	increase, significant at 5% level in both machines.

Inference :

Relatively small change in fabric hand due to this property compared to RC.

2. WC (Compressional Energy)

The test results are shown graphically in figure 5.10

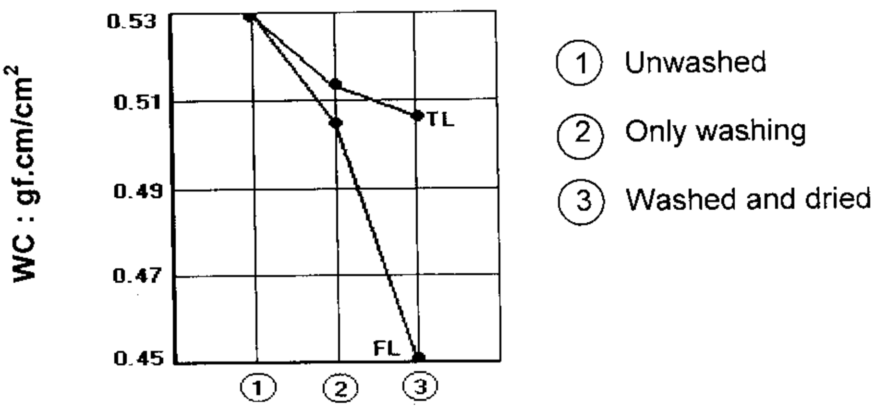

Figure 5.10 WC (COMPRESSIONAL ENERGY)

RESULTS OF 't' TEST

Effect of washing	:	decrease of WC in both TL and FL m/c but the decrease not significant.
Effect of drying	:	further decrease of WC; the decrease is significant at 5% level in FL m/c only.
Combined effect	:	decrease of WC in both m/c. Decrease significant at 1% level in FL m/c only.

Inference :

Relatively small change in fabric hand due to this property compared to RC.

3. RC (Compressional Resilience)

The test results are shown graphically in figure 5.11

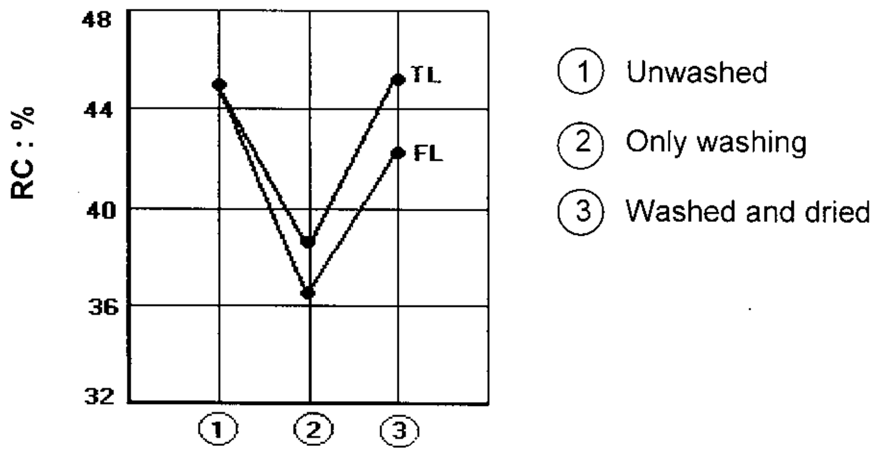

FIGURE 5.11 RC (COMPRESSIONAL RESILIENCE)

RESULTS OF 't' TEST

Effect of washing : decrease in RC, significant at 5% level in both TL and FL m/c.

Effect of drying : increase in RC in both TL and FL m/c, significant at 5% level.

Combined effect : no significant change due to opposite effects of washing and drying.

Inference :

Increase / decrease in RC results in

(i) decrease / increase in fullness and softness.

(ii) increase / decrease in crispness

5.1.5 SURFACE PROPERTIES

1. MIU (Coefficient of Friction)

The test results are shown graphically in figure 5.12

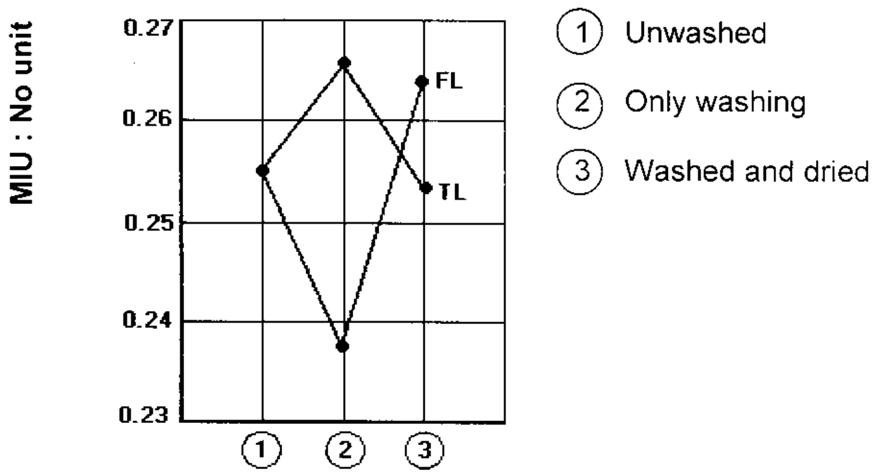

FIGURE 5.12 MIU (COEFFICIENT OF FRICTION)

RESULTS OF 't' TEST

Effect of washing	:	increase significant at 5% level in TL m/c; decrease significant at 5% level in FL m/c
Effect of drying	:	decrease significant at 5% level in TL m/c. Increase significant at 1% level in FL m/c
Combined effect	:	no significant change, the actions of washing and drying neutralising each other.

Inference :

Increase / decrease in MIU results in

Increase / decrease in fullness and softness

2. MMD (Mean Deviation of coefficient of friction)

The test results are shown graphically in figure 5.13

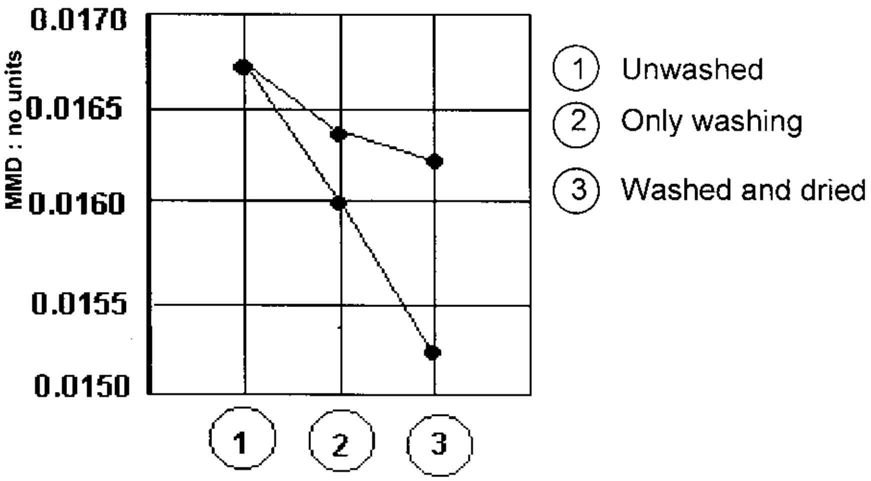

FIGURE 5.13 MMD (MEAN DEVIATION OF COEFFICIENT OF FRICTION)

RESULTS OF 't' TEST

Effect of washing	:	decrease in both m/c, but not significant
Effect of drying	:	further decrease in both m/c, not significant
Combined effect	:	decrease in both m/c but not at significant levels.

Inference :

No significant change in fabric hand due to MMD.

3. SMD (geometrical roughness)

The test results are shown graphically in figure 5.14

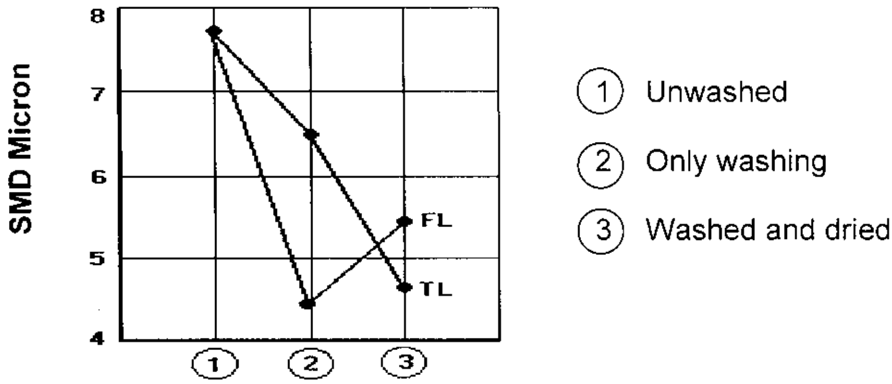

FIGURE 5.14 SMD (GEOMETRICAL ROUGHNESS)

RESULTS OF 't' TEST

Effect of washing : in both TL and FL machines, decrease of SMD, significant at 5% level in case of TL machine and 1% level in case of FL machine.

Effect of drying : spin drying in TL m/c further decrease SMD, significant at 5% level.

Drying in FL m/c has no significant effect, though SMD increase slightly.

Combined effect : decrease of SMD in both machines significant at 1% level.

Inference :

Decrease of SMD results in

(i) increased fullness and softness

(ii) reduced crispness.

5.2 PRIMARY HAND VALUES

The information that has been obtained from statistical analysis is only qualitative and general in nature. It is not possible to obtain quantitative and comprehensive information from such analysis due to the following reasons.

- Different low stress mechanical properties make different contributions to a particular hand value.
- The same low stress mechanical property while making significant contribution to a particular hand value may not make such contribution to other hand values.

Hence, to have an overall view of the effects of washing and drying on low stress mechanical properties and to understand the relative contributions of these properties towards the primary hand values, an appropriate set of Kawabata Transformation Equations must be used to evaluate the primary hand values from low stress mechanical properties.

$$Y = C_0 + \sum_{i=1}^{16} C_i X_i$$

where Y = Primary hand value

X= normalised low stress mechanical property.

$C_o, C_1, C_2, \ldots\ldots\ldots C_{16}$ = Constants of regression equation.

The Kawabata Transmation Equation KN-202-LDY meant for thin outerwear fabrics has been chosen because the reference mechanical properties used in this equation are of the same order of magnitude as the properties of our test fabric. KN-202 LDY is applicable to men's dress shirt, women's blouse and one piece dress and other thin outerwear fabrics used in summer. The four primary hand values evaluated using this transformation equation are

1. KOSHI (stiffness)
2. SHARI (crispness)
3. FUKURAMI (fullness and softness)
4. HARI (anti-drape stiffness)

The primary hand values of the fabric samples are furnished in table 5.2.

The relevant calculations can be found in Appendices 5 to 11

An average observer can recoginse the change in the hand of fabric if the change in the primary hand value is of the order of 1 or more. Accordingly washing and drying of the test fabric has resulted in recognisable changes in the primary hand values of SHARI and FUKURAMI. The properties RC, MIU, RT and LT have contributed to the change in FUKURAMI whereas the properties G, RC, SMD and RT have done so for SHARI

5.3 TOTAL HAND VALUE (THV)

The Primary Hand Values have been substituted in the Kawabata Transformation Equation KN-301-SUMMER-THV to arrive at the Total Hand Value.

$$THV = Co + \sum_{i=1}^{4} Zi$$

where $Zi = Ci1\,(Yi-Mi1)/\sigma i1 + C_{i2}(Yi^2-M_{i2})/\sigma i2$

Y - primary hand value

$C0, Ci1, Ci2, Mi1, Mi2, \sigma i1, \sigma i2$ – constants

The THV calculations are shown in Table 5.3

Though there have been perceptible changes in the two PHVs Fukurami and Shari, they have not been reflected in THV because these two PHVs make marked differencess only when they are below 4 or above 8. (Here these two PHVs have values ranging from 5 to 7)

TABLE 5.2

PRIMARY HAND VALUES

	UNWD	TLWOD	FLWOD	TLWD	FLWD
KOSHI	0.83	0.58	0.92	0.84	0.90
SHARI	6.20	5.38	5.04	5.64	5.36
FUKURAMI	6.09	7.01	6.79	6.09	6.46
HARI	1.01	0.71	1.22	0.97	1.31

TABLE 5.3

TOTAL HAND VALUE

	UNWD	TLWOD	FLWOD	TLWD	FLWD
Co	3.21	3.21	3.21	3.21	3.21
Z1 KOSHI	-0.01	-0.01	-0.01	-0.01	-0.01
Z2 SHARI	0.60	0.33	0.20	0.42	0.33
Z3 FUKURAMI	0.16	0.20	0.20	0.17	0.19
Z4 HARI	-0.12	-0.13	-0.03	-0.08	-0.02
THV	3.84	3.60	3.57	3.71	3.70

CHAPTER 6

CONCLUSION

- Washing actions of both the top-loading machine and the front-loading machine have significantly influenced the fabric low stress mechanical properties; The fabric tends to be fuller and softer and less crisp after washing.

- Washing and Drying of the test fabric has resulted in perceptible changes in the primary hand values of SHARI and FUKURAMI. The other two primary hand values KOSHI and HARI are relatively uninfluenced.

- Despite the quiet different washing actions of the top-loading agitator type machine and front-loading horizontal drum type machine they have fairly similar effect on low stress mechanical properties as well as primary hand values of the fabric.

CHAPTER 7

APPENDICES

APPENDIX – 1

TABLE 7.1

TENSILE PROPERTIES USING TENSILE AND SHEAR TESTER (KES-FB1)

Sr.No.	Institute of Sample No.	Marked as		LT	WT	RT
1	C-05116	UNWD-Unwashed	Warp	0.556	35.4	25.01
			Weft	0.617	22.75	26.93
			Avg	0.587	29.08	25.97
2	C-05117	TL WD-Top loading	Warp	0.59	38.35	21.98
		with dryer*	Weft	0.652	35.2	20.87
			Avg	0.621	36.78	21.42
3	C-05118	TL WOD-Top	Warp	0.626	33.9	21.62
		loading without dryer*	Weft	0.604	38.35	18.11
			Avg	0.615	36.13	19.86
4	C-05119	FL WD-Front loading	Warp	0.65	48.1	19.55
		without dryer*	Weft	0.666	35	20.05
			Avg	0.658	41.55	19.8
5	C-05120	FL WOD-Front	Warp	0.66	33.6	20.07
		loading without dryer*	Weft	0.729	29.55	19.27
			Avg	0.695	31.57	19.67

TABLE 7.2

SHEAR PROPERTIES USING TENSILE AND SHEAR TESTER (KES-FB1)

Sr.No.	Institute Sample No.	Marked as		G	2HG	2HG5
1	C-05116	UNWD-Unwashed	Warp	0.13	0.41	0.49
			Weft	0.17	0.50	0.69
			Avg	0.15	0.46	0.59
2	C-0.5117	TL WD-Top loading	Warp	0.20	0.40	0.74
		with dryer	Weft	0.17	0.35	0.64
			Avg	0.18	0.38	0.69
3	C-05118	TL WOD –Top	Warp	0.21	0.51	0.83
		loading without dryer	Weft	0.18	0.51	0.74
			Avg	0.19	0.51	0.78
4	C-0.5119	FL WD-Front loading	Warp	0.23	0.56	0.95
		with dryer	Weft	0.16	0.38	0.74
			Avg	0.20	0.47	0.84
5	C-0.5120	FL WOD-Front	Warp	0.22	0.43	0.79
		loading without dryer	Weft	0.20	0.49	0.70
			Avg	0.21	0.46	0.79

APPENDIX – 2

TABLE 7.3

BENDING PROPERTIES USING PURE BENDING TESTER (KES-FB2)

Sr. No.	Institute Sample No.	Marked as		B	2HB
1	C-05116	UNWD-Unwashed	Warp	0.0149	0.0178
			Weft	0.0110	0.0254
			Avg	0.0129	0.0216
2	C-05117	TL WD- Top loading	Warp	0.0135	0.0136
		with dryer	Weft	0.0113	0.0148
			Avg	0.0124	0.0142
3	C-05118	TL WOD-Top loading	Warp	0.0104	0.0127
		without dryer	Weft	0.0133	0.0167
			Avg	0.0118	0.0147
4.	C-05119	FL WD –Front loading	Warp	0.0142	0.0140
		with dryer	Weft	0.0145	0.0203
			Avg	0.0143	0.0172
5	C-05120	FL WOD-Front	Warp	0.0107	0.0162
		loading without dryer	Weft	0.0159	0.0165
			Avg	0.0133	0.0164

TABLE 7.4

COMPRESSION PROPERTIES USING COMPRESSION TESTER (KES-FB3)

Sr. No	Institute Sample No.	Marked as	LC	WC	RC
	C-05116	UNWD-Unwashed	0.342	0.529	44.42
2	C-05117	TL WD-Top loading with dryer	0.365	0.505	44.42
3	C-05118	TL WOD-Top loading without dryer	0.361	0.512	38.11
4	C-05119	FL WD-Front loading with dryer	0.360	0.449	42.41
5	C-05120	FL WOD-Front loading without dryer	0.349	0.505	36.20

APPENDIX – 3

TABLE 7.5

SURFACE PROPERTIES USING SURFACE TESTER (KES-FB4)

Sr. No.	Institute Sample No.	Marked as		MIU	MMD	SMD
1	C-05116	UNWD-Unwashed	Warp	0.265	0.0192	7.403
			Weft	0.244	0.0143	8.075
			Avg	0.255	0.0168	7.739
2	C-05117	TL WD-Top loading	Warp	0.251	0.0183	3.804
		with dryer	Weft	0.257	0.0141	5.705
			Avg	0.254	0.0162	4.755
3	C-05118	TL WOD-Top loading	Warp	0.261	0.0176	7.216
		without dryer	Weft	0.271	0.0153	5.574
			Avg	0.266	0.0164	6.395
4	C-05119	FL WD-Front loading	Warp	0.257	0.0147	4.240
		with dryer	Weft	0.270	0.0155	6.238
			Avg	0.263	0.0151	5.239
5	C-05120	FL WOD – Front	Warp	0.234	0.0171	3.280
		loading without dryer	Weft	0.245	0.0148	5.309
			Avg	0.239	0.0160	4.295

TABLE 7.6

FABRIC WEIGHT AND THICKNESS

Sr. No	Institute Sample No	Marked as	Fabric Thickness (mm)	Fabric wt. (mg/cm^2)
1.	C-05116	UNWD – Unwashed	1.230	12.58
2.	C-05117	TL WD-Top loading with dryer	1.213	14.91
3.	C-05118	TL WOD-Top loading without dryer	1.220	14.30
4.	C-05119	FL WD – Front loading with dryer	1.210	15.83
5.	C-05120	FL WOD – Front loading without dryer	1.253	15.29

APPENDIX - 4

TABLE 7.7

MODEL T – TEST (DIFFERENCE BETWEEN SAMPLE MEANS) FOR WT

	UNWD	TLWOD	FLWOD	TLWD	FLWD
	34.3	33.5	33.9	40.2	45.7
	23.1	38.4	27.0	35.9	35.5
	36.5	34.3	33.3	36.5	50.5
	22.4	38.3	32.1	34.5	34.5
$\overline{X}$	29.08	36.13	31.57	36,78	41.55
S	7.364	2.590	3.140	2.432	7.824
$(n_1-1)S^2$	162.7	20.1	29.6	17.7	183.6

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \qquad \text{where } S = \sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1 + n_2 - 2}}$$

$n_1 = 4$; $n_2 = 4$; dof = $n_1 + n_2 - 2 = 6$

Table value of $t_{0.05} = 1.94$ (Single tail test)

t-Test between	Calculated t	Table t	Comments on difference between sample means
UNWD & TLWOD	1.81	1.94	
UNWD & FLWOD	0.62	1.94	
TLWOD & TLWD	0.37	1.94	
FLWOD & FLWD	2.34	1.94	Significant at 5% level
UNWD & TLWD	1.99	1.94	Significant at 5% level
UNWD & FLWD	2.32	1.94	Significant at 5% level

APPENDIX – 5

TABLE 7.8

Formula KN – 202 – LDY

Table for $\overline{X}_i$, σ_i

Block	i		X_i	(N = 120) $\overline{X}_i$,	σ_i	Unit
Tensile	1		LT	0.7485	0.0830	-
	2	log	WT	-0.2822	0.3527	gf.cm/cm^2
	3		RT	62.5188	11.7627	%
Bending	4	log	B	-1.7749	0.3592	gf.cm/cm^2
	5	log	2HB	-2.0351	0.5126	gf.cm/cm
Shear	6	log	G	-0.3731	0.3044	gf/cm.degree
	7	log	2HG	-0.2733	0.5586	gf/cm
	8	log	2HG5	0.0295	0.4506	gf/cm
Compression	9		LC	0.7049	0.0676	-
	10	log	WC	-1.7106	0.3439	gf.cm/cm^2
	11		RC	48.1520	7.8931	%
Surface	12		MIU	0.2258	0.0452	-
	13	log	MMD	-1.6832	0.2191	-
	14	log	SMD	0.4892	0.3999	Micron
Thick & Weight	15	log	T	-0.4127	0.2058	mm
	16	log	W	0.9623	0.1768	mg/cm^2

TABLE 7.9

KN – 301 – SUMMER – THV, THE EQUATION FOR SUMMER SUIT FABRICS

C_0 = 3.2146

i	Y_i	C_i1	C_i2	M_i1	M_i2	σ_i1	σ_i2
1.	Koshi	-0.004	0.0066	4.6089	22.4220	1.0860	11.1468
2.	Shari	1.1368	-0.5395	4.7480	24.8412	1.5156	14.9493
3.	Fukurami	0.5309	-0.3741	4.9217	25.2704	1.0230	10.1442
4.	Hari	0.3316	-0.4977	5.3929	30.7671	1.2975	14.1273

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TABLE 7.10

KN – 202 – LDY COEFFICIENTS

KOSHI			HARI			FUKURAMI			SHARI		
i	C_i	R	i	C_i	R	i	C_i	R	i	C_i	R
0	5.1991		0	5.0816		0	4.7891		0	4.6833	
4	1.2622	0.794	4	1.8527	0.906	11	-1.0256	0.571	13	1.0850	0.550
5	-0.3961	0.870	5	0.0462	0.906	9	-0.1197	0.575	14	0.3082	0.578
7	-0.4317	0.906	2	-0.4025	0.931	10	-0.0559	0.576	12	-0.1014	0.577
8	0.1781	0.920	1	0.1618	0.938	13	-0.4397	0.627	6	-1.1854	0.832
6	-0.0247	0.920	3	-0.0456	0.938	12	0.4891	0.683	7	-0.0112	0.832
2	-0.4843	0.938	6	0.1293	0.943	14	-0.0911	0.685	8	0.0012	0.832
1	0.1379	0.939	7	-0.0509	0.943	3	0.3424	0.712	11	0.3593	0.856
3	0.1340	0.941	8	0.0231	0.943	1	-9.2127	0.722	9	0.0561	0.857
15	0.0737	0.943	13	0.0930	0.945	2	0.0606	0.722	10	0.0826	0.857
16	-0.0273	0.943	12	-0.0265	0.945	16	0.3946	0.754	3	-0.2746	0.866
9	0.1475	0.949	14	-0.0477	0.945	15	0.0163	0.754	2	-0.1643	0.869
11	0.1401	0.953	11	0.1812	0.947	4	0.1453	0.758	1	-0.0268	0.869
10	0.0400	0.953	9	0.0755	0.947	5	0.0092	0.758	5	-0.0623	0.870
13	0.1114	0.955	10	-0.1413	0.947	6	-0.0397	0.759	4	0.1016	0.871
14	-0.0129	0.955	16	0.0449	0.947	7	0.0354	0.759	16	0.1327	0.873
12	-0.0116	0.955	15	-0.0069	0.947	8	-0.0299	0.759	15	-0.0676	0.874

APPENDIX -7

TABLE 7.11

NORMALISED VALUES OF LOW STRESS MECHANICAL PROPERTIES OF FABRIC SAMPLES

S.No	Low Stress Mechanical Property	TEST VALUES					NORMALISED VALUES				
		UNWD	TLWOD	FLWOD	TLWD	FLWD	UNWD	TLWOD	FLWOD	TLWD	FLWD
1	LT	0.587	0.615	0.695	0.621	0.658	-1.946	-1.608	-0.645	-1.536	-1.090
2	Log WT	1.4636	1.5579	1.4993	1.5656	1.6186	4.95	5.222	5.05	5.24	5.39
3	RT	25.97	19.86	19.67	21.42	19.80	-3.11	-3.60	-3.64	-3.49	-3.62
4	log B	-1.8894	-1.9281	-1.8761	-1.9066	-1.8447	-0.316	-0.426	-0.282	-0.367	-0.194
5	log 2HB	-1.6655	-1.8327	-1.7852	-1.8477	-1.7645	0.721	0.395	0.488	0.366	0.528
6	log G	-0.8239	-0.7212	-0.6778	-0.7447	-0.6990	-1.48	-1.14	-1.00	-1.22	-1.07
7	log 2HG	-0.3372	-0.2924	-0.3372	-0.4202	-0.3279	-0.114	-0.034	-0.114	-0.262	-0.098
8	log 2HG5	-0.2291	-0.1079	-0.1024	-0.1612	-0.0757	-0.57	-0.30	-0.29	-0.42	-0.23
9	LC	0.342	0.361	0.349	0.365	0.360	-5.37	-5.09	-5.26	-5.32	-5.10
10	log WC	-0.2765	-0.2907	-0.2967	-0.2967	-0.3477	4.17	4.12	4.11	4.11	3.96
11	RC	44.42	38.11	36.20	44.42	42.41	-0.45	-1.27	-1.49	-0.45	-0.71
12	MIU	0.255	0.266	0.239	0.254	0.263	0.65	0.90	0.29	0.62	0.82
13	log MMD	-1.7747	-1.7852	-1.7959	-1.7905	-1.8210	-0.42	-0.49	-0.51	-0.50	-0.54
14	log SMD	0.8887	0.8058	0.6330	0.6772	0.7192	1.00	0.79	0.36	0.47	0.58
15	log T	0.0899	0.0864	0.0980	0.0839	0.0828	2.44	2.43	2.48	2.41	2.41
16	log W	1.0997	1.1553	1.1844	1.1735	1.1995	0.78	1.10	1.26	1.19	1.34

APPENDIX -8

TABLE 7.12

CALCULATION FOR KOSHI (STIFFNESS)

i	C_i	UNWD	TLWOD	FLWOD	TLWD	FLWD
0	5.1991	5.199	5.199	5.199	5.199	5.199
4	1.2622	-0.398	-0.537	-0.355	-0.463	-0.244
5	-0.3961	-0.285	-0.156	-0.193	-0.144	-0.209
7	-0.4317	0.049	0.014	0.049	0.113	0.042
8	0.1781	-0.101	-0.053	-0.051	-0.074	-0.040
6	-0.0247	0.037	0.028	0.025	0.030	0.026
2	-0.4843	-2.397	-2.528	-2.445	-2.537	-2.610
1	0.1379	-0.268	-0.221	-0.088	-0.211	-0.150
3	0.1340	-0.416	-0.486	-0.487	-0.467	-0.486
15	0.0737	0.179	0.179	0.183	0.178	0.178
16	-0.0273	-0.021	-0.029	-0.034	-0.032	-0.036
9	0.1475	-0.792	-0.750	-0.775	-0.784	-0.752
11	0.1401	-0.063	-0.175	-0.208	-0.063	-0.099
10	0.0400	0.167	0.165	0.164	0.164	0.158
13	0.1114	-0.046	-0.052	-0.056	-0.054	-0.060
14	-0.0129	-0.012	-0.010	-0.004	-0.006	-0.007
12	-0.0116	-0.007	-0.010	-0.003	-0.007	-0.009
Primary Hand Value (Koshi)		**0.825**	**0.578**	**0.921**	**0.842**	**0.901**

APPENDIX--9

TABLE 7.13

CALCULATION FOR FUKURAMI (FULLNESS AND SOFTNESS)

i	C_i	UNWD	TLWOD	FLWOD	TLWD	FLWD
0	4.7891	4.789	4.789	4.789	4.789	4.789
11	-1.0256	0.461	1.302	1.528	0.461	0.728
9	-0.1197	0.642	0.610	0.629	0.636	0.610
10	-0.0559	-0.233	-0.230	-0.230	-0.230	-0.221
13	-0.4397	0.184	0.216	0.224	0.220	0.237
12	0.4891	0.317	0.440	0.142	0.303	0.401
14	-0.0911	-0.091	-0.072	-0.033	-0.042	-0.052
3	0.3424	-1.065	-1.202	-1.246	-1.195	-1.243
1	-0.2127	0.414	0.343	0.137	0.326	0.231
2	0.0606	0.300	0.318	0.306	0.319	0.387
16	0.3946	0.308	0.454	0.497	0.470	0.529
15	0.0163	0.040	0.040	0.040	0.039	0.039
4	0.1453	-0.046	-0.060	-0.041	-0.053	-0.028
5	0.0092	0.007	0.004	0.004	0.003	0.005
6	-0.0397	0.059	0.046	0.040	0.048	0.042
7	0.0354	-0.004	-0.001	-0.004	-0.009	-0.003
8	-0.0299	0.017	0.009	0.009	0.013	0.007
Primary Hand Value (Fukurami)		**6.099**	**7.006**	**6.791**	**6.092**	**6.458**

APPENDIX -10

TABLE 7.14

CALCULATION FOR HARI (ANTI-DRAPE STIFFNESS)

i	C_i	UNWD	TLWOD	FLWOD	TLWD	FLWD
0	5.0816	5.082	5.082	5.082	5.082	5.082
4	1.8527	-0.585	-0.789	-0.522	-0.679	-0.359
5	0.0462	0.033	0.018	0.023	0.017	0.024
2	-0.4025	-1.992	-2.101	-2.032	-2.109	-2.169
1	0.1618	-0.314	-0.260	-0.104	-0.248	-0.176
3	-0.0456	0.142	0.166	0.166	0.159	0.166
6	0.1293	-0.191	-0.147	-0.129	-0.157	-0.138
7	-0.0509	0.006	0.002	0.006	0.013	0.005
8	0.0231	-0.013	-0.006	-0.006	-0.009	-0.005
13	0.0930	-0.039	-0.043	-0.047	-0.045	-0.050
12	-0.0265	-0.017	-0.023	-0.007	-0.016	-0.021
14	-0.0477	-0.047	-0.037	-0.017	-0.022	-0.027
11	0.1812	-0.081	-0.226	-0.269	-0.081	-0.128
9	0.0755	-0.405	-0.384	-0.397	-0.401	-0.385
10	-0.1413	-0.589	-0.582	-0.580	-0.580	-0.559
16	0.0449	0.035	0.049	0.057	0.053	0.060
15	-0.0069	-0.016	-0.007	-0.008	-0.008	-0.009
Primary Hand Value (HARI)		**1.009**	**0.712**	**1.216**	**0.969**	**1.311**

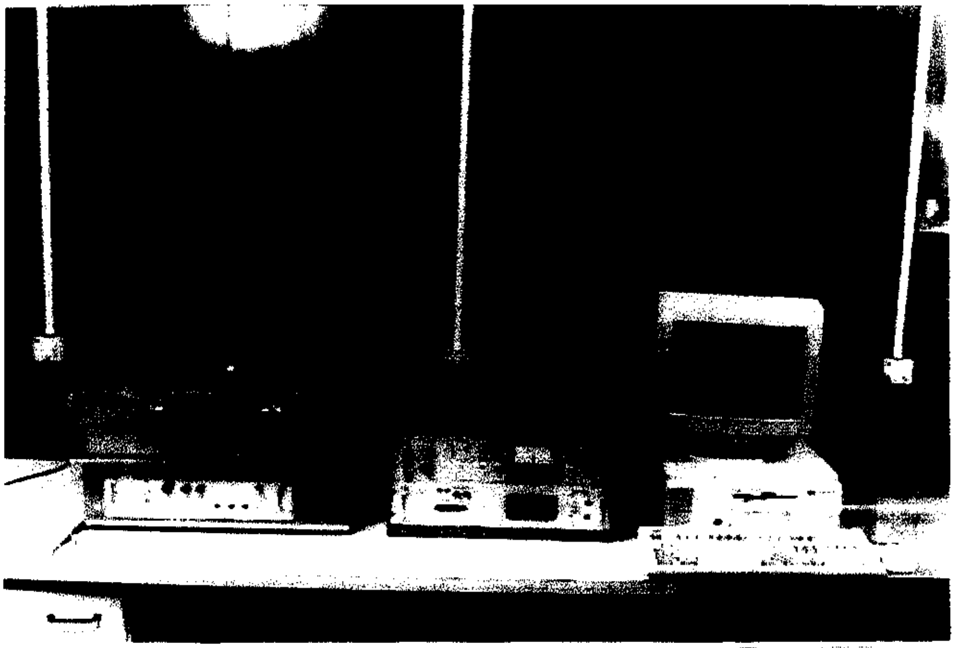
APPENDIX -11

TABLE 7.15

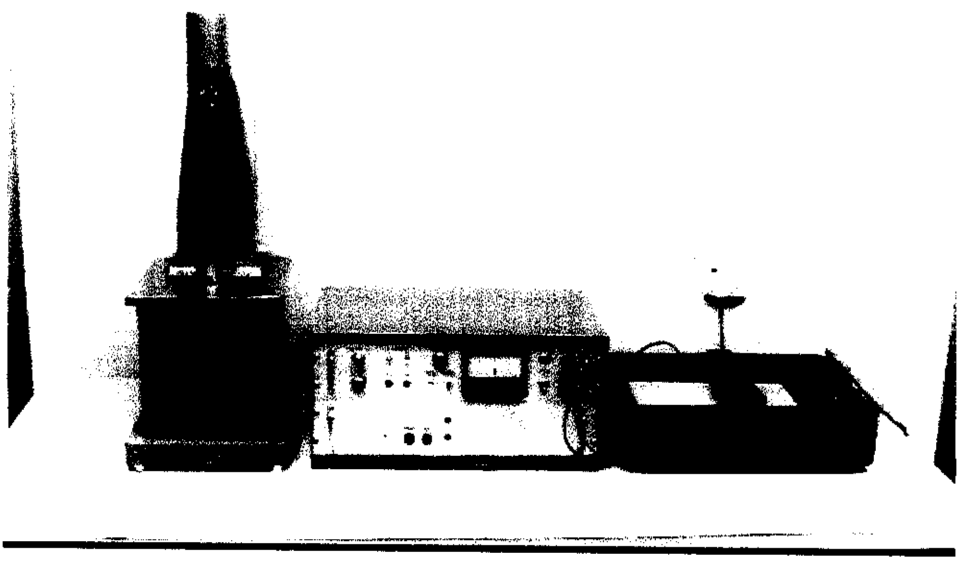
CALCULATION FOR SHARI (CRISPNESS)

i	C_i	UNWD	TLWOD	FLWOD	TLWD	FLWD
0	4.6833	4.683	4.683	4.683	4.683	4.683
13	1.0850	-0.455	-0.509	-0.553	-0.531	-0.585
14	0.3082	0.308	0.243	0.111	0.145	0.179
12	-0.1014	-0.065	-0.090	-0.029	-0.062	-0.083
6	-1.1854	1.754	1.351	1.185	1.446	1.268
7	-0.0112	0.001	0.0004	0.001	0.003	0.001
8	0.0012	-0.0006	-0.0003	-0.0003	-0.0005	-0.0002
11	0.3593	-0.161	-0.455	-0.535	-0.161	-0.255
9	0.0561	-0.301	-0.285	-0.295	-0.298	-0.286
10	0.0826	0.344	0.340	0.339	0.339	0.327
3	-0.2746	0.854	0.997	0.999	0.958	0.997
2	-0.1643	-0.813	-0.857	-0.829	-0.860	-0.885
1	-0.0268	0.052	0.043	0.017	0.041	0.029
5	-0.0623	-0.044	-0.024	-0.030	-0.022	-0.032
4	0.1016	-0.032	-0.043	-0.028	-0.037	-0.019
16	0.1327	0.103	0.145	0.167	0.158	0.178
15	-0.0676	-0.164	-0.164	-0.167	-0.162	-0.162
Primary Hand Value (SHARI)		**6.064**	**5.375**	**5.036**	**5.640**	**5.355**

APPENDIX 12

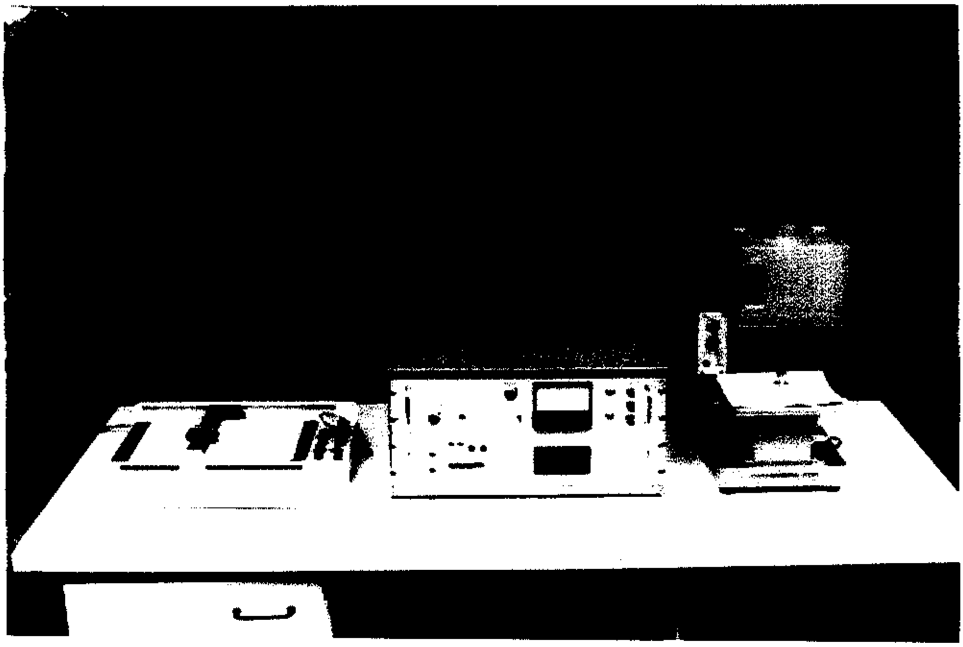


KES-FB1 Tensile and Shear Tester

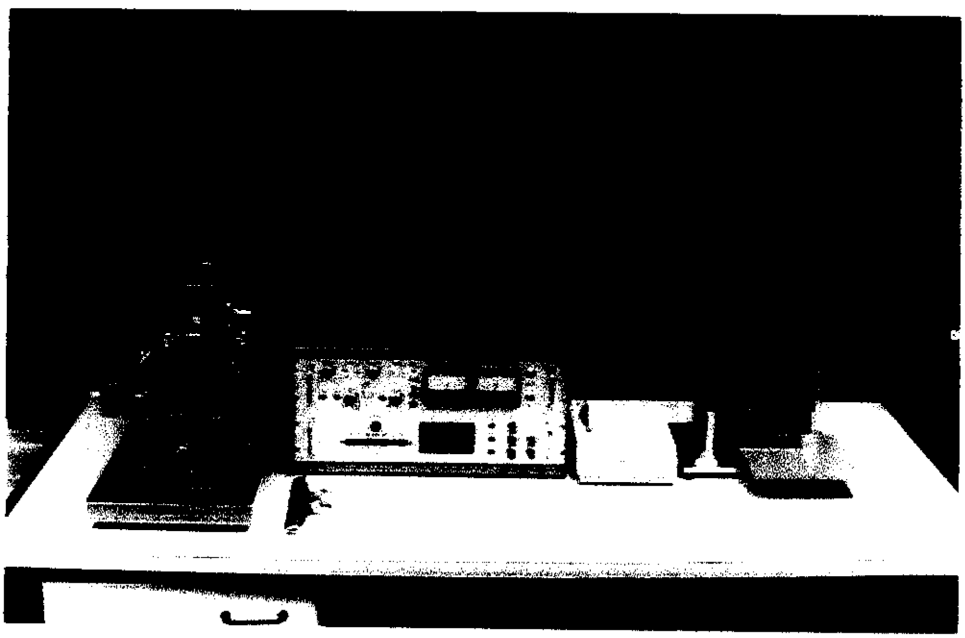


KES-FB2 Pure Bending Tester

APPENDIX 13



KES-FB3 Compression Tester



KES-FB4 Surface Tester

CHAPTER 8

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