CHAPTER 2

LITERATURE REVIEW

2.1 APPLICATION OF ENZYME TREATMENT TO CELLULOSIC FABRICS FOR IMPARTING SPECIFIC FUNCTIONAL PROPERTIES.

Cellulase enzymes have been reported to improve softness and surface appearance of cotton fabrics when applied under specific conditions. Improvement is envisaged because this treatment is not just a fabric surface coating, as in the case of chemical finishes, but the enzyme acts on the cotton fibre itself. Agarwal et al (2007) reported on the wax removal for accelerated cotton scouring with alkaline pectinases. This is accomplished through enzymatic hydrolysis of cellulose of cotton fibre in combination with mechanical action resulting especially in surface etching. Enzymatic softening becomes much more important in the case of high quality fabrics as these fabrics should have high resistance to pilling and at the same time also a smooth surface without any adverse effect on comfort characteristics or water-absorbency as reported by Das and Ishtiaque (2004). Ali and Khan (2005) developed stabilized vegetable amylases for enzymatic desizing of woven fabric with starch containing sizes. Denim wash is currently the major area where cellulase enzymes are used and different effects can be produced when these enzymes are used alone or in combination with stones or other abrasion media. Ali (1999) and Almeida (1993) made studies on Cellulase enzymes and evaluated stone-wash and softness effects.
The initial works were based on imported enzymes and currently the efficiency of various indigenously manufactured enzymes are being evaluated, and one such work was done by Ammayappan et al. (2003). How pH and temperature can be handled in Indian conditions to get desired quality products so that these new technologies can be introduced in the textile industry is the question to be addressed. In addition, the cost of the enzymes can be brought down by adding certain specific additives.

During cellulase enzyme treatment, certain weight loss and strength loss are inevitable depending on the type of fabric, concentration of the enzyme, temperature, time and mechanical agitation during the treatment as reported by Radhakrishnaiah (1999).

In the case of dyed garments, cellulases have been used to remove the fuzzy appearance of the garments and it has been shown that cellulase enzymes greatly improve the surface appearance. In the case of tubular knit fabrics, lint may get trapped inside the tube, and enzyme treatment cleans the surface effectively resulting in better appearance of the knit fabric. Studies on the effect of different softeners on bio-polishing of cellulosic textiles reveal that there is no increase in the cellulase activity with cationic softeners and at the same time there is also no decrease in its activity. Softener treatment after enzyme action results in significant increase in softness compared to enzyme alone or softener alone as per the works of Almeidia and Paulo (1993). An increase in tear strength of enzyme-treated fabric was observed after application of certain softeners.

2.1.1 Effect of Enzymatic Wet Processing on Various Characteristics

The changes in cotton yarn characteristics as a result of chemical treatments have been studied. It was observed that the yarn characteristics depended on yarn structural features, twist factor and chemical treatment.
Analysis of the mechanical surface characteristics shows that the caustic scouring remarkably improved the tenacity, abrasion resistance, dye uptake and residual shrinkage of both ring-and OE rotor-spun yarns. The improvement in each of these characteristics diminished with the increasing twist factor. Treatment of enzyme scoured-hydrogen peroxide bleached cotton yarns with G-Zyme VGB enzyme resulted in a significant decrease in their tenacity, abrasion resistance and hairiness. Additionally, enzyme softened yarns have similar breaking extension, less surface roughness and higher absorbency values as reported by Tyagi GK., et al. (2009)

2.1.2 Combination of Enzyme with Auxiliary Chemical Treatment

In view of the high cost of enzyme treatment, it was desirable to explore the possibility of cost reduction by lowering the concentration of enzyme in the treating bath from 20 to 10% and incorporating silicone-based softener along with the enzyme at concentrations of 10 to 20%. It was found that for equivalent loss in weight, handle end feel of the fabric it was possible to reduce the concentration of the enzyme by about 10-20% if 10-20% of silicone-based softener was incorporated in the treatment bath. However, in such a case the finish would not be durable to repeated washing or laundering as the effect on feel and handle arising out by chemical finish would reduce progressively, as revealed by Cavaco-Paulo et al. (2003).

2.1.3 Enzymatic Bleaching


Laccase (polyphenol oxidases)/mediator systems have been successful in bleaching of wood pulps and are applicable to cotton textiles
also. Mediators, such as violuric acid and N-hydroxy benzotriazole act as electron transfer components to support the action of laccases and these mediators are consumed (quasi-catalysts) during the reactions as revealed by Helmy and Meligi (2002). Peroxidases are used to activate oxidizing agents like hydrogen peroxide, however, rapid deactivation of these agents in bleaching process does not guarantee satisfactory bleaching effects as observed by Bernards (2004).

Glucose oxidase is a glycoprotein, produced intra-cellularly by various microbial sources, has ~ 16 - 25% carbohydrates that contribute to the stability between pH 4 - 6 at 40° C as reported by Tzanov et al.(2002) and Opwis et al (2004). Glucose oxidases generate hydrogen peroxide and gluconic acid from glucose and oxygen. Gluconic acid formed in such reactions acts as a chelator for metal ions present in the system. Oxygen availability, through transfer of oxygen from gaseous to aqueous phase and pH are the two key parameters that influence the gluconic acid production, governed by aeration rate and mechanical agitations, which in turn affect the availability of oxygen in the medium. A closed loop system with glucose oxidase using starch, generated in desizing has been attempted for bleaching by Anis et al. (2008,2009). Combination of laccase and glucose oxidase for bleaching of linen fabrics shows higher effectiveness than when one of these enzymes applied alone as observed by Ren and Diller (2007). Whiteness indices obtained in the combined enzymatic desizing - scouring -bleaching are closer to peroxide bleached fabrics. However, success of bio-bleaching mainly depends on the removal of seed coat fragments from the fabrics as reported by Losonczi et al (2004).

2.1.4 Cellulases and Biopolishing of Cotton Fabrics

Bio-polishing of cotton fabrics, using cellulases, is aimed to remove cellulosic impurities, individual and loose fibre ends that protrude from fabric
surfaces and to provide an enhanced appearance and handle, with or without the aid of mechanical agitations but without degrading the properties of the fabrics significantly. Cellulase enzymes are complex mixtures of three major constituent enzymes, namely, endo 1,4-β D glucanases (EG) which randomly cleave internal glucosidic bonds within an unbroken glucan chain. The most accessible parts of cellulose polymers and the newly created non-reducing chain ends, then, become substrates for 1,4-β D glucan cellobio-hydrolases (CBH) which cleave them into cellobioses. Hydrolysis of cellobiose into the glucose end product is completed by β glucosidases or cellobiases which split cellobiose units into soluble glucose monomers and complete hydrolysis of native celluloses, which largely, depends on the synergistic actions of these three component enzymes.


2.1.5 Enzymatic One-Bath Desizing, Bleaching, Dyeing Process for Cotton Fabrics

Min and Huang (1999) conducted dyeing studies with direct dyes in a finite bath through a one-step process. A later and recent study by Huseyin and Pervin (2009) was to develop a new process to desize, bleach, and dye starch-sized cotton fabrics in one bath using enzymes. Desizing was performed with an amylo-glucosidase/pullanase enzyme (Dextrozyme DX, manufactured by Novozymes) instead of a conventional amylase enzyme in order to hydrolyze starch into single glucose units. Multifect GO 5000L (Genencor) glucose oxidase enzyme was used to yield hydrogen peroxide from the glucose generated during desizing; and bleaching was performed by this enzymatically generated hydrogen peroxide. Decomposition of hydrogen peroxide after bleaching was done with Terminox Ultra 10 L (Novozymes) catalase enzyme. The fabric was dyed in the same bath with the selected mono-chloro-triazine reactive dyes (DyStar). The amount of glucose
generated during desizing was 4000 ± 135 mg/l and it yielded 765 ± 15 mg/l hydrogen peroxide during glucose oxidase enzyme treatment. The whiteness index of the enzymatically bleached fabric was 71 ± 1.2 Stensby degree. The color yields of the enzymatically treated samples were comparable to the conventionally treated samples. All enzymes used in this study were commercial grades having the advantages of easy storage and supply compared to the pure enzymes used in earlier studies. The advantages of the new one-bath process were: less auxiliary demand; lower environmental impact (COD and BOD lower by 42% and 21%); and energy and water savings compared to the conventional desizing, scouring, bleaching, and dyeing sequence.

2.1.6 Parameters for Assessment of Harmful Materials in Waste Water

It is an established fact that industries produce significant quantities of contaminant waste water which are discharged to municipal gutters, open lands, rivers, nullah, ponds and ocean and cause considerable pollution problems. Some parameters can be evaluated by standard test methods given in Table 2.1 and Table 2.2 gives Tolerance Limits as detailed in the book by NIIR Board (2005).

Physical, chemical, physico-chemical tests evaluate the nature of textile effluents. The physical characteristics include temperature, pH, colour etc., whereas chemical characteristics include the nature and quantity of organic and inorganic compounds and dissolved gases. The biological characteristics include different types of micro-organisms. These characteristics are determined in terms of BOD (biological oxygen demand), COD (chemical oxygen demand), THOD (theoretical oxygen demand) and TOC (total organic carbon). Table 2.1 gives the different methods for estimation.
The treatability of the effluent is illustrated by ratio of COD to BOD. COD quantifies the total oxidisable portion of the effluent. BOD is a measure of the biologically oxidisable portion of the effluent. The higher the ratio of COD/BOD, the less treatable the effluent. The organic carbon is oxidised to CO$_2$ which is expressed as TOC. Strength and treatability similar to domestic sewage is the objective of these evaluations. The textile industry’s raw waste water characteristics are given in Table 2.2. A - Effluents discharged into inland surface waters; B – Effluents discharged into public sewers; C - Effluents discharged on land used for irrigation; D - Effluents discharged into marine coastal areas.

**Table 2.1 Parameters for Assessment of Treatability of the effluent**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimation method</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>Oxidation by aerobic micro-organisms – organisms</td>
<td>mg O$_2$/l</td>
</tr>
<tr>
<td>COD</td>
<td>Oxidation with K,Cr,O$_7$</td>
<td>mg O$_2$/l</td>
</tr>
<tr>
<td>TOC</td>
<td>Catalytic burning</td>
<td>mg C /l</td>
</tr>
<tr>
<td>DOC</td>
<td>Catalytic burning</td>
<td>mg C /l</td>
</tr>
<tr>
<td>AOX</td>
<td>Adsorption on active carbon</td>
<td>micro.g x /l</td>
</tr>
<tr>
<td>N total</td>
<td>Colorimetric estimation</td>
<td>mg N/l</td>
</tr>
<tr>
<td>P total</td>
<td>Precipitation</td>
<td>mg P /l</td>
</tr>
</tbody>
</table>
Table 2.2 Tolerance Limits for Industrial Effluents

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended solids, ppm</td>
<td>100</td>
<td>600</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Dissolved solids (inorganic)</td>
<td>2100</td>
<td>2100</td>
<td>2100</td>
<td>2100</td>
</tr>
<tr>
<td>pH Value</td>
<td>5.5-9</td>
<td>5.5-9</td>
<td>5.5-9</td>
<td>5.5-9.0</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>40</td>
<td>45</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Oils and Greases</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Total residual chlorine</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Ammoniacal nitrogen (as NH₃)</td>
<td>50</td>
<td>50</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen (N)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Free ammonia (as NH₃)</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Biochemical oxygen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand (5 days at 20°C)</td>
<td>300</td>
<td>350</td>
<td>350</td>
<td>100</td>
</tr>
<tr>
<td>Chemical oxygen demand</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>250</td>
</tr>
<tr>
<td>Lead (as Pb)</td>
<td>0.1</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Cadmium (as Cd)</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Hexavalent chromium (as Cr⁶)</td>
<td>0.1</td>
<td>2</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Total chromium (as Cr)</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>2 15</td>
</tr>
<tr>
<td>Zinc (as Zn)</td>
<td>5</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent sodium, max.</td>
<td>-</td>
<td>60</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>Residual sodium carbonate</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>
2.1.7 Kawabata Evaluation of Enzyme-Treated Cotton Knitted Fabric

Industrial trial of the enzymatic treatment of cotton knitted fabric with cellulase enzyme Denifade has been carried out under optimized conditions and the various low-stress mechanical properties of the treated fabrics have been assessed on the Kawabata Evaluation System. The results reported by Gulrajani et al. (1998) showed an improvement in the surface smoothness and a decrease in the bending and shear rigidities. The improvement in handle is reflected by the decrease in tensile and compressional energies. Enzymatic treatment improves the various properties of fabrics. Thus, enzyme treatment leads to overall value addition due to the properties related to handle and feel of cotton knitted fabrics, because of various chemical and bio-chemical surface modifications achieved.

2.1.8 Determination of Handle of Knitted Fabrics Using an Objective Measuring Technique

An objective approach to assess the handle of various knitted fabrics has been made by Hasani (2009) in analyzing the force-displacement curves. In comparison to the conventional pulling-through method, a rounded sample was pulled through a hole and from the space between two horizontal plates and the required pulling force was measured with respect to the displacement of specimen, recorded as a force-displacement curve. The results of the correlation test showed that the features of the pulling-through curves associate with all mechanical and surface properties, except fabric thickness and compression energy.

The results of the correlation analysis revealed that other than compression energy and thickness, the curve features obtained from the pulling through disc and plate method (PDP method) highly correlated with all mechanical and surface properties as recommended by Kawabata.
Therefore, the features chosen from pulling-through curve cannot describe entirely the handle of summer knitted T-shirts. A combination of the features selected from pulling-through curve and the mechanical parameters, which reflect the compression properties and thickness of all kinds of fabrics, was recommended. These parameters and the features from the pulling-through curve were plotted by a polar diagram. This approach to knitted fabric handle evaluation and representation seems to be conceptually a right method as can be observed from similar works of Gulrajani and Hasani as well. The ‘Polar Diagram’ can be extended to also represent comfort characteristics such as TIV and moisture transport, MT by forming an ensemble with traditional KES primary and secondary hand characteristics.

2.2 ONE STEP PROCESS FOR DESIZING, SCOURING AND BLEACHING OF COTTON FABRIC USING A NOVEL ECO-FRIENDLY BLEACHING AGENT

Several researchers such as Ammayappan (2003) reported on the one-step process, notably by using Ozone and with H₂O₂. Pavla et al. (2005), Prabaharan and Rao (2001, 2003) worked on the same subject.

A one step process for cotton fabric preparation (desizing, scouring, bleaching) that is environmentally safe was reported by Magdy Kandil Zahran (2006). The process involved a novel bleaching agent sodium perborate, SPB which was exclusively used without any additives in the bleaching bath. The process was carried out under different conditions including pH, SPB concentration, temperature and duration of treatment. The effectiveness of SPB as an eco-friendly bleaching agent was assessed by monitoring the treated sample for whiteness index, per cent loss in fabric weight, tensile strength and carboxyl content. The process has been shown to be both ecological, economical and energy conserving. Mechanisms, signifying various changes in the fabric chemical treatment were reported. At
higher pH’s, decomposition of SPB and generation of various oxidizing active species may enhance and in turn, accelerate the oxidative degradation reactions upon the cellulosic chains. The same holds true when the concentration of SPB was increased. An assessment of cotton fabric damage through monitoring carboxyl content and examining the warp tensile strength was presented in the same work. Concentration of SPB in the range of 5-160 m.mol/l, temperature range of 40-70°C and duration of bleaching between half an hour to three hours were studied.

2.3 WRINKLE RECOVERY OF CELLULOSIC FABRIC BY MEANS OF IONIC CROSS-LIKING

Methods were developed by Sandra (2004) and Hashem et al (2003) for imparting crease recovery performance to cellulosic fabrics based on durable ionic cross-links. These methods, which avoid the formaldehyde release of conventional finishes, include treating cellulose with chloroacetic acid (or other reactive anion) and cationized chitosan (or polycation). Alternative methods include treating cellulose with 3-chloro-2-hydroxypropyl trimethyl ammonium chloride (or cationization reagent, CHTAC) and a polyanion, or with chloroacetic acid (CAA) and 3-chloro-2-hydroxypropyl trimethyl ammonium chloride. A method for producing highly cationic chitosan (CC) was also presented.

2.3.1 Introduction to Ionic Cross-Linking

Cellulose cross-linking is a very important textile process and is the basis for a vast array of finished textile products. Formaldehyde based N-methylol cross-linkers give fabrics many desirable mechanical stability properties (e.g., crease resistance, anti-curl, shrinkage resistance, durable press), but also impart strength loss and the potential to release formaldehyde, a known human carcinogen. Other systems, e.g., poly carboxylic acids, have
been tested with varying degrees of success. Developed methods of forming ionic cross-links to provide crease angle recovery performance without the potential for release of any low molecular weight reactive materials like formaldehyde, were presented by Hashem, Hauser and Smith (2003) and contributed greatly to the ‘Cationization of Cellulose’ through ionic crosslinking by CHTAC.

Materials that impart an ionic character to the cellulose, e.g., chloroacetic acid (CAA) or 3-chloro-2-hydroxypropyl trimethyl ammonium chloride (CHTAC), produce ionic cellulose that can then absorb a polyelectrolyte of opposite charge to form cross-links.

There are several possibilities for producing ionic crosslinks in cellulose, including reactions of (1) cellulose with Chloroacetate, CAA (or other anion), then treatment with a polycation, (2) cellulose with CHTAC (or other cation), then treatment with a polyanion, (3) cellulose with both CAA (or other anion) and CHTAC (or other cation), (4) polycations with CAA (or other anion) in solution, then react that adduct with cellulose, and (5) polyanions with CHTAC (or other cation) in solution, then react that adduct with cellulose. The last two methods involve no pre-treatment step for the cellulosic fabric, so that they are very similar to present commercial practice.

As a demonstration of ionic crosslinking, crosslinked cellulose by methods 1 and 3 above were presented. For method 1, Cationized Chitosan (CC, i.e., the reaction product of chitosan with CHTAC) was used as polycation, as reported previously by Kim et al., (1998) but present method of CC synthesis yielded greater degree of cationization than Kim’s method. There are many possibilities for methods 1 and 2, such as making cellulose fabric cationic with CHTAC, then reacting with carboxymethyl cellulose or polyacrylic acid.
Anionic cellulose can be produced by reaction with vinyl sulfone or chlorotriazine derivatives containing anionic groups (e.g., compounds similar to fiber reactive dyes) by reacting cellulose fabrics with CAA to produce partially carboxymethylated cellulose (CMC), or by reacting with sodium chloromethyl sulfonate (CMSA) as per the works of Hashem et al. (2000).

Method 1: Preparation of anionic cellulose by reaction of cellulose with chloroacetate (CAA):

\[
\text{CICH}_2\text{COO} + \text{Cellulose-OH} \rightarrow \text{Cellulose-O-CH}_2\text{COO}
\]  
(2.1)

Method 2: Preparation of cationic cellulose by reaction with 3-chloro-2-hydroxypropyl trimethyl ammonium ion CHTAC:

\[
\text{ClCH}_2\text{CH}_2\text{OH-CH}_2\text{-N}^+\text{(CH}_3)_3\text{+Cellulose-OH} \rightarrow \text{Cellulose-O-CH}_2\text{CH}_2\text{OHCH}_2\text{N}^{+2}\text{(CH}_3)_3
\]  
(2.2)

Crease angle recovery and strength data were correlated to the amount of polyelectrolyte add-on %. Development of an improved cationization procedure using a pad-dry-cure method in which the epoxy-propyl-trimethyl ammonium chloride solution was padded onto cellulosic fabric, then dried for 5 minutes at 35°C and cured for 4 minutes at 115 C. with a degree of fixation of typically 86%, which is appreciable, was reported by Hashem, Hauser and Smith (2003). Carboxy-methylated cotton woven fabric treated with cationized chitosan (CC) showed significant improvement in wet crease recovery angle (WCRA) without strength loss. Fabric treated with CHTAC, either simultaneously or sequentially with CAA or CMSA showed improved WCRA, generally with increased tensile strength.
2.3.2 Wrinkle Resistant and Crease Retentive Finishes


2.4 DEVELOPMENTS IN ENVIRONMENT-FRIENDLY FUNCTIONAL FINISHES FOR COTTON FABRICS AND GARMENTS

A review work of Chavan (2000) highlighted some of these finishes. Dekha and Purnima (2005) also reviewed on these functional finishes.

2.4.1 Soil Release / Soil Repellent Finishes

Soil release finishes were dealt by Tomasino (1984), Cooke (1987) and Bajaj (2001).

2.5 WATER/OIL REPELLENT FINISHES

Water/oil repellent finishes act as barriers, that lower the critical surface tension of the fiber surface. Water repellency can be achieved with a variety of chemical finishes such as waxes, wax dispersions, melamine wax
extenders, chrome complexes, silicones, and flouro-chemicals. The finishes require curing to develop the best repellency and are prone to destabilizing with shear, heat or changes of pH or ionic strength. Parthiban (2005) reported the results on curing of the finishes on fabrics.

### 2.5.1 Development of Water- and Oil-Repellent Treatment for Silk and Cotton Fabrics with Fluoroalkyl-Trimethoxysilane

The application of silane adsorbents for water-and oil-repellent treatment of textile products was developed by Tada Takenori et al (2009). A fluoroalkyl-trimethoxysilane, Heptadecafluoro-1,2-tetrahydrodecyl-1.1.1-trimethoxysilane was used, and tetramethoxysilane (TMOS) as a cross-linker, was used. The effects of the concentrations of the cross-linker and promoter were investigated in detail. Further, the effect of adding another silane adsorbent and a suitable solvent were examined. The treatment was found to be effective in imparting anti stain properties to silk and cotton fabrics. Moreover, by adding the cross-linker to the adsorption solution, the wash durability and abrasion resistance of these fabrics were improved. In order to obtain similar water- and oil-repellent properties, the solute concentrations required with methanol as a solvent are twice of those required with a hydrocarbon solvent (Shell Sol® D40). Although the use of alcohol as a solvent may be nature-friendly, its drawback was a short pot life.

### 2.5.2 Multifunctional Finishing of Textiles

It comes from combining a few characteristics of functional finishes into one; it can be three or more performance properties incorporated into the fabric by compatible combination of finishing agents in the finish application. The combinations can be formed from the list of functional finishes classified in the following:
2.5.3 Classification for Multi-functional Finishing of Textiles

(i) Water/oil and soil repellent finish with soft handle
(ii) Hydrophilic and self cleaning
(iii) Hydrophilic and soft finish
(iv) Hydrophilic and Crease-resistant
(v) Cool and soft handle
(vi) Warm and soft handle
(vii) A combination of any two of the above classes
(viii) Multiple combinations of the above classes

2.6 NANO FINISHES

Nano finishes being developed for textile substrates are at their infantile stage as reviewed by Gulrajani (2006). The basic mechanisms and the logic of some of these finishes has been explained by the inventors. Some nano finishes such as Nano Lotus Effect™ finish, Nanosphere™ finish and Ag Fresh™ finish have been commercialized.

The logic of using low molecular weight fiber-reactive fluorocarbons that form the basis of Nano-Care™ finish to impart durable hydrophobic-oleophobic characteristics to fabrics, as described elaborately in patented literature, is discussed in this section. Super-hydrophobic-oleophobic characteristics to fabrics, exhibited by lotus leaves and the finishes to get self-cleaning textile fabrics based on the Nano Lotus Effect™ have been covered giving some typical recipes, by Daoud, Sun and Luo (2005).

Development of nano finishes for textiles has been given by the dedicated R&D work of Taiwan born Dr. David Soane. The first
nanotechnology company Nano-Tex was established in 1998 to specifically cater to textile industry.

Almost at the same time, the pioneering work of Prof W Barthlott (1997) of the University of the City of Bonn, Germany, led to understanding of the mechanism by which the leaves of lotus and other plants utilize super-hydro-phobicity as the basis for self-cleaning. A patent is owned by him with the ‘Lotus Effect’ trademark. The ‘Lotus Effect’ has been the basis for the Nano-Sphere® stain protection and oil and water-repellent textile finishes of Schoeller Textiles A.G. of Switzerland.

The most recent impetus for the development of nano finishes for textiles has come from the work of Dr Walid Daoud and Dr John Xin of the Hong Kong Polytechnic University, Kowloon (2004-05). These scientists invented an efficient way to coat cotton cloth with tiny particles of titanium dioxide. These nanoparticles act as catalysts that help break down of carbon-based molecules and require only sunlight to trigger the reaction. The inventors believe that these fabrics could be made into self-cleaning clothes that tackle dirt, environmental pollutants and harmful microorganisms.

2.6.1 Easy Care - Hydrophobic Nano Finish

Hydrophobic surfaces can be produced mainly in two ways: (i) by creating a rough structure on a hydrophobic surface, and (ii) by modifying a rough surface using materials with low surface free energy.

Fluorocarbon finishes constitute an important class of hydrophobic finishes. These finishes first applied to textiles in the 1960s to impart water- and oil-repellency have shown considerable growth during last decade. This growth is due to consumer demands for easy-care properties such as water- and oil-repellency, stain repellency and soil- and stain- release properties.
Fluorocarbons are a class of organic chemicals that contain a per-fluoro-alkyl residue in which all the hydrogen atoms have been replaced by fluorine. These chemicals have very high thermal stability and low reactivity. They considerably reduce the surface tension. The critical surface tension (Yc) of -CF is 6 mN m⁻¹.

Fluorocarbon finishes are dispersions of per-fluorinated acrylates having co-monomers. The structure of the fluorinated acrylates can be chemically engineered by varying the proportion of hydrophobic and hydrophilic groups in the side chains to produce specific properties. Durable fluorocarbon finishes have reactive methanol or epoxy groups that may react to form a cross-linked net work that may also get covalently bonded to the surface of the fibers. The fluorinated side chains of a polyacrylate fluorocarbon finish are oriented away from the fiber surface in the air and hence these form low energy repellant surface as shown in Figure 2.1. In the fluorocarbon finishes, the critical surface tension (Yc) depends on the chain length of fluorinated side chain and is minimum for chain length of n= 9.

![Figure 2.1](image.png)

**Figure 2.1** Film of fluorocarbon acrylate polymer based finish (R,R', and R'' are the functional or polar groups responsible for film formation, hardness and cross-linking to increase fastness to washing, emulsification and affinity for textile surfaces)
The effect of the chain length on the oil- and water-repellency is shown in Table 2.3 (Ref. Holme, 2003).

Table 2.3  Oil- and water-repellency of fabrics treated with acrylic polymers

<table>
<thead>
<tr>
<th>Per-fluorinated group</th>
<th>Measurement of Oil-repellency</th>
<th>Spray test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>AATCC 118</td>
<td>ISO 4920</td>
</tr>
<tr>
<td>-CF₃</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>-CF₂-CF₃</td>
<td>3-4</td>
<td>70</td>
</tr>
<tr>
<td>-(CF₂)₂-CF₃</td>
<td>6-7</td>
<td>70</td>
</tr>
<tr>
<td>-(CF₂)₄-CF₃</td>
<td>7-8</td>
<td>70</td>
</tr>
<tr>
<td>-(CF₂)₆-CF₃</td>
<td>7-8</td>
<td>70</td>
</tr>
<tr>
<td>-(CF₂)₈-CF₃</td>
<td>8</td>
<td>80</td>
</tr>
</tbody>
</table>

To develop more durable hydrophobic and oleophobic finish that does not block the pores of the fabric by the formation of polymer film thereby making it more breathable, Soane et al (1999-2001) patented a large number of multifunctional nano molecules that were capable of forming covalent and non-covalent bonds with cellulosic and protein fibers. Some of these multifunctional molecules were block copolymers or graft copolymers having plural functional groups such as binding groups, hydrophobic groups, hydrophilic groups and oleophobic groups. These groups may be present in the form of hydrophobic and hydrophilic regions. In these multifunctional molecules, the hydrophilic groups such as the carboxyl groups act as reactive groups. These may be present in the form of poly carboxylic acid or as poly-anhyrides such as poly (maleic anhydride) polymer. One such multifunctional molecule may be represented as shown in Figure 2.2.
Figure 2.2 Multifunctional reactive molecule as disclosed by Dr Soane, where, $m, n = 0$ or $1$; $p = 0$ or $2$.

‘$R$’ is the linear, branched or cyclic hydrocarbon or fluorocarbon having $C_1$ – $C_{30}$ hydrocarbon or fluorocarbon groups; ‘$A$’, the $-\text{SO}_2-$, $-\text{CONH}-$, $-\text{CH}_2$ or $\text{CF}_2$ and ‘$X$’, the nucleophilic group capable of reacting with hydroxyl, amine or thiol group

The reaction scheme of a multifunctional molecule with cotton is shown in Figure 2.3, where a hydrophilic reactive molecule of poly (maleic anhydride) first reacts with the hydro- or fluoro-alkyls having preferably $C_8$ or $C_9$ (for maximum hydro- and oleophobicity as discussed above) to form multifunctional molecules having hydrophobic, oleophilic and hydrophilic groups or regions. Subsequently, these multifunctional molecules react with the hydroxyl groups of cotton or other cellulosic fibres and amino groups of wool to form hydrophobic whiskers on the surface of the fabric without blocking its pores.
Figure 2.3 Multifunctional molecule formation and attachment with cotton to form whiskers on the surface that are floating in air away from the fabric surface (a) - using poly (maleic anhydride), and (b) - starting with maleic anhydride.

It is claimed by Tzy-Jian Wang et al (2003) that the attached multifunctional molecules can impart wrinkle resistance by cross linking cellulose chains via maleic anhydride residues. The molecules can also modify the surface properties of the treated fabric and impart water-repellency, grease-repellency, soil-resistance, detergent free washing, increased speed of drying, improved strength and abrasion resistance without affecting its air permeability or breathability. Due to multiplicity of bonds and ability of the molecule to easily diffuse into fibre because of its small molecular size (nano size), the durability of the finish is much better than the conventional fluorocarbon acrylate polymer based finish.
The original research formed the basis for first commercially successful nano finish originally named as Nano-Care™ and marketed by Nano-Tex. Thus, Dr Soane demonstrated that 10-100 nm ‘whiskers’ attached to cotton fibres modify the surface tension so much that almost nothing could soak into and stain the treated fabric, be it red wine, soy sauce or chocolate syrup.

2.8.2 Super-hydrophobicity - Biomimetic Self-cleaning by Lotus Effect

Hydrophobic fluorocarbon finishes as discussed above lower the surface energy and can give a maximum water contact angle of roughly 120°. To get higher contact angles and to have self-cleaning ability, super-hydrophobic finish with a contact angle of above 150° is required. This type of finish is obtained by increasing the surface roughness. The increase in surface roughness provides a large geometric area for a relatively small projected area. The roughened surface generally takes the form of a substrate member with a multiplicity of micro-scale to nano-scale projections or cavities.

Cassie and Baxter (1944) were the first to observe that water-repellency of rough surfaces was due to the air enclosed between the gaps in the surface. This enlarges the water/air interface while the solid/water interface is minimized. In this situation, spreading does not occur; the water forms a spherical droplet. The self-cleaning propensity of plant leaves’ rough surface was investigated and reported by Barthlott and Neinhuis (1997). These investigators analyzed the surface characteristics by high-resolution SEM and measured the contact angle (CA) of leaves from 340 plant species, cultivated at the botanical garden in Bonn. The majority of the wettable leaves (CA < 110°) investigated were more or less smooth without any prominent surface sculpturing. In particular, epicuticular wax crystals were absent. In
contrast, water-repellent leaves exhibited various surface sculptures, mainly epicuticular wax crystals in combination with papillose epidermal cells. Their CAs always exceeded 150°. They observed that on water-repellent surfaces, water contracted to form spherical droplets. It came off the leaf very quickly, even at slight angles of inclination (< 5°), without leaving any residue. Particles of all kind that were adhering to the leaf surface were always removed entirely from water-repellent leaves when subjected to natural or artificial rain, as long as the surface waxes were not destroyed.

The dirt particles deposited on the waxy surface of the leaves are generally larger than the microstructure of the surface of the leaf and are hence deposited on the tips, as a result the interfacial area between both is minimized. In the case of a water droplet rolling over a particle, the surface area of the droplet exposed to air is reduced and energy through adsorption is gained. Since the adhesion between particle and surface is greater than the adhesion between particle and water droplet, the particle is ‘captured’ by the water droplet and removed from the leaf surface.

The results presented above document an almost complete self-cleaning ability by water-repellent plant surfaces. This could be demonstrated most impressively with the large peltate leaves of the sacred lotus (Nelumbo nucifera). Barthlott and Neinhuis found that according to tradition in Asian religions, the sacred lotus is a symbol for purity, ensuring from the same observations that they made. They also found that this knowledge is already documented in Sanskrit writings, which led them to call this phenomenon the ‘Lotus-Effect’.

The self-cleaning property of lotus leaf is dependent on two important factors namely the super hydrophobicity, i.e. a very high water contact angle and a very low roll off angle. The relation between roughness of hydrophobic surfaces and contact angle was established many years ago by
Wenzel (1936) and Cassie and Baxter (1944) as shown in Figure 2.4. The Wenzel equation relates to the homogeneous wetting regime and yields the Wenzel’s apparent contact angle ($\theta_w$) in terms of the Young’s contact angle ($\theta_y$) and the roughness ratio as shown below:

$$\cos \theta_w = r \cos \theta_y$$  \hspace{1cm} (2.3)

The roughness ratio is defined as the ratio of true area of the solid surface to its nominal area. This equation shows that when the surface is hydrophobic ($\theta_y > \pi/2$), roughness increases the contact angle.

The Cassie and Baxter’s (CB) equation describes the heterogeneous wetting regime and gives $\theta_{CB}$, the apparent contact angle, as

$$\cos \theta_{CB} = r_f f \cos \theta_y + (-1)$$  \hspace{1cm} (2.4)

In this equation, $f$ is the fraction of projected area of the solid surface that is wet with the liquid; and $r_f$ the roughness ratio of the wet area. When $f = 1$ and $r_f = r$, the CB equation turns into the Wenzel’s equation.

It has been shown that the heterogeneous wetting regime is practically preferred by nature as the super-hydrophobic status on lotus leaves. Moreover, the structures that trap air give low sliding angles required for self cleaning. A relationship between sliding angles and contact angles on super-hydrophobic surfaces with roughness has been worked out by Linford et al (2005) as given in Figure 2.5.
Figure 2.4 (a) Young’ wetting equation, (b) Homogeneous wetting on a hydrophobic rough surface, and (C) Heterogeneous wetting on a hydrophobic rough surface

Miwa et al (2000) prepared a transparent super-hydrophobic film whose sliding angle was approximately 1° for a 7 mg water droplet. On this film, there was almost no resistance to the sliding of water droplets. The film, thus obtained, satisfied the requirements of super hydrophobicity, transparency and a low water sliding angle.

Figure 2.5 A drop on a rough surface: (a) Contact angle $\theta$ (b) Roll-off angle, $\alpha$
Recently, Zhang (2005) and his colleagues at Peking University of China and the Ecole Normale Supérieure in Paris, France, have created a super-hydrophobic polymer structure by directly replicating the surface of a lotus leaf as shown in Figure 2.6 based on the work of Sun et al (2005). Poly(dimethylsiloxane) (PDMS) was used to replicate the lotus leaf structure. The leaf was used as a template to cast a complementary PDMS layer. An anti-stick layer was added to the PDMS, which was then used as a negative template for a second PDMS casting step. The second PDMS layer was then formed a positive image of the lotus leaf. The complex lotus surface patterns are transferred with high fidelity. The artificial PDMS lotus leaf has the same water contact angles and very low water roll-off angle as the natural lotus.

![Lotus leaf and replicated polymer structure](image)

**Figure 2.6** The lotus leaf (top) and replicated polymer structure (bottom) have the same super-hydrophobic behaviour (©American Chemical Society 2005)

The lowering of wettability by topological changes and the self-cleaning ability of the plants known as the ‘Lotus Effect’ has been patented by Barthlott (1997) where, the technical possibility of making the surfaces of articles artificially self-cleaning has been discussed, merely providing them with a surface of elevations and depressions in a range of 5 - 200 microns and the height of the hydrophobic elevations in the range of 5 - 100 microns. It
also mentions that the self-cleaning surfaces can be produced either by creating surface structures with hydrophobic polymers during the manufacture by adhesion of a hydrophobic polymer on the surface or creating the surface structures subsequently by imprinting or etching.

‘Lotus Effect’ based textile finishes have been developed, patented and commercialized by Schoeller Textil AG of Switzerland. It is claimed that the Nanospheres® formation on the surface of the treated fabrics makes it super-hydrophobic and oleophobic and hence acquires self-cleaning characteristic as reported for the lotus leaves. In the patent filed by Soane et al (2001) it is disclosed that the finish comprises of two water- and oil-repellent components. One of the two predominantly contains the gel-forming compound, while the other one is dominated by the non-polar water- and/or oil-repulsive components. A cross-linking agent is used to insolubilize the finish. During drying of the padded fabric, the contraction of the film formed takes place, resulting in anisotropic distribution of gel-forming component of the finish and a microstructure similar to that on the lotus leaf is created on the surface of finished fabric. The self organization of gel-forming component and the creation of microstructure are determined by both the phase instability and phase transitions of the components.

Recipes for the finishing of cotton, polyester, polyester-cotton, polyamide, polypropylene and lycra containing fabrics, so as to get ‘Lotus Effect’, have also been proposed by Barthlott (1997).

Nakajima et al (2000) claim to be the first to produce transparent super-hydrophobic thin films with TiO$_2$ by utilizing a sublimation material and subsequent coating of a fluoroalkyl silane that satisfy simultaneously the requirements of transparency, super-hydrophobicity and long lifetime. A process and composition for producing self-cleaning surfaces from aqueous systems having TiO$_2$ has been patented by Valpey III and Jones (2004). The
finish consists of nano particles having a particle size of less than 300 nm and a hydrophobic film forming polymer. On application to the substrate, a transparent self-cleaning coating is formed. In an experiment, an aqueous solution having 1% Titania (TiO$_2$) with a mean particle size of 25-51 nm in 1% Zonyl® 9373 (fluorinated acrylic copolymer of DuPont) was applied on cotton to create stain-resistant surface. The treated fabric was stained with ketchup, charcoal dust, vegetable oil, transmission fluid, turmeric solution, coffee, mustard, glue, used motor oil, creamed spinach and spaghetti sauce. The treated fabrics showed very good stain resistance as compared to the control sample without titania. This invention provides a process and composition that combines surface roughness and hydrophobicity for creating self-cleaning surfaces. The created substrates have many attributes that include water-repellency, self-cleaning with water and stain release.

Super-hydrophobic coatings with Al$_2$O$_3$ gel like isotactic polypropylene aligned carbon nanotubes by Lau (2003), Silica by Shang et al (2003), ZnO nanoparticles by Wu et al (2005), ZnO-coated CNTs by Huang et al. (2005), Boehmite nanoparticles by Nakajima et al (2005), and CaCO$_3$-loaded hydrogel spheres by Zhang et al (2005) and many such nanoparticles of hydrophobic film forming compositions have been developed.

A micro denier polyester fabric (2 × 2 right hand twill, and 175 warp and 80 weft yarns per inch), made by textured polyester 1/14/200 denier warp and 1/50/100 denier weft yarns, was initially abraded with diamond coated roller at a level of 1200-30-12 (1200 grit roller at 30 psi pressure-12 cycles in each direction), whereby approximately 19% of the surface areas were roughened. The fabric was then treated with a chemical solution having 1% hydrophilic silica particles (Sipemat 22 LS), 4% fluorocarbon stain repellent (Repearl F-7000) and 1% cross-linking agent (Miligard MRX) with 50% wet pick-up and cured.
The treated fabric was tested for water and oil repellency, spray rating and dynamic rolling angle (DRA). These were also carried out after 1, 5, 10 and 20 home washes as well as after 2000, 5000, 10,000 and 20,000 cycles of Martindale abrasion. The results of spray rating and DRA are shown in Table 2.4. Similar treatments were also carried out on un-abraded fabrics as well as on those where instead of fluorocarbon stain repellent agent, silicone and wax and/or nano-particles were used. The results in all these cases were found to be inferior to those obtained with abraded, fluorocarbon treated fabrics by Wang et al (2005).

Unisearch Limited has applied for a patent by Zhang et al. (2005) for converting micro-structured surface into a super- hydrophobic surface with a contact angle of >150° by applying 0.1 - 1.0 micron thick coating of tri-functional alkyl silane to the micro-structured surface that on curing forms a hydrophobic coating having a nanoscale roughness on its surface. The resultant surface has both the nano-scale and micro-scale roughness.

It is assumed that the textile fabrics have micro-structure and an application of the finish and its subsequent curing will give them nanoscale roughness. A typical finish may have 45% methyl-tri methoxy silane, 4.5% poly methyl siloxane (-OH terminated), 9% octyl triethoxy silane, 40% ethyl acetate, 0.5% dibutyltin dilaurate and 1% 3-aminopropyltriethoxysilane. It may be prepared by mixing methyl trimethoxy silane, poly methyl siloxane, ethyl acetate and 0.1% dibutyltin dilaurate in a large reaction vessel in an inert atmosphere. The mixture may be stirred and heated at 60°C for 3 h. Octyltriethoxysilane and 3-aminopropyltriethoxysilane may be added during stirring.
Table 2.4  Spray Rating and Dynamic Rolling Angle (DRA)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Spray rating</th>
<th>DRA (for 3 cm rolling) deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>After finish treatment</td>
<td>100</td>
<td>3.0</td>
</tr>
<tr>
<td>After 1 wash</td>
<td>90</td>
<td>4.5</td>
</tr>
<tr>
<td>After 5 wash</td>
<td>75</td>
<td>14</td>
</tr>
<tr>
<td>After 10 wash</td>
<td>70</td>
<td>18.5</td>
</tr>
<tr>
<td>After 20 wash</td>
<td>60</td>
<td>26.5</td>
</tr>
<tr>
<td>After 2000 cycles abrasion</td>
<td>75</td>
<td>11.0</td>
</tr>
<tr>
<td>After 5000 cycles</td>
<td>75</td>
<td>17</td>
</tr>
<tr>
<td>After 10,000 cycles</td>
<td>75</td>
<td>21.5</td>
</tr>
<tr>
<td>After 20,000 cycles</td>
<td>60</td>
<td>NA</td>
</tr>
</tbody>
</table>

Remaining 0.4% tin catalyst may be added before padding the fabric with the finish. The fabric is padded with 5 - 20% of this mixture and cured at room temperature in air for 24 h.

It is claimed that during curing the hydrolytic condensation of trifunctional silanes forms a network of polymers or polyhedral clusters having the generic formula $(RSiO_{1.5})_n$ between silica $(SiO_2)$ and silicone $(R_2SiO)$. It is more commonly known as, silsesquioxanes or polyhedral oligomeric silsesquioxane (POSS). The POSS nanoparticles are thus deposited on the surface of the fabric. It is also claimed that organically modified silicate (Ormosil) nanoscale sol-gels may also be formed, that on curing will also give nanostructures as shown in Figure 2.7.
2.7 PLASMA TREATMENT

Plasma treatment has been claimed to be responsible for creating roughness on cotton fabrics. In a study carried out by Zhang et al (2005), it is stated that the creation of super hydrophobicity by applying fluorocarbon chemicals to cotton fabrics in an audio frequency (AC) plasma chamber, is a result of the film formation as well as roughness of the treated fabric.

2.8 SPECIALITY FINISHES

The consumer requires in the present day specialty products which meet various functional advantages during durable use and also the changing fashion trends.

2.8.1 Anti Spill Finishes

These are spill resistant finishes which are brought by nano technology in which the spill beads up and rolls off. The Nano-Tex builds spill resistance into the very fibers of the fabric.
2.8.2 Odour Finishes

It is a fragrant finish for all types of substrates as it releases different fragrances of various aromas like Lavender, Rose, Jasmine, Orange, Lemon, Musk, Mint, Banana and Flower.

2.8.3 Stain Smart Finishes

A technology developed by Milliken and Company provides permanent stain repellency and stain release properties. Stain Smart is the only fabric technology proven to work on a wide variety of fabrics for a broad range including apparel, hospitality, healthcare, military, and automotive textiles.

2.8.4 Recent Advances in Functional Textiles

Clothes make people, the saying goes. But clothing does a lot more than that. Smart or intelligent textiles describe fabrics and garments that have some active sense and respond ability is the theme presented by Viswanath and Parthiban (2005). Today textiles can be treated so that they protect one from all kinds of adverse conditions and are comfortable. Natural and Synthetic materials can be used to make water-repellent raincoats and sweat-absorbing tennis shirts. Fire-proof clothing or bullet-proof vests are other obvious examples. The right chemical compounds give the materials special properties: degradation stability, flame resistance, antimicrobial and antistatic properties. On the horizon are applications that seem like something from science fiction: T-shirts with integrated thermostats, gloves with built-in telephones, fine stockings with mosquito protection, and fiber-reinforced implants for orthopedic surgery.
2.8.5 High Function (or Hi-Tech) Textiles

With ever growing competition in consumer textiles, the twin functions of maintaining micro climate and comfort are gaining importance. Therefore, various textile manufacturers are focusing their attention to this emerging area of high function textiles. The Mitsubishi Rayon Group has created materials with unique properties by applying technologies for modifying, forming and giving functionality to acrylic fibers, polyester filaments, acetate fibers, and polypropylene filaments.

The staple fibers VONNEL and FINEL are used in a wide range of applications, including blankets, sweaters, and undergarments. For example, raw fiber with irregular cross-sectional shapes is directed toward expansion of products in the pile field, and materials with a soft feel are for use in apparel. Recent well-received products include A.H.F, an acetate/acrylic hybrid fiber, anti-bacterial deodorant fibers incorporating chitosan, and white conductive fibers, comprising special particles on a fiber core, that has a thermal insulation function.

The filament fiber SILPALON is a material for women's apparel having outstanding luster; it is the only fiber of its kind in the world. GLORE is the world's only man-made acrylic leather, created using superfine spinning technology. Fibers with novel functions that put to full use of mixed spinning and composite spinning technologies are being developed. One such product that has been extremely well-received is VENTCOOL, a humidity-sensitive fiber.

2.8.6 Wind-Resistant, Insulating Material

AIR BLOCK® (Toyobo in Japan) is an extremely wearable knit fabric that's made from a unique combination of filament yarns and offers excellent wind resistance.
Outstanding Features: Wind does not penetrate the fabric even in cold and chilly environments with strong winds, keeping the wearer warm and comfortable. In addition to its wind-blocking effect, it offers comfortable wearability with high heat retention. Thanks to the use of a unique, hollow polyester. Per cent of heat retained is greater than 15%. Training wear temperature drop within garment is 7° for sweatshirts and sweat pants.

2.8.7 A Sports Material that Regulates Body Temperature during Rigorous Exercise – Dry Fast- Sports Shirts

COOL and DRY® is the registered trademark of Toyobo in Japan. It is 100% polyester sports material (available as yarn and fabric) designed to automatically regulate body temperature during and after exercise. A new type of composite spun yarn with a triple-layer structure has been developed that mimics the "heat transfer phenomenon" found in thermo-physiology.

Outstanding Features: A triple-layer structured yarn with the center core yarn being a heavy- denier polyester filament, the intermediate layer being extremely fine spun polyester and the outer layer a polyester filament, helps to control body temperature during exercise by releasing heat, allowing air to move, and breath. After exercise, heat dissipation is reduced or inhibited. With minimal clinging to moist skin, it will not hamper movement due to perspiration.

2.8.8 New Comfort Material based on First Structured Yarn

FIRACIS is the registered trademark of Toyobo in Japan. FIRACIS® is a completely new type of composite spun yarn. It preferentially bonds a special polyester filament on top of super-long-staple cotton using a new-generation spinning process. Because the surface of the yarn is almost totally sheathed in the polyester filament, there is almost no fuzz, and the yam has excellent uniformity with a rich luster. It is a fabric that combines both the
feel of filament yarn, external appearance and unique character of high-quality cotton.

**Outstanding Features:** A silky smooth hand and ample drapability that is absent in conventional spun yarns. Damp, clammy feeling is significantly reduced even with heavy perspiration. Almost no clinging to the skin as it has excellent perspiration absorption and transpiration. It dries quickly, with extremely low shrinkage when laundered. Does not wrinkle, and offers excellent shape stability. Surface effects that accentuate the texture of the filaments can be attained.

### 2.8.9 ALTIMA ® - A new type of Specialty Knit Fabric

ALTIMA is the registered trademark of Toyobo in Japan. It has a double-layer construction consisting of a dry layer and a moisture absorbing layer, and offers perspiration absorption and transpiration properties that are ideal for sports activities in which the wearer perspires heavily.

**Outstanding Features:** During and after exercise, perspiration is quickly wicked to the outside, leaving the skin always dry and comfortable. By regulating moisture on the skin surface and controlling outside air heat, it reduces the rise in body temperature during exercise and minimizes the chilly feeling after exercise. Fabric dries quickly and it has excellent physical properties. An easy-care fabric, ALTIMA® can be laundered simply and easily.

### 2.9 EASY CARE FINISHING

This section presents an overview of the various techniques available in the recent literature on the subject of ‘easy care finishing’ contributed by various researchers.
2.9.1 Introduction to Cellulase for Easy-care Finishing

Enzyme technology has been applied to improve handle, appearance, and other surface characteristics of cotton and cotton-blends. One example of such successful applications of enzyme technology is the replacement of traditional stone washing in denim processing by cellulase washing. Hydrolysis of cellulose with cellulase is useful for Bio-polishing cotton fabrics, which enhances their aesthetic performance by specific cleavage of glucosidic bonds in cellulose molecules.

Cross-linking cellulosic molecules imparts wrinkle resistance to the finished cotton fabric but also reduces its mechanical strength. The durable press, DP-finishing process reduces fiber flexibility, thus having adverse effects on fabric handle. Cellulase treatments have been successful in improving the handle of cotton fabrics. Blanchard et al. (2000) studied weight losses and strength changes as a result of cellulase treatment of cotton fabrics treated by DMDHEU and citric acid. In this research work, the effect of cellulase treatment on the tensile strength, flex abrasion resistance, and handle of cotton fabric treated with BTCA was studied. The cotton fabric was first treated with cellulase, as a pre-curing cellulase treatment and, then cross-linked by BTCA. The fabric was also cross-linked by BTCA first, followed by treatment with cellulase, as a post-curing cellulase treatment. Comparison of the tensile strength, flex abrasion resistance, and wrinkle resistance of the cottons treated with cellulase using these two different treatment procedures, and also measurement of their low-stress mechanical properties for an objective evaluation of their handle were made.

Cellulase treatment of DP finished cotton fabrics reduced their strength and abrasion resistance but improved handle as reported by Charles, Wenlong et al. (2003), Pederson and Tyndall (1992). The effects of the two cellulase treatments were different. The pre-curing cellulase treatment was
significantly more effective in improving fabric handle than the post-curing cellulase treatment. However, the pre-curing cellulase treatment also caused much higher losses in fabric tensile strength and flex abrasion resistance than the post-curing cellulase treatment. Considering the fact that a DP finishing process reduces fabric strength and abrasion resistance, the pre-curing cellulase treatment should be used only for heavy cotton fabrics with high original strength, to improve their handle.

2.9.2 Introduction to Non-Formaldehyde Resin Finishing

Hyung Min (1993) used non-phosphorous catalyst for Formaldehyde-free finishing of cotton fabric with BTCA. Several researchers contributed to this subject and notably, Yang et al. (1998,2000) reported on combining citric acid with polymers of maleic acid. The addition of polyhydric alcohols to the treating formulations results in improved fabric whiteness and increased DP ratings. Alpha-hydroxy acid was added as catalyst activator to suppress the strength losses in treated cotton fabric. The curing temperature for cross-linking was lowered to 115-125°C and the order of effectiveness of various acid catalysts was as follows:

\[
\text{Succinic} < \text{lactic} < \text{maleic} < \text{glycolic} < \text{citric} < \text{tartaric acid} \quad (2.5)
\]

A silanol-terminated silicone fabric softener appeared to exert a synergistic effect with glyoxal and aluminium sulphate in improving the DP ratings. The extent to which a straight-chain glycol increased DP performance depends primarily on the molecular chain length of the glycol. The optimum length was approximately six atoms, excluding the terminal hydroxyl groups. The role of the glycol is as a crosslink modifier, which alters the special configuration, polarity and flexibility of the three-dimensional crosslink network produced in the cellulose.
The phosphorylation of cotton cellulose can be carried out by heat curing of fabric, impregnated with either a 1:1 mixture of mono- and di-sodium phosphate, or preferably sodium hexa-metaphosphate. When the phosphorous content of treated fabric exceeds 1.6%, the fibers are found to be insoluble in cupri-ethylene diamine hydroxide solution, and the cellulose appears to be cross-linked.

Citric acid was found to be the most effective poly-carboxylic acid, in the absence of added catalyst by pad dry-cure treatment, although it produced more fabric discoloration than the other agents. The cross links were formed in cellulose by acid-catalyzed esterification with citric acid itself, furnishing the protons needed for the autocatalysis. Saponification of the ester cross-links by hot 0.1 mol/l sodium hydroxide increased the wrinkle resistance of the cotton fabric but did not restore the tensile strength.

Poly-carboxylic acid with 4 to 6 carboxyl groups per molecule in presence of alkaline catalysts were found to be more effective than with acids having only two or three carboxyl groups. Sodium carbonate or tri-ethyl amine was added as catalyst. These salts act as buffers and greatly diminished acid-induced tendering during high temperature curing. The wrinkle-resistant finishes obtained were re-curable. In the presence of heat, the trans-esterification of ester cross-links by neighboring cellulose hydroxyls caused the cross-links to be mobile.

The newer catalyst, which is more effective than sodium carbonate or tertiary amines are alkali metal salts of phosphorous containing mineral acids. The order of decreasing effectiveness is as follows:

\[
\text{NaH}_2\text{P}_2 \cdot > \text{Na}_2\text{HPO}_2 = \text{NaH}_2\text{PO}_3 > \text{NaH}_2\text{PO}_4 > \text{Na}_2\text{H}_2\text{P}_2\text{O}_2 > \]

\[
\text{Na}_2\text{P}_2\text{O}_2 > \text{NaP}_2\text{O}_{10} = (\text{NaPO}_3)_6 > \text{Na}_2\text{HPO}_4 = \text{Na}_2\text{PO}_4 > \text{Na}_2\text{CO}_3
\]

(2.6)
Sodium hypophosphite* is, however, most expensive. Thus, other catalysts are used in the mixture. The effect of highly polar additives on BTCA reaction with cellulose has been studied. Triethanolamine acted as a crosslink modifier that enhanced DP appearance rating, laundering durability of the finish and fabric strength retention. Disubstituted amides increased the conditioned and wet wrinkle recovery, as well as DP rating, but had no effect on fabric strength retention. The amides may have altered the hydrogen bonding, the degree of fiber swelling and the crystallinity of the cotton. Recently, Maleic acid activated by BTCA or small amounts of BTCA with high concentrations of citric acid as a DP finishing agent are found to be very effective with encouraging results.

Citric acid, BTCA and Glyoxal can be used as eco friendly cross-linking agents. Effectiveness of these cross-linking agents has following diminishing order: BTCA-Glyoxal-Citric acid. Higher the concentration of cross-linking agent higher is the loss in physical properties of cross-linked fabric. Extent of deterioration of physical properties of cross-linked cotton fabric depends on type of cross-linking agent, concentration of citric acid, curing temperature, curing time and concentration of catalyst. The extent of deterioration of physical properties has following trend: BTCA< Glyoxal < Citric acid. In the case of citric acid yellowing of the treated fabric can be drastically reduced by the use of PEG-600 and Polyethylene emulsion. BTCA at pH 2.8 provides high level of effectiveness for cross-linking cotton with minimized fabric strength loss. The properties of cotton fabric treated with BTCA are comparable with those of DMDHEU treated fabric.

2.9.3 ECO-friendly Resin Finishing of Cotton Fabric

With increasing awareness and environmental concerns, a significant order of legislation on eco toxicological considerations has been introduced. It is related to such important issues as health and safety during
storage, application and use, and safe disposal of chemicals into landfill, into water or release in air during application of chemical finishes.

In view of the foregoing, integrated pollution control would continue for developing eco-friendly processes. The driving forces in the recent technology, have been the economy and ecology, and finishers are therefore, trying to produce quality goods with less water and less pollution.

Wasif and Laga (2003) have made an attempt to apply Glyoxal, BTCA, citric acid and DMDHEU as cross linking agents for improving dry and wet crease recovery angles (DCRA, WCRA) of cotton fabric. These cross-linking agents at various concentrations of 60gpl to 140 gpl have been applied by pad-dry-cure technique. The effect of concentrations of cross linking agent, curing temperature, curing time, type of catalyst and concentration of catalyst have been studied. Encouraging results in terms of DCRA, WCRA, high fabric strength retention, good laundering durability have been achieved.

Cotton on treatment with glyoxal in presence of an acid catalyst such as boric acid or ammonium chloride and aluminium sulphate on heating gives monoacetals and di-acetals of glyoxal with cellulose, that takes care of the cross-linking.

2.10 OBJECTIVE EVALUATION OF THE QUALITY OF FABRICS FOR LADIES TAILORED – TYPE JACKETS FOR SPRING AND SUMMER : A REVIEW

The quality of ladies’ tailored-type jacket fabrics for spring and summer was subjectively evaluated by Inoue Takako and Niwa Masako (2009), and as with the fabrics for autumn and winter jackets, equations for the objective evaluation of the quality of ladies’ garment fabrics were derived from their mechanical properties. As a result, it has been clarified that the
mechanical properties related to silhouette formation, feel, and factors related to compression and softness, all contribute to the objective evaluation of ladies’ tailored-type fabrics.

2.10.1 Introduction to Subjective Evaluation/Judgment of Fabrics

For ladies’ garments, the compositional lines are complex and a diverse range of fibers and material designs are used. The criteria for the subjective judgment of fabrics for ladies’ garment were analyzed and clarified for each tailored-type, as Hari-type, and Drape-type. As a result, the fabric feel and the mechanical properties, which correlate to the ability to achieve a beautiful silhouette, were analyzed as criteria for subjective judgment. The goals of this report were to objectively evaluate the quality of these ladies’ tailored-type jacket fabrics, and then to classify them according to standards used to evaluate the fabric quality. Equations were derived for the objective evaluation of the quality of ladies’ garment fabrics from the mechanical properties corresponding to high-quality fabrics.

2.10.2 The Subjective Hand-Evaluation Method and Measurement of Fabric Mechanical Properties

The evaluation was based on judgment of quality as related to actual physical fabric performance (the color and pattern of the materials were excluded from the judgment). THV evaluation was standardized following the standardization of the total hand, using ranking numbers 5 (excellent), 4 (good), 3 (average), 2 (below average), and 1 (poor).

The group of judges included two female garment designers (A group), and three male fabric distributors (B group). All the judges had over 30 years of textile-related experience. In addition to the textile professionals, three female educators teaching clothing construction in textile-oriented
schools formed the C group. The characteristic values of the mechanical properties were measured by a KES-FB-AUTO system under high-sensitivity condition.

The THV equations for men’s suiting fabrics for autumn/winter and spring/summer were developed in 1980. Fabrics for spring and summer tailored-type ladies’ jackets were also objectively evaluated in the same way from their mechanical properties. To examine the criterion for the subjective evaluations of the judges, how the mechanical properties of ladies’ tailored-type spring and summer jacket fabrics were related to the individual subjective evaluations, were studied. To analyze the subjective evaluation, a regression analysis was conducted by stepwise block regression for the criterion variable of a judgment, using six blocks (tensile, bending, shearing, surface, compression, and construction) of the 16 mechanical properties involving the warp and weft directions.

In the present research work, the subjective parameters graded in the range of 1 to 5, are assessed in proportion to the mechanical characteristics and also by the ‘feel’ of the different fabric samples based on the implicit subjective judgment by the fabric experts. A special computer software, first developed by IBM and then improvised by DCM data products (Delhi) and further modified in the Department of Textile Technology of A. C. College of Technology (Chennai) was used for the purpose of analyzing the data for ANOVA and through Correlation Matrix.

2.10.3 Tactile Properties: A preamble

A systematic understanding of the Tactile properties forms the preamble and also the basis for the present research work. Tactile properties are classified under primary hand and secondary hand as per the Table given below:
| Table 2.5 Tactile Properties |

<table>
<thead>
<tr>
<th>Primary hand</th>
<th>Secondary hand</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stiffness</strong>: A stiff feeling from bending and springy properties promotes this feeling. High density fabric made by springy and elastic yarn has this feeling strongly. KOSHI is the equivalent Japanese Term for this subjective parameter.</td>
<td>Objective measurement of fabric handle by Kawabata Evaluation System (KES) involves a set of instruments which would measure the appropriate fabric properties that correlate these measurements with the subjective assessment of handle.</td>
</tr>
<tr>
<td><strong>Smoothness</strong>: A mixed feeling coming from smooth and soft feeling. The fabric woven from Cashmere fibre gives this feeling (NUMERI).</td>
<td>The 16 parameters measured by the Kawabata Evaluation System describing fabric low stress mechanical and surface properties.</td>
</tr>
<tr>
<td><strong>Fullness &amp; Softness</strong>: A bulky rich and well formed feeling. Springy property in compression and thickness accompanied with warmth are closely related with this feeling (FUKURAMI).</td>
<td>Tensile (LT, WT, RT): Linearity of load extension curve, Tensile energy, Tensile Resilience.</td>
</tr>
<tr>
<td><strong>Crispness</strong>: The feeling of a crisp and rough surface of fabric. This feeling is brought by hard and strongly twisted yarn, accompanied by cool feeling (SHARI).</td>
<td>Shear (G, 2HG, 2HG5): Shear rigidity, Hysteresis of shear force at $0.5^\circ$, Hysteresis of shear force at $5^\circ$.</td>
</tr>
<tr>
<td><strong>Anti-Drape Stiffness</strong>: Anti-drape stiffness, no matter whether the fabric is springy or not (HARI).</td>
<td>Bending (B, 2HB): Bending rigidity, Hysteresis of bending moment</td>
</tr>
<tr>
<td><strong>Scroopiness</strong>: A kind of silk fabric possesses this feeling strongly (KISHIMI).</td>
<td>Lateral compression (LC, WC, RC): Linearity of compression-thickness curve, Compressional energy, Compressional Resilience</td>
</tr>
<tr>
<td><strong>Flexibility and Softness</strong>: Soft, flexible and smooth feeling (SHINAYAKASE).</td>
<td>Surface characteristics (MIU, MMD, SMD): Coefficient of friction, Mean deviation of MIU, Geometrical roughness</td>
</tr>
<tr>
<td><strong>Soft touch</strong>: Soft feeling. A mixed feeling of bulky, flexible and smooth feeling (SOFUTOSE).</td>
<td>Fabric construction (W, T): Fabric weight per unit area, fabric thickness</td>
</tr>
</tbody>
</table>
2.10.4 Correlation between Subjective and Objective Assessment of Cotton Fabrics: The potential area for research

The corresponding definitions for the eight subjective parameters and the eight objective mechanical parameters used in the present work are given below:

<table>
<thead>
<tr>
<th>Mechanical parameter</th>
<th>Subjective parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric Weight and Thickness, W and T</td>
<td>W and T</td>
</tr>
<tr>
<td>Fabric Smoothness, flexibility and fullness, designated by Tensile Resilience, RT</td>
<td>FS</td>
</tr>
<tr>
<td>Fabric Extensibility/ Elasticity, designated by Maximum Tensile Elongation, EMT</td>
<td>E</td>
</tr>
<tr>
<td>Compressibility and Fabric softness, designated by Compressional Resilience, RC</td>
<td>C</td>
</tr>
<tr>
<td>Anti-drape stiffness or Shear Rigidity, designated by Anti-drape stiffness or Shear Rigidity, designated by</td>
<td>D</td>
</tr>
<tr>
<td>Bending stiffness or Bending Rigidity, designated by Fabric Frictional resistance or Frictional roughness, designated as Geometric Roughness, SMD</td>
<td>S</td>
</tr>
</tbody>
</table>

Owing to the several limitations of the subjective assessment and because of the importance of the scientific understanding of fabric hand, many trials for replacing the subjective method with an objective method have been carried out by many researchers in the textile field, beginning with the trials by Peirce in 1930 and Kawabata in 1969. Peirce proposed a correlation between fabric hand and fabric mechanical properties. Many textile scientists conducted research in this field after Peirce. Because of the difficulty in linking human sensitivity to fabric properties, progress in this field has been slow. However, the importance of the understanding of fabric
hand has been continuing throughout. In the present work, computerized software program was used to establish statistical correlation between the above stated subjective and objective parameters by interpretation through ‘Correlation Matrix’.

The first step of the earlier research was to standardize the fabric hand expressions that were traditionally used by the experts in wool textile mills. Based on this standard, a numerical expression of fabric hand, known as Total Hand Value (THV) became possible; and then subjective hand judgment was transferred to an objective evaluation system based on fabric mechanical properties. The concept of the objective evaluation system is as follows. Instead of using the touch of a fabric by a hand or finger, we measure fabric mechanical properties and express them by mechanical parameters. Then these parameters are converted into the hand values (HV) with a conversion equation (equation type I). Next, these values are converted into a total hand value (THV) with the second conversion equation (equation type II).

The HV equation is as follows:

\[ Y_k = C_o + \Sigma C_i X_i \quad (2.7) \]

Where \( Y_k \) is the kth hand value such that, \( k = 1 \) is stiffness, \( k = 2 \) is smoothness, and \( k = 3 \) is fullness for winter/autumn suiting, and \( k = 1 \) is stiffness, \( k = 2 \) is crispness, \( k = 3 \) fullness, and \( k = 4 \) is anti-drape stiffness for summer suiting. The term \( X_i \) is the normalized ith (\( i = 1-16 \)) mechanical parameter, normalized as,

\[ X_i = (X_i - M_i) / \sigma_i \quad (2.8) \]
where, \( X_i \) is the mechanical parameter. Note that a logarithm is used for some parameters. \( M_i \) and \( \sigma_i \) are the mean and standard deviation of \( X_i \) for the men’s suiting population. \( C_0 \) and \( C_{ki} \) are constant coefficients, with \( M_i \) and \( \sigma_i \).

The value of THV value is derived by substituting \( Y_k \) that are derived from Eq. (1) into Eq. (3) as follows:

\[
\text{THV} = C_0 + \Sigma Z_k \tag{2.9}
\]

where

\[
Z_k = C_{ki} (Y_k - M_{k1})/\sigma_{k1} + C_{ki2} (Y_i^2 - M_{k2})/\sigma_{k2} \tag{2.10}
\]

Thus \( Z_k \) is the contribution of the kth primary hand to THV. The constants \( M_{k1} \) and \( \sigma_{k1} \) are population means and standard deviations of \( Y_k \), and \( M_{k2} \) and \( \sigma_{k2} \) are population means and standard deviations of \( Y_k^2 \), respectively, the constant coefficients \( C_{k1} \) and \( C_{k2} \), and the constant \( C_0 \).

The regression formula is as follows:

\[
\text{THV} = C_0 + \sum_{i=1}^{19} (C_{i12} X_i - M_{i1})/\sigma_{i1} + C_{i12} X_i^2 - M_{i2})/\sigma_{i2} \tag{2.11}
\]

The primary hand equations and THV equations have been derived on the basis of experts’ judgment for the men’s and women’s suiting population from the stated expressions.

Automatic Recognition of Woven Fabrics by using ANN: A new concept for subjective assessment, has been attempted in the present work.

A neural network and image processing technology were introduced for classifying woven fabric patterns by Boong Soo Jeon, J1 Hyun.
Bae and Moon W. Suh (2003). An autocorrelation function was used to determine one weave repeat of the fabric. The reflected fabric image was captured and digitized by the computer system. The learning vector quantization algorithm as a learning rule of the artificial neural network (ANN) enabled recognition of woven fabric types more effectively. The results demonstrated that three fundamental weave types namely plain, twill, and satin fabrics, can be classified accurately, and structural parameters such as yarn spacing, its variance, and the ratio of warp spacing to weft spacing can also be obtained. The authors have trained and tested vector form of these ratios with the LVQ algorithm to recognize the unknown pattern. Their classification results of unknown fabric showed good agreement with manual measurements. Attempt has been made to use the LVQ algorithm for the present research work for processing ‘handle and comfort’ quality related equations derived from ‘Octagonal Diagram’ as explained in Chapter 9.

2.10.5 Modeling Studies on Comfort Characteristics: A new bridge to fill the key gaps in the current research

The present research was undertaken to establish a common simple Model for comfort evaluation of an apparel fabric, intended for its grading/ranking of the desired ‘comfort quality’ in the finished fabric. The key gaps in the in the literature available so far are stated below.

(1) The comfort quality grades can be put in the same range of 1 to 10, as that of THV, even though the major range for ‘good’ grading/ranking lies in the first half of 1 to 5. All the grades above 5, up to 10, exemplify ‘Excellent’ grade for THV, based on KES, or comfort quality in terms of the newly evolved ‘3T’ expression.
‘3T’ means the ensemble of Tactile or Tensile, Thermal and Transport (invariably of moisture vapor and not air-permeability). ‘3T’ is first estimated by a simple ‘mathematical model’, as given below.

Basic expression:

$$3T = THV + TIV + MT$$  \hspace{1cm} (2.12)

Derived expression:

$$3T = THV + a_1 \cdot TIV + a_2 \cdot MT$$  \hspace{1cm} (2.13)

The second equation forms the best correlation for 3T (at $R^2 > .9$ or $R^2 \approx 1$) with THV, TIV and MT. To increase the range of variation of TIV and scale up its weightage in the ‘3T’ expression, $a_1$ is chosen as the scale up or weightage factor for TIV. When it is include in the ‘3T’ expression as $a_1 \cdot TIV$, the resulting ‘3T’ attains higher correlation coefficient in terms of $R^2$. Similarly, $a_2 \cdot MT$ results in higher $R^2$ for ‘3T’ expression. Thus, $a_1$ and $a_2$ are arbitrary constants (in the present set of data) are, $a_1 = 1.475$; $a_2 = 10$. These may be varied according to the necessity, as applicable for the given set of data, pertaining to a certain finished substrate of an apparel fabric, of certain construction variables (namely, gsm, count of warp, count of weft, epi, ppi) the underlying condition is only that ‘3T’ should bear a high correlation coefficient ($R^2$) with THV, TIV and MT. Such a plot of 3T vs THV; 3T vs TIV and 3T vs MT in a single graph is named as ‘3T’ - plot or ‘tri-plot graph’. The regression formulate are as given below:

$$Y_1 \text{ (Stands for THV)} = m_1(3T) + c_1$$  \hspace{1cm} (2.14)

$$Y_2 \text{ (Stands for TIV)} = m_2(3T) + c_2$$  \hspace{1cm} (2.15)

$$Y_3 \text{ (Stands for MT)} = m_3(3T) + c_3$$  \hspace{1cm} (2.16)

$$Y_4 \text{ (Stands for TMkes)} = m_4(3T) + c_4$$  \hspace{1cm} (2.17)
The seven expressions, 2.10.3 to 2.10.9 form part of the ‘statistical’ modeling by taking into consideration, a set of \( n = 6 \) values of any of the three prime variables, such as, THV or TM or NPA in combination with TIV and MT. The seven expressions, 2.10.3 to 2.10.9 are called ‘regression equations of 3T’.

In the third stage, ‘computerized modeling’ is contemplated through Artificial Neural Network (ANN) by making use of the seven regression equations of 3T, to initializing the input vectors and equalizing the target target vectors. For an unknown fabric, the ‘3T’ can be computed by inputing the seven criterion variables, namely, THV, TIV, TM\textsubscript{KES}, TM\textsubscript{INS}, TM\textsubscript{BAST}, and NPA. The seven ‘3T’ values thus derived by computation, can be interrelated by regression formulae / equations as give below.

\[
\begin{align*}
Y_5 \text{ (Stands for TM}_{\text{ins}}) &= m_5(3T) + c_5 \quad (2.18) \\
Y_6 \text{ (Stands for TM}_{\text{BAST}}) &= m_6(3T) + c_6 \quad (2.19) \\
Y_7 \text{ (Stands for NPA)} &= m_7(3T) + c_7 \quad (2.20)
\end{align*}
\]

The five expressions for 3T, namely, 3T\(_1\) to 3T\(_5\), are utilized for the grading / ranking purpose by a ‘cumulative’ approach, as the 3T stated above, dwindle the grades / ranks for the same given finished fabric, by virtue of the different origin of evaluation, measurement or estimation. However, the five different grades / ranks obtainable for a given finished fabric, for 3T, can
be normalized to one grade / rank of vicinity or reference, on the basis of THV, the already well established expression for ‘total handle value’ corresponding to the equation (2.10) for 3T.

\[ \text{NPA}_{\text{OD}} \]

the Net Positive Area of the Octagonal Diagram (OD), which is constructed by a methodical approach, as explained in Chapter 9, makes use of the eight parameters (can be called as the ‘Octet’ of the OD) determined from KES, or any other measuring device, which gives the eight estimates for the following.

<table>
<thead>
<tr>
<th>Weight (W)</th>
<th>Thickness (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressional Resilience (RC)</td>
<td>Geometric Roughness (SMD)</td>
</tr>
<tr>
<td>Tensile Resilience (RT)</td>
<td>Shear Rigidity (G)</td>
</tr>
<tr>
<td>Max. Tensile Elogation (EMT)</td>
<td>Bending Rigidity (B)</td>
</tr>
</tbody>
</table>

Following definite order and magnitude / units as specified in Table 9.1, is imperative.

In place of NPA, which is defined as the ratio of positive area to the total area \(\frac{p}{p+n}\), the two actual areas, \(p\) & \((p+n)\) can be digitized by digitizer and the same values can be fed to the input vector (more details in Chapter 9). Further processing of data using ANN can be done in the same way as explained before, with reference to equation 2.14. The actual feeding of ‘areas’ from the Octagonal Diagram (OD) leads to use of the image analysis technique, with CCD camera.