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Interaction of textile parameters, wash-ageing and use of fabric softener during the laundry with mechanical properties of the knitted fabrics and correlation with textile hand

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GENERAL INTRODUCTION:

Over the years, the diversity of washable fabrics, and in particular machine-washable textiles, has increased dramatically. This diversity includes fibre types, fibre parameters, yarn construction, textile manufacturing method, dye class and fabric finish combinations to wash. On the other hand, world wide fashion trends and changing lifestyles have led to increasingly full shades and bright hues in new types of casual and sportswear. These are predominately of knitted constructions for which dimensional instability and distortion after repeated laundry is a big concern.

The fabrics that we deal with in everyday life are not in a relaxed condition and come to their relaxed condition after several washings [Morton *et. al.*, 1962.]. Many researchers have reported that this relaxation process during ageing will depend on the laundry parameters. Each separate step of the laundering has an influence on dimensional stability and distortion of knitted fabrics, that's why it is very important to select optimum laundry parameters to minimize the distortion of fabrics [Anand *et. al.*, 2002; Fijan *et. al.*, 2007; Morris, 1970].

These dimensional changes and distortion of the knitted fabrics result changes in mechanical properties and textile hand as well. In order to overcome the problem of deterioration of textile-hand, laundry softeners were introduced.

Softeners are luxury products which obviously are not critical to the basic laundry cleaning process. Use of fabric softener depends on consumer perception that they deliver added comfort and are a gesture of caring and affection. Their market viability depends upon the availability of discretionary income and convenience in use. The fabric softener market is growing. It is following the rise in living standards around the world [Levinson L. Matthew, 1999], a clear picture of fabric softener market is shown in Table 1.1.

Table 1: Global Fabric Softener Consumption[a] Estimates [Levinson L. Matthew, 1999]

Region/Year	1995	2000	2005	Growth[b] (%)
Europe	115	130	140	2.5
United States	72	86	104	3.5
Mexico	7	10	15	7
South America	17	23	31	6
Asia	50	50-75	50-100	0-8
Total	261	300+	350+	4

[a] Fabric softener consumption is in 000's of metric tons per annum.
[b] Growth based on a 10-yr projection from 1995–2005.

The fabric softener markets in United States, Europe, Japan, Australia, South Korea and New Zealand are well developed. The use of fabric softener is estimated at 1.2 million tons/year in EU and estimated 90-95% of consumers use fabric softener [Ecolabelling Denmark, Febuary 2009]. This shows that fabric softeners already share a large portion of the laundry business. While on the other hand in developing countries like China, this product still has a huge market potential. In China the production of fabric softener per year has increased from 300 kilograms to 19000 tons (1980 to 2000). According to the statistic of ACN elsen, from 2005 to 2007, the sales and revenue of China's fabric softener is increasing by more than 7% per year [Pangato and Wen, 2010].

With continuous growth in demand of fabric softeners the market-competition is also growing. Manufactures are trying to identify products to meet real consumer needs and to provide extra benefits to consumers. The effects of household fabric softeners on textiles, especially on cotton, have been explored in various areas, such as, fabric weight, fabric strength, dimensional stability, wrinkle recovery, pilling, whiteness, hand, static electricity, odour, absorbency, flammability, and stain release.

Statement of the problem:

This thesis is concerned about interaction of wash ageing and the use of fabric softener during laundry with different textile parameters. It is still a challenge for the softener manufacturer and textile processors to define the softener deposition amount, softener deposition uniformity, simultaneous influence of wash-ageing and use of fabric softener on mechanical properties and hand-feel of different textiles varying in construction, fibre types and other textile parameters.

Secondly, in the textile/garment industry, fabric evaluation is performed in two ways: subjective/sensory and objective evaluation. On one hand, sensory evaluation gives an idea of consumer perception of fabric handle; however it is difficult to use due to a lack of consistency and standardisation. On the other hand, by standard objective tests, we can obtain a set of precise quantitative data describing the fabric hand but their relationship with consumer perception is not completely understood. Objective parameters are easier to define and can be correlated to material and process parameters. This leads to the fact that the relationship between sensory evaluation attributes and mechanical parameters need to be defined.

Purpose of the study:

In this study, the simultaneous influence of repeated machine laundry and use of the fabric softener on sensory, mechanical and physico-chemical properties of the knitted textiles was investigated. The block diagram of the working-scheme of this thesis is shown in the figure below.

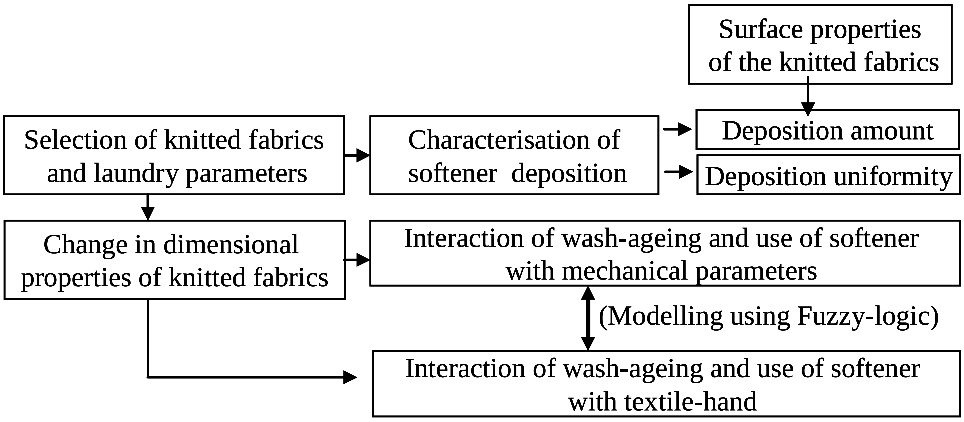


Figure: Block diagram of the scheme of this work

This study was carried out using 13 knitted fabrics varying in fibre type, fibre fineness, knitting construction. We used viscose and PET knitted fabrics of micro and regular fibres, made up of three basic knitting constructions- jersey, rib and interlock. We used the most market relevant laundry practices with European washing machine for this study and 40 repeated wash cycles were considered as the life cycle of a garment during use. The influence of wash-ageing with/without use of the fabric softener up to 40wash-cycles on dimensional, sensory and mechanical properties is investigated. The low stress mechanical properties were evaluated by means of the Kawabata Evaluation System for fabric (KES-F) and Universal Surface Tester (UST). The sensory evaluation of the fabrics was carried out by a trained panel using pair-comparison method.

Furthermore, an intelligent system based on Fuzzy logic for correlating the physical and sensory parameters was developed in order to predict the performance of a knitted fabric which has gone through a number of laundry cycles.

The study was carried out with following objectives:-

1. We tried to find the influence of fibre type, fibre fineness and knit construction on the amount of softener pick up by the fabric. The influence of the type of load (mixed

fibre load and individual fibre load) on the amount of softener deposited on the fabric was also studied. We have also quantified the nonuniformity of softener deposition. We used an image processing tool to define non-uniformity of the softener deposition. It evaluates the spatial uniformity of softener deposition by evaluating the difference between observed patchy distribution and a random process which would lead to a uniform distribution.

2. We categorised the surface properties of knitted fabrics by electro-kinetic behaviour and liquid up-take phenomena of the knitted textiles in order to understand the interaction of the surface properties of the knitted textiles with cationic softener deposition. The electro-kinetic and liquid uptake properties of textiles were represented by the parameters Zeta-potential and liquid absorption ability. We also examined the influence of fabric softener on surface characteristics of the textiles.
3. This study involved the sensory evaluation of knitted textiles, which have gone through different domestic laundering treatments: identifying whether the sensory attributes or combination of different sensory attributes can best predict the preference of consumers for the comfort aspect. We defined the parameter 'Degree of influence' for sensory attributes in order to check the level of influence of ageing and use of domestic fabric softener on each attribute.
4. We tried to identify the critical mechanical parameters which are influenced by ageing and the use of fabric softeners during life cycle of garments. The low stress mechanical properties were evaluated by means of the Kawabata Evaluation System for fabric (KES-F) and Universal Surface Tester (UST) revealing that the tensile, shear, bending, compression and surface properties were altered by both ageing during the wash cycles and the use of fabric softener.

5. An intelligent system based on Fuzzy-Logic for correlating the physical and sensory parameters was developed. We defined the tracking criterion to calculate the relevancy between sensory attribute and mechanical parameters in order to find out the most relevant mechanical parameters for each sensory attribute. This tracking criterion decreases the model complexity by reducing the model inputs, which makes model more reliable.

The originality of our research lies in the idea of developing an intelligent system, which can be used for predicting the fabric-hand of the textiles during cradle to grave state of a garment using relevant mechanical parameters. At the same time the interaction of wash ageing and laundry softener with sensory, mechanical and physicochemical properties of the knitted fabrics was analysed thoroughly.

This project was supported by Unilever Research and Development Laboratory, Port Sunlight, U.K. with the aim of having better understanding of influence of wash-ageing and use of fabric softener on knitted textile properties. In the context of innovation, environment, infrastructure the laboratory GEMTEX (Génie et Matériaux TEXtiles) is equipped with Kawabata Evaluation System, Universal Surface Tester and has expertise in sensory studies of textiles. All the experimental work was carried out in GEMTEX. The collaboration and financial management was facilitated by ADRINORD.

This thesis is organized in four chapters. The first chapter deals with state of art of laundry, fabric softener and its influence on textiles. It describes the importance of laundry parameters for textiles and the basics of cationic fabric softeners. It also includes the description of fabric surface properties- zeta-potential and wicking properties, which are the key factors in deposition of the softener deposition. This chapter also gives an overview in depth regarding the textile hand-evaluation by subjective and objective methods and the application of soft computing techniques for quantifying the fabric hand.

The second chapter concerns the details of material, laundry process and characterization of softener deposition with respect to softener pick-up amount and deposition uniformity. This chapter also includes the study of the interaction between surface properties of the textiles and deposition of cationic softener on textiles.

The third chapter deals with the simultaneous influence of wash-ageing and the use of softener during laundry on sensory and mechanical properties of the knitted textiles. In this chapter section: 3.1 concerns with the method of establishing a panel for sensory evaluation and the influence of wash-ageing and use of fabric softener during laundry on different sensory attributes has been analysed. While section: 3.2 deals with the influence of wash-ageing and the use of fabric softener on mechanical properties of knitted fabrics.

In forth chapter, an intelligent system based on Fuzzy-Logic for predicating the score of sensory attribute using two most relevant mechanical parameters has been proposed. The sensory attribute and mechanical properties defined in chapter: 3 were used for developing model and a relevancy criterion was defined to select the most relevant mechanical parameter for each sensory attribute.

The thesis ends with a general conclusion bringing together a synthesis of presentation of results and perspectives to be considered in the further study.

CHAPTER: 1

STATE OF THE ART

This chapter deals with a literature review of the interaction of textile parameters, wash-ageing, use of fabric softener with textile-hand. The chapter starts with the basics of laundry and laundry parameters and is followed by the significance of use of the fabric softener during laundry. The deposition of softener is expected to be a function of surface properties of the textiles i.e. electro kinetic beviour and liquid up-take phenomena of the textiles. Hence, an in-depth literature of these two key factors is presented.

The change in consumer perception with respect to textile-hand of a fabric due to wash-ageing and use of the fabric softener can be evaluated by sensory evaluation. Therefore, a brief introduction of sensory science with it's importance in textiles is being presented. This chapter ends with significance of soft computing techniques to correlate the textile-hand with mechanical parameters of the textiles.

1.1 Textile Comfort:

Comfort of an apparel is a qualitative term and it one of the most important aspect of the clothing. The term comfort is defined as "the absence of unpleasantness or discomfort" or a neutral state compared to the more active state of pleasure".

The clothing comfort can be divided into three groups i.e. psychological, thermal and tactile comfort. Psychological comfort is mainly related to the latest fashion trend (style, size, fashion-compatibility, colour, lustre etc.) and acceptability in the society and bears little relation to the properties of the fabric. The thermal comfort is related to the ability of a fabric to maintain the temperature of skin through transfer of heat perspiration generated within the human body. The tactile comfort has relationship with fabric surface and mechanical properties, especially initial low stress region of those properties [Behera et. al., 1997].

Saville distinguished two aspects of wear comfort of the clothing; i) "thermo-physiological wear comfort which concerns the heat and moisture transport properties of the clothing and the way that clothing helps to maintain the heat balance of the body during various levels of activity", and ii) "skin sensational wear comfort which concerns the mechanical contact of the fabric with the skin, its softness and pliability in movement and its lack of pricking, irritation and cling when damp" [Saville, 1999].

The response of a user towards tactile comfort is called fabric handle. Fabric handle is related to basic mechanical properties, especially initial low stress region of those properties. The term fabric "hand" or "handle" has been defined as the quality of a fabric or yarn assessed by the reaction obtained from the sense of touch or the sum total of the sensations expressed when a textile fabric is handled by touching, flexing of the fingers and so on. It implies the ability of the fingers to make a sensitive and discriminating assessment, and of the mind to integrate and express the results in a single-valued judgment [Mitsuo, 1996].

The hand of the fabrics does not remain the same after going through number of wash-cycles. Mackay *et. al*. identified some of the factors that lead to consumer dissatisfaction with the washing performance of cotton, wool and acrylic knitwear. These include increase in weight and stiffening of cotton by calcium phosphate deposits, felting of shrink-resist wool at normal machine agitation levels and stretching of acrylics in tumble drying. [Mackay *et. al*., 1999].

A single laundry cycle does not have a significant effect on fabric drape, shear or bending properties. However, after a repeated laundry cycles, drape values increased overall, while shear and bending modulus and hysteresis decreased, resulting in a more drapable, pliable fabric after five laundry cycles [Orzada *et. al*., 2009].

The level of change in handle of the fabric due to laundry depends on the number of wash cycles fabric had gone through and laundry parameters. Hence, an overview of life cycle of a garment during use and the laundry parameters is being given in the next sections.

1.2 The influence of laundry process and parameters on textile-hand

1.2.1 Laundry and life cycle of garment:

A garment goes through number of alternate wear and laundering cycles during the use. There is good evidence that washing processes generally contribute more to fabric damage than do use or wear. For example data from a typical wash and wear trial showed 43% tensile strength loss in hospital uniforms (made of 50/50 Polyester/cotton) after 25 wash/wear cycles, and 39% strength loss in the 'washed only' control article and thus almost 90% of the total damage was caused by wash process in this particular case [Mohamed, 1982]. That's why the period of life cycle of a garment during use can be represented by the number of laundry cycles for which a garment can be withstand in usable condition. The prediction of wear life for a fabric in terms of number of laundry cycles is an enormous piece of work because of the diversity of laundry practices such as: dissimilar water quality at different localities, dissimilarity in water temperature, washing load etc [Munshi *et. al.*, 1993] but still the performance of a garment has been obtained in terms of the number of wash cycles that a garment could withstand before showing the first sign of damage and it was found that cotton woven fabrics could be withstand for 30-50 washing cycles [Neelakantan, 1981].

1.2.2 Influence of laundry parameters:

A typical laundry process includes the following stages: - Loading of cloths, detergents and water → wash mode→ draining → rinse mode→ spin-mode. Each stage of a washing cycle and related parameters have a contribution to the change in dimensional properties of the knitted textiles [Anand *et. al.*, 2002] [Figure 1.1].

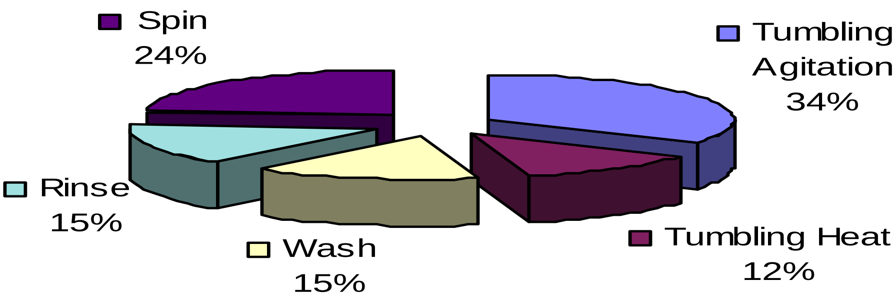


Figure 1.1 Contribution of different washing stages in change in dimensional properties of knitted fabrics after 5 washing cycles [Anand *et. al.*, 2002]

The agitation was found to have caused 34% of the changes during laundering, followed by the spin cycle during washing, which caused 24 % of the dimensional changes and distortion.

1.2.2.1 Washing temperature:

Water affects the second order of glass transition temperatures (T_g) of textile fibres. Some typical dry and wet T_g values for common washable fibres are give in Table1.1, together with their recommended washing temperatures.

Table 1.1: Principal dry and wet glass transition temperatures for common fibres and their recommended wash temperature [Bishop, 1995]

Fibre type	T_g (°C) in dry air	T_g (°C) in water	Recommended wash temperature range (°C)
Cotton	None before thermal	< 0	All temperatures up to 60
Viscose Rayon	decomposition at ~ 200	< 0	
Cellulose triacetate	~ 180	~ 90	Up to 40
Cellulose diacetate	~ 180	~ 60	Up to 40
Polyester	~ 100	~ 85	Up to 60
Nylon 6	~ 56	Close to 0	Up to 60
Nylon 6.6	~ 62	Close to 0	Up to 60
Acrylics	70-90	50-70	Up to 40
Wool	None before thermal degradation	< 0	Up to 40

The extent to which the laundry temperature affects the physical and dimensional properties of the textiles depends on chemical and physical structure of that particular fibre. The knitted cotton fabrics were found to shrink more with increase in temperature while silk gave maximum area shrinkage at 35°C [Quaynor, 2000]. The influence of laundry temperature on handle value has been also studied for the fabrics and it was found that samples washed in hot water (60°C) were whiter, softer and smoother than those laundered in cold water (21°C) [Morris, 1970].

1.2.2.2 Washing products formulation:

Washing products do significantly modify the physical effects of the mechanical action applied during washing. Foam, generated by agitating surfactant solutions, cushions fabrics against the beating and rubbing action, thereby reduces fabric damage. The volume and quantity (bubble size distribution and stability) of the foam generated is of course dependent on the surfactant and antifoam types and levels used in a given formulation, as well as on product dosage, and the mode of mechanical action. It should be borne in mind that excessive foam cushioning reduces soil removal as well as minimising fibre damage [Bishop, 1995]. The effect of using detergent during laundry is minimal during the first five laundry cycles but for prolonged wash ageing the use of detergent may have significant influence on the dimensional stability and fabric shrinkage [Higgins *et. al.*, 2003].

1.2.2.3 Water hardness:

It has long been recognised that calcium and magnesium ions, present in supply waters are deleterious to laundry process. The precipitation of insoluble calcium and magnesium ions results not only the waste of soaps and anionic detergents, but these salts are often also deposited on and bound to textile fibres, where they build up to cause greying or yellowing and the development of rancid, fatty odours on the fabric.

If the rinsing at the end of washing is carried out in hard water, hardness ions are invariably bound to fibres containing carboxylic groups or other anionic sites provided by dyes and fluorescers. All fibres also carry dried-on hardness ion from the last rinse into the next use, wear and subsequent wash cycle. The hardness ions present in washed textiles provide potential sites for the attachment of anionic soils during use. Especially in knitted fabrics the deposition of high level of these ions can show effects on fabric handle attributes like stiffening [Bishop, 1995].

1.2.2.4 Drying method:

In most countries, drying is still done mainly by hanging the clothing in the open air (line drying), but in western countries, drying is being increasingly being done using tumble dryers. In tumble drying fabric is further subjected to the mechanical action, which cause changes in dimensional characteristics of the fabrics. Studies of relaxation process of cotton woven and knit fabrics have shown that tumble drying causes greater levels of shrinkage than line drying in first few laundry cycles [Collins, 1939; Hearle, 1971]. The level of shrinkage continues to increase if the fabrics are tumble dried below normal moisture regain [Higgins *et. al*., 2001; Leah, 1986]. Tumble drying is beneficial in reducing the level of wrinkling but it increases damage to the fabrics as evident from the increased lint loss as compared to line drying. The over drying of the textiles in tumble dryer was found to be beneficial to the appearance of the fabrics, with lower levels of wrinkling being exhibited after tumble drying for 45 minutes in compared with 30 minutes [Higgins *et. al*., 2003].

Tumble drying also has influence on handle of the acrylic knitted fabrics. Tumbled fabrics have softer hand and a limper drape. It was also noted that fabric hand would become progressively soft if the fabric is tumbled at temperatures above 60°C [Brown, 1970].

The above discussion concerning the laundry parameters shows that selection of laundry parameters according to the type of textile is very important. Machine laundering left fabrics with an uncomfortable hand as a result of harsh mechanical action and the removal of the finishes applied on the fabric when the synthetic detergents removed dirt and oil. Especially for knitted garments, dimensions stability, deterioration, pilling, deterioration of fabric handle, and shape distortion, after laundering are perceived by consumers as caused for concern. These consumer concerns suggest a need for improvement in the care of textiles during domestic washing. The household softening agents, so called fabric softener or fabric conditioner were introduced in market so that consumers can "refinish" their own textile products in an attempt to capture the elusive but desirable fabric hand.

1.3 Fabric softener:

With repeated laundering, clothes lose some of their original mechanical properties because of the intense stress they experience during laundering and the textile fibres tend to entangle. Through the drying process, the fibers remain entangled and clothes become stiff. Textiles made with synthetic fibers tend to get charged with static electricity during tumble drying causing static cling [AATCC Technical Manual, 2010]. As a result of concerns related to these issues of the textiles during laundry, textile finishing is accomplished in home laundering with the goals of reducing the influence of laundry by many available laundry aids. A fabric softener is one such product designed to increase the consumer's satisfaction with the wash.

Fabric softeners were introduced to the United States market in the early 1950s and 10 years later in Europe to modify the hand and to restore lost physical properties of laundered clothes [Ward, 1957; Simpson, 1958; Egan, 1978]. This type of product is also widespread in Japan and is still expanding and growing worldwide. By coating yarn and fibres with lubricants and humectants, softeners make fabrics feel smooth, soft and flexible by internal lubrication of the fibres. The most appropriate definition for fabric softener was given by Laughlin, 1991.

“Fabric softeners are the products which impart to clothing and fabrics a feel of handle which is soft and pleasing during wear or use”.

1.3.1 Types of fabric softeners:

Fabric softeners can be roughly classified in two groups- nonpermanent softener which can be removed fairly easily by every washing and the permanent softeners which still exhibit a distinctly soft handle even after several washes [Prasad A.K., 2007]. The fabric softeners used during the laundry process are non permanent type of fabric softeners.

Technically, there are three types of fabric softeners. They are classified according to the electrical charge possessed by the hydrophilic portion of the softener molecule. The softeners are referred to as anionic, cationic, or nonionic [Hallows H.B., 1965].

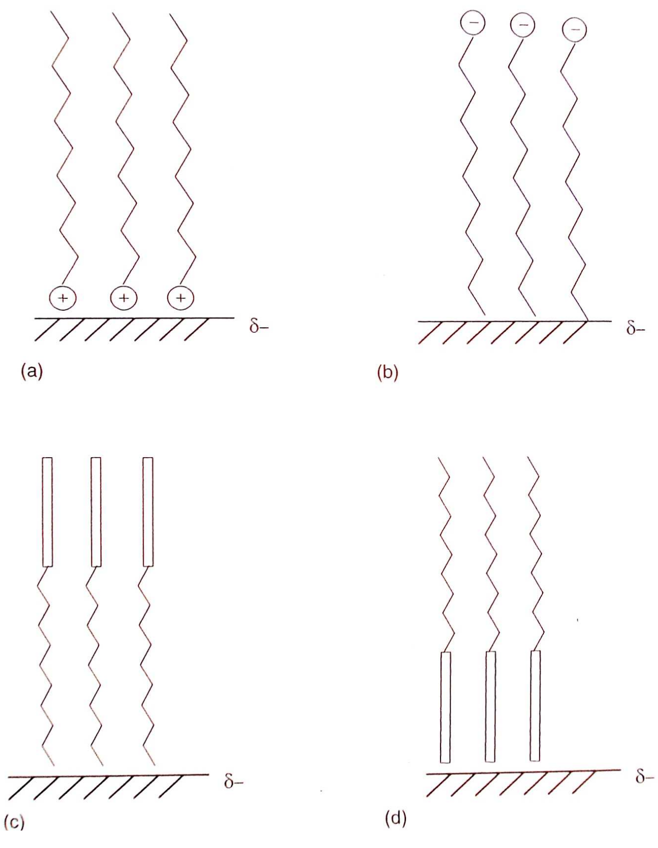


Figure 1.2: Schematic orientation of softener on fibre surfaces. (a) Cationic softener (b) anionic softener (c) non-ionic softener at hydrophobic surface (d) non-ionic at hydrophilic fibre surface [Schindler, 2004]

Cationic softeners orient themselves with their positively charged ends toward the partially negatively charged fibre (zeta potential), creating a new surface of hydrophobic carbon chains that provide the characteristic, excellent softening and lubricity seen with cationic softeners.

Anionic softeners on the other hand, orient themselves with their negatively charged ends repelled away from the negatively charged fibre surface. This leads to higher hydrophilicity but less softening than with cationic softeners. The orientation of non-ionic softeners depends upon the nature of the fibre surface, with the hydrophilic portion of the softener being attracted to hydrophilic surfaces and the hydrophobic portion being attracted to hydrophobic surface [Schindler, 2004].

The laundry softeners can be classified in three categories according to method of applying softeners to textiles: - (a) water cycle softeners – softeners that are used in the wash cycle, (b) rinse cycle softeners – softeners that are used in the final rinse, and (c) dryer sheet fabric softeners – softeners that are used in the dryer.

The rinse cycle softeners were the first to appear in the market, followed by the water cycle softeners. Rinse cycle softeners are the most popular and the most effective way to soften the fabrics. The dryer sheet fabric softeners, which are fabric softeners saturated onto sheets of a non-woven fabric or polyurethane foam, were introduced to the market in the early 1970s [Williams, 1982].

The effects of these three fabric softener treatments on softness and static electricity vary. The rinse cycle cationic softeners formulated with quaternary ammonium compounds yield the highest softness, which make them most popular and acceptable category of fabric softener, but they are less convenient to use because they are added into the final rinse process [Baumert & Crews, 1996]. Wash cycle softeners, in the same formulation of dihydrogenated dimethyl ammonium compounds, need two to three times more softener agents to reach the same level of softness compared to the rinse cycle softeners, which makes laundering more expensive, and they also have the tendency to decrease the cleaning properties of the detergent used. However, wash cycle softeners are convenient to use because they are added at the very beginning of the laundering process. As for dryer sheet fabric softeners, they are convenient to use and yield the best anti-static properties because of the formulation of imidazolinium compounds used in the dryer type softeners [Williams, 1982]. However, dryer sheet fabric softeners are less effective in softening fabrics than rinse cycle softeners because of erratic deposition of softener and less lubrication on the fabric.

1.3.2 Mechanism of Fabric Softeners (Cationic type):

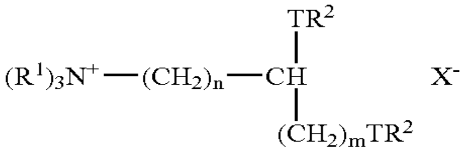
Liquid fabric softeners function by depositing cationic active compounds or ingredients onto fabric surfaces during the rinsing cycle is the most popular category of fabric softener since many years.

a) Chemical aspects:

The majority of commercial fabric softeners consists of dispersion of dialkyl quaternary amonioum salt which is characterized by an ammonium group attached to one or more long chain hydrocarbons (Hughes, 1965). The preferred cationic fabric softening compounds are those having two or more alkyl or alkenyl chains each having an average chain length equal to, or greater than C_8, especially C_{12-28} alkyl or alkenyl chains connected to a nitrogen atom.

Early fabric softener formulas were simple dispersion of fatty materials like dehydrogenated tallow dimethyl ammonium chloride (DHTDMAC) better known as quaternary ammonium compounds or quarts.

Later on quaternary ammonium salts containing ester groups have replaced traditional cationic surfactants in fabric softeners. In 1977, esterquats based on triethanolamine (TEA) were patented for use as fabric softener [Casanova, 1970]. The new generation of fabric softening agent combines a good environmental profile with the structural features required for an effective fabric softener [Mishra and Tyagi, 2007]. The ester- amide quaternaries have certain advantages over all the conventional and old generation cationic fabric softeners such as easier preparation, cheaper raw materials, excellent biodegradability, OECD approval, and ease of formulation etc [Mishra and Tyagi, 2006].



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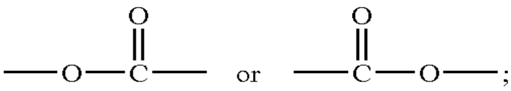


Figure 1.3: Ester softening compound [Boardman *et. al.*, 2008]

One preferred type of ester softening compound is shown in Figure 1.3. Each R^1 group is independently selected from C_{1-4}, alkyl or hydroxyalkyl or C_{2-4} alkeynyl group; wherein each R^2 group is independently selected from C_{8-28} alkyl or alkenyl groups, X^- is any suitable anion including a halide, acetate or lower alkosulphate ion, such as chloride or methosulphate [Boardman et al., 2008].

b) Deposition at fiber surface

The physical arrangement of the usual cationic softener molecules on the fibre surface form close-packed monolayers or multilayer is shown in Figure 1.4.

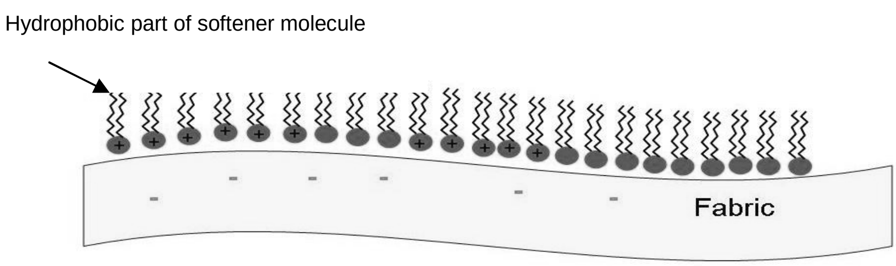


Figure 1.4: Schematic orientation of cationic softener on fabric surface

Their hydrophilic parts containing quaternary ammonium adsorb readily on negatively charged fiber surfaces. The long aliphatic chains are then oriented towards the outside of the fiber which act as excellent boundary lubricants between yarns and fibers [Linfield, *et. al.*, 1958; Prasad, 2007].

A typical rinse conditioner consists of a concentrated dispersion of gel phase (L_β) particles in water. These positively charged liposomal particles are attracted to the negatively charged fabric surface. As the fabric is removed from the solution, the water dries from the surface, resulting a thin layer around each fibre. As drying continues the air-water interface is ruptured by the deposited particles. Softener molecules spread rapidly from the air-water-particle three phase contact line across the air-water interface as the interface moves past the particle. The softener molecules form a well ordered Langmuir film at the air-water interface. As the remaining water supporting this monolayer evaporated, the surfactant molecules are transferred as a well ordered film to the fabric surface [Kong *et. al*., 1997].

Ultimately, the effectiveness of a fabric softener is dependent on the amount that is adsorbed onto a fabric surface. Rinse added softener target a delivery of 0.2-0.25% of softener active ingredient on weight of fabric [Bishop, 1995]. With optimal conditions, most of the fabric softener (up to 80%) is adsorbed onto the fabric surface thus producing the desired softening and anti-static properties [Obendorf, 2009].

The adsorption level of the cationic surfactants on different fibres has been reported in following descending order: - Wool> rayon> cotton > polyester > acrylic [Schindler, 2004]. But it is still difficult to predict the adsorption level of the softeners on the textiles surface as it depends on factors like fiber type, construction, type of yarn used and textile parameters, laundry conditions etc.

A microscopic study of distribution of laundry fabric softener on cotton fabric shows that the fabric softener was distributed throughout the cotton fibers with higher concentrations of fabric softener observed in the lumen and crenulation than in the secondary wall and non-crenulated fiber surface. This distribution of fabric softener is consistent with deposition on both external fiber surfaces and internal fibril surfaces. The deposition and final surface coverage is strongly dependent on the pH value of the washing medium. Repeated treatment cycles with fabric softener using a higher pH washing media resulted in higher concentrations of fabric softener on and within the cotton fibers. Neutral or lower pH washing media resulted in a somewhat constant concentration of fabric softener on and with cotton fibers with increased number of treatment cycles. Differences in perception of softness of the treated fabrics are not explained by differences in distribution of the fabric softener; it appear that there is an optimum amount of softener to achieve the desired sensory response and that further deposition buildup does not increase perception of softness [Obendorf, 2009].
The evenness of application appeared to be related to slow rates of exhaustion. Evenness can be demonstrated visually by a bromo-phenol blue staining technique [Linfield, 1958].

Fiber characteristics such as molecular structure, surface energy, surface and internal morphology, capillary structure, and fiber packing in the yarn structure play an important role for the adsorption of fabric softeners during the laundering process. Cationic softener deposition is a combination of two phenomena- molecular ion attraction which depends on electro-kinetic properties of textiles and physical adsorption which depends on the moisture transmission behavior of textile. Electro-kinetic and liquid uptake of textiles are represented by the parameters Zeta-potential and liquid absorption ability respectively.

1.3.2.1 Zeta-potential:

The electrokinetic surface properties of a solid material (fibres) are generated by the electrochemical double layer (EDL), which exists at the phase boundary between a solid and solution containing ionic moieties in which the solid is placed. The net charge at the surface of a material in contact with a polar medium is governed by three processes: association/dissociation of surface chemical groups, adsorption of ionic species, and dissolution of ions from the material into the solution [Ribitsch *et. al*., 1998].

Zeta potential is the electrical potential at the shear plane between a charged surface and a liquid when moving with respect to each other; this was explained by Stern by his double layer model for negative surface charge [Hunter, 1981].

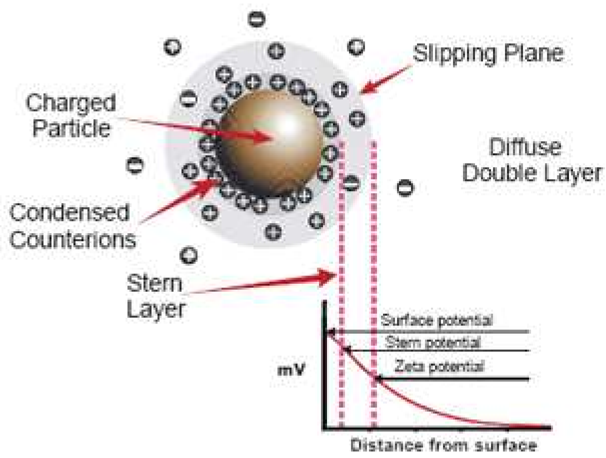


Figure 1.5 Distribution of ions around a charged particle [Bioresearch online, 2005]

Figure 1.5 shows a schematic detailing the distribution of ions around a charged particle in solution. The layer closest to the surface of the charged particle is composed of condensed or absorbed counter ions. The outer boundary of this layer is defined as the Stern layer. The second layer is composed of ions that diffuse with the charged particle. The boundary of this layer is defined as the slipping plane, and it is the summation of charge within the slipping boundary that defines the strength of the electrostatic interaction, i.e. surface charge +

absorbed ions + diffusing ions. The charge or electrostatic potential at the slipping plane is defined as the zeta potential.

1.3.2.1.1 Determination of Zeta-potential:

The zeta potential can be determined by four kinds of measurements- 1. Fall potential 2. Streaming potential 3. Electro-osmosis 4. Cataphoresis [Harris, 1958]. The zeta potential measurements of fabrics are made by measuring the streaming potential [Guo *et. al.*, 2009]. The determination of the streaming potentials, which are produced by the electrical fields set up when a liquid flows past a charged surface, indicates the nature of the surface charge [Capablanca, 1986]. Various studies had been carried out related to zeta potential of cellulosic fibres, wool and synthetic fibers and the negative zeta potential for all these fibres was reported [Algie *et. al.*, 1974; Bismarck *et. al.*, 2002; Bellmann, 2004; Hubbe, 2006]. The importance of the zeta potential for interaction of PET fibres with composite materials and for modification of surface properties has been also investigated [Campagne *et. al.*, 2002; Teli, 1995; Stephe *et. al.*]. The zeta-potential of textile fibers at neutral pH is given in Table 1.2.

Table 1.2 Zeta potential of textile fibres [Jacohasch, 1969]

Fibre	Zeta-potential (mV)
Viscose-Rayon	-22
Glass	-28
Nylon-6	-33
Cellulose triacetate	-37
Polyester	-52

The natural fibres have the smaller hydrophilic character and they are less reactive than the regenerated ones, so the zeta-potential of cotton is the highest. It has been found that even if electrostatic interactions are not the driving force; the surfactant adsorption can be investigated, due to the changes in the net surface charges during the adsorption process. It can be assumed that the surface potential is mainly responsible for different kinds of solid–liquid interactions. The cellulose fibres are negatively charged due to the adsorbtion of hydroxyl-groups. The adsorption of water or electrolyte solutions causes an interfibrillar swelling of the surface layers and so the size of the active surface is increased, but the nature of ionic species should not change. The swelling itself causes a reduction in zeta-potential because of the shift of the shear plane into the liquid phase and can therefore be used for characterization of the accessibility of the ionic groups by means of measured pH- zeta potential functions [Stana-K. *et. al.*, 2002].

This negative zeta potential of the polyester fibre is related to the presence of carboxylic groups (-COOH), which dissociate in basic pH in the presence of the electrolyte solution [Benistant, 2010].

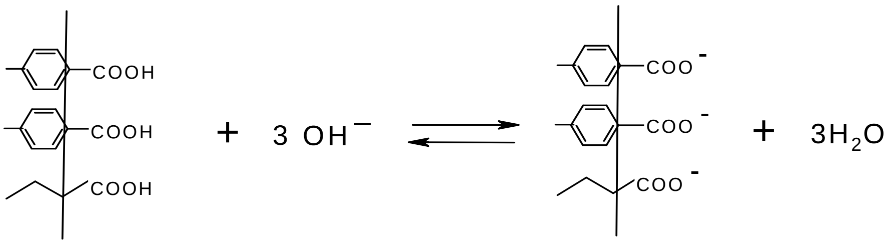


Figure 1.6 Dissociation of carboxylic groups in basic pH [Benistant, 2010]

It can be assumed that the surface potential is mainly responsible for different kinds of solid–liquid interactions. Electrokinetic potential of the fibre surface is an appropriate tool to describe the purification of textile fibres and the interaction properties that are modified by different textile finishing processes [Gonzales-Caballero, 1988; Espinosa-Jimenez, 1991; Ribitsch, 1996].

The above studies show that the zeta-potential has been used to study the deposition of textile finishes still there are no studies about the influence of electrokinetic properties on the interaction between fibres and laundry softeners. It has been found that even if electrostatic interactions are not the driving force; the surfactant adsorption can be investigated, due to the changes in the net surface charges during the adsorption process. In this thesis, influence of zeta potential on laundry-softener deposition is investigated.

1.3.2.1.2 Interaction of Zeta-potential with softener:

Zeta-potential of the fibre depends on the pH, electrolyte concentration and the surfactant presence on the surface of the fibre. Anionic surfactants increase negative zeta potential, the effect increasing with increase in effective carbon chain length up to an optimum. Cationic surfactants decrease negative zeta potential and in sufficient concentration can change the sign of the charge. Nonionic surfactants exhibit a slight cationic effect on zeta potential [Harris, 1958].

1.3.2.2 Liquid up-take by textiles:

The second phenomenon involved in liquid softener deposition on the textile is liquid up take behavior of a textile. In this respect, total amount of the liquid that can be absorbed is important and also the speed of adsorption process. Liquid uptake into a material involves many processes and parameters. Initially, the process of wetting, the exchange of a fiber air interface with that of a fiber liquid interface, must take place. Directly resulting from wetting is the contact angle. The contact angle has been shown to play an important role not only in the determination of whether a liquid from an infinite reservoir will penetrate a material, but also in determining the rate of liquid flow within the material and the amount of liquid absorbed into the material. If the contact angle is less than ninety degrees the liquid will begin to flow into the material. If this flow is spontaneous, i.e. no outside pressure difference resulting in the imbibition of the material, then the flow is referred to as wicking [Kissa, 1996; Perwuelz, 2000].

When liquid comes into contact with fabric, the liquid starts to rise in capillaries to an equilibrium height (h_{eq}), which can be expressed by Jurin's law [Kawase *et. al.*, 1986].

$$h_{eq} = \frac{2\gamma Cos\theta}{r\rho g} \qquad (1.1)$$

If water density is considered as 1 gm/cm^3 then:

$$w_{eq} = \varepsilon x_1 x_2 h_{eq}$$

Where: w_{eq} = weight of liquid at equilibrium, ρ =Liquid density, γ = surface tension, ε =Porosity, x_1 and x_2 = dimensions of the lower base of the fabric layer, r = pore radius, θ = Contact angle.

The equation (1.1) shows that contact angle and pore radius are two key parameters, responsible for the liquid transmission through textiles.

1.3.2.2.1 The influence of various textile parameters on liquid transmission through textiles:

The pores within the structure are responsible for liquid flow through a material and the size and connectivity of the pores in the fabric influence how fast and how much liquid is transported through the material. The porosity of a material is defined as the fraction of void space within the material [Hsieh, 1995].

The liquid adoption capacity and diffusion rate depends on the fabric characteristics like, fibre type, blend ratio, fibre fineness, cross sectional shape of the fibre, yarn compactness and fabric structure [Su *et. al.*, 2007].

The wicking mechanism of knitted fabrics has been also investigated and saturated and unsaturated regions were defined. It was observed that, during the initial wicking period, the liquid fills the loops of the knitted fabrics and then there is a small area in the leading water front where liquid travel along the yarns. With the laps of wicking time, the liquid transport in the inter-yarn pores tended to cease because of the balance between gravitational force and capillary force. However, liquid continued to travel in the intra-yarn pores due to high capillary pressure until the equilibrium between gravitational forces and capillary force was reached in this region. Thus, there formed a saturated wicking zone where liquid filled both the inter-yarn pores and intra-yarn pores and an unsaturated wicking zone where liquid filled only intra-pores in vertical wicking [Zhuang *et. al.*, 2002].

1.3.2.2.2 Influence of fabric softener on liquid up take phenomenon:

The influence of fabric softener on the liquid transportation through textiles has been studied a little before. Use of fabric softener makes hydrophilic fiber like cotton more hydrophobic and water repellent. It decreases the water absorbing capacity of the fabrics and increased its contact angle [Kawase *et. al.*, 1986] [Aycock *et. al.*, 1972].

The experimental results of wicking with n-octane showed that fabric conditioners do not influence the absorption capacity of the fabric, indicating that the physical parameters of the fabric, such as porosity and pore size are not changed by the use of fabric conditioner. On the other hand there is pronounced effect of the fabric conditioners on the wicking rate. There is a large reduction in the wicking rate when using a liposomal fabric conditioner but not significant effect when using the isotropic formulation. This clearly shows the importance of fabric conditioner type and indicates that conditioning of cotton does not necessarily change the wettability and resulting wicking rate of the fabric [Mareen *et. al.*, 2002].

1.3.3 Effects of fabric softeners on fabric properties:

The effects of household fabric softeners on textiles have been studied in various areas, such as, fabric weight, fabric strength, dimensional stability, wrinkle recovery, pilling, whiteness, hand, static electricity, odor, absorbency, flammability, and stain release.

1.3.3.1 Effects on fabric weight and fabric strength:

The effects of three fabric softener treatments on the properties of three types of flame retardant finished woven cotton fabrics after 75 laundering cycles was investigated by Simpson and Silvernale. The three fabric softeners were different in their formulation for adding during wash cycle, rinse cycle or dryer spray process. The results regarding fabric weight showed that, after 75 launderings, the fabric treated with the dryer spray softener lost weight, but both rinse cycle softener and wash cycle softener resulted in gaining weight. The authors also examined the effect of fabric softeners on tensile strength. The results showed that the laundering without softener and the use of the dryer spray resulted in better strength retention in the warp direction than the laundering with the rinse cycle or wash cycle softeners. For the filling direction, the laundering without softener resulted in better strength retention than the use of softeners [Simpson and Silvernale, 1976].

These results were similar to the study of Chiweshe and Crews (2000), which found that the tensile strength of the cotton flannel and polyester woven fabrics decreased significantly after the fabrics, were treated with rinse cycle softeners. The authors suggested that the lubrication of the softener on fibers increased fiber mobility, resulting in weak spots and fiber slippage, which caused yarn to break more easily and reduced the tensile strength of the fabric [Chiweshe and Crew, 2000].

1.3.3.2 Effect on dimensional stability:

The effect of fabrics softener on dimensional stability of the fabrics was found contradictory in the literature. It depends on the type of textiles.

The washed flame retardant fabrics without a softener and with the dryer spray show a higher degree of shrinkage. The rinse cycle softener and the wash cycle softener gave better dimensional stability in both the warp and filling directions of the fabric. The authors suggested that the application of wash cycle and rinse cycle fabric softeners helped stabilize the fabric and minimize the shrinkage of the tested flame retardant-finished cotton fabrics [Simpson and Silvernale, 1976].

This result was consistent with the study conducted by Kaiser and Riggs (1980), who investigated the effects of wash and rinse cycle fabric softeners on the dimensional stability of fire retardant flannelette fabric and tricot fabric for use in children's sleepwear. The findings showed that the rinse cycle softener provided the most favorable results regarding dimensional stability for flannelette fabric. The authors suggested that the rinse cycle softener might leave some form of film on the warp yarns which prevented progressive shrinkage to some extent. However, they found that the tricot fabric was not stable in dimension after the treatments of wash and rinse cycle softeners. A significant shrinkage was observed in the course direction of the fabric [Kaiser and Riggs, 1980].

1.3.3.3 Effect on wrinkle recovery:

The inclusion of rinse cycle and dryer sheet fabric softeners influenced wrinkle recovery of the 100% cotton and the polyester/cotton woven fabrics with and without the durable press finish after three laundering cycles. The authors used the recovery angle test method and found that rinse cycle fabric softeners markedly improved wrinkle recovery angle in most test fabrics. The dryer sheet fabric softeners only significantly improved the wrinkle recovery angle of the 100% cotton broadcloth without a durable press finish, and showed no effect on other fabric types. The authors suggested that these results were possibly caused by non-uniform application of softener from the dryer sheet. [Baumert and Crews, 1999].

The results from the Higgins *et. al.* were not the same. They reported that use of rinse cycle softener during laundry increases the amount of wrinkling after line drying. It was claimed that when liquid softener is applied during rinsing cycle, fibres and yarns are at their most swollen state, and are jammed against each other within the fabric structure. It is possible that cationic softener forms a coating that spreads across the adjacent fibres and holding them in a more rigid configuration. This may "lock in" wrinkles that have formed in the wet fabric; without the action of tumbling to break these locks, this causes worse wrinkling after line drying [Higgins et al., 2003].

1.3.3.4 Effect on pilling:

The effect of softeners on pilling is inconclusive and contradictory in the literature. Smith and Block stated that fabric softeners may sometimes be effective in reducing pilling, since they lubricate the surface of the cloth and reduce the abrasive forces. On the other hand, they also promote the migration of fibers within spun yarns, especially synthetic fibers, so this technique is not always effective [Smith and Block, 1982].

Niemann and staff members of the Hosiery and Allied Trades Research Association (HATRA) who studied the effect of household softeners on pilling found that an overdose of fabric softener increased fabric pilling [HATRA, 1984; Niermann *et. al.*, 1986].

Peberdy also reported that cationic fabric softeners limit inter fibre friction and tapering entanglements of fibres which can result decrease in a pilling of the fabrics [Peberdy *et. al.*, 2008].

Further more Chiweshe and Crews reported that visual examination of the specimen showed that the softener treatment perceptibly influenced the size and nature of the pill formed on the cotton flannel fabric. Specifically, cotton flannel laundered with rinse cycle softeners tended to form bigger and softer pills than the specimen treated with dryer sheet softeners or without fabric softeners, which formed smaller and harder pills. However, when the researchers analyzed the experimental data statistically, they did not find a significant difference in the effect of softener treatment on pilling ratings. Similar results were found with cotton jersey, cotton interlock knit, and cotton/polyester jersey fabrics. The authors also indicated that softener dosage had no significant effect on the amount of pilling or on the size and nature of pills formed on cotton flannel and cotton interlock knit [Chiweshe and Crews, 2000].

1.3.3.5 Effect on fabric-hand:

Daukantiene *et. al.* showed that cyclic washing causes the deterioration of textile hand parameters. A significant deterioration in textile hand was observed after 20 washing cycles. Fabric finishing with chemical liquid softeners significantly influences the slower deterioration of the hand parameters during the use of the fabric [Daukantiene *et. al.*, 2005].

The influences of softening agents on yarn pull out force of a plain weave fabric had been investigated. It was found that softening treatment reduces the inter yarn adhesion at cross over and inters sliding friction by 40%. The use of fabric softener also reduces shear modulus and pull-out yarn tensile modulus by approximately 75% of the original value [Sebastian *et. al.*, 1986]. The study by Sabia and Pagliughi showed that Kawabata Evaluation System (KES) is sensitive enough to discriminate between different classes of the silicone softeners [Sabia and Pagliughi, 1987]. We found limited literature on the influence of laundry softener on the fabric-hand. In this thesis the influence of fabric softener on textile hand as a result of change in mechanical properties is presented.

The change in consumer perception with respect to textile-hand can be evaluated by the sensory evaluation. Hence in the next section, a brief introduction of sensory evaluation and it's importance in textiles is being represented.

1.4 Sensory evaluation:

Sensory engineering was founded in Japan 30 years ago and defined as Kansei engineering or Kansei ergonomics. It can be applied to investigate the relationship between customer's feeling and demands with product function and appearance. This technique has been widely used in consumptive products development to meet the trend of market change towards the consumer oriented [Mitsuo, 2002; Wang *et. al.*, 2008].

"Sensory evaluation can be defined as a scientific discipline used to evoke, measure, analyze, and interpret reactions to the characteristics of products as they are perceived by the sense of sight, smell, taste, touch, and hearing" [*Stone et. al.* , 1993].

Initially, sensory evaluation analysis was developed for studying the reaction of consumers to certain characteristics of food products. These reactions are generally in the form of scores given to attributes or descriptors perceived in the food stimuli. Based on the success of sensory evaluation in food industry, this research topic has been recently developed in other industrial areas for characterizing quality of products and providing new design criteria and sales arguments. Nowadays, apart from food industry, sensory evaluation is widely used in the fields of cosmetic industry, textile industry, chemical industry, packaging techniques, sportive products design, and automobile industry. In all these industrial sectors, automobile industry plays some leading role in the development of sensory techniques in product evaluation. In many big international automobile groups can be found research department specialized in characterization and aggregation of the reactions of customer's five senses to different part of automobiles. The results of this multi-sensory study are taken into account in the new design of personal cars for supporting efficient, safe and comfortable travel [Zeng *et. al.*, 2008].

There are four basic elements of sensory evaluation: evaluation product, evaluation panel, evaluation target, and evaluation environment. The development of an attribute list, description of the attributes and panel training are the crucial steps of descriptive sensory evaluation test [Philippe *et. al.*, 2004]. According to different cases of these factors sensory evaluation can be divided into two levels [Zeng *et. al.*, 2004];

- Design oriented sensory evaluation (DOSE)
- Market oriented sensory evaluation (MOSE)

DOSE and MOSE

Design oriented sensory evaluation is done by trained panel composed of experienced experts or consultants in the expertise of judging industrial products on a number of analytical and non-hedonic linguistic descriptors in a controlled evaluation environment, such as evaluation laboratory. The evaluation target of design oriented sensory evaluation is to obtain the basic sensory attributes of products to improve the quality of product design and development. It is necessary to interpret the relation between different panels. This relationship is generally determined using a genetic algorithm with penalty strategy. It can be considered to be a dictionary for understanding between different panels. Using this dictionary, an evaluation term used by one panel can be transformed into one or several terms used by another panel. It will be very helpful for solving commercial conflicts between producers and consumers at the level of understanding of evaluation terms (B2B: Business to Business). Market oriented sensory evaluation is given by untrained consumer panels using analytical and hedonic descriptors according to their preference on the products to be evaluated in an uncontrolled evaluation environment such as super markets. The evaluation target of market oriented sensory evaluation is to obtain the preference degree of consumers in order to forecast market reaction to the evaluated product. Afterwards the key issue is to compute data provided by a DOSE in order to forecast the consumers preference (B2C:Buissness to Consumer) assuming the data are obtained for a precise context and end use for the industrial product, since sensory evaluation is context dependent. Now a day's sensory evaluation is widely used in industry especially for quality inspection, product design and marketing. It is also concerns other specialized areas such as risk evaluation, investment evaluation and safety evaluation [Koehl *et. al.*, 2005].

1.4.1 Sensory evaluation in textiles:

The textile sector is also not untouched by sensory evaluation. When a person runs their finger across the surface of a fabric, or when we travel out on a shopping trip for clothing where we engage in a selection process that involves touching and trying on clothing, a complex multi-sensory, emotional and cognitive experience takes place. A memory is stirred, an emotion, feeling and association is evoked and a decision is made, an impression becomes embossed in the mind. When we shop for clothes for example, this eruption of activity extends itself into a manifestation of building and development of the 'self'. Decisions and motivations are based on anticipated reality of preference, personality, emotion and moods, for audience or non-audience participation.

In the textile/garment industry, fabric evaluation is performed in two ways:

- Subjective Evaluation
- Objective Evaluation

Fabric evaluations carried out by people (subjects) are usually called subjective evaluations, whereas evaluations made by using instruments (objects) are called objective measurements. The objective evaluation is performed by measuring a set of physical parameters on fabrics;

particularly the mechanical parameters on KES (Kawabata Evaluation System).These parameters include tensile properties, bending properties, shearing properties, compression properties, surface properties. In contrast Kim and Vaughan applied an alternative method to selecting properties to be measured among all parameters measurable in a textile laboratory, they focused on those whose correlation coefficient with subjective assessed sensory evaluation of fabric hand were higher than an arbitrary critical value [Kim and Vaughan, 1979]. This method had the advantage of taking the human factor into consideration, but it is well established that subjective human judgments brings uncertainty and bias into conclusions.

Pan and Zeronian were combining principal component analysis with D-Optimal method and have proved that 16 parameters measured by KES-FB system give data overlap. They have extracted nine parameters that give sufficient characterization of fabric [Pan *et. al*., 1993].

Tester and De Boos reported that "for routine measurements and applications of those fabric objective properties particularly relevant to industry, only a fraction of the information obtained from KES system was required". The CSIRO in Australia developed its own routine fabric measurement system named FAST (Fabric Assurance by Simple Testing). This is a much simpler system compared with the KES and measure fewer parameters (Tester and De Boos, 1990].

The surface properties of the textile in context with touch-handle have been measured using different devices. KES surface and friction tester (KES-FB4) and Textile Friction Analyser has been used to reproduce the friction of a finger touch on a fabric [Ampureo and Derler, 2002]. Ramkumar *et. al.* developed a polymeric human finger sensor with realistic shape and contours to measure the frictional properties of textiles and to evaluate frictional feel [Ramkumar *et. al.,* 2003]. Bueno et. al. proposed a non-contact method to study the state of the fabric. This method gives roughness–friction criteria, based on the principle of a "blade-disc" type tribometer, where the analyzed surface is the disc [Bueno et. al., 2000].

The literature shows that objective-evaluation of textile-hand is still a area to be explored. In this thesis, in chapter 4, we will define tracking criteria to select the most relevant mechanical parameters to predict the textile-hand.

There are two fundamental psychological dimensions that comprise all sensation produced by contact of clothing fabrics with the skin. The first qualitative (descriptive) and relates to the specific sensory quality or attribute that is being perceived, e.g., roughness, stiffness etc. The second is quantitative (intensive) in nature and relates to the perceived magnitude of the sensation, e.g., very rough, slightly stiff etc. Both dimensions of experience are involved in the perception of fabrics on the skin, and the psychophysical methodologies used to identify and define these dimensions are critical factors determining the validity of the data and the conclusions that can be drawn from them [Cardello *et. al.*, 2003].

The sensory study of textiles started in 1926 and is still continuing today, not only by consumers but is also used in textile production units for quality assessment [Bishop, 1996]. There is no standard technique for the sensory evaluation of the textiles, but still it can be classified in two groups: (a) Creating a sensory evaluation scale and comparing the samples using it (b) ranking the samples by paired comparison [Sular *et. al.*, 2007]. Harada tried to describe different fabric attributes and translate them into ordinary terms used by the consumers [Harada *et. al.*, 1971].

In sensory evaluation of textiles, the establishing of the list of attributes is crucial. Attributes should account for consumer's perceptions and be understood by professionals for efficient communication. The most appropriate attributes for fabric description from the terminology associated with both experts and novices was selected by some of the researchers. It was found that perceptive organization of the handle of the fabrics was similar regardless of the level of expertise; It was found that the most relevant dimensions of the haptic space were labeled: soft harsh, thin thick, supple stiff showed that these terms may have a high communicative value and that they should be considered as core descriptors to be included in fabric description [Soufflet *et. al.*, 2004].

Still some of the researchers have reported that level of expertise plays an important role in sensory evaluation of the textiles. Yick *et. al.* studied subjective handle assessment and used a panel of 199 judges. They were divided into two groups based on their academic and industrial experiences in the textile and clothing industries: people who had less than five years of experience and people who had five or more years experience in the clothing industry. More experienced judges exhibited a higher percentage of significance and gave a higher level of overall agreement [*Yick et. al.*, 1995].

In the work of Cardello *et. al.* a standardized hand evaluation methodology was checked for its sensitivity and reliability and used to characterize military fabrics. Panelists participated in a six-month training program that consisted of training in the basic methodology and operational (manual) evaluation techniques employed in the Hand-feel Spectrum Descriptive Analysis method (HSDA). In order to assess the reliability and sensitivity of this method, they conducted a test-retest reliability study at the completion of training and to assess long-term reliability, two fabrics were tested again six month later. They concluded that in conjunction with the panel training program, result in a sensory hand evaluation method is highly sensitive and reliable over extended period of time [Cardello *et. al.*, 2003].

The improvement in tactile feel of the fabric by application of various chemical products has been recognized for many years. In the study of Philippe *et. al.*, seven finishing treatments were selected and applied to the same woven cotton fabric, and the sensory profiles showed significant differences between the touch of the treated fabrics and that of the non-treated one. The effects of finishing products were in accordance with the manufacturers' technical specifications and with the finishing industrialists' expectations. The major advantage of this technique is that it provides a quantification of these modifications [Philippe *et. al.*, 2004].

Already significant research had been done on the sensory evaluation of the textiles for different applications [Hollies *et. al.*, 1979; Winakor *et. al.*, 1980; Paek, 1983; Harda *et. al.*, 1997; Sular and Okur, 2007]. It can be summarized that sensory evaluation represents a real perception of consumer towards the textile product but it is always associated with lack of consistency and standards.

1.4.2 Difficulties in sensory evaluation:

In sensory evaluation, the main difficulties can be summarized as follows:

- For an individual, the evaluation of sample (in numerical score or linguistic expression) gives a relative result depending on the comparison with the other samples. This score is significant only for one specific set of products and for one particular individual. It is not normalized in a general background.
- The terms used by different panels in an evaluation are not normalized either. Each panel uses its own terms. Even if they use a common term, its significant is not necessarily the same for them.
- In the same panel, the used terms are generally identical. However, the scales and the upper and lower bounds used by different individuals are often different, which should be unified to the same scale so that the aggregated sensory data for the panel could be obtained.

1.5 Relationship between objective tests and sensory evaluation:

As mentioned above, on one side, sensory evaluation gives the idea of consumer perception towards fabric handle but difficult to use because of lack of consistency and standard. On the other side, by standard objective test, we can obtain a set of precise quantitative data describing the fabric hand but their relationship with consumer perception is not completely discovered. Secondly, objective parameters are easier to define and can be correlated to material and process parameters. It was reported that the hand, liveliness and shape retention of fabrics are controlled in a large measure by 3 fiber properties: the initial stiffness, the change in stiffness as the deformation of the load is increased and the recovery behavior when load is removed [Hoffman and Beste, 1951].

In developing objective fabric hand measurements researchers have faced two major problems: how to measure fabric hand, which is a result of various mechanical properties, and which physical properties should be measured to best reflect hand. Hand is influenced by flexibility, compressibility, foldability, stretchability, pliability and surface friction. Some researchers suggest measuring all of these properties to determine hand. Other researchers propose instruments to objectively assess hand-related mechanical properties believed to be related to subjective ratings and preference of sensory attributes. [Alley and Mchatton, 1978; Kawabata, 1980; Bahery, 1986; Tester, 1990; Pan et. al., 1993].

It was found that extraction method (by measuring the friction and force required to extract the fabric through a slit) is an effective method for evaluating overall fabric hand. It is used for qualifying any changes in hand resulting from different weave structures or from the presence of finishes or wetness. Hand measured with this method may more closely approximate what human hands may actually feel in contrast with other objective measurements of hand-related physical properties. In other words, fabric hand values measured by the extraction method represent overall hand, not as one individual aspects of fabric hand (e.g., friction resistance, roughness, flexibility, and other related properties), but overall hand determined by a combination of various physical properties [Kim and Slaten, 1999]. Sular and Okur suggested a practical solution to predict fabric handle by using simple laboratory instruments. To predict total handle value, a two staged prediction procedure was suggested. The first stage was to calculate a new total handle value (THV_{SC}) by using subjective evaluation results of primary handle attributes called handle components (thickness-thinness, stiffness-softness, roughness- smoothness). In the second stage, THV_{SC} was used as a dependent variable to predict total handle from objective measurements, termed THV_{OBJ} (objective total handle value). The higher correlation coefficients between objective test results and THV_{SC} were interesting in comparison to the correlation coefficients between objective test results and THV_{SUBJ} values [Sular and Okur, 2008].

The relationship between friction and the tactile properties of woven and knitted fabrics had been investigated. The investigations were made using subjective tests such as the prickle test and the touch assessment with the thumbs and using objective tests such as the TFA (Textile Friction Analyzer) and the KES for woven and knitted fabrics. For knitted fabrics the rank correlations between friction and touch properties were systematically higher. This was attributed to the surface structure of the knitted fabrics. Principal component analysis showed that other parameters such as hairiness, bending, basis weight and thickness play an important role in these relations. In the study it was identified the difficulties in evaluating the touch properties of fabrics with subjective tests: problems such as repeatability, consistency of the panel subjects, or scaling of the properties have to be dealt with in order to have a reliable assessment. The paired comparison method has proved to be a good method for quantifying the properties of fabrics while overcoming some of these problems [Bertaux *et. al.*, 2007].

Many researchers had already reported that consumers are consistently able to detect differences in some mechanical properties of knits, such as lateral compression and fabric stiffness, through the subjective assessment of touch. The principles of the instrumental measurements of these properties are considered to be the same as situation arising when consumers handle fabrics. Hence, the existence of a strong positive correlation has been reasonably reported between the sensory assessment of fabric stiffness and the instrumental measure of fabric bending rigidity, the sensory assessment of fabric thickness and the instrumental measure of fabric thickness etc. [Cassidy *et. al.*, 1989; Chen *et. al.*, 1992; Hallos *et. al.*, 1990; Jacobsen *et. al.*, 1992; Kim and Piromthamsiri, 1984, Jeguirim *et. al.*, 2010].

On the basis of the above research Alimma *et. al.* assumed that a difference in a mechanical parameter can be linearly related to difference in the corresponding sensory quality as follow (table 1.4):-

Table: 1.4 Relevant mechanical and sensory parameters [Alimma *et. al.*, 2000].

Mechanical parameter	Sensory Attribute
Bending rigidity (B, $gf.cm^2/cm$)	Stiff/pliable
Fabric thickness (T, mm, at a pressure of 50 gf/cm^2)	Thick /thin
Compression energy (WC, gf cm/cm^2), EMC (%) and WC/ T	soft/hard
Coefficient of friction	Sticky/slippery

Alimma *et. al.* defined coefficient (K_i) to convert the sensory difference of two fabrics in to the corresponding mechanical property difference:-

$$X_i^{est} = X_{ic}(1 + K_i x_i)$$

Where i is the mechanical parameter to be measured by sensory test, X_i^{est} is the estimated value of the mechanical parameter i of the sample to be measured by sensory test, X_{ic} is the instrumentally measured value of the standard and x_i is the difference (grade) in the sensory test of the mechanical parameter i between the sample to be measured and the standard. The results of the sensory measurements for the main mechanical parameters are as follow- The estimation of fabric thickness by the sensory method yields are most accurate results. Fabric thickness can be effectively estimated by choosing the value of K_T within the range of 0.2-0.3. The estimation of fabric bending rigidity is effective but K_B values tend to be higher, ranging from 0.3- 0.5. Compressibility WC related with fabric softness can be estimated effectively by choosing K_{wc} values within the range of 0.2-0.4. The coefficient of friction can be estimated when K is 0.2 [Alimma *et. al.*, 2000].

The relation between the magnitudes of instrumental measurement and subjective assessment of the surface topography of three series of plain weave, weft pile and knitted fabrics was reported by Ajayei *et. al.* It is found that the surface feel of fabrics is influenced by the number, height and relative variation of surface asperities. In woven fabrics, a systematic increase in yarn sett greatly altered the peripheral boundaries and hence smoothness of fabric surface. The tactile smoothness of cord fabrics is influenced by the number, height and variation of heights of the fiber piles. Surface fuzziness and number of detectable ribs appear to govern the smoothness of knitted fabrics. Magnitude estimation and surface contour causal factors such as number and height of irregularities correlate linearly [Ajayi *et. al.*, 1996].

Furthermore, numerous methods have been used for predicting objective fabric hand or for correlating the objective measurable parameters of the fabric with feel sensory attributes of a fabric, for example a linear regression model [Kawabata, 1982], Weber-Fechner's law, Steven's power law, rank correlation [Sudnik, 1972], multiple factor analysis [Abott, 1951; Howorth and Oliver, 1958], and weighted euclidean distance. All these methods proved to have limitations owing mainly to the lack of established linear/nonlinear relationship between sensory attributes and measurable parameters. This unknown relationship has resulted in a situation of in complete reliance on the knowledge and experience of investigator. That's why, intelligent artificial techniques or soft computing techniques came into the picture for quantifying the fabric handle.

1.5.1 Application of artificial intelligence techniques:

The techniques of artificial intelligence such as fuzzy logic and neural networks have been known for some years with increasing success in various areas of engineering. These new technologies are indeed powerful tools modeling because of their strong nonlinearity, flexibility and flexibility of computing. It designs interest in regulating and enslavement of complex manufacturing processes for which information is often imprecise, uncertain, or even only qualitative, or sometimes contains incomplete control loops. In the next section, we recall first the basic concepts of neural network and fuzzy logic.

1.5.1.1 Artificial Neural Network (ANN):

Neural networks are family of nonlinear functions parameterized whose functioning is inspired by the architecture of the human brain. They offer approach implicit "black box" of knowledge representation very similar to the approach of system identification in automation. These techniques are applied successfully to the modeling of industrial systems in which the relationship between input variables and output are complex and the rules of operation are unknown [Jelil, 2010].

ANNs seem to be ideal for developing models in such industrial processes that are 'data-rich and knowledge-poor' [Chattopadhyay and Guha, 2003]. ANNs do not require expert knowledge but require large quantities of process data for training. In ANNs, a large number of simple functions (artificial neurons) are connected to each other by weights of variable strengths to form the network. The knowledge of the system is embedded in the connections (weights) and the network 'learns from examples'. It is this capability, namely, the ability to react correctly to situations it has not encountered previously, which puts ANN apart from the other attempts at process modelling. ANN trained in such a way can be invaluable to a manager as a decision-making tool. The main advantages of using ANNs for predictive modelling can be summarized as follows: ANNs require little human expertise, have non-linear dependence on parameters, save manpower by moving most of the work to the computer. ANNs typically work much better than traditional rule-based expert systems for modelling complex processes when relationships are difficult to discern, or when their number increases [Messiry EI Magdi, Abd-Ellatif Mohsen, 2010].

In textiles, ANN has been successfully used in various applications like-in Fiber Identification and Analysis System (FIAS) [Leonard *et. al.*, 1998], classification of card-web defects, control of sliver evenness [Majumdar *et. al.*, 2006], to predict the count strength product (CSP) of ring-spun yarn [Majumdar *et. al.*, 2004]. ANNS has been also used by the researcher for modelling of textile hand, to predict garment drape from fabric properties such as fabric weight, warp and weft shear rigidity, warp and weft bending rigidity, warp and weft tensile extensibility and thickness [Fan *et. al.*, 2001], to predict the thermal resistance of textile fabrics [Bhattacharjee *et. al.*, 2007], and to predict the performance of fabrics during garment manufacture using the properties measured by the KES system [Guha *et. al.*, 2001].

Park *et. al.*, have used neural networks to predict fabric hand but their work was concerned only with total hand evaluation and could not predict each individual hand attribute for a particular fabric [Park *et. al.* , 2001]. Wong *et. al.* also used a neural network to predict human psychological perceptions of clothing sensory comfort but did not specifically treat sensory fabric hand [Wong *et. al.*, 2003].

Hui et al. [Hui *et. al.*, 2004] identified reliable sensory fabric hand attributes with correlated attributes of fabric properties and proposed a novel approach for predicting sensory hand based on measurable properties using a resilient back-propagation neural network. Twelve fabric properties are fed into the network to predict fourteen sensory ratings of fabric hand. The 12 fabric properties and 14 sensory attributes used by them were as following (table 1.5):-

Table 1.5 Measurable fabric properties [Hui *et. al.*, 2004]:

S.N.	Fabric parameter		S.N.	Fabric parameter
1	Formability in the warp direction (F1)		7	Fabric thickness at $2gf/cm^2$ (T)
2	Formability in the filling direction (F2)		8	Shear rigidity (G)
3	Bending rigidity in the warp direction (B1)		9	Fabric weight (W)
4	Bending rigidity in the filling direction (B2)		10	Coefficient of friction (MIU)
5	Bending length in the warp direction (C1)		11	Mean deviation of coefficient of friction (MMD)
6	Bending length in the filling direction (C2)		12	Mean of geometric roughness (SMD)

Table 1.6 Definition and English world descriptor of 14 bipolar pairs of sensory fabric hand attributes [Hui *et al.*, 2004]:

Definition	Descriptor	Definition	Descriptor
Flat	Smooth and level	Textured	Having a certain kind of texture
Not bulky	Slim size, shape, mass or quantity	Bulky	Great size, shape, mass or quantity

Light	Easy to be seen in: bright	Heavy	Having a certain weight
Thin	Small distance between opposite surfaces	Thick	Large distance between opposite surface
Silky	Like silk, soft, smooth or shiny	Scratchy	Spoilt by scratches
Smooth	Even surface, not rough	Rough	Uneven surface, not smooth
Fine	Very thin	coarse	Not fine or smooth, rough
Limp	Lacking strength or stiffness	Crisp	Firm, fresh
Flexible	Can be bent easily	stiff	Not easily bent
soft	Not firm against pressure	Hard	Firm and stiff, not easily broken or bent
Firm	Strong, solid, hard	Flimsy	Not strong, light and thin
Compact	Pressed, joined together, or united firmly and closely	Loose	Not fastened and tied together
High drape	Easy to hang or stretch out loosely and carelessly	Low drape	Difficult to hang or stretch out loosely and clearly
Cool	Neither warm or cold; pleasantly cold	Warm	Having or giving off a pleasant feeling of heat

The proposed ANN model improves the prediction of consumer’s sensory hand rating rather than total hand value, taking such an approach, industries can more closely evaluate their fabrics to match customer’s expectations. The main draw back of this model was the number of input parameters. This model can be further improved by selecting the most relevant physical parameters for each attribute in order to reduce the complexity of this model.

1.5.1.1.1 Advantages of ANN:

The advantage of neural networks is that they accept incomplete and noisy data. They have the distinction of being the only computer component that implements directly the principle of induction. Moreover, thanks to their ability to generalize, the neural networks are typically used in problems such as statistics and perceptual, such as classification or evaluation. Similarly, they present high robustness against technical failures and enrich their experiences.

1.5.1.1.2 Drawbacks of ANN:

ANN has certain drawbacks which includes the following points:

- ✓ The ANN requires real cases used as learning data. These cases must be more numerous than the problem is complex.
- ✓ The effectiveness of the learning algorithm used. Some algorithms, such as gradient, are easily trapped in local minima.
- ✓ The difficulty of integrating expert knowledge.
- ✓ The difficulty of interpretation and understanding of the logic of reasoning.

1.5.1.2 Fuzzy Logic:

Fuzzy system is an alternative to traditional notions of set membership and logic that has its origins in ancient Greek philosophy. The precision of mathematics owes its success in large part to the efforts of Aristotle and the philosophers who preceded him. In their efforts to devise a concise theory of logic, and later mathematics, the so called "Laws of Thought" were posited [Korner, 1967]. One of these, the "Law of the Excluded Middle," states that every proposition must either be True or False. Even when Parminedes proposed the first version of this law (around 400 B.C.) there were strong and immediate objections: for example, Heraclitus proposed that things could be simultaneously true and not true. It was Platon who laid the foundation for what would become fuzzy logic, indicating that there was a third region (beyond True and False) where these opposites "tumbled about."

Fuzzy Logic is basically a multivalued logic that allows intermediate values to be defined between conventional evaluations like yes/no, true/false, black/white, etc. Notions like rather warm or pretty cold can be formulated mathematically and processed by computers. Fuzzy logic is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical logic. It was introduced in 1965 by Lotfi Zadeh at the University of California, Berkeley [Zadeh, 1965]. This theory proposed making the membership function (or the values **F** and **T**) operate over the range of real numbers [0, 1].It can be thought of as the application side of fuzzy set theory dealing with well thought out real world expert values for a complex problem. The membership function is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response.

1.5.1.2.1 Fuzzy set and membership function:

A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership.

$$\text{If } U = \{x_1, \ldots\ldots\ldots\ldots x_n\}$$

A classic set may be expressed as:

$$A=\{x \,/\, x \in U\}$$

A fuzzy set is an extension of a classical set. If U is the universe of discourse and its elements are denoted by x, then a fuzzy set A in U is defined as a set of ordered pair.

$$A = \{x, \mu_A(x) \mid x \in U\}$$

$\mu_A(x)$ is called the membership function (or MF) of x in A. The membership function maps each element of X to a membership value between 0 and 1. The function itself can be an arbitrary curve whose shape we can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency [NETO, 1989].

Fuzzy sets represent commonsense linguistic labels like slow, fast, small, large, heavy, low, medium, high, tall, etc. A given element can be a member of more than one fuzzy set at a time. A fuzzy set A in U may be represented as a set of ordered pairs. Each pair consists of a generic element x and its grade of membership function; that is, $A = \{x, \mu_A(x) \mid x \in U\}$, x is called a support value if $\mu_A(x)>0$. A linguistic variable x in the universe of discourse U is characterized by $T(x)= \{T_x^1, T_x^2,\ldots T_x^k\}$ and $\mu(x)=\{\mu_x^1, \mu_x^2,\ldots\mu_x^k,\}$, where T(x) is the term set of x i.e. , the set of names of linguistic values of x, with each T_x^i being a fuzzy number with membership function μ_x^i defined on U. For example, if x indicates height, then may refer to sets such as short, medium, or tall. A membership function is essentially a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. As an example, consider a fuzzy set tall. Let the universe of discourse be heights from 40 inches to 90 inches. With a crisp set, all people with height 72 or more inches are considered tall, and all people with height of less than 72 inches are considered not tall. The crisp set membership function for set tall is shown in Figure 1.7. The corresponding fuzzy set with a smooth membership function is shown in Figure 1.8. The curve defines the transition from not tall and shows the degree of membership for a given height. We can extend this concept to multiple sets.

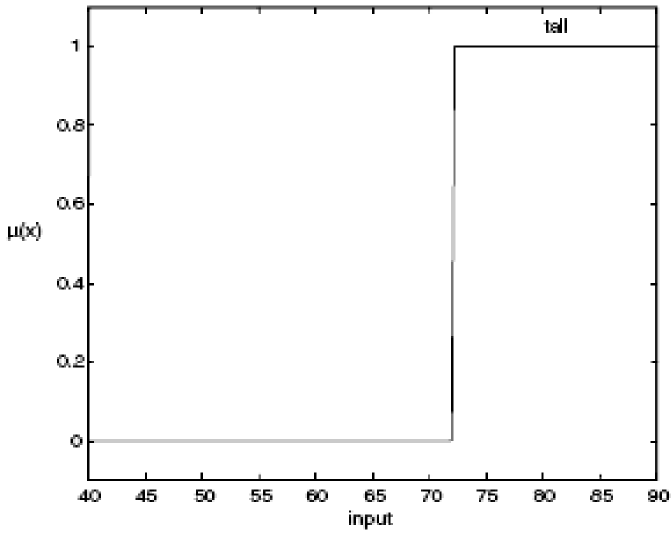


Figure 1.7 Crisp membership function [Cao, 1997; BERRIAH, 2000]

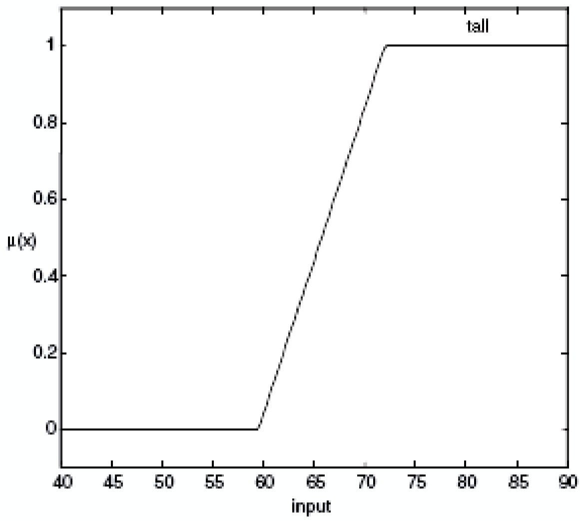


Figure 1.8 An example of a fuzzy membership function [Cao, 1997; BERRIAH, 2000]

If we consider a universe of discourse from 40 inches to 90 inches, then, to describe height, we can use three term values such as short, average, and tall. In practice, the terms short, medium, and tall are not used in the strict sense. Instead, they imply a smooth transition. Fuzzy membership functions representing these sets are shown in Figure 1.9. The Figure shows that a person with height 65 inches will have membership value 1 for set medium, whereas a person with height 60 inches may be a member of the set short and also a member of the set medium; only the degree of membership varies with these sets. Various types of membership functions are used, including triangular, trapezoidal, generalized bell shaped, Gaussian curves, polynomial curves, and sigmoid functions. The choice of form depends on the scope and degree allowable loss of information. The forms most often used are of type triangular and trapezoidal [Cao, 1997; BERRIAH, 2000].

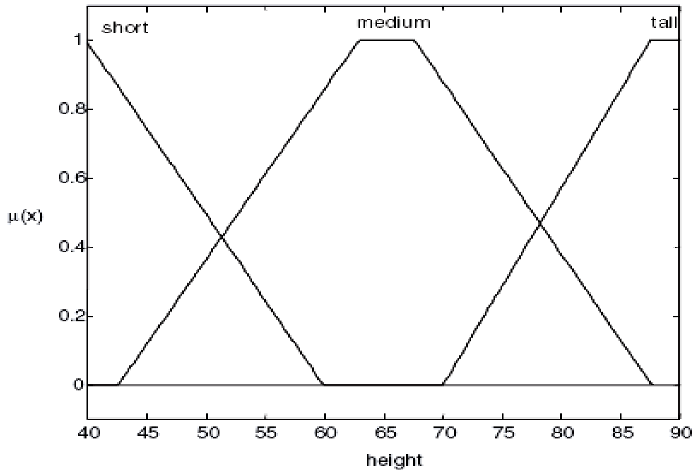


Figure 1.9 Trapezoidal membership functions [Cao, 1997; BERRIAH, 2000]

1.5.1.2.2 Linguistic variables:

The concept of linguistic variable is fundamental to applications of Fuzzy-Logic control process. It differs from numeric variables by taking as value of words or phrases in natural language. For example value of linguistic variable 'Height' to describe the height of a certain population can be: very small, small, medium, large and extra large.

Typically, a linguistic variable is described by the triplet $(x, X, T(x))$, where x is a variable defined on a set of reference X. All $T(x)$ contains Fuzzy subsets X to define variable x [Koehl, 1998].

For example: heights of a given population, there will be $x =$ height, which is defined in reference set [0, 150] and $T(height) =$ {Very small, small, medium, large and extra large}.

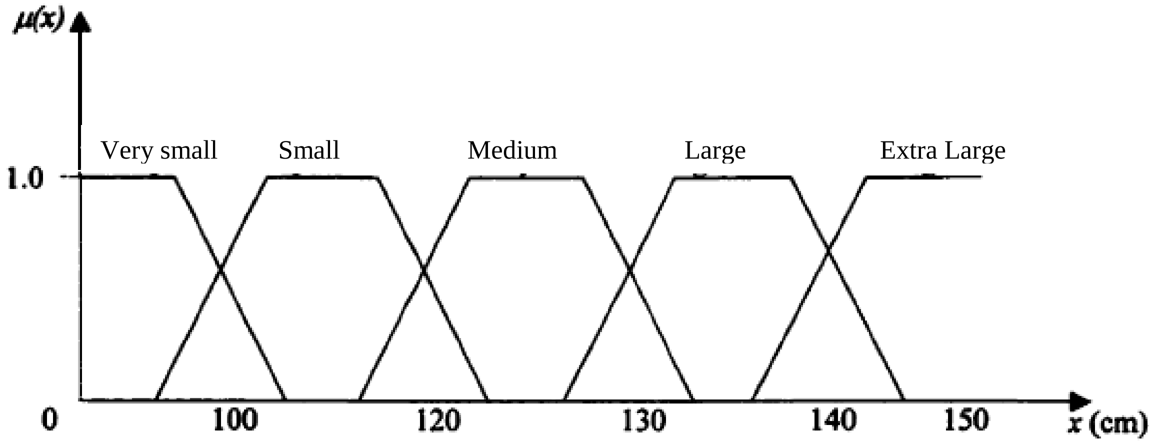


Figure 1.10 Linguistic variable- Height [CAO, 1997]

1.5.1.2.3 Fuzzy operations:

Fuzzy set operations are analogous to crisp set operations. The important thing in defining fuzzy set logical operators is that if we keep fuzzy values to the extremes 1 (True) or 0 (False), the standard logical operations should hold. A fuzzy set operation creates a new set from one or several given sets. For example, given the sets A and B the intersection in new fuzzy set with its own membership function.

Let A and B be fuzzy sets on a mutual universe.

(a) The intersection of A and B is

$$\mathrm{A} \cap \mathrm{B} \equiv a \min b$$

The operator minimum is an item by item minimum comparison between corresponding items in a and b.

(b) The union of A and B is

$$\mathrm{A} \cup \mathrm{B} \equiv a \max b$$

Where max is an item by item maximum operation.

(c) The complement of A is

$$\overline{A} \equiv 1 - a$$

Where each membership value in A is subtracted from 1.

1.5.1.2.4 Fuzzy Interference System:

A Fuzzy Inference System (FIS) essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if–then rules, aggregation of output sets, and defuzzification. An FIS with multiple outputs can be considered as a collection of independent multi input, single-output systems. A general model of a Fuzzy Inference System is shown in Figure 1.11. The FLS maps crisp inputs into crisp outputs. It can be seen from the figure that the FIS contains four components: the fuzzifier, inference engine, rule base, and defuzzifier. The rule base contains linguistic rules that are provided by experts. It is also possible to extract rules from numeric data. Once the rules have been established, the FIS can be viewed as a system that maps an input vector to an output vector. The fuzzifier maps input numbers into corresponding fuzzy memberships. This is required in order to activate rules that are in terms of linguistic variables. The fuzzifier takes input values and determines the degree to which they belong to each of the fuzzy sets via membership functions. The inference engine defines mapping from input fuzzy sets into output fuzzy sets. It determines the degree to which the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one clause, fuzzy operators are applied to obtain one number that represents the result of the antecedent for that rule. It is possible that one or more rules may fire at the same time. Outputs for all rules are then aggregated. During aggregation, fuzzy sets that represent the output of each rule are combined into a single fuzzy set. Fuzzy rules are fired in parallel, which is one of the important aspects of an FIS. In an FIS, the order in which rules are fired does not affect the output. The defuzzifier maps output fuzzy sets into a crisp number. Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number. Several methods for defuzzification are used in practice, including the centroid, maximum, mean of maxima, height, and modified height defuzzifier. The most popular defuzzification method is the centroid, which calculates and returns the center of gravity of the aggregated fuzzy set. FISs employ rules. However, unlike rules in conventional expert systems, a fuzzy rule localizes a region of space along the function surface instead of isolating a point on the surface. For a given input, more than one rule may fire. Also, in an FIS, multiple regions are combined in the output space to produce a composite region.

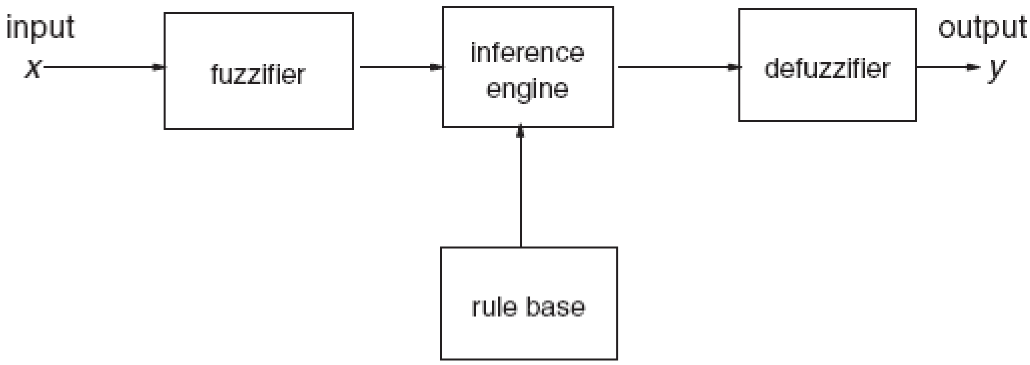


Figure 1.11 Block Diagram of Fuzzy Interference System.

The inference process can be described completely in the five steps shown in Figure

Step 1: Fuzzy Inputs

The first step is to take inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions.

Step 2: Apply Fuzzy Operators

Once the inputs have been fuzzified, we know the degree to which each part of the antecedent has been satisfied for each rule. If a given rule has more than one part, the fuzzy logical operators are applied to evaluate the composite firing strength of the rule.

Step 3: Apply the Implication Method

The implication method is defined as the shaping of the output membership functions on the basis of the firing strength of the rule. The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Two commonly used methods of implication are the minimum and the product.

Step 4: Aggregate all Outputs

Aggregation is a process whereby the outputs of each rule are unified. Aggregation occurs only once for each output variable. The input to the aggregation process is the truncated output fuzzy sets returned by the implication process for each rule. The output of the aggregation process is the combined output fuzzy set.

Step 5: Defuzzify

The input for the defuzzification process is a fuzzy set (the aggregated output fuzzy set), and the output of the defuzzification process is a crisp value obtained by using some defuzzification method such as the centroid, height, or maximum.

1.5.1.2.4.1 Types of Fuzzy Interference System

There are two types of Fuzzy Inference Systems that can be implemented:

- Mamdani-type
- Sugeno-type

These two types of inference systems vary somewhat in the way outputs are determined.

In Mamdani type of fuzzy inference, fuzzy sets from the consequent of each rule are combined through the aggregation operator and the resulting fuzzy set is defuzzified to yield the output of the system. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. While in Sugeno-type Fuzzy Inference System, the consequent of each rule is a linear combination of the inputs. The output is a weighted linear combination of the consequents.

1.5.1.2.4.2 Applications of FIS in textiles:

Fuzzy theory has been largely applied to the representation of subjective and the description of the procedure of subjective evaluation. [Dubois and Prade, 1997]. The fuzzy logic methods deal with a great number of industrial applications: evaluation of complex concepts such as comfort [Levrat *et. al.*, 1997], evaluation of credit worthiness of customers in a bank, etc.

Fuzzy Logic has been approached by different researchers in the field of textile hand evaluation. A Fuzzy-Logic based method for analyzing sensory data on fabric hand evaluation was proposed by Zeng *et. al.* The sensory data were transformed into fuzzy sets each representing the evaluation results of one individual. The 2-tuple linguistic model was used for aggregating multi-granular data of different individuals of each panel [Zeng *et. al.*, 2004].

Zeng and Koehl proposed a fuzzy logic–based method for representing and analyzing results of subjective evaluation on the fabric hand given by experts in fashion or quality inspection. This method permits the generation of a quantitative criterion characterizing the quality of textile products and modelling relationships between the subjective fabric hand evaluation and objective numerical data measured on the Kawabata evaluation system [Zeng and Koehl, 2003].

A method for modelling the relationship between objective and subjective fabric hand evaluations and between adjusting parameters of fabric production and objective fabric hand features has been further proposed. Human knowledge on fabric production and numerical data measured on instruments were used in a complementary way for selecting relevant physical features and extracting fuzzy rules [Zeng *et. al.*, 2004].

Fuzzy logic has also been used for developing a system for supporting the fashion product development. The study of Lau *et. al.* attempted to use a fuzzy expert system with gradient descent optimisation for prediction of fabric specimens in fashion product development. They claimed that the system could cope with the subjective fabric hand descriptors to incorporate the psychological effects from individuals into the prediction of fabric specimens. This feature could model to the natural fabric selection process made by consumers effectively [Lau *et. al.*, 2006]. The author of this thesis has also suggested an intelligent system for supporting the design of fashion oriented personalised garment. It permits to model the relationship between fabric parameters and fashion design elements via fashion images [Agarwal *et. al.*, 2009].

1.5.1.2.5 General observations about Fuzzy Logic:

Here is a list of general observations about Fuzzy Logic:

- Fuzzy logic is conceptually easy to understand.

  The mathematical concepts behind fuzzy reasoning are very simple. What makes fuzzy nice is the "naturalness" of its approach and not its far-reaching complexity.

- Fuzzy logic is flexible.

  With any given system, it's easy to massage it or layer more functionality on top of it without starting again from scratch.

- Fuzzy logic is tolerant of imprecise data.

  Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.

- Fuzzy logic can model nonlinear functions of arbitrary complexity.

  You can create a fuzzy system to match any set of input-output data. This process is made particularly easy by adaptive techniques like Adaptive Neuro-Fuzzy Inference Systems (ANFIS), which are available in the Fuzzy logic toolbox.

- Fuzzy logic can be built on top of the experience of experts.

In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you rely on the experience of people who already understand your system.

- Fuzzy logic can be blended with conventional control techniques.

  Fuzzy systems don't necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.

- Fuzzy logic is based on natural language. The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic.

The last statement is perhaps the most important one and deserves more discussion. Natural language, that which is used by ordinary people on a daily basis, has been shaped by thousands of years of human history to be convenient and efficient. Sentences written in ordinary language represent a triumph of efficient communication. Since fuzzy logic is built atop the structures of qualitative description used in everyday language, fuzzy logic is easy to use.

Although, it is difficult to make a choice between ANN and FIS and to investigate the predictability potential of these modelling methodologies but still it can be concluded that ANN is always associated with difficulty of interpretation and understanding of logic of reasoning. While in the case of fuzzy logic use of self defined rules make, it self explainable and understandable.

Jeguirim *et. al.* proposed Fuzzy-Logic and neural modeling of finishing treatment effects on the compression and surface properties of the fabrics. They reported that fuzzy models were slightly better than neural models and found that neural models act like a “black box” without revealing any physical information about the mechanics of process [Jeguirim *et. al.*, 2010].

Behra and Guruprasad investigate the predictability of air permeability of cotton plain-woven fabrics from their structural parameters using ANN and AFIN (Adaptive neuro-fuzzy inference system). The average absolute prediction error of ANN model was 5.78% whereas that of ANFIS model was 3.26% [Behra and Guruprasad, 2010].

The literature review presented in this chapter indicates that laundry results in undesired textile hand, which can be prevented or limited up to a certain extent by the use of fabric softener during laundry. The amount of deposition and level of uniformity of this deposition is expected to be depending on textile parameters such as fibre type, fibre fineness and fabric-construction. In chapter 2, the interaction of these textile parameters with softener deposition is presented experimentally.

The section 1.2.2 and 1.3.3 give an overview of influence of laundry and use of fabric softener on different fabric properties. The studies on repeated laundry and use of fabric softener on mechanical parameters and textile-hand with respect to textile parameters are still found to be limited. In chapter 3, the simultaneous influence of wash-ageing and use of the fabric softener on mechanical and sensory attributes knitted textile is being presented thoroughly.

The section 1.5 shows that establishing the relationship between sensory perception of the consumers and mechanical properties of the textiles has been always a challenge for the researchers. In chapter 4, we proposed a tracking criterion to select the most relevant mechanical parameter for each sensory attribute introduced in chapter 3. The section 1.5.1.2.4 indicates that fuzzy logic is based on natural language and permits to observe the trend of change in output with inputs, hence it was chosen for making the models to predict the sensory score of knitted fabrics using most relevant mechanical parameters.

Chapter: 2

Characterisation of deposition of fabric softener on textiles & interaction with surface properties

In this chapter, firstly, the details of textile material and laundry process used for this project are given. This chapter includes the characterization of fabric softener deposition on the bases of deposition amount and deposition uniformity. Furthermore, interaction of fabric softener with surface properties of the textile is described in this chapter.

2.1 Material and process :

For knitted garments, dimensions stability, deterioration, pilling, deterioration of fabric handle, and shape distortion, after laundering are perceived by consumers as causes for concern. These consumer concerns suggest a need for improvement in the care of knitted fabrics during domestic washing, which may, perhaps, be achieved through a better understanding of how, why, and at what stage of the wash and wear process these problem occur, and through the use of softeners. Fabric softener helps to reduce or delay the perceived negative effects of laundering.

2.1.1 Selection and sourcing of material:

The literature review presented in chapter: 1 shows that the influence of laundry and the effectiveness of softener varies with the type of textile and textile parameters. Therefore, it was critical to select the most appropriate textiles for our research work.

Selection of fibre type:

This study is focused on the sports wear and undergarment application of the textiles. Knitting is the most popular fabric manufacturing technology for these applications. Therefore, all the fabrics chosen for this study were knitted. In the apparel market, man-made fibres are more and more used (60% of the market) to the detriment of natural fibres (40%) [Source: CIRFS 2005].Polyester represents 70% of the synthetic fibres on the market. On the natural fibres market, cotton is by far the most used fibre. Synthetic fibres are hydrophobic whereas cellulosic ones are hydrophilic. The cellulosic fibre (cotton, viscose) and synthetic fibres (PET, PP) are dissimilar in their morphology, physical properties and chemical characteristics. So they are expected to be different in terms of sensory perception and behaviour during wash-ageing. Polyester was chosen because it is the most used man-made fibre. We chose not to work on cotton (despite it representing an important part of the knitted fabrics market) because the morphology of cotton may vary depending on source and quality, understanding the influence of the different parameters would therefore be difficult. Instead we chose to work on viscose. It is a cellulosic fibre, so it is quite close to cotton in terms of chemical nature. However, because viscose is a man-made fibre it is possible to fully control its morphology and all the other yarn parameters.

The study is therefore focused on 100% Polyester and 100% Viscose/100% Modal knitted fabrics varying in fibre fineness (micro/regular) and knitting construction (jersey/rib/interlock). Modal is a high wet modulus regenerated-cellulosic fibre having a high degree of crystallinity and polymerization [Kreze *et. al.*, 2001; Bredereck and Hermanutz, 2005]. Although knitted fabrics are usually made with a mix of two or more fibre, for example, elastane is often added to increase the elasticity, it is critical to work on pure viscose and pure polyester fabrics to understand the influence of the fibre nature on the deposition of the softener.

Selection of fibre fineness and construction:

The fibre fineness is expected to play a significant role in the touch-handle of the fabrics, hence the fabrics made of both micro and regular fibres were included in this study. All the knitted fabrics are made up with three basic knitted structures or their derivatives: jersey, rib and interlock. These three structures differ in their physical properties, appearance and textile-hand (Appendix A).

Selection of areal density:

For sportswear, T-shirts and underwear, the areal density of knitted fabric lies between 100 to 180 gsm and sometimes up to 250 gsm for winter t-shirts (Source: *Tissages de l'Aigle" 2007*). Therefore the gsm of knitted fabrics was chosen in this range.

Selection of machine gauge:

The gauge of a knitting machine is the number of needles per unit of working width (expressed in inches) across the wales. For sportswear and underwear, the most common gauges are between 20 and 28. These gauges provide fabrics with an important moisture exchange surface, which facilitate the moisture transfer as well as heat transfer.

Yarn construction:

One Open end, jersey knitted fabric is also included to observe effect of yarn construction on softener performance. All the knitted fabrics used in this thesis were made in Tricot, France.

In Table 2.1, details of the knitted fabrics used in study are given.

Table 2.1 Yarn and knit parameters of the fabrics of the study

Code	Fiber type	Fiber fineness & yarn construction		Knitting structure	gsm	Gauge
VµJ	100% Viscose	Micro modal Fiber (1.30 dtex)	Ring-Modal 50 Nm	Jersey	145	28
VµR	100% Viscose	Micro modal Fiber (1.30 dtex)	Ring-Modal 50 Nm	1x1 Rib	180	20
VµI	100% Viscose	Micro modal Fiber (1.30 dtex)	Ring-Modal 50 Nm	Interlock	240	20
VRJ	100% Viscose	Regular (1.95 dtex)	Ring 50 Nm	Jersey	160	28
VRR	100% Viscose	Regular (1.95 dtex)	Ring 50 Nm	1x1 Rib	175	20
VRI	100% Viscose	Regular (1.95 dtex)	Ring 50 Nm	Interlock	250	20
VROJ	100% Viscose	Regular (1.95 dtex)	Open End 50 Nm	Jersey	150	28
PµJ	100% Polyester	Micro Fiber (1.13 dtex)	Multifilament 60 Nm	Jersey	130	28
PµR	100% Polyester	Micro Fiber (1.13 dtex)	Multifilament 60 Nm	1x1 Rib	165	20
PµI	100% Polyester	Micro Fiber (1.13 dtex)	Multifilament 60 Nm	Interlock	230	20
PRJ	100% Polyester	Regular (1.83 dtex)	Multifilament 60 Nm	Jersey	172	28
PRR	100% Polyester	Regular (1.83 dtex)	Multifilament 60 Nm	1x1 Rib	200	20
PRI	100% Polyester	Regular (1.83 dtex)	Multifilament 60 Nm	Interlock	250	20

Nm= meter/gram dtex = gram/10000 meter

In Table 2.1 the code of the fabrics sample represents fibre type, fibre fineness and knitting construction, for example VμJ indicates that it is a viscose fabric having micro fibre with jersey structure.

All 13 knitted fabrics were pre-cleaned in order to remove any remaining impurities of the knitting process (wax, oil, finish treatment on the yarn). For this cleaning, standard procedures are used: It consists of a bath of 70°C-deionised-water added with a special soap (Silvatol: 1ml/l) and Na_2CO_3: 1 g/l. A liquor ratio of 1/40 is used and the fabrics are washed for 1 hour in a winch beck to agitate the sample. Then the fabrics are rinsed three times with hot deionised water for 30 minutes.

2.1.2 Laundry process and parameters:

All the knitted fabrics involved in this work were subjected to laundry with/without use of the fabric softener. A front loading washing machine from Miele (model: A W3268) was used for laundering to meet the following conditions:-

- Consumer relevant (Front loading automatic, loading up to 6 kg load, spin speed of 1400rpm)
- Reliable in terms of repeatability. Wash cycles have to be identical (no fuzzy logic control)
- A durable “high end” machine

Figure 2.1 shows set up for laundering facilities used for the project. The tap water (containing water hardness of 45 – 50 °F) was mixed with deionised water in order to reach a hardness of 25° F. The hardness is checked after each tank filling.

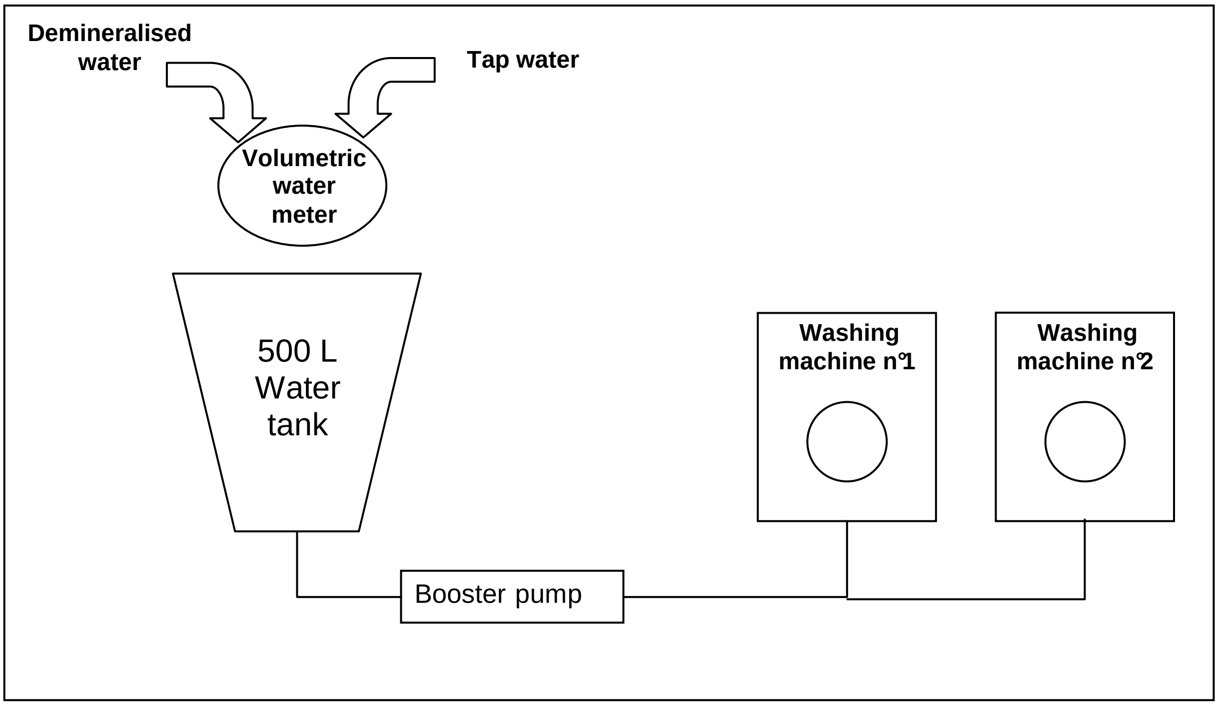


Figure 2.1 Set up for laundering

The whole study requires running washing cycles under the same conditions: same cycle, same softeners, same water hardness, same loading weight. All the washing experiments were done under the following conditions:-

a) Load: 1 Kg for individual load and 3 Kg for mixed load.

b) No prewashing

c) Washing product :45ml non-bio concentrated liquid detergent

d) Fabric Conditioner: concentrated, 35ml (Rinse cycle cationic conditioner: Comfort pure (white), provided by Unilever in 2008

e) 40^{o}C Cotton cycle

f) Water hardness: 25^{0}F

g) pH=7 (pH of input water and drained water)

h) All fabrics have to be line dried.

The laundry conditions should be close to consumer laundry practices in order to make this study market relevant. However, in order to ensure evenness of deposition, in this study the fabric load used is low compared with consumer habit. This result in a ratio of softener to fabric that is high compared with that expected in practice.

The recommended temperature for washing of these fibres is up to 60°C, so we decided to use a 40°C cotton wash cycle. The use of a tumble dryer may have caused more shrinkage, resulting in a change in structure, so we chose to use line drying instead.

Two loading conditions were studied:-

a) Softener is applied individually to all fabrics: the machine is loaded with each viscose and polyester knitted fabric separately.
b) Softener is applied to all 13 knitted fabrics together in a mixed load.

As, we applied softener in the rinse stage of the wash cycle, so these may also be referred to as fabric conditioners. We considered 40 wash-cycles as the life cycle of a garment during use. Therefore, all the 13 knitted fabrics were subjected to 40 wash-cycles.

The protocol used for the laundry of mix load of 3 kgs containing 230 grams of each sample is shown in Table 2.2. We used two loads of 3 kgs, one set was washed without softener and another was washed with softener. The portions of the load removed for testing was substituted with additional fabric of the same textile type to keep the load size constant. The mechanical testes were performed after 1, 5, 20 and 40 wash cycles. In the Table 2.2, A (W) and B(S) denotes the use of washing machine A for fabrics to be treated without the use of fabric softener and washing machine B for fabrics to be treated with the use of fabric softener. In order to avoid the influence of washing machine, the two sets of fabric were alternated in two washing machines after each 5 washing cycles. The washing machines were washed with water at 60°C after each 5 washing cycles in order to remove remaining washing product and softener.

Table 2.2 Protocol for the washing of Mix load (x kg (n) represents the load of x kg which had gone through n washing cycles.):

Washing cyles	Washing Machine	Initial Load	Removed load	Added	Remaining
1	A(W), B (S)	3 kg (1)	0.65Kg(1)	0.650 kg(0)	2.35kg (1), 0.65 kg (0)
2 to 5	A(W), B (S)	2.35kg (5), 0.65kg(4)	0.65 kg (5)	0.650kg(0)	1.7kg(5), 0.65kg(4), 0.65kg(0)
Washing without load and washing products					
6	A(S), B (W)	1.7kg(6), 0.65kg(5), 0.65kg(1)	0.65kg(5). 0.65kg(1)	1.30kg(0)	1.7kg(6), 1.30kg(0)
7to 10	A(S), B (W)	1.7kg(10),1.30kg(4)	No	No	1.7kg(10), 1.30kg(4)
Washing without load and washing products					
11 to 15	A(W), B (S)	1.7kg(15), 1.30Kg(9)	No	No	1.7kg (15), 1.30kg(9)
Washing without load and washing products					
16 to 20	A(S), B (W)	1.7kg(20), 1.30kg(14)	1.7kg(20)	1.70kg(0)	1.7kg(0), 1.30kg(14)
Washing without load and washing products					
21 to 25	A(W), B (S)	1.7kg(5), 1.30kg(19)	No	No	1.7kg(5), 1.30kg(19)
Washing without load and washing products					
26 to 30	A(S), B (W)	1.7kg(10), 1.30kg(24)	No	No	1.7kg (10), 1.30kg(24)
Washing without load and washing products					
31 to 35	A(W), B (S)	1.7kg(15), 1.30kg(29)	No	No	1.7kg(15), 1.30kg(29)
Washing without load and washing products					
36 to 40	A(S), B (W)	1.7kg(20), 1.30kg(34)	No	No	1.7kg(20), 1.30kg(34)
Washing without load and washing products					
41 to 45	A(W), B (S)	1.7kg(25), 1.30kg(39)	No	No	1.7kg(25), 1.30kg(39)
Washing without load and washing products					
46	A(S), B (W)	1.7kg(26), 1.30kg(40)	1.30kg(40)	No	1.7kg(26)
Out put= 1.30kg(1), 1.30kg(5), 1.70kg(20), 1.30kg(40)					

2.2 Characterisation of knitted fabrics:

2.2.1 Fabric thickness:

The procedure ISO 07-153 NFG was followed. Thickness measurements were taken on Sodemat disc type instrument under pressure of 0.1kPa load. An average of five readings was recorded for the thickness of each specimen.

2.2.2 Fabric porosity:

Porosity can be defined as the fraction of void space in a porous medium.

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b} \tag{2.1}$$

Where ρ_a is the fabric density (g/cm^3) and ρ_b is the fibre density (g/cm^3). Fabric density is calculated by dividing the fabric mass per unit area by the fabric thickness. This equation gives the total porosity, including the inter fibre porosity as well as the inter yarn porosity of the fabric. In the calculation the mean density of Viscose and Polyester is accepted as 1.52 g/cm^3 and 1.38 g/cm^3 respectively.

2.2.3 Capillary radius:

The wicking property of the textiles depends on two porosity scales i.e. macro pores (spaces between yarns) in the structure and micro pores (spaces between fibres in the yarn). In knitted fabrics. The intra yarn pore radius (R) can be determined by the mathematical model proposed by Benltoufa *et. al.* for jersey knitted fabrics [Benltoufa *et. al.*, 2008].

$$R = \sqrt{\frac{t^2}{32n} - \frac{d^2}{8}} \tag{2.2}$$

Where: t = thickness of fabric, n = number of fibres in yarn cross section and d = diameter of fibre.The fibre's equivalent radius is calculated from the following relationship (by considering the fibre as a perfect cylinder):

$$\frac{d}{2} = 17.84\sqrt{\frac{N}{\rho_f}}$$

(2.3)

Where N is fibre fineness in tex and ρ_f is fibre density.

The main characteristics of the knitted textiles used in this work were calculated using equation: (2.1), (2.2), (2.3) and given in Table 2.3.

Table 2.3 Characteristics of the knitted fabrics:

Fibre Type	Fibre fineness (dtex)	Porosity (%)	Density (gm/cm^3)	Fibre diameter (µm)	Intra yarn radius (µm)
Micro Viscose	1,3	89	1,52	10,4	8.90
Viscose	1,95	89	1,52	12,8	12.95
Micro PET	1,13	87	1,38	10,2	11.73
PET	1,83	87	1,38	13,0	15.55

2.2.4 Zeta potential measurement:

The streaming potential experiments were carried out with apparatus provided by Zetacad (Figure 2.2). For each measurement 1 gram of sample was inserted as a fibre plug (1) together with filters of having pores of 70 µm diameter (2), these are placed between the Ag/Agcl electrodes (3). We used 0.001 N KCl as an electrolyte solution, which was circulated between the containers (4) under the nitrogen pressure (0 to 500 mbar) by means of admission valve (5). The direction of circulation is controlled by valve (6) and (7) while (8) is the sensor to maintain the level of solution in container.

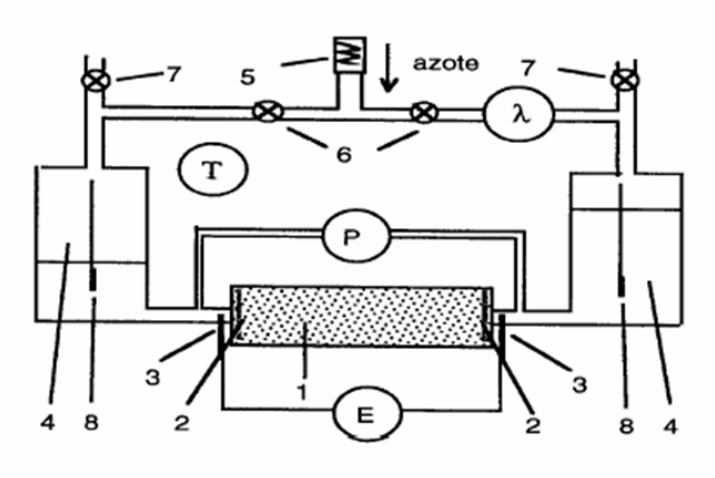


Figure 2.2 Diagram of apparatus for zeta potential measurement

The pH of KCl solution was adjusted with 0.1N NaOH and 0.1N HCl. The fabric samples were dipped in electrolyte solution for 24 hours before the start of the experiment. The potential difference (E) is measured at the extremities of the column with change in pressure (P). The potential difference (E) is measured at the extremities of the column with change in pressure (P) (Figure 2.3).

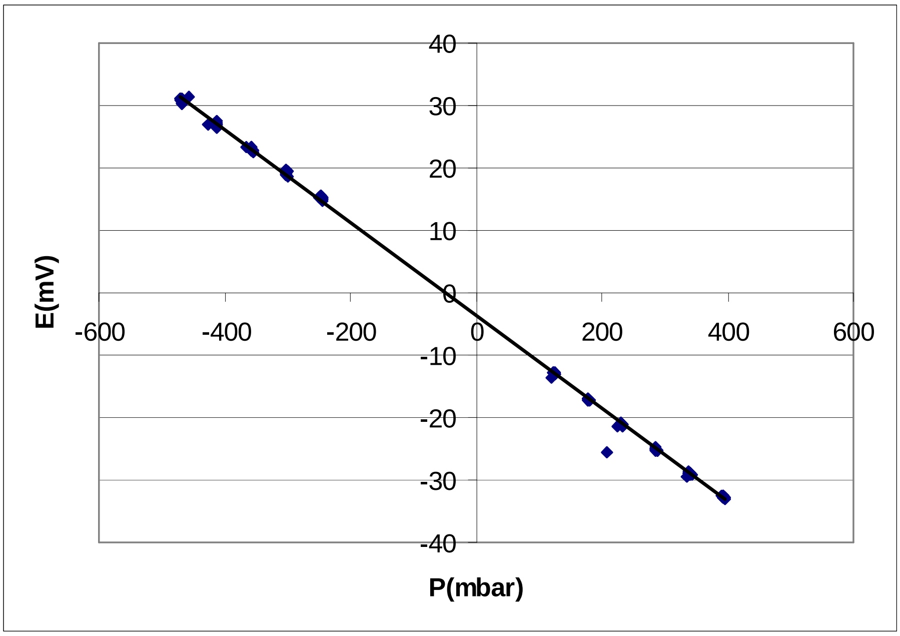


Figure 2.3 Change in potential difference with pressure

Zeta potential (ξ) in mV is calculated by the following equation:-

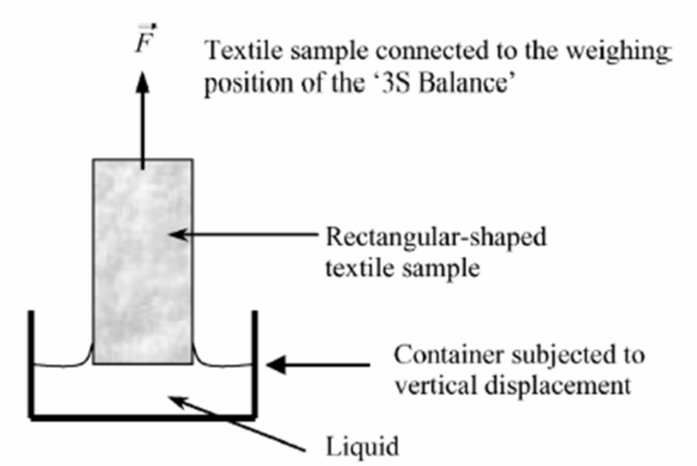
$$\xi = 13{,}55.10^4 . \frac{E}{\Delta P} . C . \gamma$$

$$C = 16.32 - 0.35197T + 0.00351T^2 \qquad (2.4)$$

Where E and P are in mV and mbar respectively, γ is solution conductivity in $S.cm^{-2}$ and constant C gathers the medium permittivity and solution viscosity, both depend on the temperature (T).

2.2.5 Liquid adsorption ability:

The experimental system used to observe the liquid uptake by the textiles was the 3S balance from GBX Instruments (France). A vertically-suspended sample is brought in contact with the surface of the liquid in the container (Figure: 2.4). As soon as the sample comes into contact with the liquid surface, a sudden increase in sample weight is detected by the balance and is plotted as a function of time. After 3 minutes, the liquid and the fabric are separated and the liquid retained by the fabric is measured.



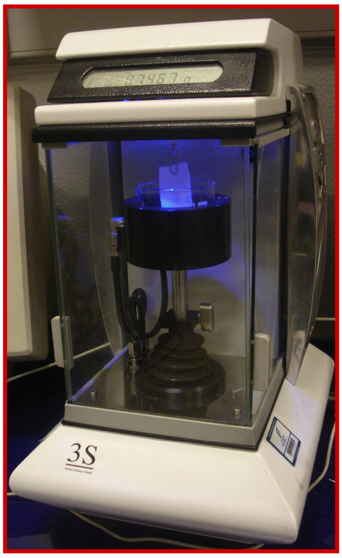


Figure 2.4 Liquid take up by textile on 3S balance

The total weight (W_t in grams) is due to the meniscus weight (W_m in grams) and the weight of the liquid entrapped inside the fabric by capillarity (W_c in grams).

$$W_m = W_t - W_c \qquad (2.5)$$

The meniscus weight depends on liquid wettability at the fabric surface tension.

$$W_m g = p\gamma_L cos\theta \qquad (2.6)$$

Where θ is the contact angle (°),γ_L the surface tension of the liquid (mN/m) , $g = 9.81 m/s^2$, p is the sample perimeter.

The magnitude of the capillary pressure (ΔP) is given by the Laplace equation:

$$\Delta P = \frac{2\gamma Cos\theta}{r} \qquad (2.7)$$

γ = Surface tension of liquid, r = pore radius and θ = Contact angle.

We chose decane and water to study the liquid transportation behaviour of knitted textiles. Decane has zero contact angle with all the fabrics, so initial wetting due to meniscus formed between the liquid and the sample and capillary weight are independent of the fibre type and fabric treatment for the decane.

The wicking phenomena of softener treated fabrics were observed with decane and water in order to understand the influence of softener, geometry of capillaries and surface of the fibre respectively. The density of the decane is accepted as $0.73 g/cm^3$. We have used 7cm x2.5 cm strip of fabric for this experiment and kept the fabric in contact with the water for 3 minutes. In order to limit the effects of solvent evaporation during the experiment, work was carried out in a closed chamber.

The textile characters explained in section 2.2 play critical role in the softener deposition on the surface of the textile. This softener deposition can be characterised by softener-pick up amount and the level of uniformity of the deposition and are explained in next section.

2.3 Softener deposition characterization:

Softener deposition can be characterised by the amount deposited on the fabric and the uniformity level of the deposition.

2.3.1 Extraction and quantification of cations deposition on fabric:

This was done by cationic titration method, was carried out by Intertek, Port Sunlight. Two grams of each fabric was extracted with ethanol using an accelerated solvent extraction system (ASE from Dionex) at a temperature of 85^0C. The surfactant determination involves the titration of an aliquot of an aqueous solution of the sample in a two phase water-dichloromethane system using a mixture of a cationic dye (dimidium bromide) and an anionic dye (Disulphine blue V) as indicator. The cationic forms a salt with the anionic dye, which then dissolves in the dichloromethane layer to give this layer a blue colour. The end point of the titration with sodium dodecyl sulphate (SDS) is reached when the SDS anion displaces the disulphine anion from the dichloromethane soluble salt and the blue colour leaves the dichloromethane layer as the dye passes to the aqueous layer. The dichloromethane layer at the end point of the titration is a grey colour. An excess of the SDS titrant turns the dichloromethane layer pink in colour indicating the presence of anionic material, as all the cationic has been displaced.

2.3.2 Nonuniformity of softener deposition:

We used Bromo Phenol Blue (BPB, Figure 2.5) to visualise the nonuniformity of softener deposition. It is an acid-base indicator, its useful range lies between pH 3.0 and 4.6. It changes from yellow at pH 3.0 to purple at pH 4.6; this reaction is reversible.

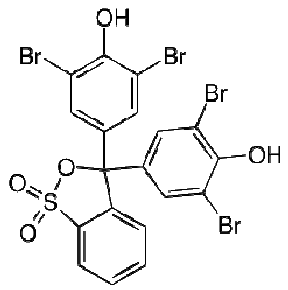


Figure 2.5 Structure of Bromo Phenol Blue

Since BPB carries a slight negative charge at moderate pH, it has a tendency to have an ionic attraction with cationic fabric softeners giving a permanent blue colour. Therefore, by analyzing the fabric surface visually it is possible to access the uniformity of the dye, which depends on the softener pick up. The dyeing of knitted fabrics with BPB was followed by image processing and Quadrant method.

2.3.2.1 Dyeing with BPB:

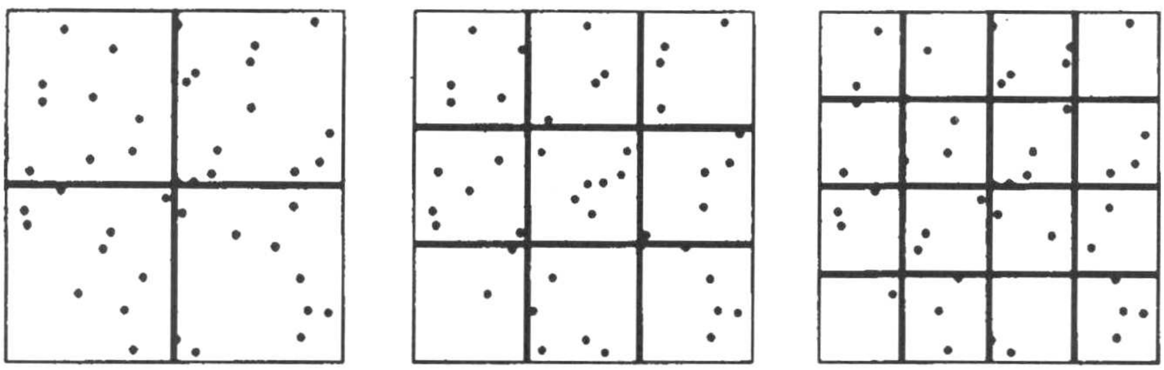
BPB powder (0.7g) is dissolved in 10ml of ethanol. This is then stirred and mixed with 20ml of hot water. This solution was then diluted to 10 litres with cold water and the fabric placed into the dye solution at liquor to cloth ratio of 50:1. The fabric was then agitated and left for about 30 minutes. After soaking, the fabrics are rinsed with warm water until the rinse water becomes clear. The fabric is than line dried.

2.3.2.2 Image processing:

The dried fabrics have been scanned using a HP scanner G4050 with a resolution of 200 dpi and then the image of the sample fabric was digitized in the RGB format and converted into a gray scale. All the basic knitted structures (jersey, rib and interlock) have different texture on the surface, to avoid this background effect, very low dpi has been chosen for scanning the images. The jersey structure is not the same front and back while rib and interlock are balanced structures, having the same texture on both sides. Here, only the front of the jersey is taken in to account. MATLAB was used as a software tool to calculate the uniformity index of the images by the quadrant method explained below.

2.3.2.3 Quadarant method:

For comparing the nonuniformity of different knitted samples, the quadrant method and image processing have been used [Pourdeyhimi and Koehl, 2002]. The digital form of the image is a two-dimensional array of numbers whose values represent the intensity of light at a particular small area. Each small area to which a number is assigned is called a pixel. The scanned BPB dyed images were converted into binary image (having pixels of value 0-Black and 1- white), where the black part of the image corresponds to deep blue coloured or patchy portion of fabric, while white corresponds to background.



i=2; n=4 **i=3; n=9** **i=4; n=16**

a) Image is divided into number of windows.(4,9,16,,,,,,,i^2)
b) The mean and the variance (% black fraction) is calculated.
c) Chi square values are computed for each value of n.
d) Uniformity index is computed.

Figure 2.6 Procedure for computing Uniformity

For the case of a non uniformly dyed fabric (which corresponds to patches of dye), the distribution of black pixels among windows will be clustered. On the other hand, if the cationic (and therefore the dye) is uniformly distributed then the Poisson distribution is the appropriate statistical descriptor of the data [Devore, 1999].

$$P_x = e^{-\mu} (\frac{\mu^x}{x!}) \tag{2.8}$$

Where P_x =the probability of observing x individuals, x= an integer counter 0,1,2,3……., μ= the true mean of distribution and $x! = (x)(x-1)(x-2)$………. Poisson is a discrete frequency distribution which only depends on the mean.

For each window, we record the area fraction (% black part in the image which represents the coloured part of the fabric) of the fabric. For each value of n, a distribution of this area fraction is obtained with its mean and variance. These observed distributions are then compared with standard Poisson distribution

The χ^2 goodness-of-fit test compares expected (theoretical) frequencies of categories from a population distribution to the observed frequencies from a distribution to determine whether there is a difference between what was expected and what was observed.

The chi-square test is defined for the hypothesis that data follows a specific distribution.

$$\chi^2_{\text{Observed}} = \sum_{x=1}^{x=N} \frac{(fo_x - fe)^2}{fe}$$

$$fo_x = \text{frequency of observed value for } x^{th} \textit{obsevation}$$
$$fe = \text{frequency of expected values} = \text{Mean value}$$
$$\text{N} = \text{Total number of observations}$$

(2.9)

This observed value of chi square is compared with standard χ^2, i.e. the value of χ^2 with (n-1) degree of freedom n= number of quadrants (windows). If the observed value is greater than the standard one then hypothesis is rejected and data is not considered to be described by the Poisson distribution. Hence the observed value of chi square can represent the level of uniformity of the surface: the greater the observed value of χ^2, the higher will be the probability of a clustered distribution. To determine an index describing χ^2 data, we divide the data by the total sum of windows as follows:

$$UniformityIndex = \left(1 - \frac{\sum_{i=2}^{i=n} \chi_i^2}{\sum_{i=2}^{i=n} (n_i - 1)} \right) \times 100 \tag{2.10}$$

The lesser value of χ^2 will correspond to higher uniformity. This normalized results is an uniformity index, its values are between 0 and 100, where 0 represents the least uniform and 100 the most uniform.

2.4 Data analysis using decision tree:

We tried to characterise the softener deposition on knitted textiles with respect to knitting parameters. Decision trees were used to explain the large amounts of data to reveal previously unknown relationships between inputs and output[Breiman *et. al.*, 1984; Masataka, 210].The application of decision trees as a data mining system for Textiles industry was reported in NTC report in 2002 [Hodge *et. al.*, 2002].

The decision tree subdivides the data into different clusters based on the same input parameters. The leaves of the decision tree correspond to the centre of gravity of the cluster. Each branch in the tree is labelled with its decision rule, and each terminal node is labelled with the predicted value for that node. For each branch node, the left child node corresponds to the points that satisfy the condition, and the right child node corresponds to the points that do not satisfy the condition. This method builds a tree which is used to mine the large amounts of data to reveal previously unknown dependency of multi dimensional inputs with single dimension output.

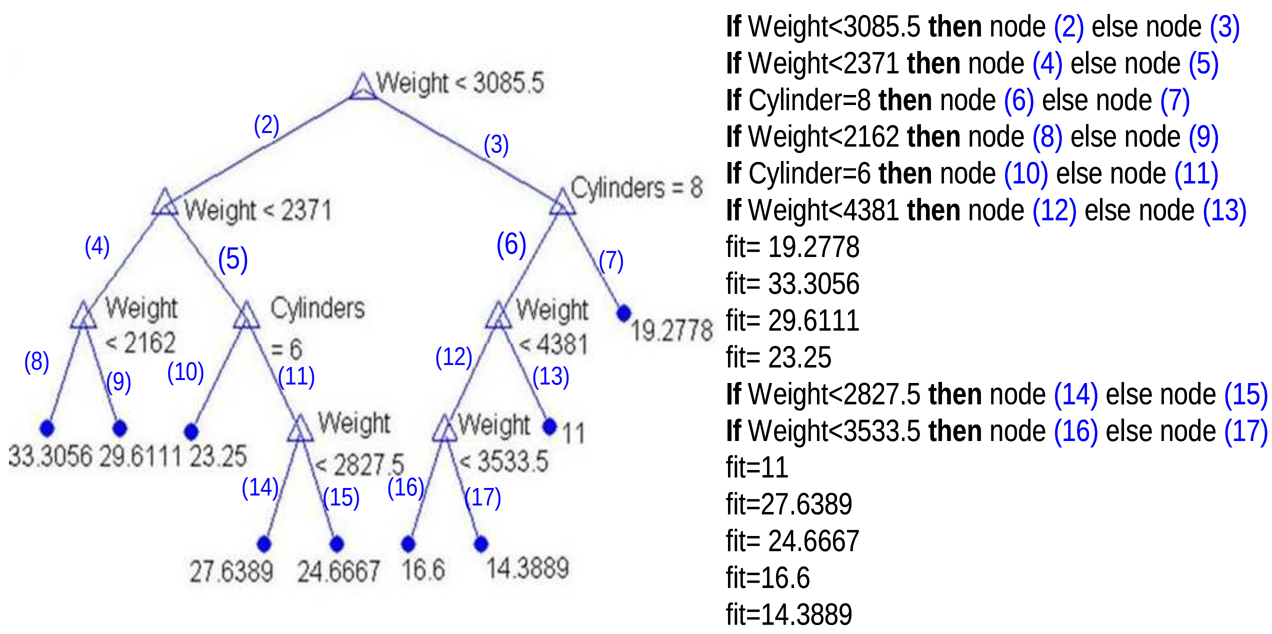


Figure 2.7 Decision tree example

An example of how to read a decision tree for predicting mileage using measurements of weight and the number of cylinders as predictors is shown in Figure 2.7. We will be using fibre type, fiber fineness, yarn construction and knitting structure as input and softener pick up and uniformity index as the output. (Figure 2.8).

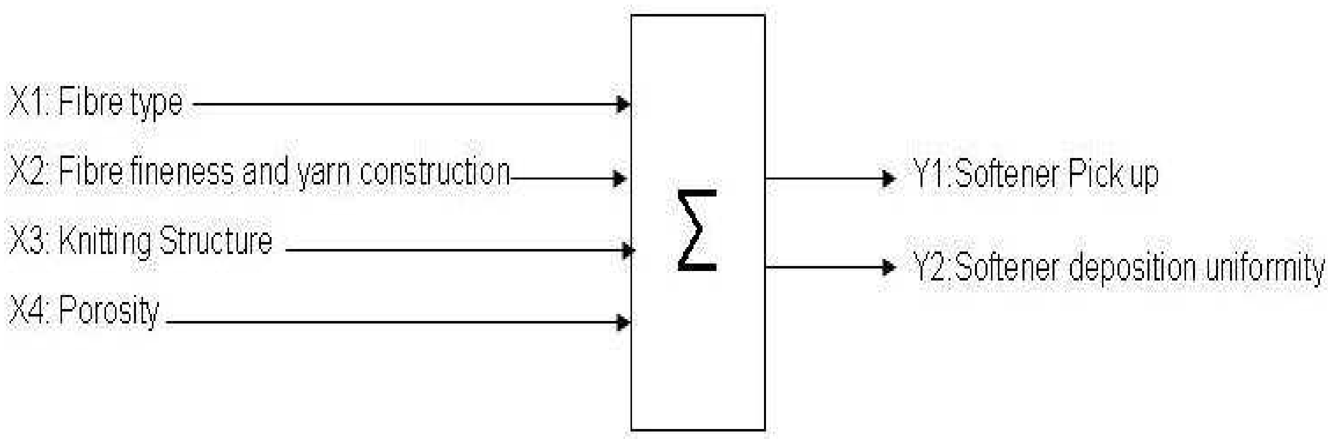


Figure 2.8 Scheme for present work

2.5 Results:

2.5.1 Fabric Porosity:

The fabric porosity of knitted structures mainly depends on the type of construction. Interlock is the most compact structure because of inter looping between front and back side of the structure. It therefore always gives minimum porosity.

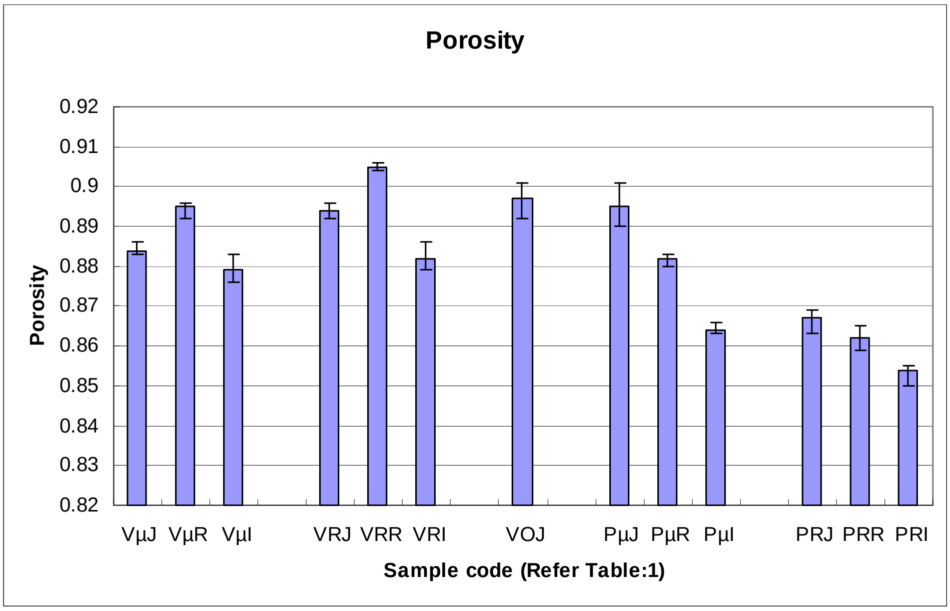


Figure 2.9 Porosity of all samples

In Figure 2.9, the porosity of fabric samples have been shown, which are based on average thickness of 5 positions of each sample. In general, porosity of the knitted structure for the same gauge and same yarn count and twist is expected to decrease in the order from jersey, rib to interlock structure. However, the jersey and rib fabrics, we used are made on different gauge (Refer Table 2.1), so we didn't get same order of porosity for all samples.

2.5.2 Softener pick-up:

The softener pick-up amount was determined in two load conditions:- individual load condition (D) and mix load (E). In the case of a mixed load, the pickup increases for Polyester fabrics, compared to the level of pickup in separate loads (i.e. loads involving a single fibre type). The opposite is the case for viscose fabrics (Figure 2.10 and 2.11).

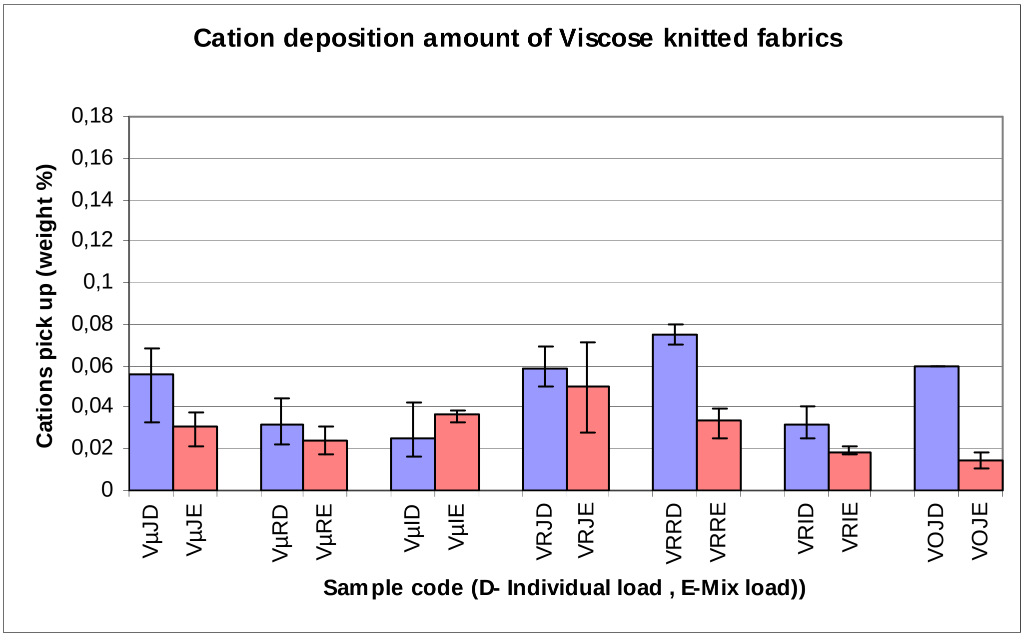


Figure 2.10: Softener pick up for Viscose fabrics

The bar value (cationic pick up in term of fabric weight %) is the average of four values. The error bars show maximum and minimum value of cationic %.

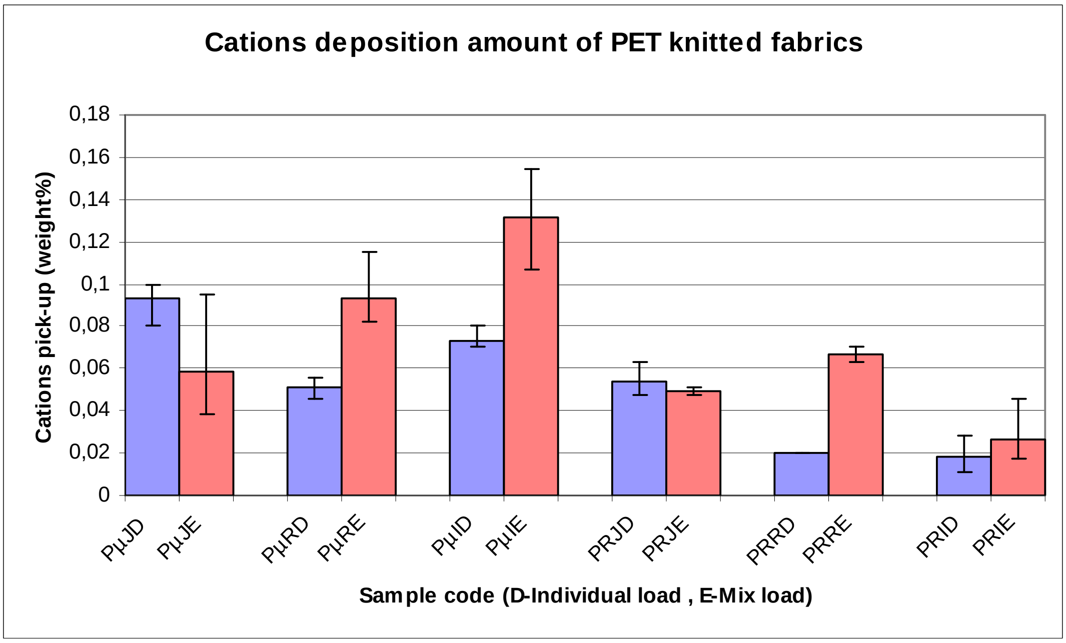


Figure 2.11: Softener pick up for PET fabrics

As the form of relationship between softener pick up (response) and different structural properties (predictors) is unknown, we developed a decision tree. A tree can be obtained splitting the source set (input matrix) into subsets based on an attribute value test. This process is repeated until further splitting is either not feasible or a single classification can be applied to each element of the derived subset. As discussed, we have selected structural properties (fibre type, fibre fineness, knitting construction, porosity) of the fabric as input parameters (predictors), which influence the softener deposition (response) on Knitted fabrics.

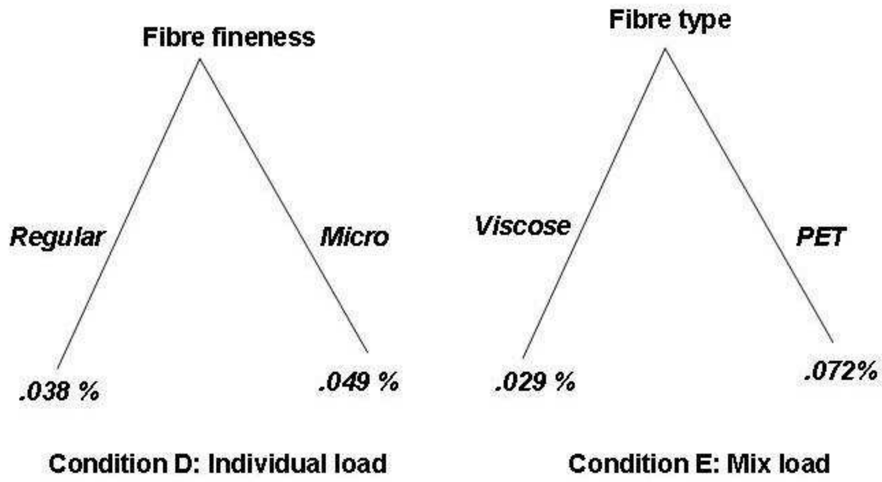


Figure 2.12 Decision tree for cation pick up in Individual Load and Mix Load condition

Figure 2.12 is a decision tree for cation pick up amount in individual load and mix load condition. It shows that in individual load fiber fineness is the key factor for softener pick up. It because of higher surface area provided by the same mass of the micro fibres. In mixed loads we noticed that fibre type is a key factor.

2.5.3 Softener uniformity :

The uniformity of the softener deposition was quantified using image processing method with the assumption that fabric will be dyed by the BPB dye only if the softener is present on the surface of the fabric. Hence, first of all experiments have been realized to check the reliability of BPB method using 5 conditions:

A: Without any treatment

B: Fabric washed without fabric softener and dyed with BPB.

C: Fabric washed with cationic softener but not dyed with BPB.

D: Fabric washed with cationic softener in separate load and dyed with BPB.

E: Fabric washed with cationic softener in a mixed load and dyed with BPB

Figure 2.13 represent the effect of laundering under different conditions.

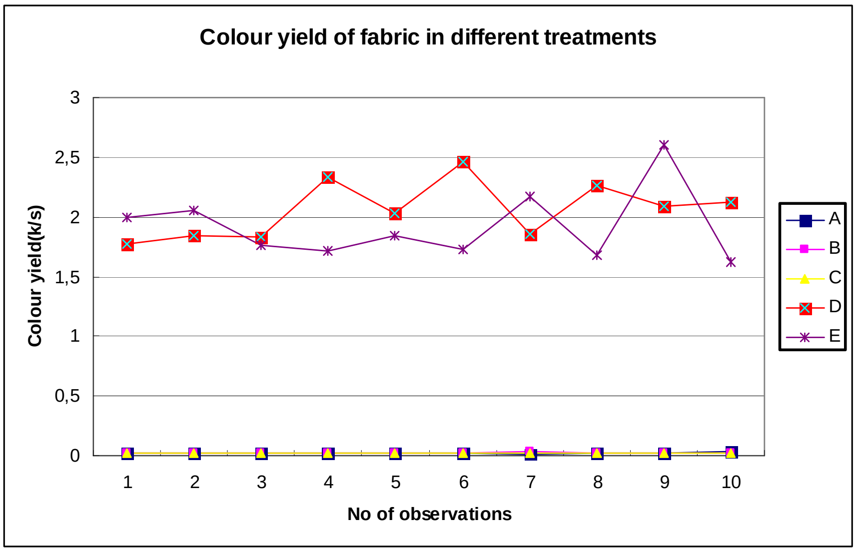


Figure: 2.13 Effect of laundering in Different conditions on BPB deposition

The colour yield of the BPB dye was found maximum at 620nm wavelength, which was recorded at 10 different position of the fabric. The colour yield for condition B is almost zero (the same as reference A) this confirms that if there is no cationic (softener) present on the fabric then the fabric doesn't show any dye pick up. This supports the use of BPB dye for use measuring the unevenness level of softener deposition. Condition C also shows the same results which implies that softener has no impact on whiteness of the fabric. Condition D and E are individual and mix loading condition respectively.

Figure 2.14 shows the uneven surface of the softener treated fabrics in the case of a mixed load, which can be visualised with BPB dye. From these images, the uniformity index has been calculated using the quadrant method. It is very important to minimise the background effect of the image as it may influence the texture significantly.

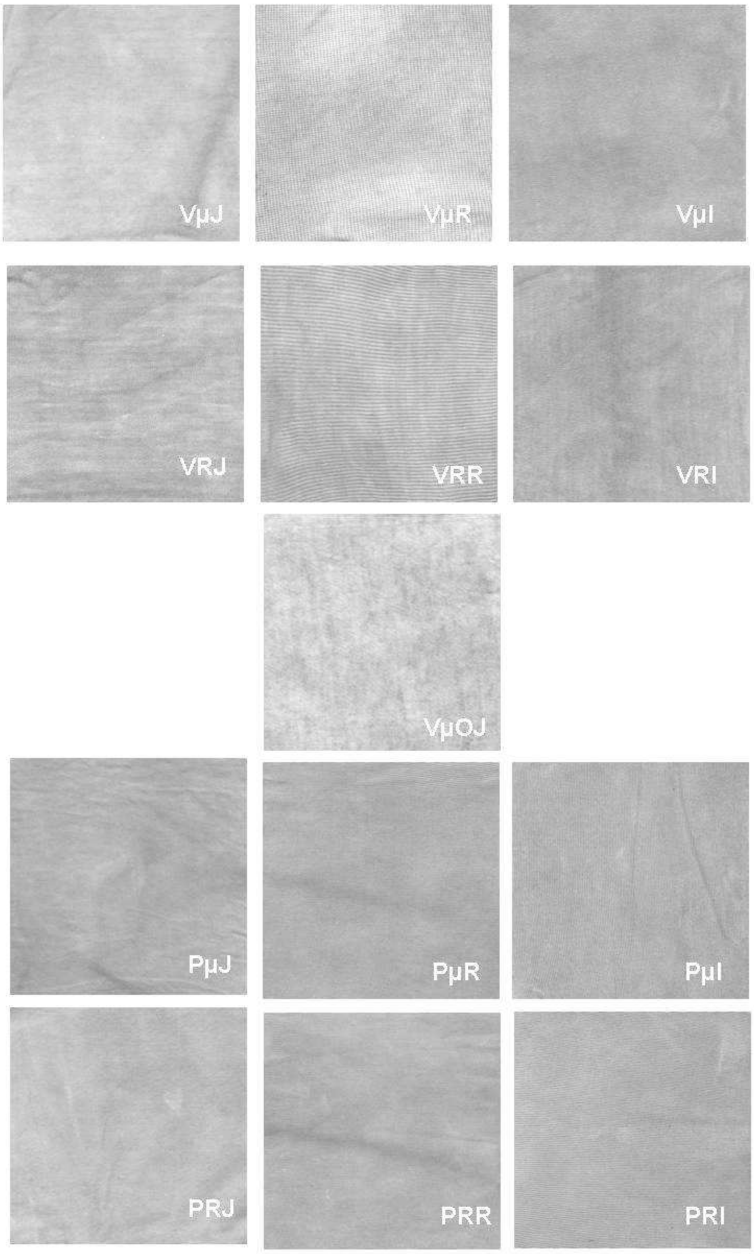


Figure 2.14 Gray scale images of all BPB dyed samples

Softener uniformity analysis and discussion:

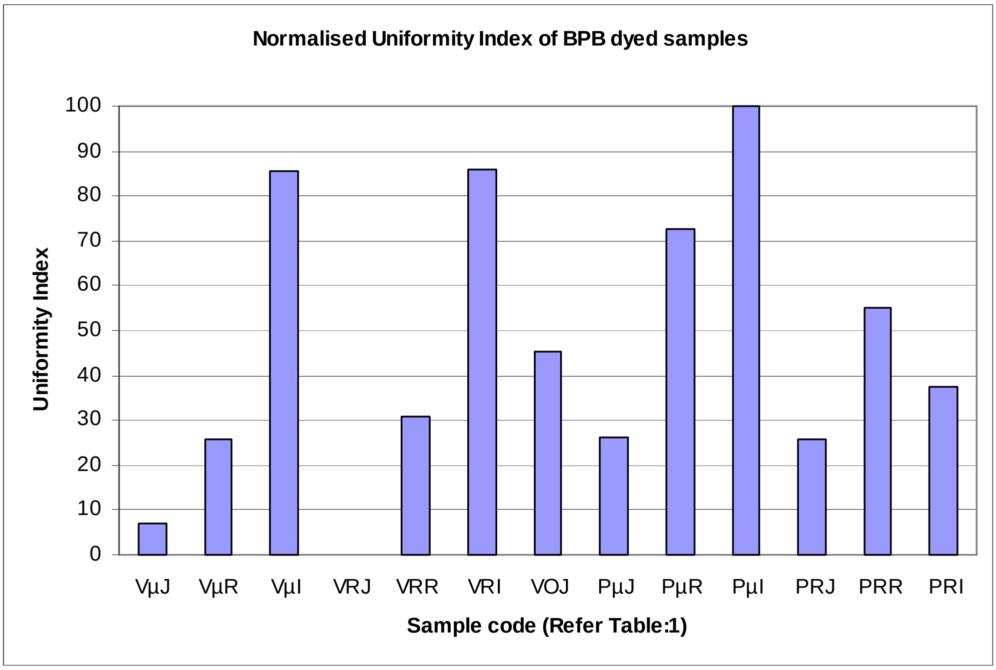


Figure 2.15 Uniformity index of all BPB dyed samples

As samples were line dried, there was probability of darker patches on bottom of fabrics (when line dried) because of gravity effect. But we didn't notice the nonunifomity because of gravity effect. This indicates that capillarity force is strong enough to resist the gravity.

It can be observed (Figure 2.15) that the uniformity of softener deposition on the fabric mainly depends on the structure, the interlock structure has most uniform deposition among each group of same kind of fibre.

Figure 2.16 indicates that fabric porosity is the most important characteristic for uniform deposition of the softener on the surface. If porosity is lesser than 0.88 than value of uniformity index is 66 otherwise it is 22.

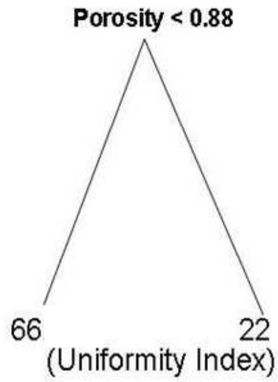


Figure 2.16 Decision tree for Uniformity index of different knitted samples

The proposed method for quantification of the softener deposition is to efficiently differentiate the uniformity level of deposition on different textiles. A compact surface will always show more uniform deposition. The jersey and rib structure always show non-uniform surface because of loose and open structure. Interlock is the most balanced and stable structures, which provide a uniform surface for softener deposition. The other factor which could play an important role in nonuniform softener deposition is the fibre fineness, variation in constructional parameters of yarn i.e. fineness and twist level. Micro fibre provides a larger surface area for softener deposition which enhances the possibility of uniform deposition.

2.5.4 Zeta potential:

2.5.4.1 Zeta potential of the fabrics:

First we measured the zeta potential of all thirteen fabrics at neutral pH and then two fabrics (VµI and PRI) were used to investigate the zeta potential as a function of the pH and the number of washing cycles.

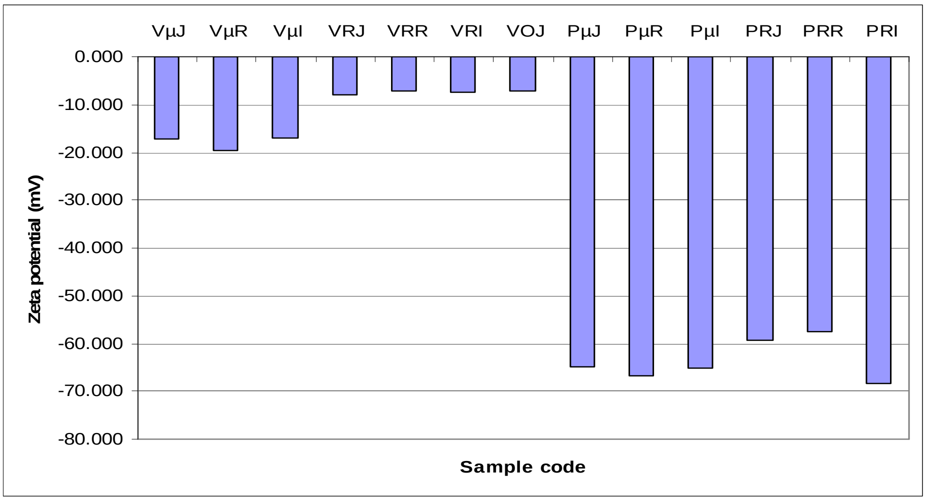


Figure 2.17 Zeta potential of Viscose and PET knitted textiles at pH=7

Figure 2.17 represents the zeta potential of Viscose and PET knitted fabrics washed without the use of the fabric softener at pH=7. PET and viscose fibres are negatively charged due to the presence of carboxyl and hydroxyl groups. The average zeta potential of viscose and PET fabrics were -12 mV and -64 mV respectively.

Construction type and fibre fineness do not influence the zeta potential of the fabrics. However viscose-modal (Vµ) fibers show a slightly higher negative zeta-potential than viscose fibers, this is probably due to the distinct reactive groups accessibility, which is determined by the different structures of regenerated cellulosic fibers in spite of having the same chemical composition.

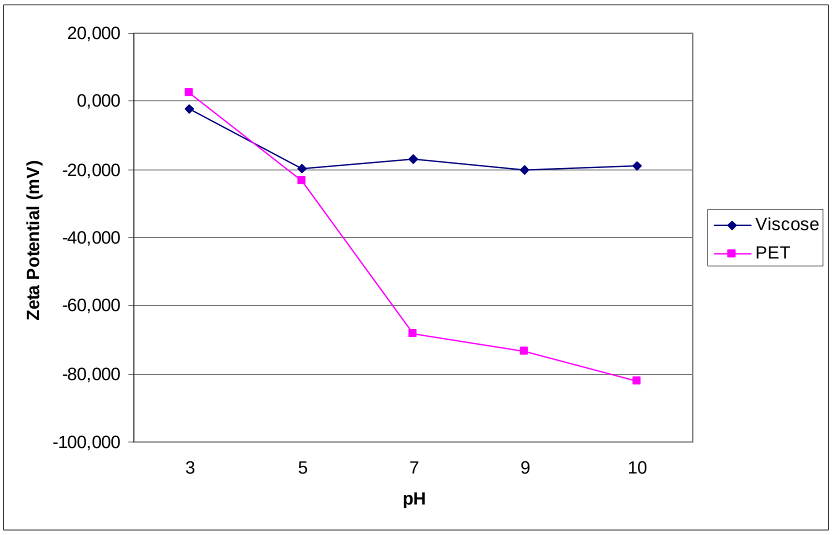


Figure 2.18 Zeta potential of Viscose and PET knitted textiles as a function of pH

Figure 2.18 presents zeta potential versus pH plots for viscose and PET knitted textiles (VµI and PRI). Viscose and PET shows variable zeta potential-pH functions because of different association/dissociation processes taking place at the fiber surface. The maximal negative zeta potential of the fiber surface occurs in the alkaline range. PET fibres contain acidic surface groups which are completely dissociated in the alkaline range, a pronounced negative plateau in zeta potential was observed [Ribtitsch *et. al.*, 2001]. While Cellulosic fibers like viscose, show smaller negative zeta potentials due to the OH groups, these groups are not pH sensitive and the zeta potential is almost constant.

2.5.4.2 Change in zeta potential during laundry process:

A characteristic feature of cationic softeners is, of course, their positive charge. This can lead to increased zeta potential (i.e. more positive) for textiles washed with fabric softener compared to textiles which are washed without using fabric softener.

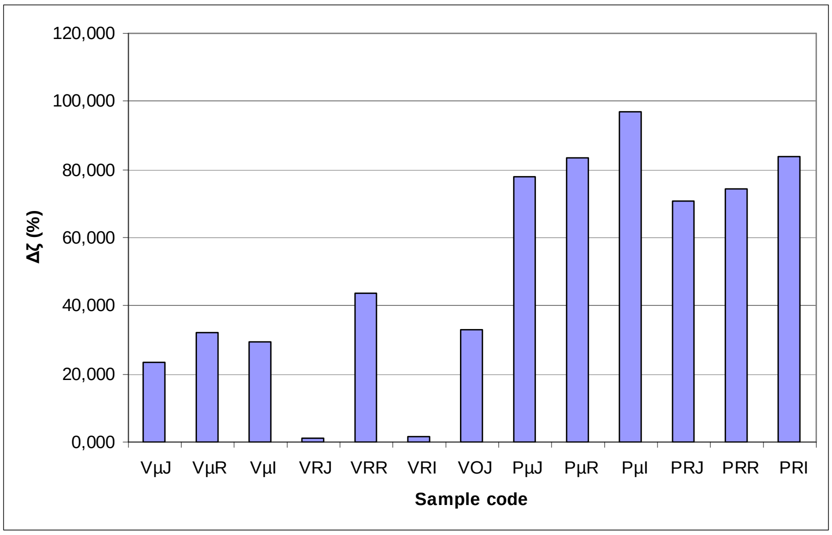


Figure 2.19 percentage Change in zeta potential of viscose and PET knitted textiles after washing with cationic softener

It can be observed from Figure 2.19 that the change in zeta potential depends on the magnitude of the zeta potential of the virgin fabrics. The general a trend is that larger magnitude of the negative zeta potential, the larger the change in zeta potential resulting from the use of fabric softener. This may be due to the larger (negative) zeta potential resulting in a higher cationic pick up on the fabric surface.

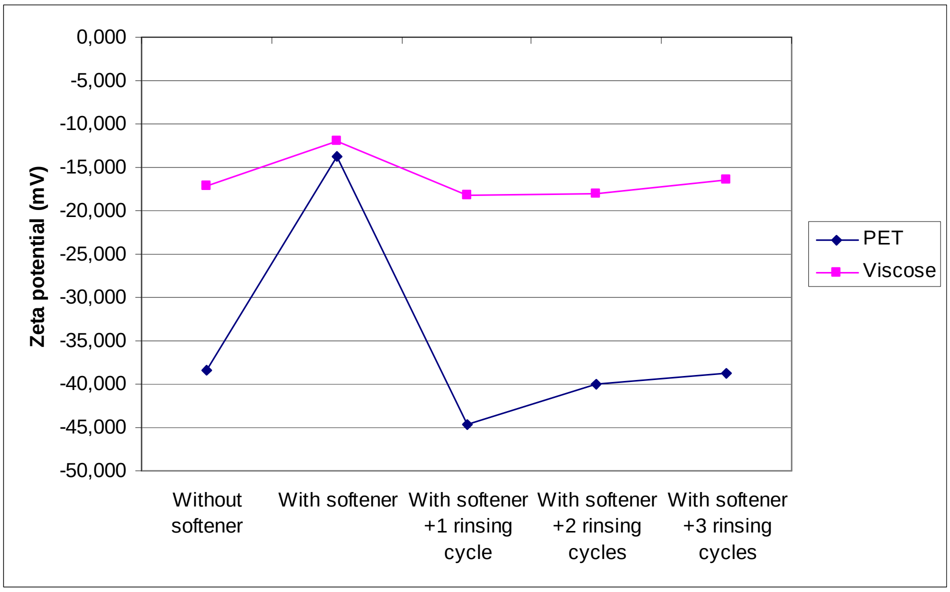


Figure 2.20 Change in Zeta potential as a result of washing product and cationic softener

Figure 2.20 represents the change in zeta potential of the fabrics as a result of the use of fabric softener and washing product. It can be clearly observed that the zeta-potential shifts in the positive direction after treating with cationic softener. When this softener treated fabric goes through a another wash cycle (with washing product) and one rinse cycle, the zeta potential again shifts in the negative direction and the resultant zeta potential has a greater magnitude than the initial value. This indicates that most of the softener is removed during the first rinsing cycle of the next laundry cycle. Residual wash product contributes to the negative zeta potential. At the end (after the third rinsing cycle), the zeta potential reaches to its initial value, which shows that the two successive rinsing cycles results in complete removal of the remaining wash product.

2.5.5 Liquid up-take:

The liquid up take phenomena of knitted fabrics is a function of their inter yarn and intra yarn porosity. The inter-yarn porosity contributes to the filtration efficiency of the fabrics while intra-yarn porosity is primarily responsible for the capillary effect of the fabrics.

2.5.5.1 The filtration efficiency of the knitted fabrics:

The inter-yarn porosity is mainly responsible for the filtration efficiency of the fabrics. As the softener in the rinse liquor is in the form of liposomes, the filtration efficiency of the textile material can also play an important role in softener deposition. We measured air-permeability of all the knitted samples to check the filtration efficiency. The air permeability of the all knitted samples on 20 cm^2 area was measured using Textest-FX 3300 air permeability tester. Figure 2.21 represents the air permeability of the 13 knitted fabrics expressed as fractions i.e. ratio of air permeability of fabric sample (l/m^2/ sec) and air permeability of test area without any sample (l/m^2/ sec). Error bars in Figure 10 represent standard deviation (±σ) of respective values.

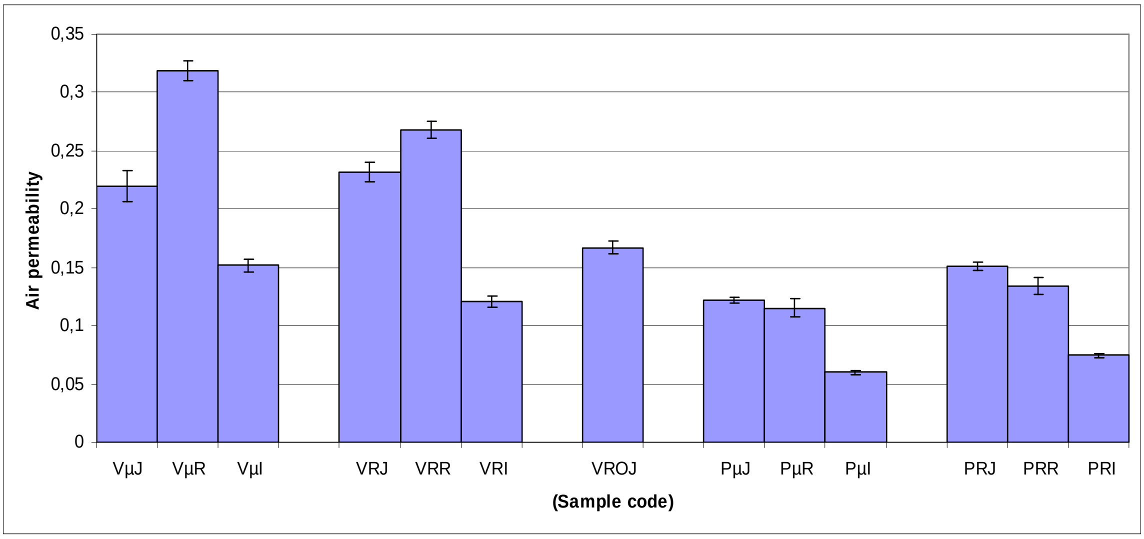


Figure 2.21 Air permeability of knitted fabrics

The lower air permeability of PET fabrics indicates that higher filtration efficiency of PET fabrics can be another reason for higher softener pick-up amount than viscose fabrics.

2.5.5.2 Liquid adsorption ability of knitted fabrics:

Figure 2.20 shows decane absorption capacity of the knitted fabrics, the error bar in the graphs represents standard deviation (±σ) of values of absorption capacity.

The decane adsorption ability of knitted fabrics is obtain by taking the ratio of mass of the liquid absorbed by capillarity at 3 minutes and the mass of the dry sample (w_o).

$$CA = \frac{w_{eq}}{w_o}$$

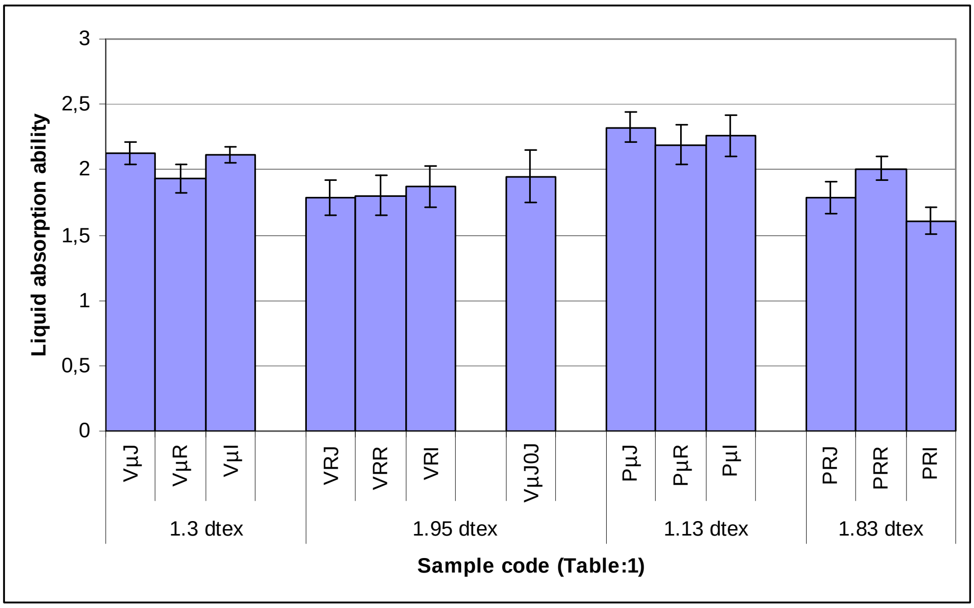


Figure 2.22 Decane absorption ability of knitted fabrics

It was found to be higher for micro fibre knitted fabric than for regular fibres. With microfibres, the pores size is smaller (Table 2.3), this results in a better capillary retention. The smaller pore size radius provides higher capillary pressure (eq.2.7), this results in a better capillary retention.

2.5.5.3 Influence of laundry softener on liquid transmission through knitted textiles:

We selected two viscose fabrics (VRI and VRJ) and two Polyester fabrics (PRR and PRI) to study the influence of cationic softener on adsorption kinetics of the knitted textiles. In Figure 2.23 and 2.24, W, R and S indicates that fabric is without softener treatment (W) or with retaining water (R) or with softener treatment (S). The error bars represents one standard deviation (±σ) of respective values. The condition R in Figure 2.24 corresponds to the actual situation of the fabric during last rinsing cycle of the laundry.

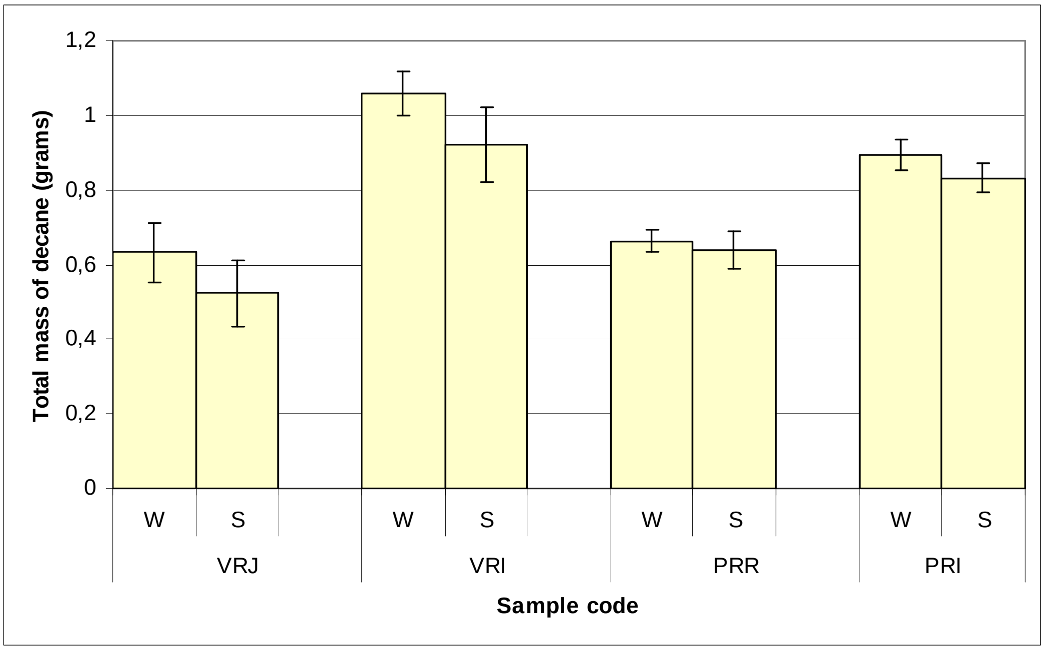


Figure 2.23 Change in liquid (Decane) liquid adsorption weight after treating fabrics with cationic softener

For the softener treated fabrics, almost no change in liquid adsorption weight was observed. This is due to the fact that decane absorption remains unchanged with change in surface of the material.

As mentioned, the fabric softener (rinse conditioner) was applied to fabrics in the beginning of the last rinsing cycle. At the stage of the last rinsing cycle, fabrics had already gone through washing and two rinse cycles followed by extraction of excess water from the fabrics through centrifuging. The softener is applied to fabrics which already contain water, the level of water depending on water-retention capacity of the fabrics. In order to study condition R, the fabric samples were removed from the laundry machine after two rinsing cycles, in order to study the adsorption kinetics of the samples, which already contain some liquid. The condition R in Figure 2.24 corresponds to the actual situation of the fabric at the start of the last rinsing cycle of the laundry.

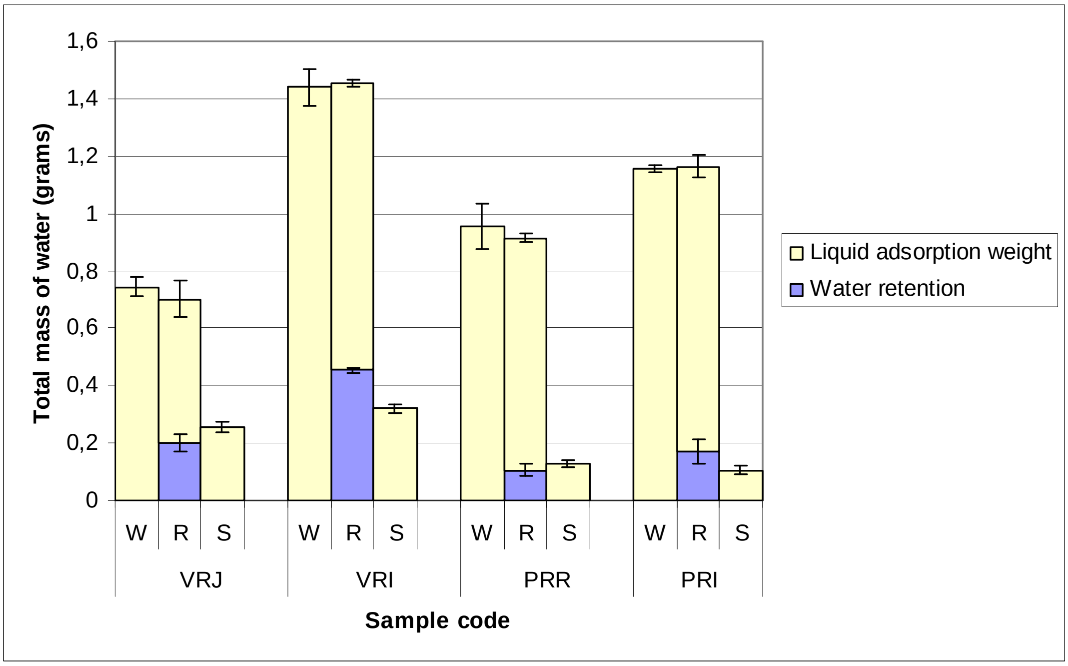


Figure 2.24 Change in liquid (water) liquid adsorption weight after treating fabrics with cationic softener

Viscose is a highly hydrophilic fibre; it has a good absorbency and high affinity for water. This results in high water retention capacity of the viscose fabrics, it was found to be 72 % and 104 % of fabric weight for VRJ and VRI respectively. Whereas being hydrophobic in nature, polyester has a lower water retention capability. This was found to be 30% and 38% for PRR and PRI fabrics. Thus, the lower retention capability of PET fabrics allowed them to absorb more water (with softener) during last rinsing cycle of laundry.

In the case of water (Figure 2.24), it was found that there is a significant reduction in liquid adsorption weight for softener treated fabrics. Fabric conditioner consists of combination of liposomal particles and smaller particles. The small change in liquid adsorption weight of decane and very significant change weight of water indicates that with the use of softener geometry of the capillary remains almost unchanged but interaction of water with fabric surface change due to boundary lubrication.

The typical rinse cycle conditioner has particles of size 2 to 50 microns [Harmalker *et al.*, 1994]. While intra-yarn pore diameter of knitted fabric lies in range of 10 microns. Although, there is a possibility that softener particles may enter inside the capillaries, they will not stay as solid particles in the dry fabric: during drying the quaternary ammonium active is spread over the surface of the fibres resulting in a very thin surface coating [Kong, 1997]. The reduction in adsorption weight may therefore be due changes in the fibre wetting properties resulting from the surface coating, rather than any plugging of the capillaries.

We found that for the mixed load, fiber type was the only critical factor to decide the cationic pick-up level on the fabric surface, while for the individual load, fibre fineness is a critical factor (Figure 2.12). It can be concluded that the competition between PET and viscose fabrics for cationic pick-up may be due to the difference between their Zeta-potential values, filtration efficiency and water retention capability of fibres as seen with capillary study. In the case of an individual fibre load, fiber fineness is responsible for competition of softener pick up because of higher capillary pressure and greater surface area.

2.6 Conclusions:

The important finding of the work was the result of the decisions trees for the softener pick up, which not only describe the important constructional factors responsible for the cationic softener deposition but also can be used for the prediction of softener pick up for a given fabric of a particular fibre type and structure. It was found that fibre type (cellulosic or polyester) and fibre fineness are the deciding factors for softener pick up depending upon load condition. It was found that in a mixed load, the PET fibre will pick up more cationic than in an individual treatment.

Fiber type plays the most critical role in determining the zeta potential of the fiber, which in turn plays the most important role in softener deposition on the textile. The charge on the textile surface is negative; this along with water retention capability plays a key role in deposition of the cationic softener in both kind of loading condition. The capillary diffusion could be a key parameter only in the individual load condition. It was found that there is a very significant reduction in water adsorption weight of the softener treated fabrics.

The higher filtration efficiency of PET fabrics and lower water retention capability were two other identified reasons, which are responsible for higher amount of softener deposition on PET fabrics than viscose fabrics. As we used very low load of 1kg, so it has to be noted that changes in water retention may not be the same as seen under typical consumer use.

The porosity of fabric is the key parameter affecting deposition uniformity. The non-uniformity of softener deposition plays an important role in handle of the fabric at different positions; the quantification of non-uniformity by the quadrant method can help in the further development in softeners in order to improve deposition uniformity.

Chapter: 3

Simultaneous influence of wash-ageing and use of fabric softener on sensory and mechanical properties of knitted textiles

This chapter involves the evaluation of sensory and mechanical properties of knitted textiles, which have gone through different domestic laundering treatments. The interaction of textile characteristics and dimensional parameters of knitted fabrics with mechanical parameters was also examined.

3.3 Sensory evaluation of knitted fabrics:

3.3.1 Methodology:

The sensory evaluation of knitted fabrics which had gone through laundry cycles in different conditions was carried out by following two basic steps: - selection of a panel and selection of attributes.

3.3.1.1 Screening of the Panel:

To join a sensory panel, it is critical to be both motivated and able to perceive differences between fabrics and to describe what is felt. As there are no standards to screen panellists, a screening procedure has been set up to check panellists' abilities for touch sense, based on the type of evaluation they will be asked to do. This aims to check abilities in terms of understanding tasks such as ranking, discrimination tests: triangle test, generation of terms. The screening should also enable one to check if people can discriminate products in terms of softness and of smoothness, two parameters that are very common for fabric evaluation. The screening procedure consists of the tasks listed on the Table: 3.1.

Table 3.1 List of tasks for screening sessions

Attributes	Type of evaluation	Products	Instructions given to the panellist	Requirements to pass

Smoothness	Triangle test	Sandpapers with different grains (3 tests: 0 vs. 0', 0 vs. 2 and 2 vs. 4)	For each sheet, three pieces of sandpaper are stuck on. Two are the same, one is different. Please indicate the odd one out.	To get the correct answer for the two more different pairs of products (2 vs. 4 and 0 vs. 2)
Softness	Ranking	Four nonwoven fabrics with different softness.	Please rank those products from the least soft to the most soft.	To organise in the right order or no more than one shift.
Any	Generation of terms	Different objects: - Sand paper - Sponge - Enamelled paper - Elastic - Non-woven fabrics	Please give 2 to 3 terms that better describe the products you handle.	To be able to generate spontaneously (within 2 minutes) 3 or more accurate terms to describe the objects

Any	Generation of terms	One woven fabric and one knitted fabric	You are presented with 2 different fabrics. Please describe the differences between them	To be able to provide an accurate description of the differences between the samples (within 2 minutes and at least a list of 3 differences)

Each panellist goes through the different tasks individually. The tests are run with panellists being blind-folded. The screening process is planned to be run in a 10-to-15-minute-session.

3.3.1.2 Selection of a attributes:

In subjective evaluation, the establishing of the list of attributes is crucial. Attributes should account for consumer's perceptions and be understood by professionals for efficient communication. The generated attributes should be a complete representation of the end product. Then, it is critical to ensure that all the panellists understand the terms and use them accurately with an agreed way of evaluation.

The panel members were six textile-engineering students, who therefore have textile backgrounds. They were asked to generate different sensory attributes for 13 knitted fabrics independently irrespective of time limit. About 50 terms have been generated by the panellists. Among the most used there were: soft, light, flexible, thin, undulating, cool, warm, fluffy, with pills, slippery, crease, draped, smooth, cottony, downy, flabby, elastic (lengthwise), elastic (widthwise), stretch (lengthwise), stretch (widthwise), crumplable, synthetic, coarse, heavy, with relief, thick, natural, transparent. After a round table discussion between the panellists on the meaning of the terms they used, the list of terms is reduced:

- The terms that were generated by a single person only are removed.
- The terms with a similar meaning are merged.
- The opposite terms are associated with each other, for example: cool and warm are reduced into coolness and a cool sample is scored with a high score for coolness, whereas a warm sample is scored low in coolness.

The above generated terms were used for sensory evaluation of 13 knitted fabrics to get an overview of these fabrics with respect to sensory perception (section: 3.1.2.2 of this chapter). After passing through a number of washing cycles, the physical surface appearance and handle of the fabrics was expected to be different than for the fresh knitted fabric or the fabric washed only once. So it was important to recheck the attribute list for the ageing cycled knitted samples.The panellist were asked to regenerate sensory attributes for 52 fabric samples composed of four subset of 13 different knitted fabrics which had gone through four different process- 1) Fabrics gone through 1 washing cycle without use of the fabric softener 2) Fabrics gone through 1 washing cycle with use of the fabric softener 3) Fabrics gone through 40 washing cycles without use of the fabric softener 4) Fabrics gone through 40 washing cycles with use of fabric softener. This time the terms generated were almost the same as before, but some attributes were removed and new attributes were added:

- ‘Thickness’ and ‘Elastic’ were removed as according to the panelists, these attributes can’t be differentiated from ‘Light’ and ‘Stretchable’ respectively.
- Panelists introduced three new attributes: Wrinkle, Flairy and Mellow which can be considered as synonyms of crease, undulating and flabby respectively.
- New attribute was introduced: ‘Greasy’.

The table 3.2 presents the list of 14 attributes with their ways of evaluation and definitions. These attributes were used for the sensory evaluation of knitted fabrics which had gone through multiple wash-cycles.

Table 3.2 Sensory Attributes and way of evaluation:

S.N.	Attribute	Definition (+)	Ways of evaluation
1	Fluffy	Give the sensation of having loose fibres	Feel the fabric between thumb, fore and index finger with slight to and fro strokes.
2	Stretchable	Stretching under pulling in both directions.	Take the fabric in the middle of the widths and pull
3	Slippery	Sensation of roughness/smoothness of surface of fabric.	Lay the fabric on the table and make your index finger slip on it
4	Cool	Providing a cooling sensation when getting in contact with the skin	Take the fabric at one of its angles with one hand and make the fabric pass on the back of the hand
5	Drapable	Behaviour of the fabric to drape	Put the fabric on the back of your hand with your fingers slightly separated and evaluate the behaviour of the fabric to drape.
6	Mellow	Can be compressed	Fold the fabric 3 times (i.e. 8 stratums) and compress the fabric between the thumb and the index finger

7	Synthetic	Having a feeling of cotton or synthetic fibre.	Slight vigorous sensation by mashing the fabric in one hand.
8	Wrinkle	Keep the creases even after removing the load.	Make a bowl with the fabric in your hand, then lay it on the table and evaluate visually the amount of remaining creases
9	Light-heavy	Make an impression of lightness due to the weight of the sample	Lay the piece of fabrics down flat in the hand hollow and make it jump up. Evaluate the weight when falling down
10	Flairy	Making some undulations	Lay the fabric on the table. Put your fingers on the middle of the fabric and make the fabric move, following a circle trajectory. Observe the undulations during and after the moving.
11	Flexible	Ability of fabric to fall down.	Pinch the center of the piece of fabrics and raise it. The more the fabric is falling, the more it is flexible.
12	Pilling	Having some irregular pills	Observe the irregular pills
13	With relief	Make an impression of relief due to the construction and	Take the piece of fabrics between the thumb and the index finger and press slightly and pull the fabric widthwise

		especially to the Wales.	(perpendicularly to wales).
14	Greasy	Feeling of presence of greasy or fatty material on the surface.	Lay the fabric on the table and move your fingers on surface.

Note: The panellists were asked to perform sensory evaluation in length- wise direction.

Panel Assessment:

The computation of the dissimilarity between two metric spaces is a common approach in many application problems such as data visualization, document retrieval, image annotation, collaborative filtering, and machine translation can be formalized as a task that utilizes a similarity function between objects in two heterogeneous spaces [Wu et. al., 2010, Huang and Yihui, 2008]. We used dissimilarity criteria defined by Zeng *et. al.*, which permits to compute the dissimilarity between the panellists in different evaluation spaces of fabric hand.

It is important to assess the panel members because, for each individual the evaluation of a sample gives a relative result depending on the comparison with the other samples. The sensitivity for each attribute is different for each individual, so it is important to check the sensitivity and similarity of the all the panel members. Panel assessment by calculating the standard deviation and covariance of sensory data is the most common approach. We used a more appropriate approach based on internal relative variation of data. The idea behind choosing the internal variation approach is that standard deviation and covariance gives us only an over all idea about evaluation, while this approach gives us more information about, contribution and sensitivity of each individual panelist. These designed criteria are better when the number of available samples is small (lack of samples). The proposed method is more adapted to processing of small data sets and permits to set up a suitable compromise between the accuracy and the capacity of interpretation of the obtained results.

The sensory data of two panelists P_a and P_b constitute two evaluation spaces U_a and U_b, for the data of these two different spaces, a new dissimilarity criterion between two panelists P_a and P_b was defined by Zeng and Koehl [*Zeng et. al.*, 2007; Koehl *et. al.*, 2008].

The principal behind calculating the dissimilarity between the panelists was to check the internal relative variation of data. If the internal relative variation of data between two panelists is close to each other then the dissimilarity between the panelists is small. Otherwise, dissimilarity is great. The dissimilarity between two panelists can be defined by

$$D_{ab} = \frac{2}{n \times (n-1)} \sum_{i<j}^{n} d_{ab}(i,j)$$

Where n denotes number of samples. (3.1)

It depends on following elements:

- The dissimilarity between P_a and P_b is related to the relative variation between fabric samples t_i and t_j:

$$d_{ab} = \left| vr_a(i,j) - vr_b(i,j) \right|$$

- The relative variation between t_i and t_j for the panelist P_k:

$$vr_a(i,j) = \frac{1}{\sqrt{m(k)}} \left| U_{ki} - U_{kj} \right|$$

m(k) denotes number of attributes used by P_k

U_{ki} and U_{kj}: normalized scores (which values lie between 0 and 1). Where $vr_a(i,j)$ characterizes the relative variation of sensory data given by panellist P_a from the sample t_i to t_j.

Here we can also define the criterion in order to compare two panellists according to the sensitivity of the data for the evaluation of samples of T; the sensitivity of P_a can is defined by:

$$S_a = \frac{2}{n \cdot (n-1)} \sum_{i<j} vr_a(i, j)$$

(3.2)

The definition of D_{ab} permits comparison of the two panelists on the bases of relative variation of samples. The dissimilarity between two panelists reaches its minimum only when the internal variations of sensory data of these panelists are identical.

The ability of panelists to score like each other can be defined by the dispersion:

$$Disp = \frac{2}{n \times (n-1)} \sum_{a=1}^{n-1} \sum_{b>a}^{n} D^2{}_{ab}$$

(3.3)

If an attribute has a lower dispersion value, this shows that panel members have understood that attribute in a similar way and evaluated in the same manner.

We can also define the contribution of every panellist in the sensory evaluation in terms of contribution dispersion (percentage): It computes the ratio between one panelist and all the others.

$$Contrib_B = \frac{2}{(Disp)_{wb}} \sum_{a=1}^{n} D^2{}_{ab}$$

(3.4)

Where $(Disp)_{wb}$ is dispersion without considering the sensory data of panellist b .

For sensory evaluation samples, a paired comparison method was used, i.e. comparison of two samples with respect to a particular attribute. Then a new sample is ranked with respect to one of the sample that had been already compared. Panellists were asked to concentrate on the particular parameter being evaluated at a time. The procedure of evaluation for each attribute was explained in detail. The samples were cut into A4-sheets. Using a rectangular shape enables to give instructions regarding the direction of the knitted fabric. All samples were conditioned for a minimum of 24 hours under standard atmospheric conditions (20±2°C temperature, 65±2 % relative humidity) because these conditions can influence the mechanical properties of textiles. On the basis of screening of panellists, three members were selected for the evaluation.

3.3.2 Results:

3.3.2.1 Panel assessment:

Each panellist was given a set of 52 fabric samples composed of four subset of 13 different knitted fabrics (Table: 2.1). Each panellist was asked to rank these 52 fabrics according to sensory attributes defined in Table 3.2.

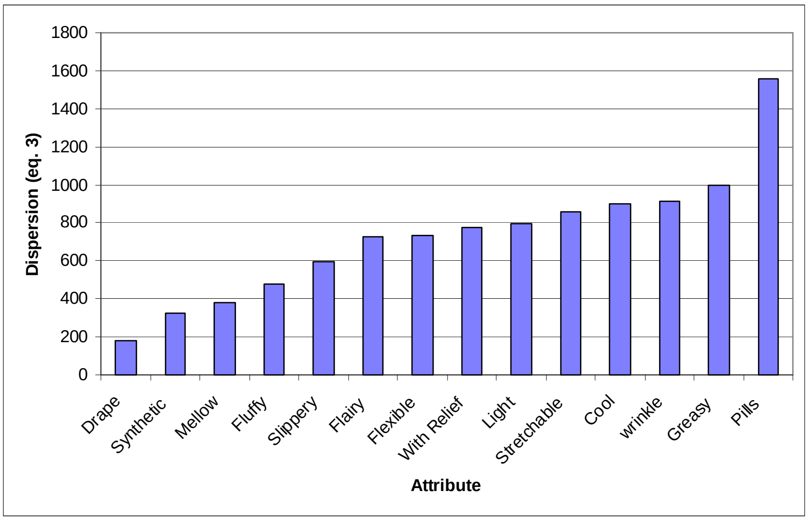


Figure 3.1 Dispersion values of different attributes

It can be observed from figure 3.1 that the dispersion of attributes related to the handle of fabric i.e. Drape, Synthetic, Mellow, Fluffy, Slippery, Flairy, Flexible is lower than attributes, which corresponds to appearance (pilling, wrinkle), thermal feeling (cool), structural relaxation (Stretchable, With Relief), surface feel (Greasy) and mass (Light). It implies that panellists are able to understand handle of the fabrics in similar way with respect to handle attributes, but for the attributes related to appearance, their ranking criteria is quite different. The reason behind this variation could be flaws in the method of evaluation of particular attributes, or the involvement of some external factors in sensory evaluation of particular attributes. If we take the example of coolness, they found frequent changes in sensation of coolness for a sample with time. As they used pair composition method, they had to feel the sensation of cool for each fabric several times in order to compare it with the others, they found this sensation quite different every time. For pilling they found a number of samples, which don't have pills at all, so it was difficult to rank all these samples.

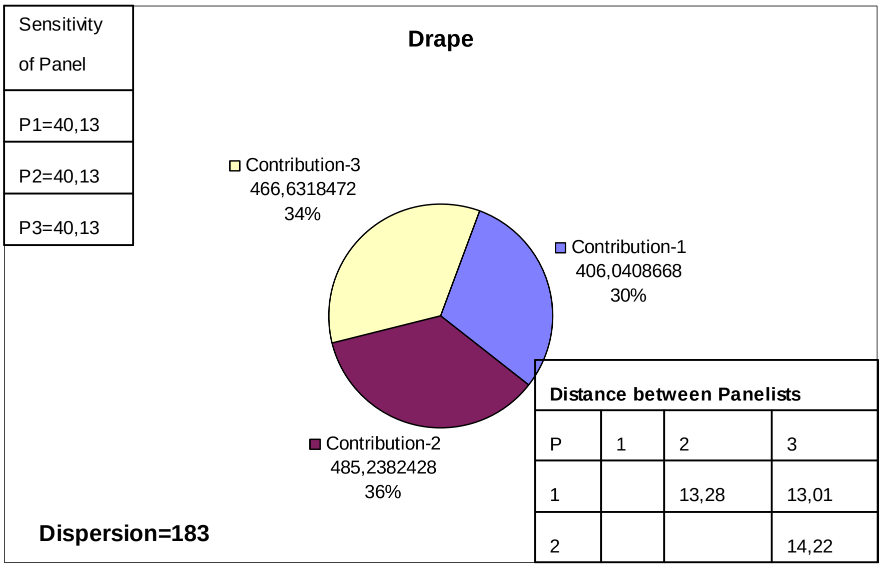


Figure 3.2 Panel assessments for attribute 'Drape'

Figure 3.2 represents the value of all criteria for panel assessment for attribute 'Drape'. The dispersion value of this attribute was found to be the least among all attributes. This implies that the panellists could do the evaluation for it in a similar way. The distance between panellists (eq. 3.1) is also the least among all the attributes and it has the same level between any two panellists. The percentage contribution for evaluation of drape is almost equally distributed; it means the data provided by panellists has equal importance.

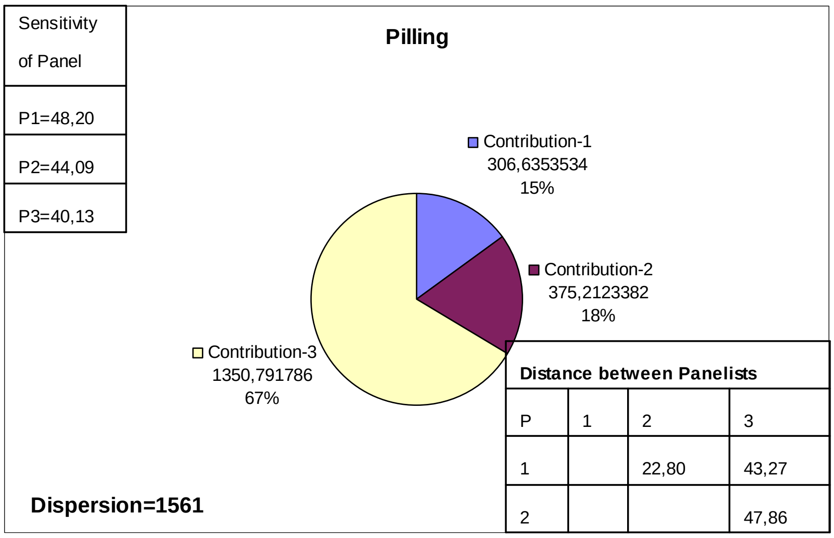


Figure: 3.3 Panel assessment for attribute ‘Pilling’

Dispersion value for attribute ‘Pilling’ is maximum, i.e. maximum variation between panellists, which is clear from the value of distance between panellists. The value of the distance of the 3rd panellist from the 1st and 2nd panellist is very large, because of the large distance, the contribution of 3rd panel in the evaluation is also high i.e. 67%.

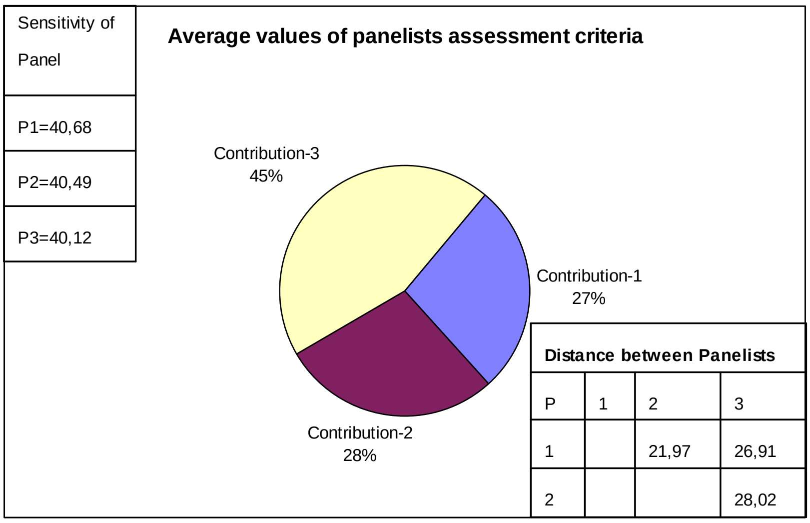
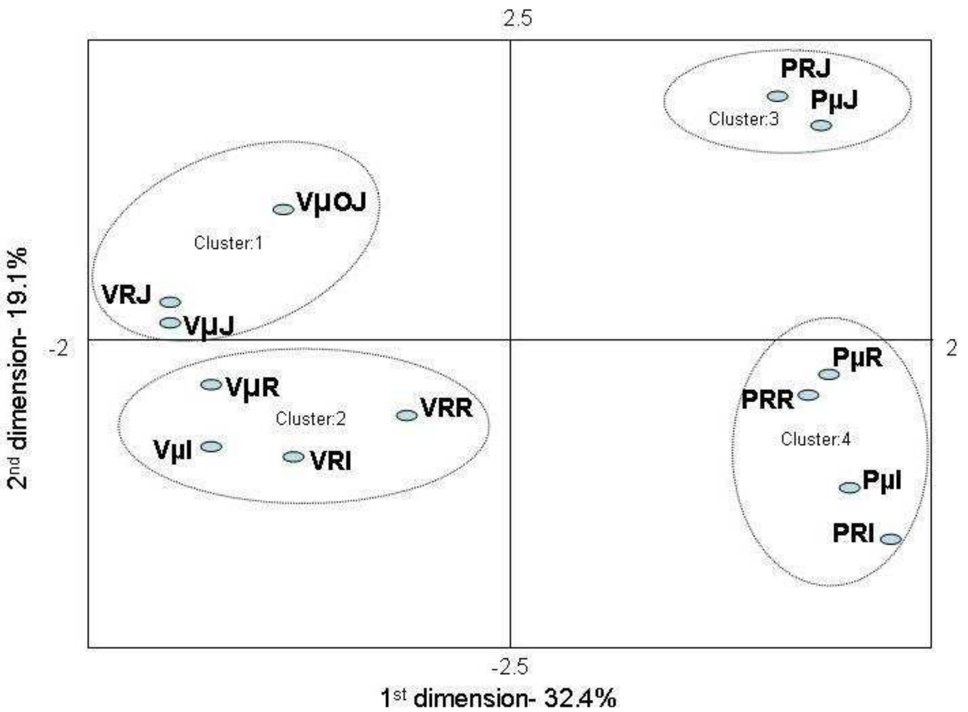


Figure 3.4 Average values of panellists assessment criteria

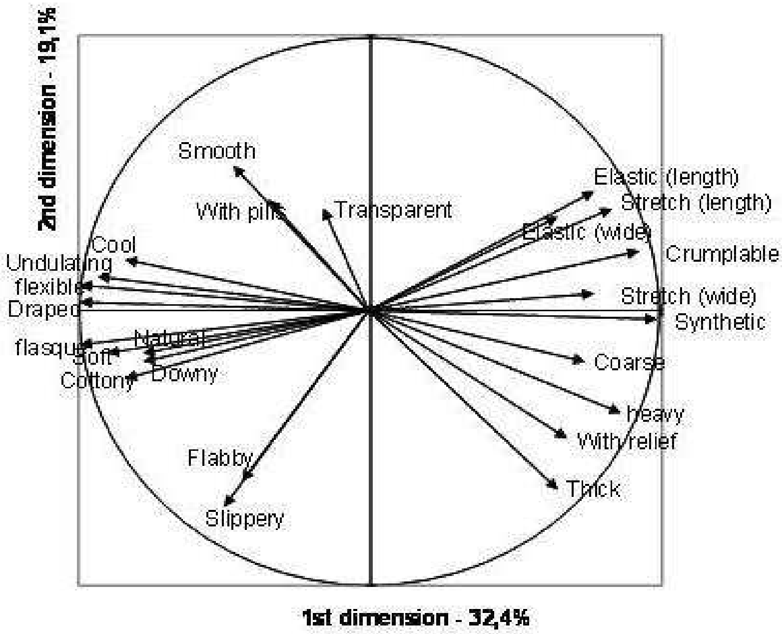
Figure 3.4 shows the average of different panel assessment parameters defined in this paper, ideally the contribution of each panellist should be 33.33%, for our panel we got 27% ,28% and 45% for first, second and third panellist respectively, which is assumed to be acceptable. Sensitivities of the panellists were obtained almost same. On the basis of these criteria our sensory data for this study was assumed to be acceptable for second part of this study.

3.3.2.2 An overview of different Knitted fabrics with respect to sensory attributes:

The first sensory evaluation session was aimed to provide an overview of the fabrics and the way to be perceived attributes. The panellists were presented with the 13 knitted fabrics. They were asked to evaluate the fabrics by ranking them from 1 to 13 with respect to each attributes. To analyse data, a correspondence analysis is run. As for PCA (Principal components analysis), this statistical analysis aims to reduce multidimensional data sets to lower dimensions for analysis.



(a)



(b)

Figure 3.5 (a), 3.5 (b) First two dimensions of fabric and attributes maps of non treated fabrics

Figure 3.5(a) is two dimensional PCA map of 13 knitted fabrics and 3.5(b) is of corresponding attributes.

1st dimension

On the fabrics map (3.5 a) it appears that there is a strong opposition of the viscose fabrics (on the left of the map) vs. the polyester fabrics (on the right of the map), on the first dimension. This means that this is the main difference that the panellists perceived when they run the grouping tasks. It represents 32.4% of the whole variability between products described by panellists. Looking at the terms map, it appear that panellists had a strong tendency to gather the viscose fabrics together because their “cottony”, “downy”, “draping”, “undulating”, “cooling” and “soft” characteristics. Some panellists mentioned that the viscose fabrics gave the feeling of being “natural” fabrics, as opposed to the polyester fabrics that qualified as “synthetic” / “plastic”. The polyester fabrics were put together because of the “synthetic” sensation they provide. They were also described as being creased.

2nd dimension

The second dimension opposes fabrics that have different constructions. The main opposition is between the “Polyester jersey” fabrics vs. the “Polyester 1x1 rib” and the “Polyester interlock”. The jersey is perceived as elastic and stretch lengthwise, whereas the 1x1 rib and the interlock are described as having relief, flabby and being heavy and thick.

To a lower extent, there is also an opposition between the “viscose jersey” (being perceived as smooth and undulating) vs. the “viscose 1x1 rib” and “viscose interlock” (being described as slippery).

We can also observe four clear clusters in figure: 3.5 (a).

- Cluster 1 Viscose with a jersey construction, i.e. fabrics VµJ, VRJ and VµOJ. They were often gathered as they were all perceived as flexible, well-draped, and undulating and smooth.
- Cluster 2 : Viscose with a 1x1 rib or an interlock construction, i.e. VµR, VµI, VRR and VµJRI. They are perceived as downy, cottony, soft, flexible, well-draped and providing a feeling of “natural” fabric.
- Cluster 3 : Polyester with jersey construction, i.e. PµJ and PRJ (perceived as elastic and stretch in length). Those two fabrics were perceived as creased, elastic and stretch lengthwise.
- Cluster 4: Polyester with a 1x1 rib or an interlock construction, i.e. PµR, PµI, PRR and PRI, characterised by their heaviness, their thickness and their relief.

The material and the construction are the two key-parameters for sensory perception on our range of products. For our panellists and the list of linguistic terms they used, the fibre fineness (regular or micro) was of lesser significance than fibre type and structure for sensory perception.

3.3.2.3 Influence of ageing process with and without fabric softener on sensory hand:

The important objective of this part of the work was to check the effect of repeated washing with and without softener on the sensory hand of knitted textiles. All of the washing process variables were the same as previous. Table 3.3 shows the lower and upper boundaries of the sensory attributes defined in table 3.1.

Table 3.3 Lower and upper boundary of the sensory attributes:

	Wrinkle	Fluffy	Stretchable	Slippery	Light-Heavy	Flairy	Flexible
lower boundary	Wrinkle free	Most fluffy	Most stretchable	Most slippery	Heavy	Most flairy	Most flexible
Upper boundary	With wrinkles	Least fluffy	Least stretchable	Least slippery	Light	Least flairy	Least flexible
	Cool	**Drapable**	**Mellow**	**Pills**	**With Relief**	**Greasy**	**Synthetic**
Lower boundary	Coolest	Most Drapable	Most compressible	Least pills	Maximum relief	Most greasy	Cottony
Upper boundary	Warmest	least drapable	Least compressible	maximum pills	No relief	Least greasy	Synthetic feeling

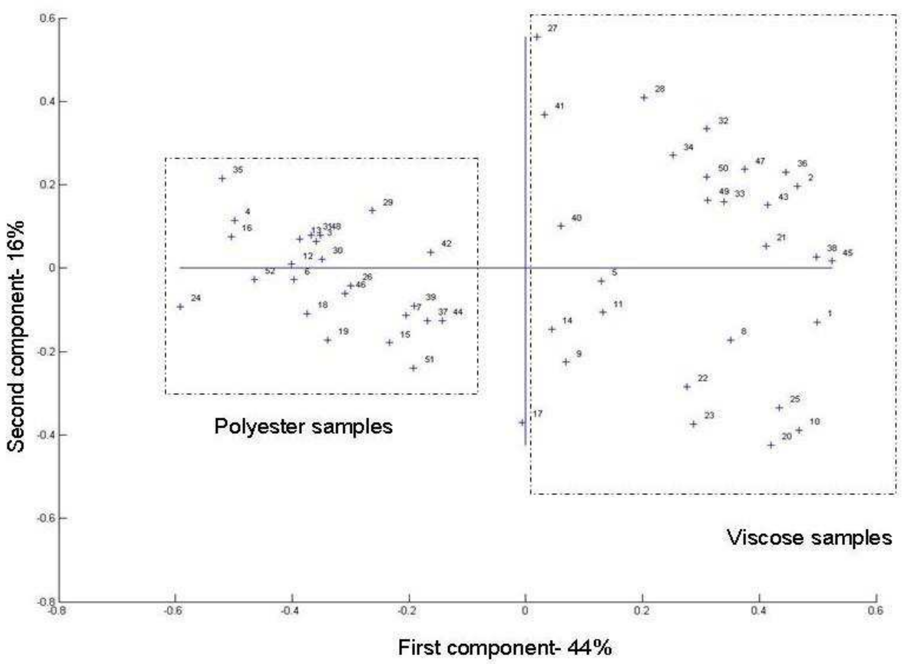


Figure 3.6 Fabric mapping for all 52 knitted fabric samples

Figure 3.6 shows fabric mapping of 52 knitted fabrics, obtained from matrix of size 52x14 (Number of fabric samples x number of attributes). The main objective of the work is to check the influence of ageing and softener on sensory properties of fabric but in fabric mapping of all fabrics together the influence of fibre type is so high that we could get two clear clusters of viscose and polyester samples. So to check the results for the influence of other factors, the matrix has to be divided in sub matrices (Table 3.4).

Table 3.4 Sub matrices of sensory evaluation results

S.N.	Fabric samples	Matrix size	Objective
1	All Viscose samples	28X14	To Check the influence of ageing of 40 cycles on viscose knitted textiles
2	All Polyester samples	24X14	To Check the influence of ageing of 40 cycles on Polyester knitted textiles
3	All Viscose samples gone through 1 ageing cycle (with and without softener)	14X14	To check the influence of softener on Viscose knitted textiles.
4	All Polyester samples gone through 1 ageing cycle (with and without softener)	12X14	To check the influence of softener on Polyester knitted textiles.
5	All Viscose samples gone through 40 ageing cycle (with and without softener)	14X14	To check the influence of softener on Viscose knitted textiles after 40 ageing cycles.

6	All Polyester samples gone through 40 ageing cycle (with and without softener)	12x14	To check the influence of softener on Polyester knitted textiles after 40 ageing cycles.

***Degree of Influence*:** For each sub matrices, we also calculated the degree of influence of key attributes i.e. variation of sensory score around average score. The greater value of DOI for an attribute indicates a greater influence on it by the parameter (constructional parameter, wash-ageing, use of domestic softener) explained by PCA map.

$$DOI = \sum_{i=1}^{n} /\mu - \mu_{av} /$$

Where μ = Normalised score between 0 and 1 (3.5)

μ_{av} = Average score

n= Number of sample

3.3.2.3.1 All Viscose Samples:

Figure 3.7 and 3.8 shows fabric and attribute mapping of all viscose fabrics respectively. The sample codes VµJW40 and VµJS40 represents knitted fabric of micro fibre with jersey construction, which had gone thorough 40 wash cycles without and with use of the fabric softener respectively.

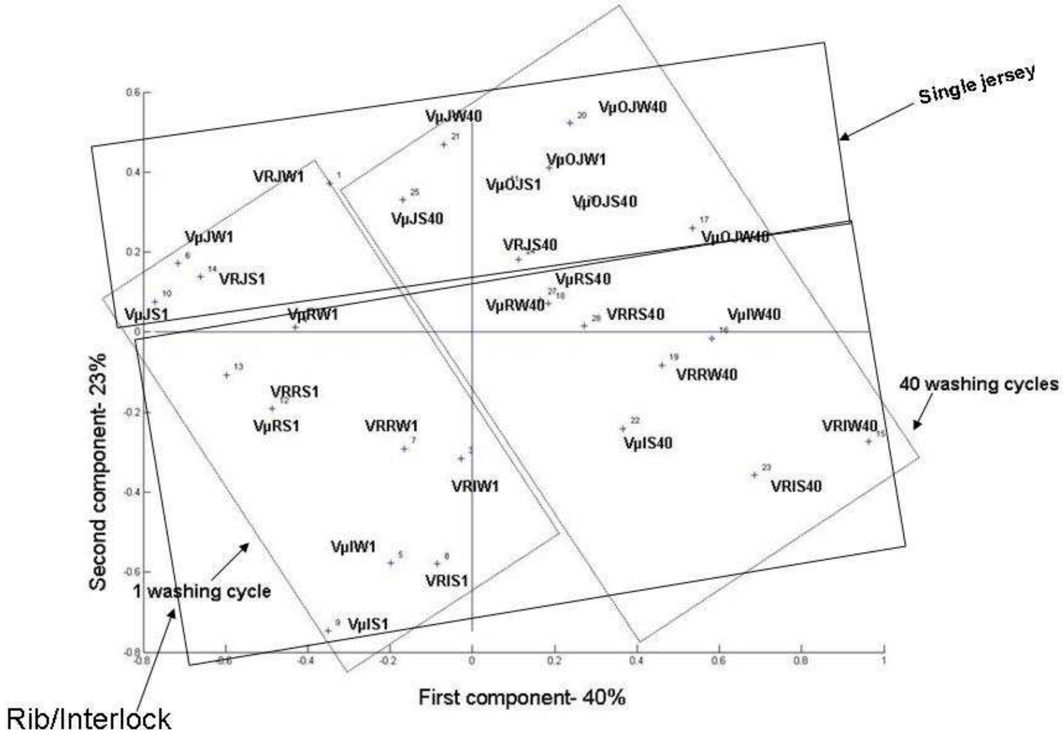


Figure: 3.7 Fabric mapping for all viscose fabric samples

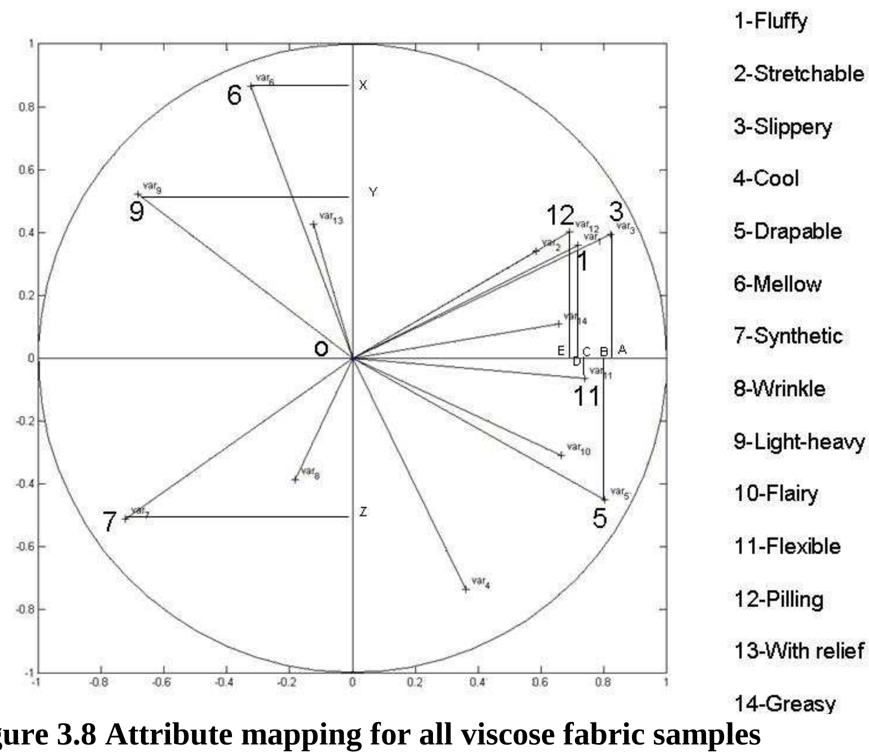


Figure 3.8 Attribute mapping for all viscose fabric samples

On the fabrics map, it appears that there is a strong opposition of the viscose fabrics gone through 1 washing cycle (on the left of the map) vs. the fabrics gone through 40 cycles (on the right of the map), on the first dimension. This means that this is the main difference that the panellists perceived when they run the grouping tasks. It represents 40% of the whole variability between products described by panellists. It implies that the influence of ageing can be mainly explained by 1st component. While second principal component is separating the clusters because of the knitted construction.

Looking at the terms map, the projection of attributes drapable, slippery, flexible, fluffy and pilling (OA, OB, OC, OD, OE) is maximum on the first principle component, which means that these attributes are most relevant attribute with respect to this component. It appears that panellists had a strong tendency to gather the viscose fabrics which have gone through 40 wash cycles, together because their drape, slippery, flexible, fluffy and pilling characteristics or we can conclude these are the sensory attributes which are influenced by the repeated washing. On the fabric map there is an opposition of single jersey and double jersey (rib and interlock) fabrics on the second component of the map. The attributes mellow, light-heavy and synthetic have maximum projection (OX, OY and OZ) on the second principal component.

For light- heavy, if we consider the first component, the left hand side favours the high value (upper boundary in Table: 3.3) of this attribute. It means that samples on the left side (Fabrics gone through 1 ageing cycle) of the fabric map are lighter than the samples on right side (samples gone through 40 aging cycles).

On the other hand if we consider the second component for this attributes, the upper half of the fabric map favours the upper boundary of the attribute. It implies that fabrics on the upper half side of fabric map (single jersey fabrics) are light and fabrics on lower side of the fabric map are heavy.

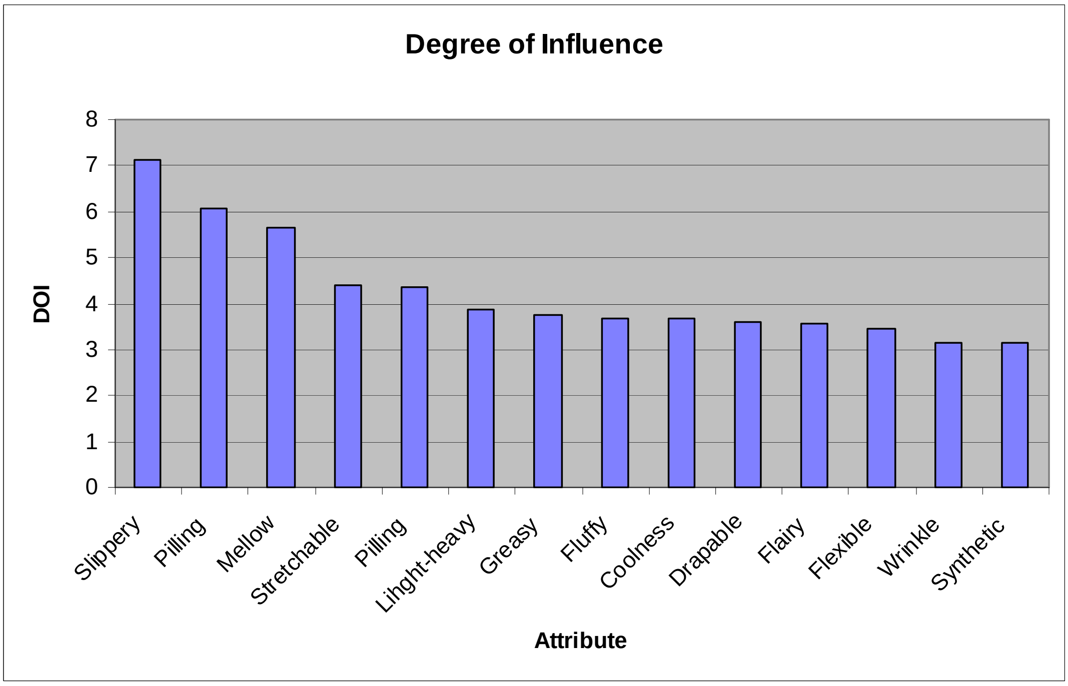


Figure 3.9: Degree of influence for all viscose fabrics

Degree of Influence for all viscose fabrics was calculated using equation (3.5), slippery and pilling have maximum DOI, which implies that the major influence of ageing is on slippery and Pilling while fluffy, drapable and flexible were affected to a lesser account.

3.3.2.3.2 All PET samples:

Figure 3.10 is the fabric map for all Polyester samples, it appears that there is a strong opposition of the single jersey and double jersey (rib and interlock) on the first dimension. The panellists found that single jersey fabrics can be represented by their light feeling, mellow and with relief characteristics, while double jersey fabrics are flairy, greasy, and give more synthetic feeling on touch.

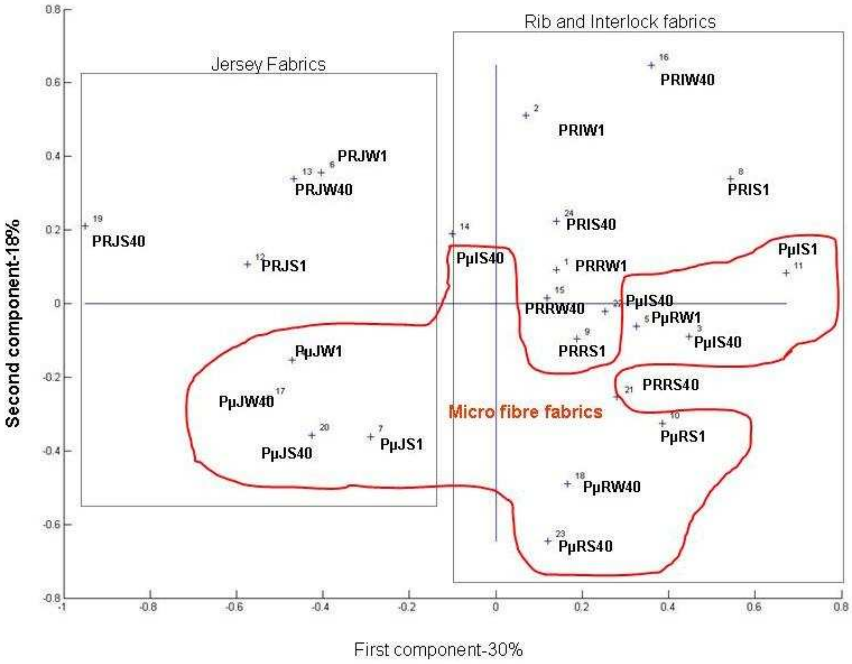


Figure 3.10 Fabric mapping for all PET fabric samples

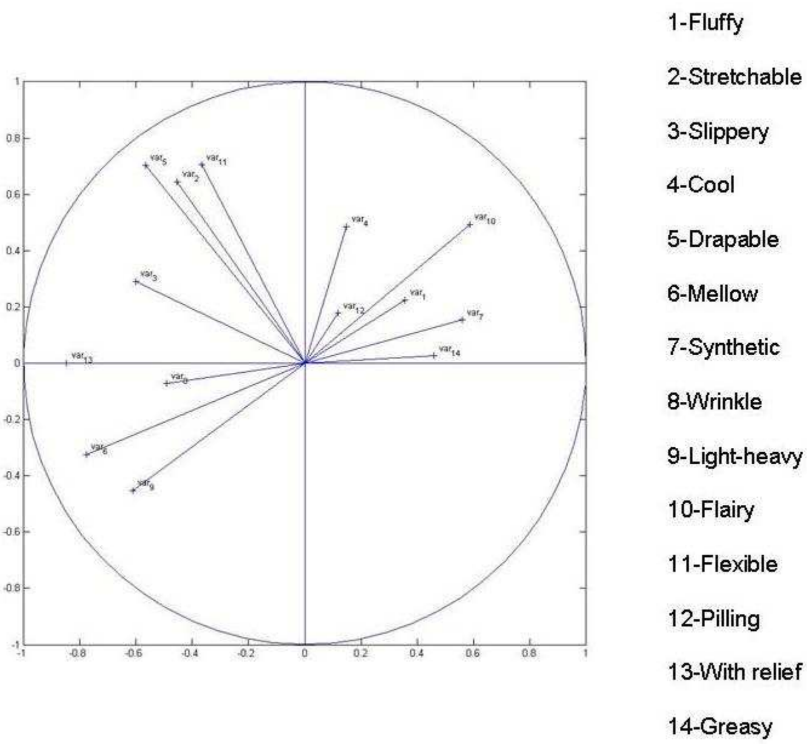


Figure 3.11 Attribute mapping for all PET fabric samples

First component represents 30% of the whole variability between products described by panellists. The second component which represents 18% of data variability, distribute the fabrics on the map on the basis of fibre type i.e. micro or regular. It seems that the effect of ageing on polyester is not as much as on viscose because of polyester's highly crystalline region, hydrophobic and mechanically tough characteristic.

3.3.2.3.3 Viscose samples gone through 1 ageing cycle:

Figure 3.12 is the fabric map for viscose fabrics, which were subjected to one washing cycle. There was not a clear cluster of softener treated and non treated fabric but it can be observed that there is a significant change in sensory properties of all interlocks, single jersey regular fibre and rib regular fabric.

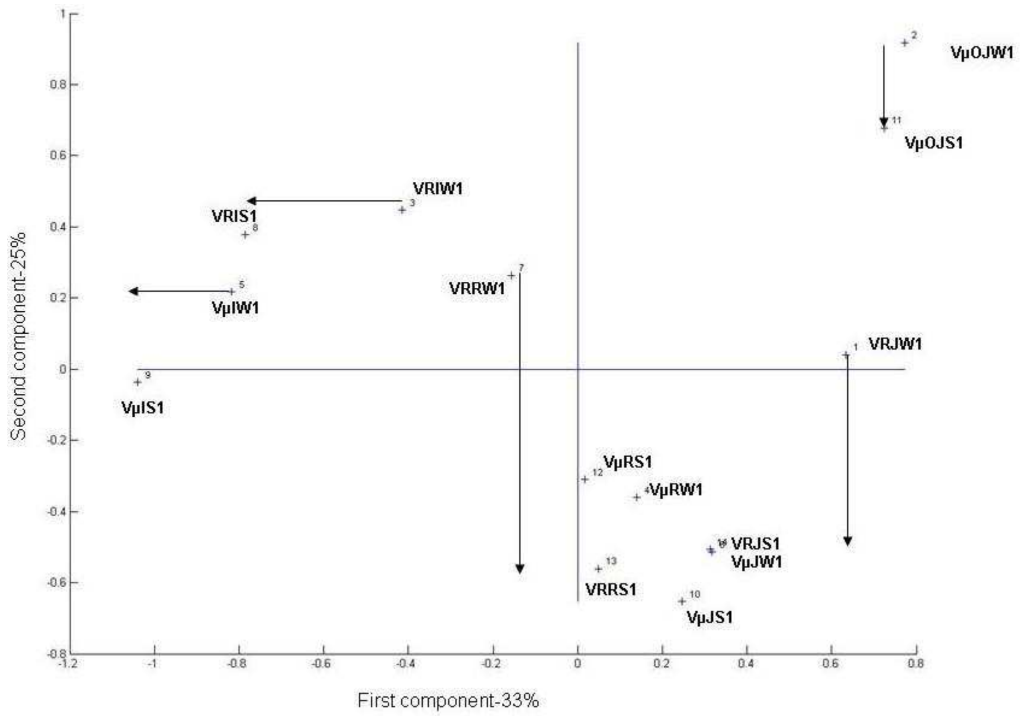


Figure: 3.12 Fabric mapping for viscose fabric samples, gone through 1 washing cycle

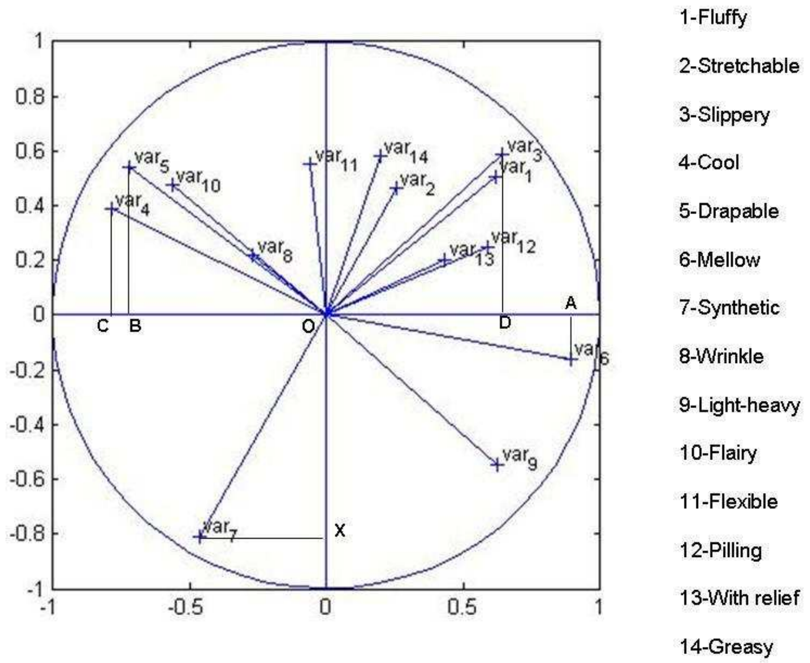


Figure 3.13 Fabric mapping for viscose fabric samples, gone through 1 washing cycle

In Figure 3.13 Mellow, drapable, cool, slippery has maximum projection (OA,OB,OC,OD) on first principal component, it implies that interlock viscose fabric have better handle in respect to these attributes when are treated with fabric softener.

Cool/Drape: - This attributes increase to the left that means, use of fabric softener for interlock fabrics is favouring the upper boundary (least drape and warmest) of these attributes but at the same time it can be observed that these changes are small (especially for viscose-micro fibre. As interlock is a dense and higher area density structure so it was found to be mellow and less drapable.

Slippery/ Mellow:- As the direction of these vectors is towards right while the use of fabric softener is shifting interlock fabrics towards left, It indicates that use of fabric softener is favouring the lower boundary of the attribute. So fabric softener is making interlock fabrics more compressible and more slippery.

The change in position of jersey regular fabric and rib regular fabric on the fabric map can be explained by the second principal component. 'Synthetic' has maximum projection (OX) on the second component, it implies that the panellist could feel more synthetic feel with softener treated fabric.

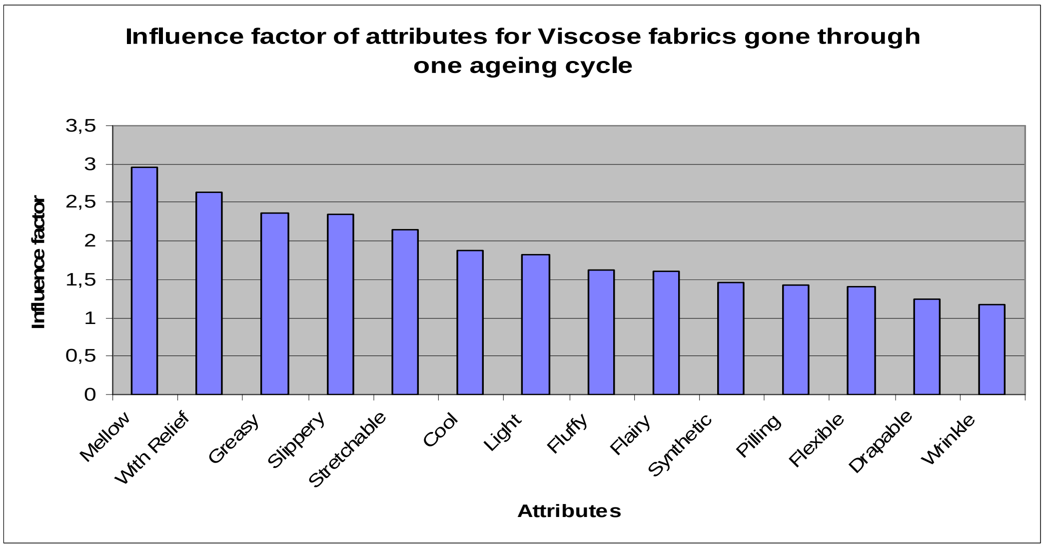


Figure: 3.14 Degree of Influence for viscose fabrics gone through 1 washing cycle

The order of influence of attributes, which are influenced by fabric softener is Mellow> Slippery>Cool>Synthetic >Drapable, it implies that for jersey and rib fabrics, softener affect their cottony feeling but with a low DOI, while in the case of interlock fabrics mellow (compressibility) of fabric is enhanced with use of fabric softener.

3.3.2.3.4 Viscose samples gone through 40 ageing cycles:

Figure 3.15 is the fabric mapping for viscose textiles, subjected to 40 ageing cycles. The second component of the map separates softener treated and non treated fabrics clearly. This separation is due to the attribute 'stretchable' and synthetic. It implies that fabric softener changes the synthetic feeling and stretchable behaviour of the viscose fabrics, when they are subjected to several washing cycles with softener. The reason behind the change in stretchable behaviour and synthetic feeling of softener treated fabrics is the boundary lubrication of the fibres and yarn which enhance the mobility by reducing inter fibre friction.

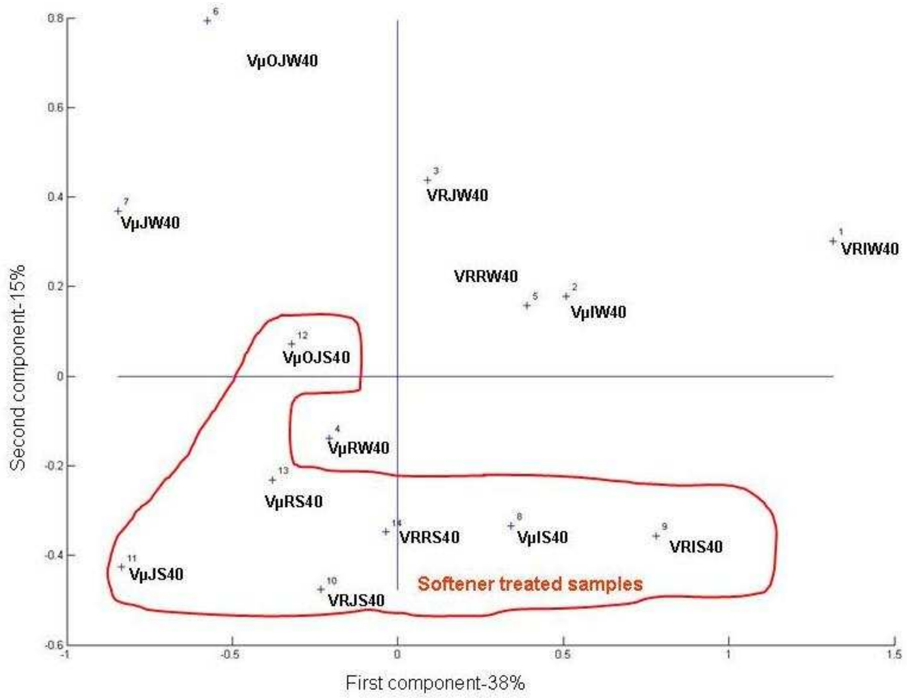


Figure 3.15 Fabric mapping for viscose fabric samples, gone through 40 washing cycles

Stretchable: - Here the direction of vector of attribute 'Stretchable' is up, while the softener treated fabrics are down side of the fabric map. It implies that softener treatment is favours the lower boundary of this attribute i.e. most stretchable. So softener makes the fabrics more stretchable.

Synthetic: - The direction of this vector is down and softener treated fabrics are also at the lowers side of the fabric map. It indicates that softener is favouring upper boundary of this attribute i.e. fabrics more synthetic feeling.

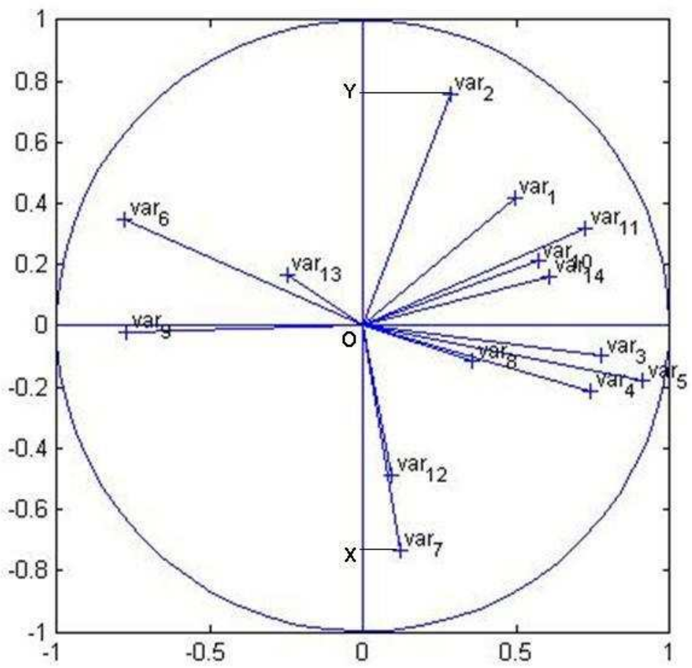


Figure: 3.16 Attribute mapping for viscose fabric samples, gone through 40 washing cycles

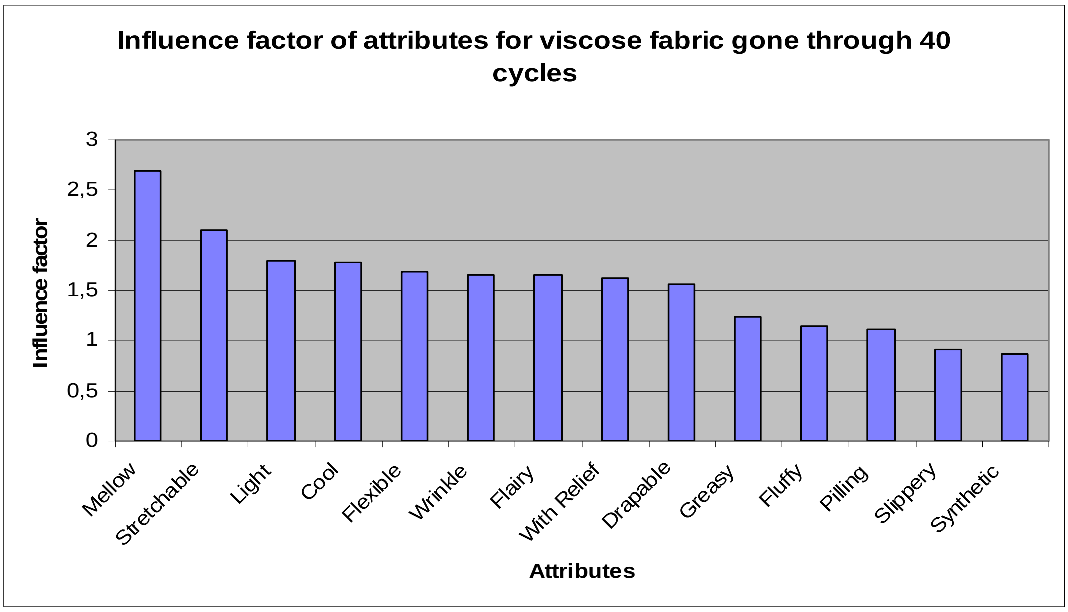


Figure 3.17 Degree of Influence for Viscose fabrics gone through 40 washing cycles

Figure: 3.17 shows that use of softener for 40 washing cycles influence Stretchability of viscose fabrics with higher degree of influence, while affect of cottony feeling exists but with lower degree of influence.

3.3.2.3.5 PET samples gone through 1 ageing cycle:

Figure 3.18 is fabric mapping of PET fabrics, subjected to 1 washing cycle. Because of curling behaviour of the single Jersey fabrics, the sensory evaluation could not be performed accurately specially for the attributes like: ‘Drape’, ‘Flairy’, and ‘Wrinkle’. The behaviour of single jersey fabrics is quite different than other fabrics (Figure 3.10). So these fabrics were not included in the mapping of polyester fabrics in order to check the effect of softener.

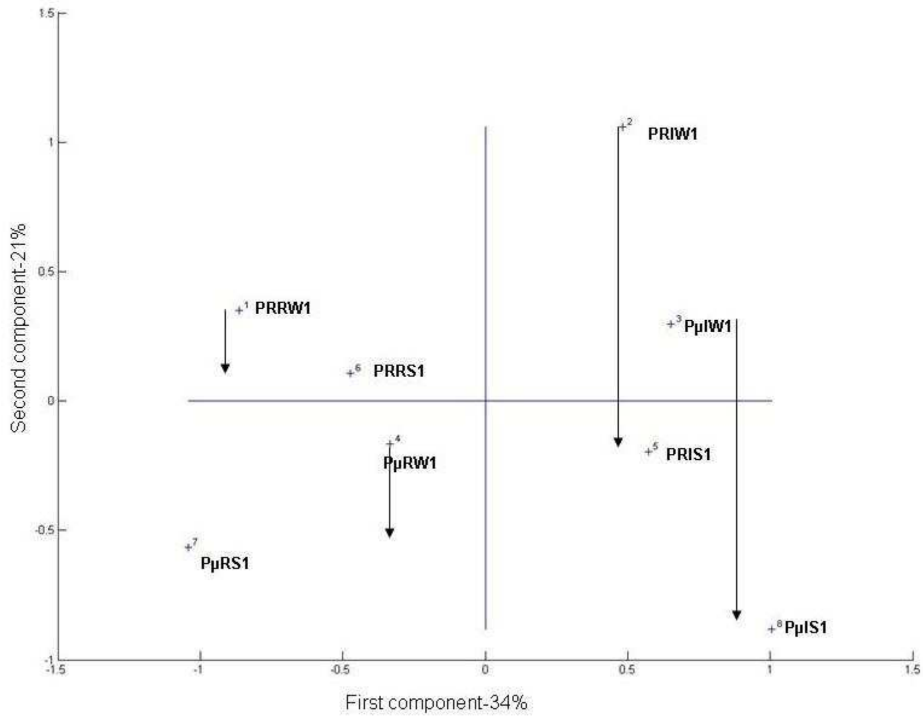


Figure: 3.18 Fabric mapping for PET fabric samples, gone through 1 washing cycle

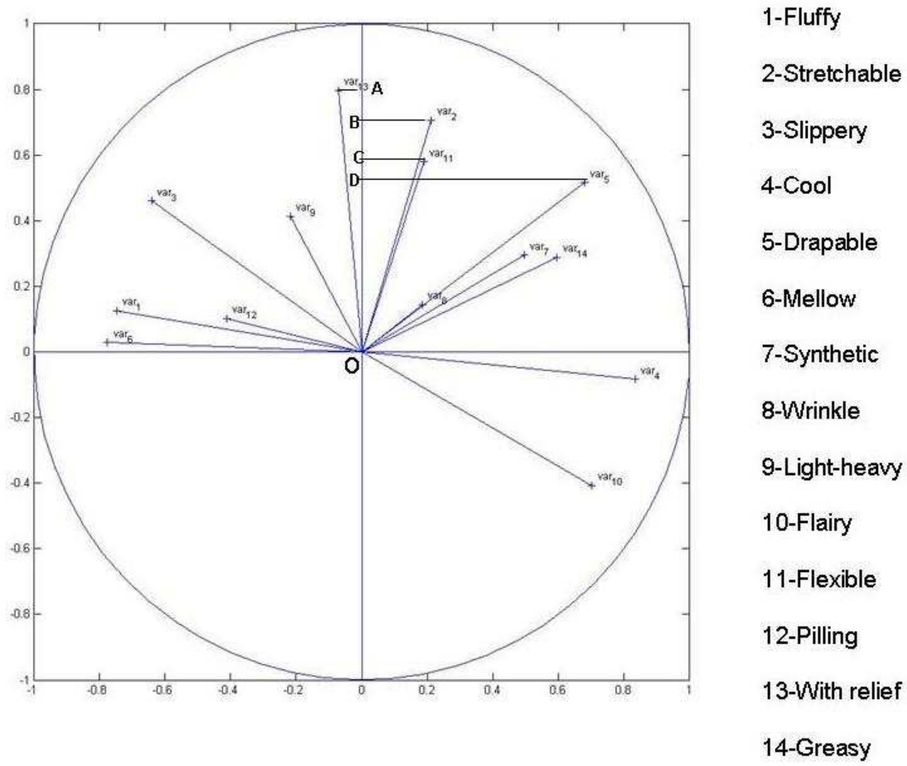


Figure: 3.19 Attribute mapping for PET fabric samples, gone through 1 washing cycle

The second component of fabric map explains the influence of the softener on the PET fabric, subjected to 1 washing cycle. The change in position, when fabric is washed with softener is due to attributes ‘With relief’, ‘Stretchable’, ‘Flexible’ and ‘Drape’.

As fabric conditioner treated samples are shifting towards lower side of the fabric map, while vector of with relief, stretchable, flexible and drape are on upper side of the attribute map. It indicates that the softener treatment favours the lower boundary of attributes i.e. more relief, more stretchable, more flexible and more drapable.

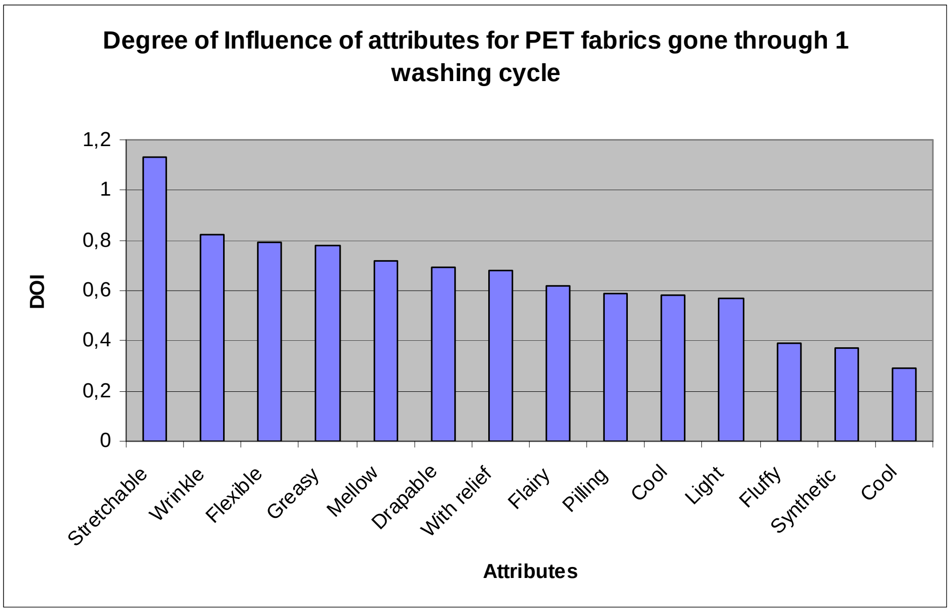


Figure: 3.20 Degree of Influence for PET gone through 1 washing cycle

On the basis of DOI, it can be said that, stretchable and flexible are most influencing attributes for PET fabric gone through 1 washing cycle.

3.3.2.3.6 PET samples gone through 40 ageing cycles:

Figure 3.21 is fabric mapping of PET fabrics, subjected to 40 washing cycles. Panellists perceived the difference on the base of structure i.e. rib and interlock.

The first component of map distributes the rib and interlock fabrics on the bases of attributes 'Light-heavy', 'Mellow', 'Drapable' and 'Flexible'. Interlock fabrics are on left hand side of the fabric map, It implies here that these fabrics favour the upper boundary of drapable and flexible and lower boundary of mellow and light-heavy i.e. less drapable, least flexible, most compressible and heaviest.

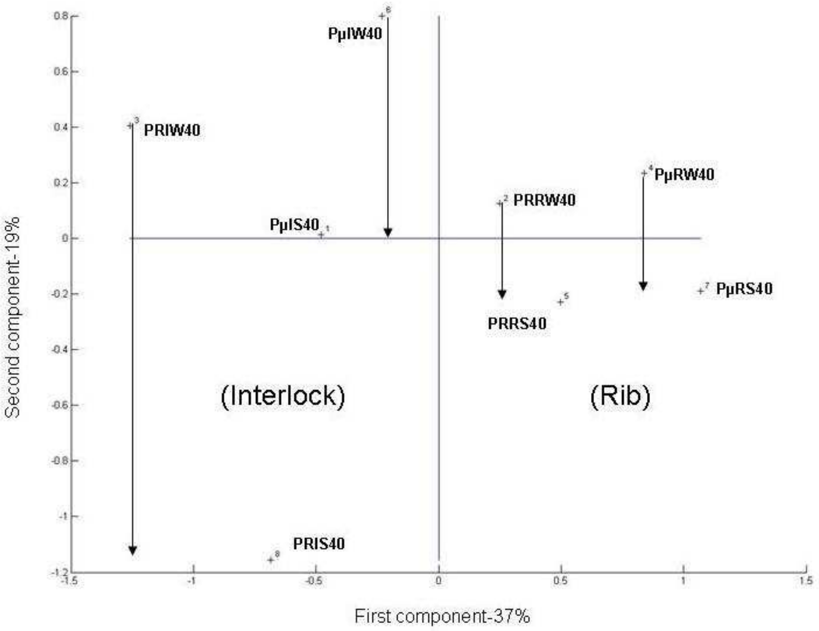


Figure 3.21 Fabric mapping for PET fabric samples, gone through 40 washing cycles

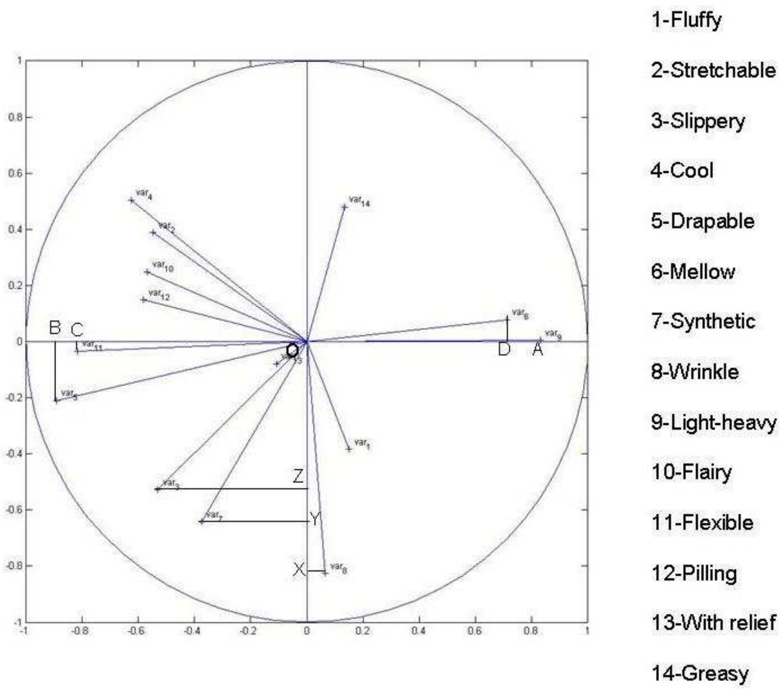


Figure: 3.22 Attribute mapping for PET fabric samples, gone through 40 washing cycles

The second component represents the influence of softener on fabrics. The position of rib and interlock polyester fabrics treated with softener, changes on the fabric map, because of sensory attributes 'Wrinkle', 'Synthetic' and 'Slippery'. The position of softener treated fabrics and the direction of the attribute vectors are on the lower side of the fabric and attribute map respectively. So softener treatment favours the upper boundary of these attributes: - more wrinkles, more synthetic feel and more slippery.

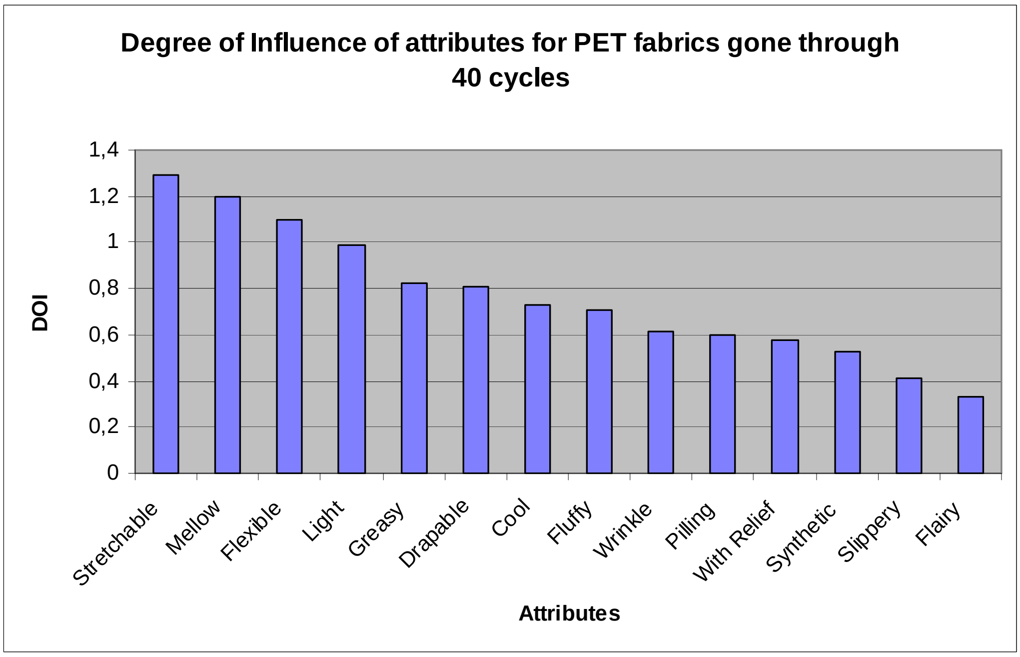


Figure 3.23 Degree of Influence for PET gone through 40 washing cycles

The use of fabric softener on PET fabrics for 40 ageing cycles influence wrinkle, synthetic and slippery feeling but not with a high degree of influence.

3.3.3 Conclusions:

The type of fibre and construction of knitted fabrics play important role in sensory evaluation of knitted fabrics. It seems difficult to perceive the difference in sensory feeling between micro fibre and regular fibre. The influence of ageing on sensory feeling is significant only for viscose fabrics, PET fabrics don't change with ageing cycles. The use of softener significantly changes the sensory feeling of different attributes for both Viscose and Polyester knitted fabrics. The Influence of Ageing and use of fabric softener can be summarised in below table:-

Table 3.5 Summary of Effect of ageing and softener on Knitted textiles

S. N.	**Factor**	**Fibre type**	**Influenced Attributes**
1	Ageing	Viscose	Drape(+), Slippery(+), Flexible(+), Fluffy(+), Pilling(+)
2	Ageing	PET	Almost no effect
3	Softener	Viscose (One ageing)	Mellow(-), Drape(+), Cool (+), Slippery(-), Synthetic(+)
4	Softener	Viscose (Forty ageing)	Synthetic (+) and Stretchable(-)
5	Softener	PET (One ageing)	With Relief(-), Stretchable(-), Flexible(-) , Drape(-)
6	Softener	PET (Forty ageing)	Wrinkle(+), Synthetic(+), Slippery(+)

+ indicates that treatment favours upper boundary of sensory attribute.

- indicates that treatment favours lower boundary of sensory attribute.

3.4 Simultaneous influence of wash-ageing and use of fabric softener on mechanical properties of knitted textiles:

This section of the chapter seeks to demonstrate the interaction of wash ageing and the use of fabric softener during laundry with different textile parameters during the life of a garment. The 13 knitted fabric samples were put through a varying number of ageing cycles (1, 5, 20, 40) under two different conditions (with and without softener). The change in dimensional characteristics of these knitted fabrics along with prolonged washing was obtained. The change in these dimensional properties result change in mechanical and sensory properties of the knitted textiles.

3.4.1 Dimensional properties:

The six knitted fabrics were used to determine the dimensional properties of knitted fabrics. Samples which had gone through 1, 5, 20 and 40 wash cycles, were obtained. Loop length (l) was determined as mean length of yarn in each loop. Courses and wales were determined as the mean courses and wales per inch. Length constant and width constants were defined as K_L= courses/inch x loop length, K_W= wales/inch x loop length and K_L / K_W = loop shape factor. The progressive changes that occurred in the geometry of knitted fabrics which had gone through 1, 5, 20 or 40 wash cycles are shown in figure 3.24 to 3.27.

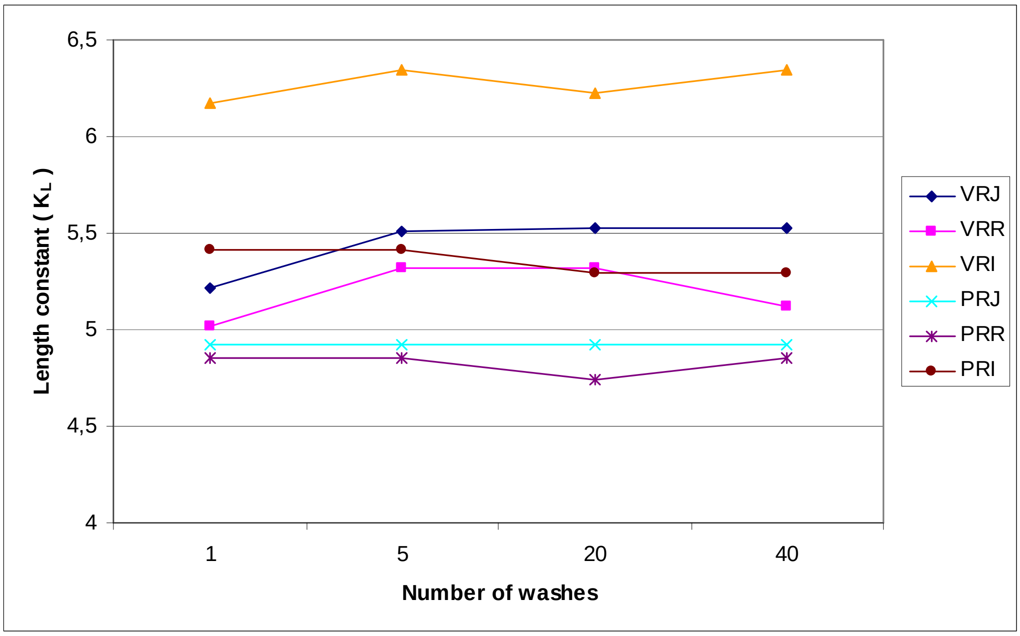


Figure 3.24 Progressive change in length constant with successive washing cycles

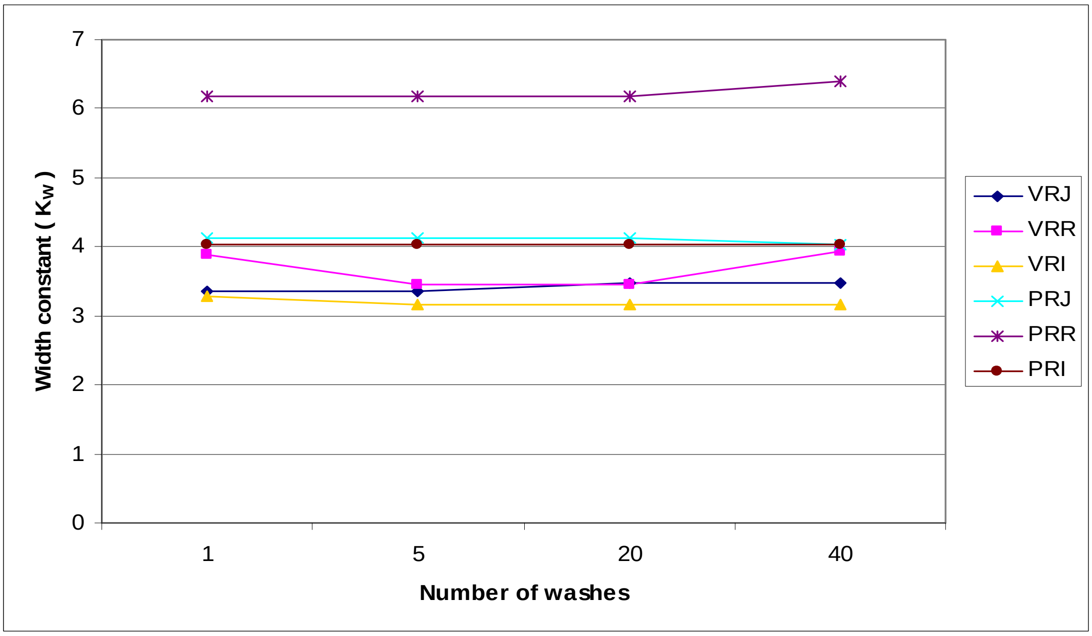


Figure 3.25 Progressive changes in width constant with successive washing cycles

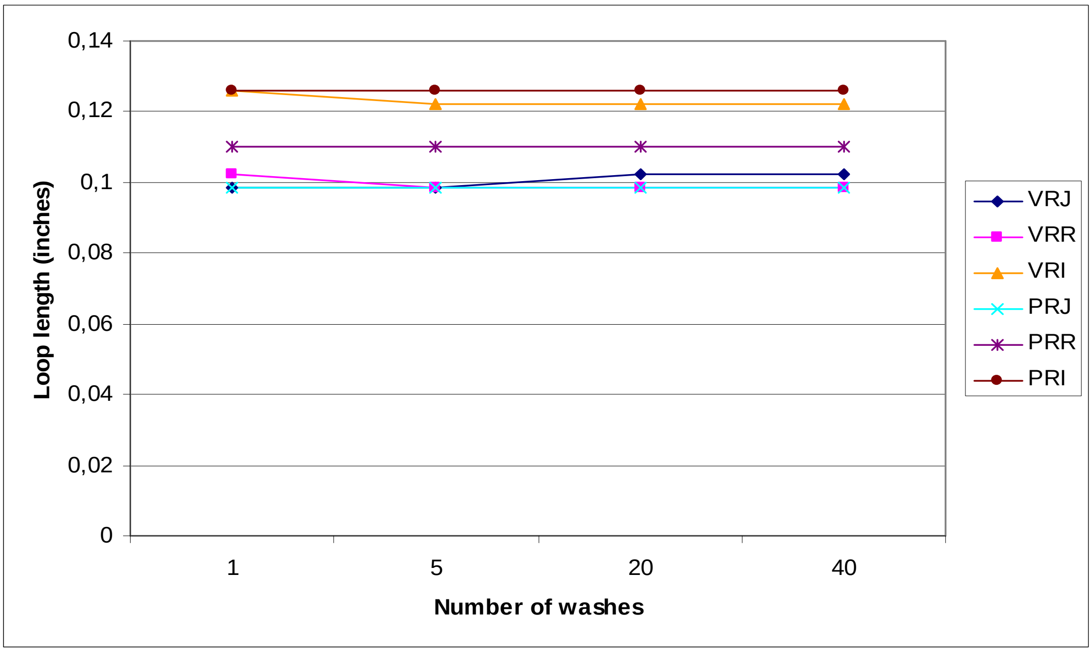


Figure 3.26 Progressive change in loop length with successive washing cycles

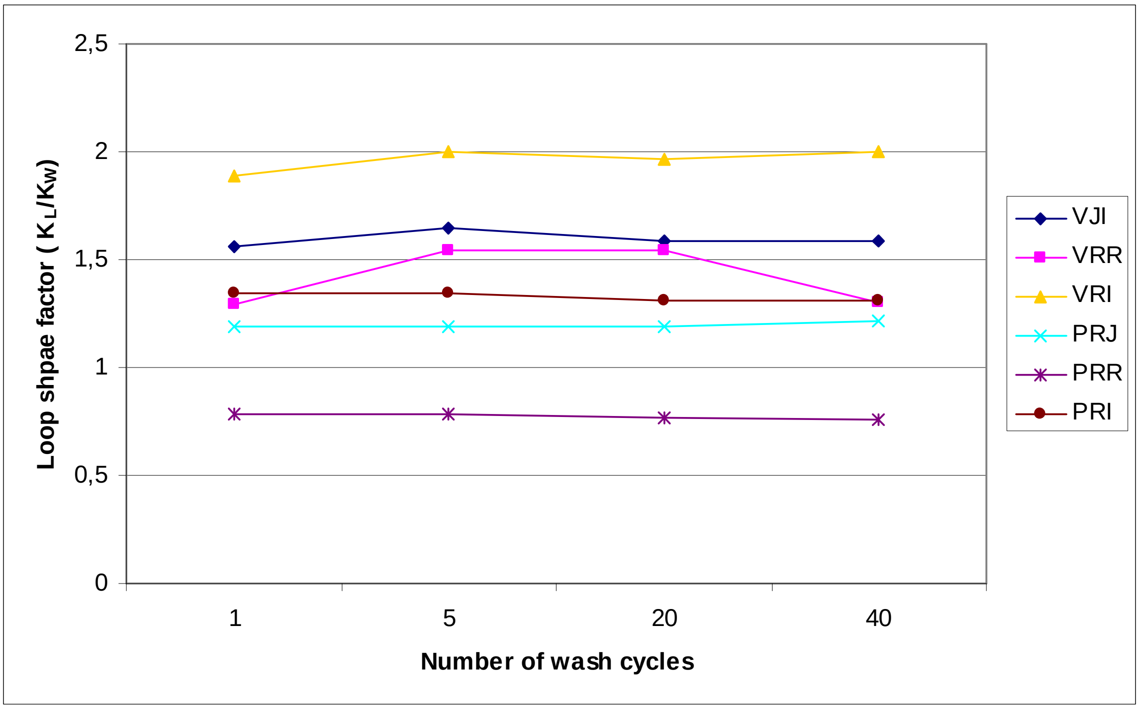


Figure 3.27 Progressive change in loop shape factor with successive washing cycles

It can be observed from Figure 3.24 to 3.27 that the changes in fabric geometry occurred only during the initial 5 wash cycles of viscose fabrics. These changes occur due to swelling of viscose fabrics, while PET fibres do not swell in water. The constant loop length throughout the 40 wash cycles and increase in loop shape factor during first 5 wash cycles indicates that fabric relaxation is brought about by change in loop shape (Figure 3.28) rather than loop length.

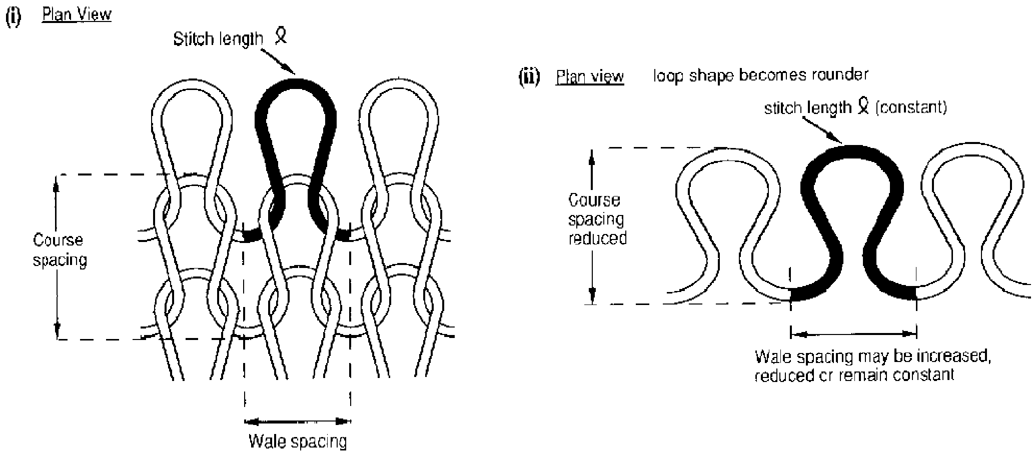


Figure 3.28 Change in loop shape during initial 5 washing cycles

The width constant of viscose-rib fabrics was found to be reduced during the initial 5 washing cycles. Due to high stretchability of rib structure, harsh mechanical action of washing causes more extension in rib structure. This results decrease in wales/inch.

3.4.2 Mechanical properties:

The different kinds of deformations (tensile, shear, bending, compression, surface) to which a garment is subjected during use are quantified by the mechanical parameters. The objective measurements, chosen to represent major changes that occur during the life cycle of apparel are given in Table 3.6. All measurements were made on fabric samples conditioned at 20 ± 2°C and 65 ± 2 % RH for 24 hours. We measured these mechanical parameters after initial wash cycles (1 and 5 wash cycles), in the middle of the life-cycle (after 20 wash cycles) and at the end of life-cycle (after 40 wash cycles). We used KES (Kawabata Evaluation System) to measure tensile, shear, bending and compression properties while UST (Universal Surface Tester) was used for surface properties.

Table 3.6 List of main mechanical properties

Properties	Characteristic value	Unit	Definition
Tensile	Tensile Extension (EMT)	%	% of extended length after applying known tensile force
	Tensile Resilience (RT)	%	Ability of fabric to recover after applying tensile stress.
Shear	Shear Rigidity(G)	gf/cm.degree	Ability of the fabric to resist shear stress.
	Shear Hysteresis (2HG3)	gf/cm	Fabric recovery ability after applying the shearing stress
Bending	Bending Rigidity (B)	$gf.cm^2/cm$	Measure of elastic resistance to the bending of yarn
	Bending Hysteresis (2HB)	gf.cm/cm	Measure of interfiber and inter yarn friction opposing fiber and yarn movement arising from bending
Compression	Compression Energy (WC)	$gf.cm/cm^2$	Energy associated in applying a certain amount of load
	Compression Resilience (RC)	%	Determine the recoverability of the fabric after

			compression deformation.
Surface	Roughness (Ra)	µm	Deviation of surface from mean position
	Roughness Depth(Rz)	µm	Mean of distance between the 5 highest peaks and the 5 deepest holes.
	Total Deformation (D)	µm	Deformation corresponding to surface of the textile
	Elastic Deformation (ED)	µm	Recoverable deformation corresponding to surface of the textile

Note: All the measurements were carried out in length-wise direction of samples.

3.4.2.1 Experimental details:

3.4.2.1.1 ***Tensile Properties:*** KESFB-1-A system was used to measure the tensile properties of knitted samples. All the tests were conducted under the high sensitivity condition i.e. maximum tensile load 120gf/cm, elongation speed: 0.1 mm/sec, sample size: 20x20 cm^2.

3.4.2.1.2 ***Shear properties:*** KESFB-1-A system was used to measure the shear properties of knitted samples. All the tests were conducted under the standard condition i.e. Maximum shear angle ± 8°, sample size: 20x20 cm^2, Fabric tension 200gf (10gf/cm), speed of shearing deformation 0.468 degree/sec.

3.4.2.1.3 ***Bending properties:*** KESFB2-A system was used to measure bending properties, all the tests were conducted under the standard condition i.e. maximum curvature (K): ± 2.5 cm^{-1}, bending rate: 2.5 cm^{-1}/sec and sample size: 20x20 cm^2.

3.4.2.1.4 ***Compression properties:*** KESFB-3-A system was used to measure the compression properties of knitted samples. All the tests were conducted under the standard condition i.e. Compression speed: .02mm/sec, Maximum pressing load: 50gf/cm^2 and with area of pressing plate 2 cm^2 (circle).

3.4.2.1.5 ***Surface properties:*** Universal Surface Tester (UST) was used to measure the surface properties of the knitted fabrics. UST is an instrument for the determination of micro mechanical properties of the material by determining the deformation behaviour of material near its surface. The structural pattern of knitted fabrics depends on the appearance of knitting loops on their surface. In general, for knitted fabrics so called 'rows` are created parallel to the wales direction. In this direction (course direction) the influence of construction has its major impact. So we decided to trace the surface profile only in 'rows' direction. Surface properties obtained using different styluses will not be the same, so it is very important to select the correct stylus according to the material. The fine styluses (0.8mm, 1.8mm diameter ball) give the roughness value with a high influence of structure but our objective is to check the influence of ageing and softener, ignoring the influence of construction as much as possible, the stylus should also represent human feeling. Ramkumar *et. al.* developed a polymeric human finger sensor with realistic shape and counters to measure the frictional properties of textiles and to evaluate frictional feel. The papillary stylus was selected for all surface parameters measurements in order to get results which represent human feeling [Ramkumar *et. al.*, 2003]. The roughness and roughness depth was measured by scanning the sample at 15 mm length at the speed of 0.10 mm/sec. without using any load, while permanent and elastic deformation of surface was measured using sample of

10 x 5 mm at the speed of 0.10 mm/sec. using 1 mN, 25 mN and 1 mN load respectively for three successive scans.

3.4.3 Results:

The 13 knitted fabric samples were put through a varying number of ageing cycles (1, 5, 20, 40) under two different conditions (with and without softener). In this way for each mechanical property we have a space of 104 (13 x 4 x 2) fabric samples. In order to reduce the complexity of the data we used a classification method of data mining called a 'decision-tree'. We developed two separate decision trees for each mechanical parameter for studying the influence of wash-ageing and the use of the fabric softener during laundry:-

1. Percentage change in mechanical parameter (μ_{wn}) due to wash ageing as a function of the following parameters:-
    a) Fibre type (viscose / PET)
    b) Fibre fineness (micro/ regular)
    c) Knitting construction (jersey/ rib/ interlock)
    d) Wash-ageing duration(*n1 to n2* i.e. 1 to 5, 5 to 20, 20 to 40 cycles)
    e) Use of fabric softener (yes/ no)

$$\mu_{wn} = \left(\frac{M_{n2} - M_{n1}}{M_{n1}} \right) X 100$$

………(3.6)

Where μ_{wn} = % Change in mechanical properties due to washing or ageing during $n1$ to $n2$ wash cycles..

M_{n2} = Value of mechanical parameter after *n2* washing cyles

M_{n1} = Value of mechanical parameter after *n1* washing cycles.

2. Percentage change in mechanical parameter (μ_{SN}) due to use of fabric softener as a function of the following parameters:-
    a) Fibre type (viscose / PET)
    b) Fibre fineness (micro/ regular)
    c) Knitting construction (jersey/ rib/ interlock)
    d) Washing stage during life cycle (N: 1st , 5th 20th or 40th cycle)

$$\mu_{SN} = \frac{1}{4}\sum_{N=1,5,20,40}\left(\frac{M_{NS} - M_{NW}}{M_{NW}}\right)X100$$

……………………(3.7)

μ_{SN} = % Change in mechanical properties due to use of fabric softener at N washing cycles.

M_{NS} = Value of mechanical parameter after N washing cycles with fabric softener.

M_{NW} = Value of mechanical parameter after N washing cycles without fabric softener.

The influence of the use of fabric softener during laundry is being presented in two ways. The decision trees based on eq. (3.6) represent the influence of the softener on ageing phenomena i.e. change in mechanical parameters of the fabrics which had gone through *n1* to *n2* wash cycles without the use of fabric softener and the fabric which had gone through same wash cycles but with the use of fabric softener. The decision trees based on the eq. (3.7) represent the influence of the use of fabric softener at particular a wash cycle (N) i.e. comparison of mechanical properties of the fabrics which had gone through N wash cycles without the use of fabric softener and the fabrics which had gone through N wash cycles with the use of fabric softener. In this chapter, we are explaining the influence of wash ageing and the use of fabric softener on EMT, G, B, WC and Ra. All of the mechanical parameters listed in Table 3.6 will be used in the chapter 4 of the thesis for correlating these mechanical parameters with sensory attributes.

3.4.3.1 Tensile extension (EMT):

In Figure 3.29, the decision tree for the change in EMT with respect to textile parameters, wash-ageing and the use of fabric softener is shown. An example of how to read a decision tree is shown by the darker lines in the decision tree for Viscose fabric. The darker portion indicates that if washing duration is from 1 to 5 cycles, and if softener was used during these 5 wash-cycles then there is a change of 17% of the EMT value for viscose fabrics.

The negative value of the change in EMT in the decision tree indicates that in general, wash-ageing of fabrics reduces EMT. While positive value in the lower decision tree (Figure 3.29) shows that the use of fabric softener during laundry increases the value of EMT. The first node of both the decision trees concerns the influence of the initial (up to 5) washing cycles. This implies that the behaviour of the knitted textiles in terms of the change in EMT due to wash ageing and the use of fabric softener is different during the initial wash cycles than in prolonged washing.

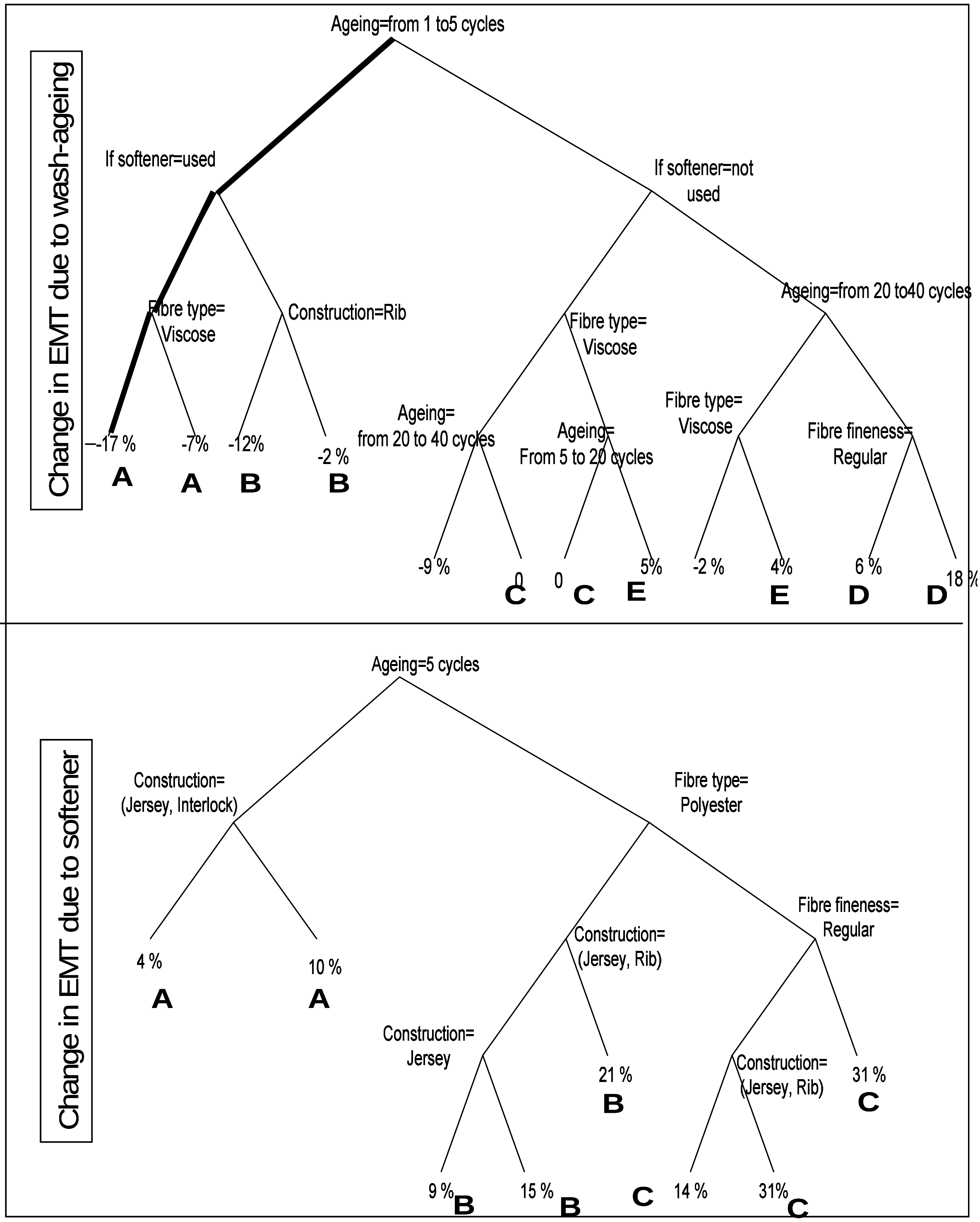


Figure 3.29 Decision tree for influence of wash-ageing and use of fabric softener on EMT

All the results in the above decision trees are noted with letter A, B, C, D, E and are explained as following:-

Change in EMT due to wash-ageing:

A. It can be noticed from the decision tree of the influence of ageing (condition A and B vs all other conditions) that the influence of ageing during the initial 5 cycles (from 1 to 5 cycles) is more prominent than wash-ageing after 5 cycles. This is due to the fact that knitted fabrics obtain their minimum energy state during the initial cycles (Figure 3.24 to 3.27). This causes a reduction in EMT value. This reduction in EMT is greater for viscose fabrics than PET fabrics. Regenerated cellulosic fibers such as viscose swell about 70-130% by volume in water, because of this swelling viscose knitted fabric's shape and the orientation of their loops change (Figure 3.28), this fiber swelling causes cellulosic textiles to become jammed, this jamming persists in the dry state causing an increased resistance to fabric extension. Because PET fibers are highly crystalline, mechanically tough and hydrophobic, and do not swell significantly in water, the change in EMT was for PET fabrics was not as much as for viscose fabrics.
B. The influence of wash-ageing during the initial cycles without the use of fabric softener is maximum for the rib structure. This may be because the rib structure is the most extensible structure among the three knitted structures. That's why harsh mechanical action of washing, causes more extension in rib structure. So, rib structure have already obtained an extended state at the end of 5 wash cycles, so they are less able to extend during EMT measurement (Figure 3.25).
C. The change in EMT, as a result of wash-ageing in the absence of fabric softener was observed to be minimum during 5 to 20 washing cycles. As explained above, during

the initial wash-cycles, knitted fabrics have already achieved their minimum energy state, so the change in EMT from 5 to 20 cycles is not significant. While after 20 washing cycles fibers may start to damage or serious fiber fibrillation may start because of vigorous and repeated mechanical action, which will further effect EMT value.

D. It was also found that the influence of wash ageing during 5 to20 washing cycles can be altered by the use of fabric softener. It can be observed in the decision tree that the EMT value increases during 5 to 20 wash ageing cycles when fabric softener was used and this is more prominent for the micro fibres.

E. The PET fabrics show a positive influence of ageing during 20 to 40 wash ageing cycles irrespective of the use of the fabric softener.

Change in EMT due to use of fabric softener:

A. This influence is lower for 5 ageing cycles because the influence of ageing is maximum during this duration. During the initial cycles the influence of softener is greater for the rib structure than other two knitted structures.

B. After the 5 cycles of washing, the influence of softener for Polyester fabrics was found to be in the order of interlock > rib > jersey.

C. For regular Viscose fabrics, Interlock showed maximum change in EMT during the later wash cycles because of use of fabric softener but for micro viscose fabrics, construction type does not play an important role for influence of softener.

3.4.3.2 Shear rigidity (G):

Figure 3.30 represents the change in shear rigidity of the knitted fabric due to wash-ageing and the use of fabric softener. In general, it can be noticed in the decision trees that wash-ageing increase the shear rigidity while the use of fabric reduces the value of shear rigidity.

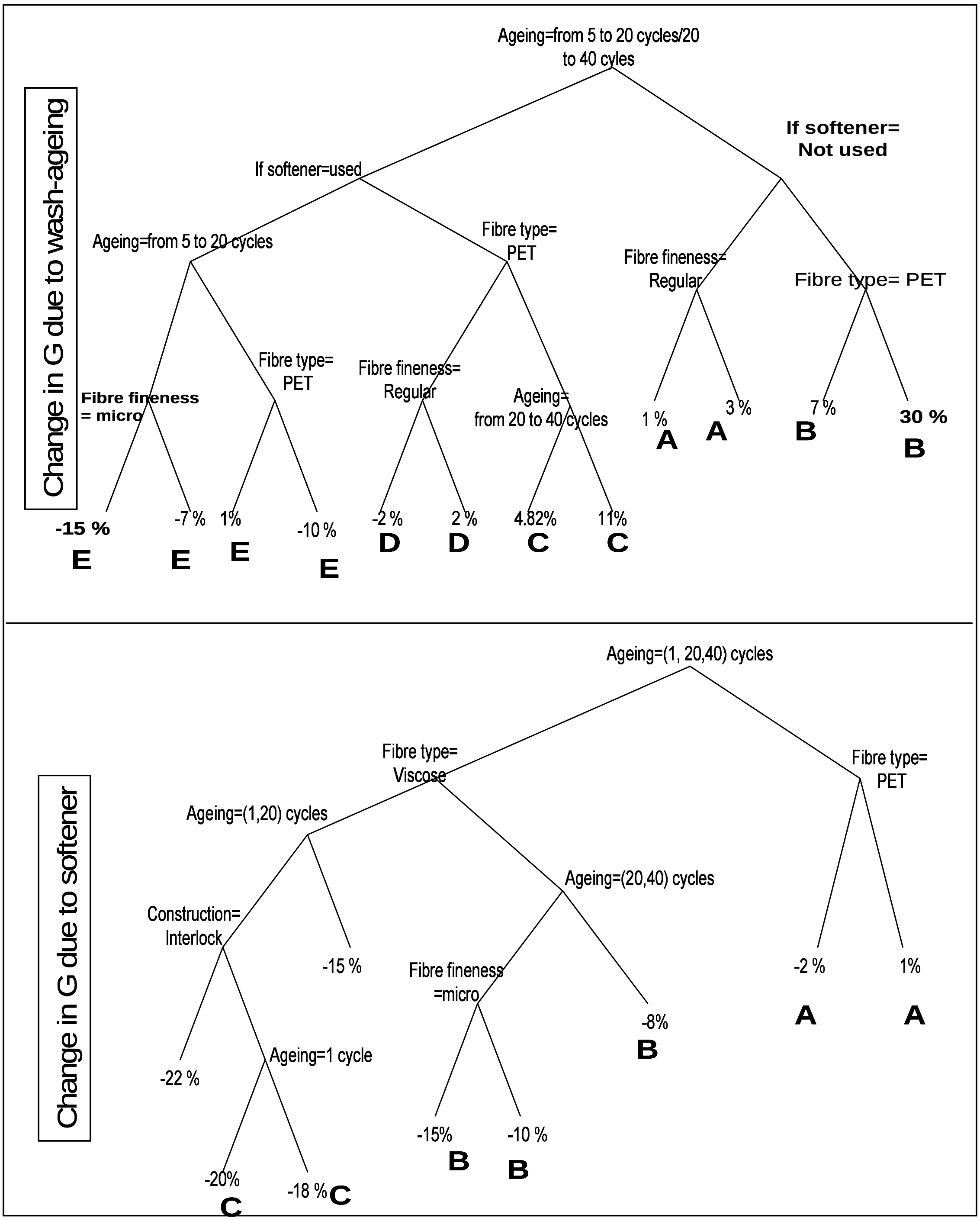


Figure 3.30 Decision tree for influence of wash-ageing and use of fabric softener on G

Change in G due to wash-ageing:

A. It can be noticed in the decision tree that the influence of wash ageing without the use of fabric softener during the initial 5 cycles is not as prominent as for prolonged wash ageing. When softener is not used, the increase in G during the initial 5 cycles is only 1 % and 3 % respectively for the fabrics made up of regular and micro fibres respectively.

B. The use of fabric softener enhances the influence of initial ageing to 7.48% and 29.96% for PET and viscose fibre respectively.

C. Prolonged ageing (from 5 to 20 or 20 to 40 wash cycles) without using fabric softener increases the value of shear rigidity of viscose fabrics.

D. When softener is not used for prolonged wash-ageing (from 5 to 20 or 20 to 40 wash cycles) for PET fabrics, they remain almost unchanged with respect to shear rigidity.

E. The use of fabric softener for prolonged washing cycles can eliminate the negative influence of the wash-ageing of viscose and PET fabrics, this may be due to the boundary lubrication provided by the softener molecules. This was more prominent during 5 to 20 wash-ageing cycles and was more effective for the fabrics made up of micro fibres.

Change in G due to softener:

A. The use of fabric softener at 5^{th} washing cycle was not as effective as at 1^{st}, 20^{th} and 40^{th} cycle.

B. The regular use of fabric softener for prolonged ageing (20^{th} and 40^{th} cycle) was found to be more effective than a single use (1^{st} wash-cycle) for PET fabrics. This was not the case for viscose fabrics. This is due to fact that PET fabrics remain almost unchanged with prolonged ageing while there are drastic changes in structure and surface of viscose fabrics during prolonged wash-ageing.

C. The influence of the use of fabric softener is greater for PET fabrics which are made up of micro fibres than the fabrics of regular fibres. This may be due to micro fibres providing a greater surface area for deposition than is available for the regular fibres.

D. For viscose fabrics, the decrease in G due to the use of fabric softener at the 40^{th} washing cycle is not as high as at the 1^{st} or 20^{th} washing cycle.

E. For viscose, interlock fabrics, the influence of softener at 1^{st} and 20^{th} wash-cycle was found to be more effective than for jersey and rib structures.

3.4.3.3 Bending rigidity (B):

Change in B due to wash-ageing:

A. The influence of wash-ageing mainly depends on the fibre-type; it can be observed from the decision tree that the influence of wash-ageing is very much less for PET fabrics which were washed without the use of fabric softener.

B. The influence of wash-ageing for PET fabrics was maximum during initial wash-ageing (1 to 5 cycles) cycles and this is more prominent if softener was used.

C. The maximum changes in B of viscose fabrics occur during the 5 to 20 cycles. This may be due to the deposition of Ca^{++} and Mg^{++} ions, which impart stiffness to the fabrics. This was found more prominent for the rib structure.

D. The use of fabric softener during prolonged ageing (5 to 20 / 20 to 40 cycles) of PET fabrics can result in a decrease in the value of bending rigidity of the wash-ageing.

E. There was very significant increase in the value of B for viscose- regular –jersey/ interlock during 1 to 5 or 20 to 40 wash-ageing cycles with the use of fabric softener.

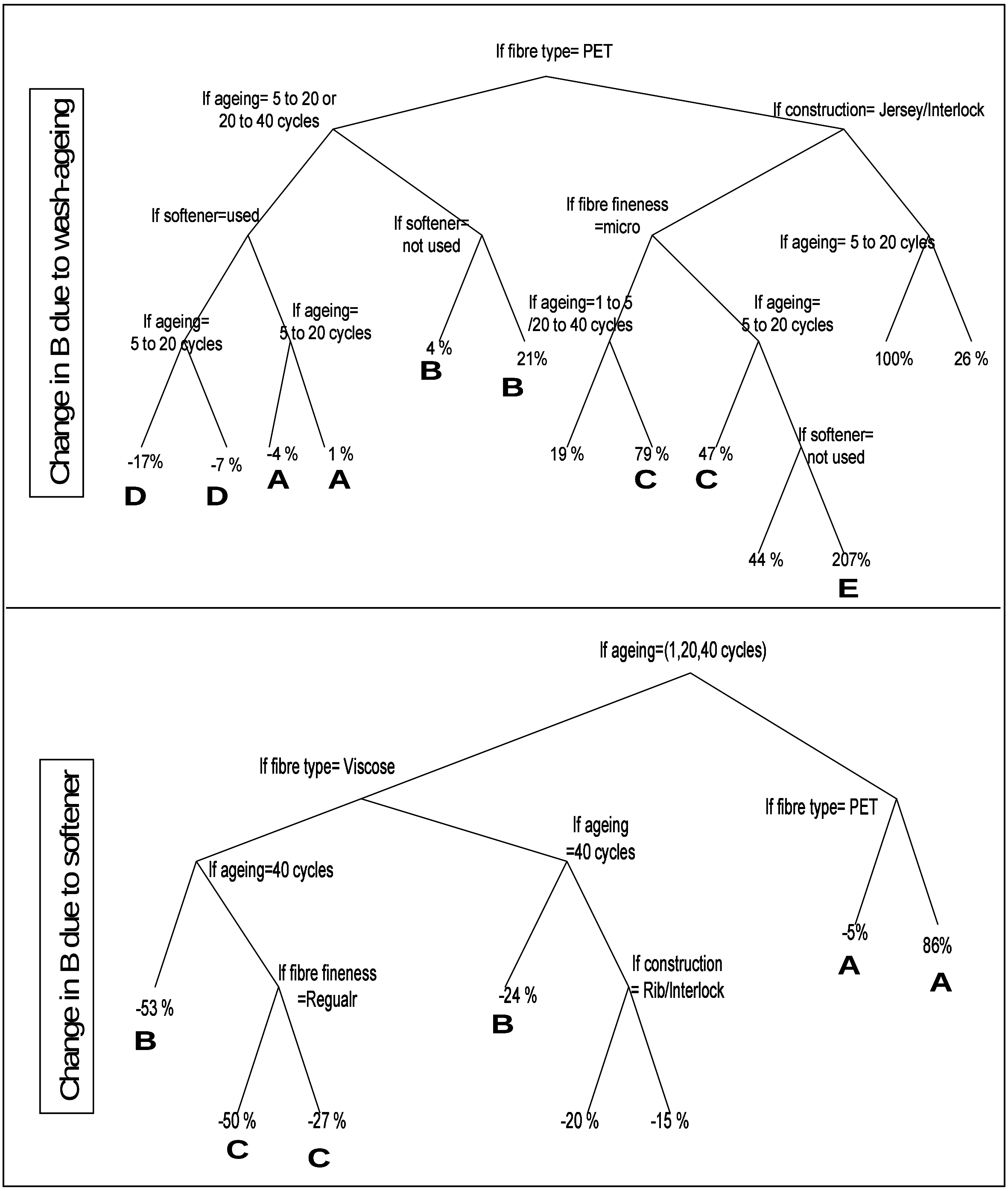


Figure 3.31 Decision tree for influence of wash-ageing and use of fabric softener on B

Change in B due to fabric softener:

A. The use of fabric softener during the 5th wash cycle shows an–increase in bending rigidity influence for viscose fabrics and a decrease in bending rigidity influence for PET fabrics
B. The regular use of fabric softener (up to 40 wash cycles) results in a maximum decrease in the value of bending rigidity for both viscose and PET fabrics.
C. The influence of the use of softener in improving bending rigidity (i.e. decreasing the value) of viscose fabrics was found to be more for fabrics of micro fibres in compare to regular fibres.

3.4.3.4 Compression energy (WC):

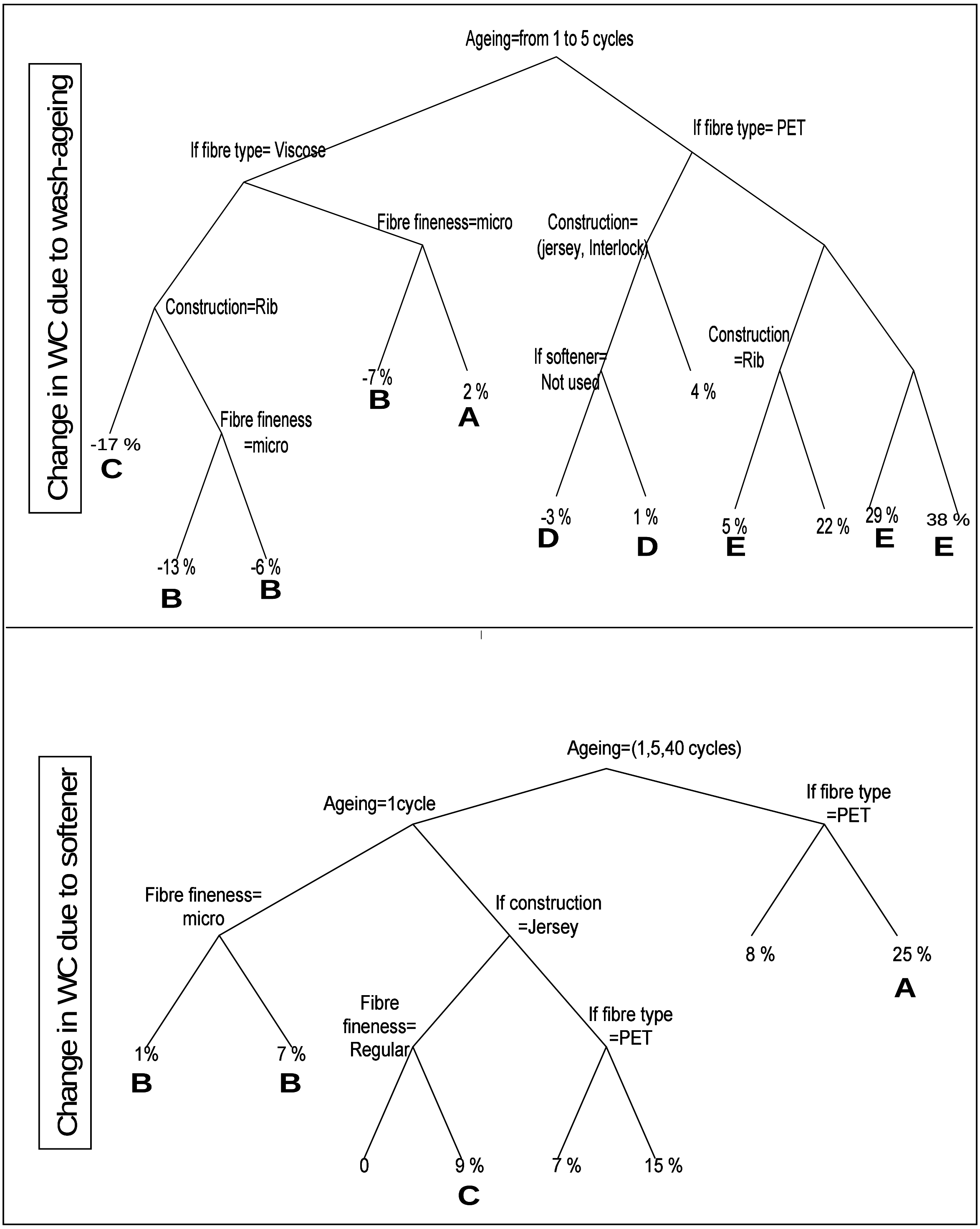


Figure 3.32 Decision tree for influence of wash-ageing and use of fabric softener on WC

Change in WC due to wash-ageing:

A. Compression properties of the textiles were found to be dependent mainly on the number of wash-ageings and fibre type. During the initial washing cycles (up to 5) the change in WC of fabrics of PET regular fibres was only 2 %.

B. During initial washing cycles the loops of knitted structures are expected to become rounder in shape (Figure 3.28), hence less energy is required to compress the fabric, therefore, for both viscose and PET fabrics the influence of initial wash ageing was negative (reduced value of WC) more so for the fabrics made up of micro fibres than the fabrics made of regular fibres.

C. It was found that, similar to the case for EMT, the decrease in WC of viscose-rib fabrics was maximum. It has been reported in figure 3.25 that rib structures shows extension rather than shrinkage in width direction after going through laundry. The extension in width direction results in a reduction in thickness and hence WC. This may be the reason that rib structure shows maximum reduction in WC.

D. During prolonged ageing, WC increases for both viscose and PET fabrics. This is more prominent in viscose fabrics (5 % to 38 %, which is indicated in condition E in the decision tree) than PET fabrics (-3 % to 4 %).The reason for the increased WC of viscose fabrics may be the presence of loose fluffy fibers and pills on the surface of the fabrics; alternatively it may be a bulk effect due to greater relaxation of the textile.

E. The increase in compression energy of viscose fabric, which has gone through prolonged ageing, was greater for regular fibres than micro fibres.

Change in WC due to fabric softener:

In general, it can be observed from the decision tree that the use of fabric softener during laundry results in an increase in compression energy of the knitted fabrics. Hence, fabric treated with fabric softener is expected to appear fuller.

A. The influence of the use of fabric softener on WC was found to be maximum during 20 wash-cycles for viscose fabrics. This may be due to the fact that during the initial wash cycles these fabrics tends to obtain their most stable state. After 20 wash cycles fibre damage occurs due to harsh mechanical action of washing which results in the presence of fluffy fibres and pills on the surface of the fabrics and hence softener is not as effective as before.

B. The use of fabric softener for the 1^{st} wash-cycle does not result in as large an increase in WC as does longer use of fabric softener.

C. The influence of the use of fabric softener for 5 or 40 washing cycles is more effective for micro-jersey fabric than regular-jersey fabrics.

3.4.3.5 Roughness of the fabrics (Ra):

Figure 3.33 represents the decision tree for the change in roughness of the knitted textiles due to wash-ageing and the use of fabric softener.

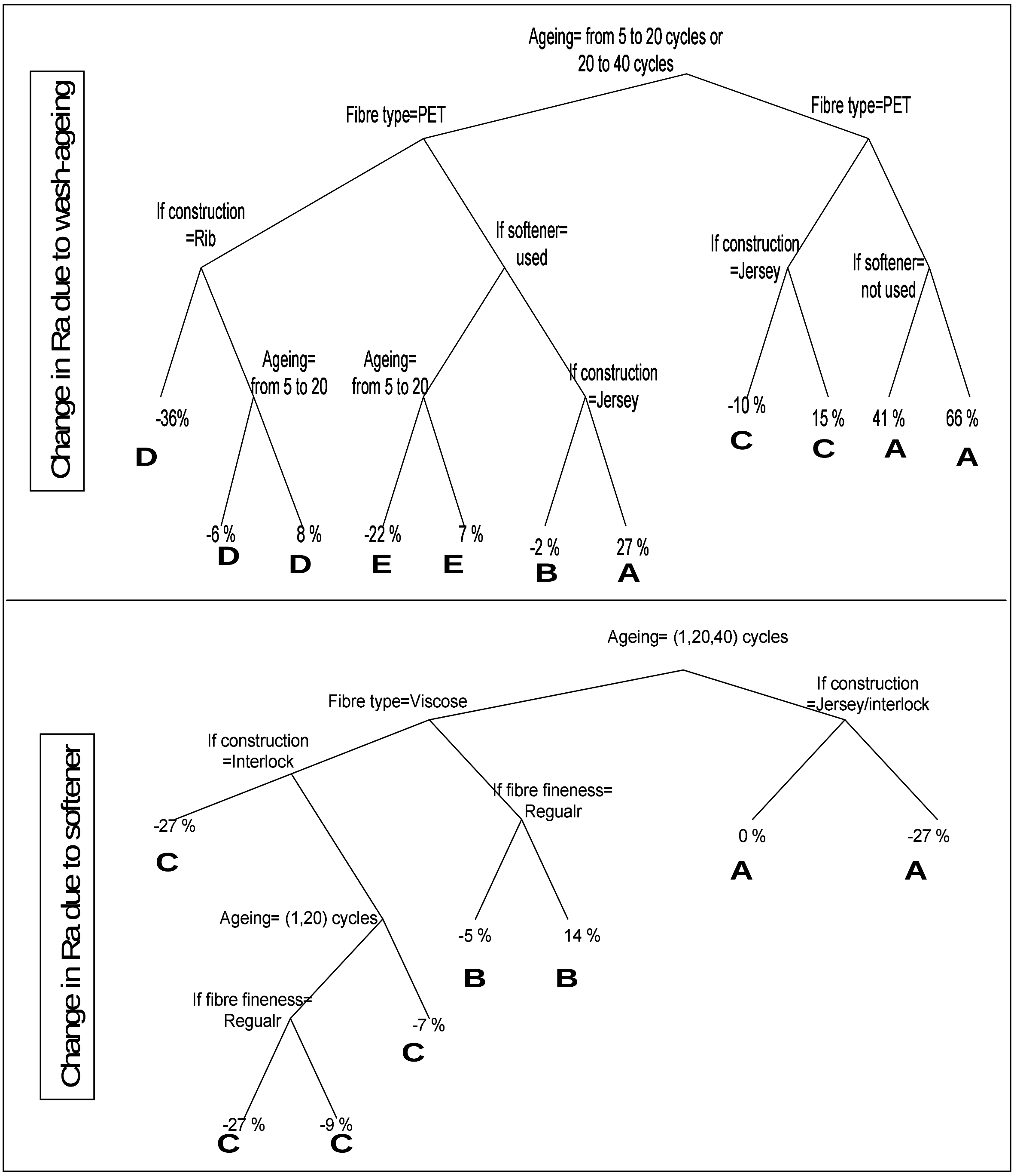


Figure 3.33 Decision tree for influence of wash-ageing and use of fabric softener on Ra

Change in Ra due to wash-ageing:

A. It can be clearly observed in the decision tree that the roughness value for viscose fabrics during initial wash cycles (1 to 5 wash cycles) and prolonged washing (5 to

20 and 20 to 40 wash cycles) increase. The cause of enhanced roughness during initial ageing cycles may be the increase in roundness of the loops (Figure 3.28). While during prolonged ageing the reason for increased roughness is fibrillation phenomenon, which occurs at the surface of the textiles due to the harsh mechanical action of washing. The fibrils form on the surface and result in strongly tangled forms i.e. lint and pills, which contribute to increase in roughness.

B. It was found that prolonged wash-ageing (5 to 20 and 20 to 40 wash cycles) of viscose-jersey fabrics does not result in increased roughness value, which shows that fibrillation process is not significant on jersey fabrics.

C. The influence of initial wash-ageing for PET fabrics results in an increase in roughness value of only rib and interlock structures. A jersey fabric even shows a decrease in value of roughness during initial ageing cycles.

D. The influence of prolonged washing of PET was found to be very small, and for rib fabrics, it was found that the value of roughness decreased by 36 %.

E. The use of fabrics softener for viscose fabrics can eliminate the influence of wash-ageing and can result in a reduced value of roughness.

Change in Ra due to softener:

A. The use of fabric softener up to the 5th wash cycle reduces the roughness of only rib structure.

B. There was only a small decrease (5 %) in roughness due to the use of the fabric softener during 1, 20, and 40 ageing cycle for PET-regular fabrics. While for micro fabrics, an increased value of roughness was observed.

C. The use of fabric softener during 1, 20 and 40 ageing cycles reduces the roughness value of the viscose fabrics. This can be explained by the fact that the use of softener limits the fibrillation at the surface of fabric.

The detailed analysis of the influence of wash ageing and the use of fabric softener for a knitted fabric is presented in this paper through decision trees. In general it was found that the influence of wash ageing and the use of fabric softener on mechanical properties of PET fabrics were lower than viscose fabrics. This can be observed in the decision trees; for tensile extension (Figure 3.29: Condition C and E in the upper decision tree and condition B vs C in the lower decision tree), shear rigidity (Figure 3.30: C vs. D in the upper decision tree and D,E vs. B,C in the lower decision tree), bending rigidity (Figure 3.31: A,B,D vs. C, E in the upper decision tree and C vs. B in lower decision tree) , compression energy (Figure 3.32: D vs. E, A vs. B,C in the upper decision tree and condition A in the lower decision tree), roughness (Figure 3.33: A vs. C, D vs. A,B,E in the upper decision tree and B vs. A,C in the lower decision tree).

3.2. 4 Conclusions:

In this section we tried to find the level of simultaneous influence of ageing and the use of fabrics softener on different mechanical parameters with respect to different textile parameters. We found that the influence of wash ageing on different mechanical parameters is prominent only for viscose fabrics, PET fabric remain unchanged even after the 40^{th} laundry cycles. The behavior of knitted fabrics with regard to mechanical properties is not the same for the initial wash-ageing cycles (up to 5 cycles) and for prolonged wash-ageing. During the initial wash cycles, fabrics tend to achieve their maximum relaxation state, hence maximum increase in tensile extension and minimum changes in shear rigidity were noticed. We also noticed that during the initial wash-cycles, compression energy of the fabrics reduces.

We found that the use of fabric softener for prolonged wash cycles can eliminate the influence of wash ageing. This was noticed for changes in tensile extension during 5 to 20 wash cycles, changes in shear rigidity during 5 to 20 wash cycles, changes in roughness of viscose fabrics during 5 to 20 wash cycles and changes in roughness of viscose rib fabrics during 5 to 20 and 20 to 40 wash cycles. In general, use of fabric softener diminished the influence of ageing and results in an opposite influence.

The influence of wash-ageing and the use of fabric softener was also found to be dependent on the knitted structure and fibre fineness. Rib structure shows maximum change in EMT and WC in comparison to jersey and interlock structures during the initial wash cycles. Fabric softener was found to be more effective for interlock structure, this may be due to the fact that interlock is the most stable structure because this structure has more interaction between yarns which provides more area where lubrication may be effective and also results in the most uniform deposition of the fabric softener on the fabric surface. The influence of fabric softener was also found to be more effective for micro fibres than regular fibres, with respect to EMT, G, B and WC.

An overall effect of wash-ageing (μ_w) and the use of fabric softener (μ_s) are shown in Table: 3.7. This table shows an average change in mechanical parameter irrespective of fibre fineness, yarn construction and number of wash ageing cycles. The values are characterised in four categories as following:-

1. Very significant changes (+++/---): $|\mu_w / \mu_s| \geq 30\,\%$
2. Significant changes (++/--): $10\% \leq |\mu_w / \mu_s| \leq 30\,\%$
3. Slight changes (+/-): $5\% \leq |\mu_w / \mu_s| \leq 10\,\%$
4. No Change (0): $5\% \leq |\mu_w / \mu_s| \leq 0\,\%$

Table 3.7: Influence of ageing and use of fabric softener on mechanical properties:

Parameter	Fibre-type	Ageing	Softener
EMT	Viscose	--	++
	PET	0	++
RT	Viscose	--	+
	PET	-	++
WC	Viscose	+++	++
	PET	-	+
RC	Viscose	--	+
	PET	-	0
G	Viscose	++	--
	PET	0	--
2HG3	Viscose	++	0
	PET	+	--
B	Viscose	+++	--
	PET	0	--
HB	Viscose	+++	--
	PET	+	--
Total Deformation	Viscose	++	++
	PET	-	--
Elastic Defromation	Viscose	0	0
	PET	0	0
Roughness	Viscose	+++	--
	PET	--	0
Roughness Depth	Viscose	+++	--
	PET	--	0

Note: Sign (±) has to be considered for the direction of the change.

Chapter: 4

Development of Fuzzy-Logic based model for correlating the sensory attributes with relevant mechanical parameters

In this chapter an intelligent system based on Fuzzy-Logic in order to predict the sensory attribute score using two most relevant mechanical parameters is proposed. We defined the tracking criterion to investigate the relevancy of mechanical parameters with different sensory attributes.

4.1 Methodology:

Figure 4.1 represents the methodology for developing a fuzzy logic based model for predicting the sensory-scores for the attributes defined in chapter 3.1.

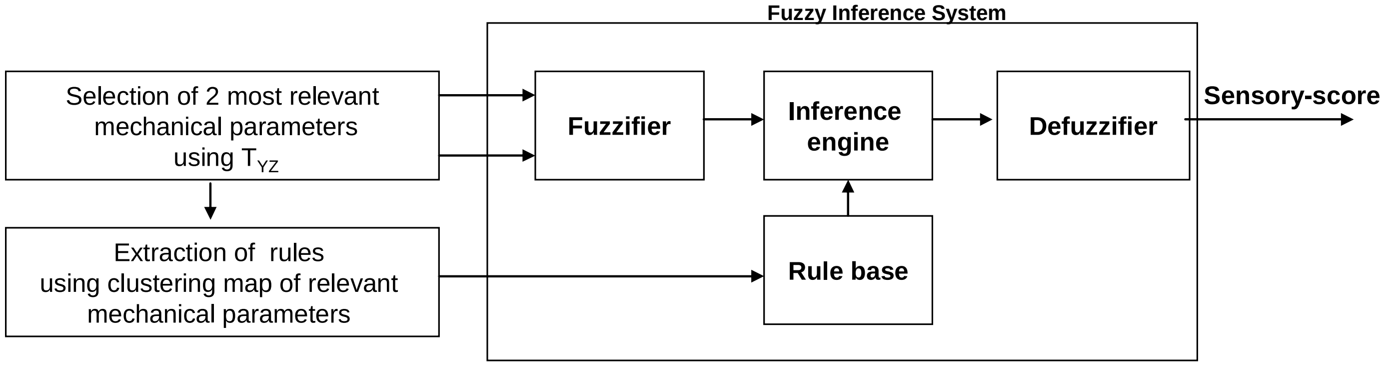


Figure 4.1 Block diagram of the scheme for Fuzzy logic modelling

The two most relevant mechanical parameters were selected as inputs for the Fuzzy Interference System. These two mechanical parameters were mapped to obtain the clusters of samples having similar values of these parameters. The conditional rules (If-then) were extracted from PCA clusters, which were converted in to fuzzy-rules and used in FIS. The mechanical and sensory behaviour of the fabrics was found to be changed after going through 40 wash cycles. Hence, the fuzzy models were developed individually for the fabrics which had gone through 1 washing cycle and 40 washing cycles. We also found a strong correlation between objective and subjective assessment of drapability of the fabrics, hence could developed a model for all the knitted fabrics.

4.1.1 Relevancy of mechanical parameters with sensory-score:

The linear correlationship between mechanical parameters itself and between mechanical parameters and sensory attributes was to be found to be very low (Appendix C). Hence, we used a criterion (T_{YZ}) for determining the relevancy of mechanical parameters with sensory score, as defined by our research team. This criterion compares the variation in two different spaces (attributes and mechanics). The basic idea is that variation in one space is accompanied by variation in the other space then this means the two variables are in accordance.

$$T_{YZ} = \frac{2\sum_{i\neq j} t_{YZ}(i,j)}{q(q-1)} \tag{4.1}$$

$$t_{YZ}(i,j) = \frac{|Y_i - Y_j|}{|Z_i - Z_j|} + \frac{|Z_i - Z_j|}{|Y_i - Y_j|} - 2$$

Where Y_i and Y_j denote the normalised value of the mechanical parameter for the i^{th} and j^{th} samples respectively while Z_i and Z_j denote the normalised sensory score for the relevant attribute and q is the total number of samples. This criterion is designed so that a lower value of T_{YZ} indicates that there is a better relevancy between physical parameter and sensory attribute. The ideal value of T_{YZ} is zero, which is very rarely obtained. In Table 4.1 the most relevant mechanical parameters for the sensory attributes are highlighted.

Table 4.1 Relevancy of mechanical parameters with sensory attributes

	Fluffy	Stretchable	Slippery	Light-Heavy	Flairy	Flexible	Drape	Mellow	With Relief	Greasy	Synthetic
EMT	8,56	7,03	11,54	8,64	6,69	7,36	6.93	8,63	16,76	23,37	17,59
RT	8,42	6,15	12,04	11,44	12,65	10,12	10.66	11,83	13,64	21,33	15,99
WC	6,76	9,00	6,91	14,35	7,78	8,32	8.3	10,95	13,64	18,79	11,07
RC	14,54	12,95	17,93	17,26	12,56	7,75	8.1	22,88	14,20	17,64	24,48
B	10,17	10,81	12,91	8,64	9,08	8,43	7.36	7,76	18,84	22,15	14,47
HB	7,52	9,69	9,67	5,86	7,36	7,36	4.58	6,12	18,11	25,52	10,43
G	7,79	4,29	6,72	5,97	6,02	4,52	5.25	6,13	11,10	15,72	16,48

2HG3	14,08	24,88	14,99	14,62	9,73	17,74	10.58	11,48	15,68	18,21	18,53
Ra	18,00	14,07	11,62	21,74	16,85	15,39	11.52	20,29	17,09	14,72	25,59
Rz	13,11	7,99	13,86	14,60	11,03	11,96	10.23	8,72	11,29	17,35	18,38
TD	10,52	8,86	10,80	12,71	7,10	8,06	12.22	9,22	9,66	19,70	13,13
ED	9,65	13,91	12,67	9,98	6,01	8,26	12.52	12,33	19,64	37,88	11,86

It was observed that shear rigidity (G) shows a high relevancy (lower value of relevancy criterion) with most of the sensory attributes, which implies that it plays the most important role in overall handle of the knitted textiles. The behaviour of a fabric when it is subjected to shearing forces is the most important factor that determines how it will perform when subjected to a wide variety of complex deformations during use. We did not find the relevant parameters for the surface feeling attributes- With relief, Greasy and Synthetic. The Fuzzy logic based model was developed for each sensory attribute in order to predict the score of a particular attribute using the two most relevant mechanical parameters.

4.1.2 Extraction of rules using clustering:

We provide here an example of a model for knitted fabrics which had gone through one wash cycles to predict the score of attribute ‘Fluffy’. It can be observed from Table 2 that the two most relevant parameters for fluffy are compression energy (WC) and bending hysteresis (HB). Figure 4.2 is a mapping of these 2 mechanical parameters. The two principal components represent the two mechanical parameters.

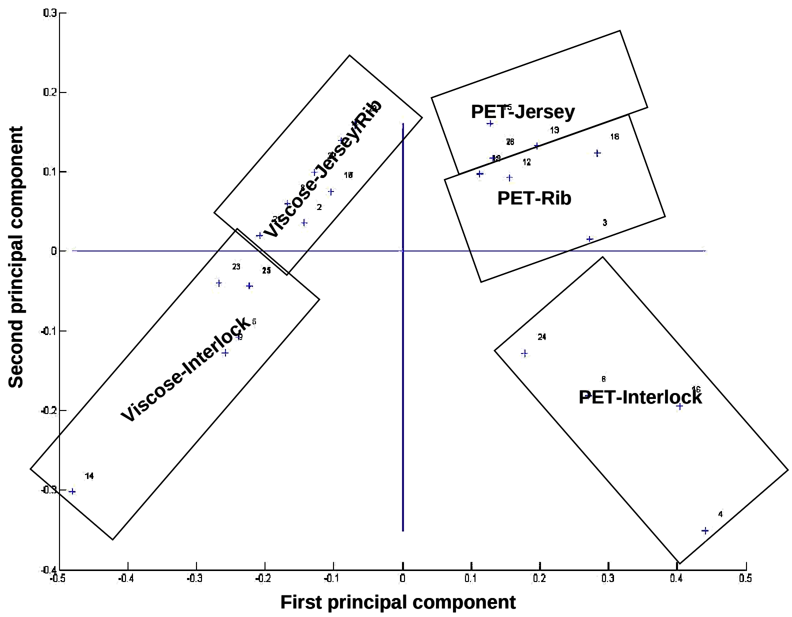


Figure 4.2 Mapping of knitted fabrics with respect to WC and HB

We observed the 5 clusters on this map:- 1) Viscose interlock fabrics 2) Viscose jersey and rib fabrics 3) PET jersey fabrics 4) PET rib fabrics 5) PET interlock fabrics. The set of 52 knitted fabrics was divided into 5 subsets and the following rules were extracted Fluffiness of the fabrics with WC and HB:-

Table 4.2 Rules extracted form the data

Cluster	Rule
Viscose-interlock	**If** 0.41≤ WC ≤ 0.53 & 0.02 ≤ HB≤ 0.03 **then** 0 ≤ Fluffy-score ≤ 0.12
Viscose-jersey/rib	**If** 0.31≤ WC ≤ 0.41 & 0.01 ≤ HB≤ 0.02 **then** 0.12 ≤ Fluffy-score ≤ 0.52
PET-jersey	**If** 0.251≤ WC ≤ 0.26 & 0.066≤ HB≤ 0.07 **then** 0.57≤ Fluffy-score ≤ 0.82

PET-rib	**If** 0.23≤ WC ≤ 0.28 & 0.06 ≤ HB≤ 0.11 **then** 0.88 ≤ Fluffy-score ≤ 1.00
PET-interlock	**If** 0.28≤ WC ≤ 0.31 & 0.12 ≤ HB≤ 0.22 **then** 0.83 ≤ Fluffy-score ≤ 0.89

4.1.3 Fuzzy Inference System:

Various steps of fuzzy modeling procedure are described as following:-

Step:1 *Fuzzification of input variables (WC and HB):* WC was divided into three fuzzy values named as: low, medium and high, on the scale of 0.2-0.60 gf.cm/cm^2 (Figure 4.3). The scale of mechanical parameter was decided according to the minimum and maximum value of those parameters among our knitted samples.

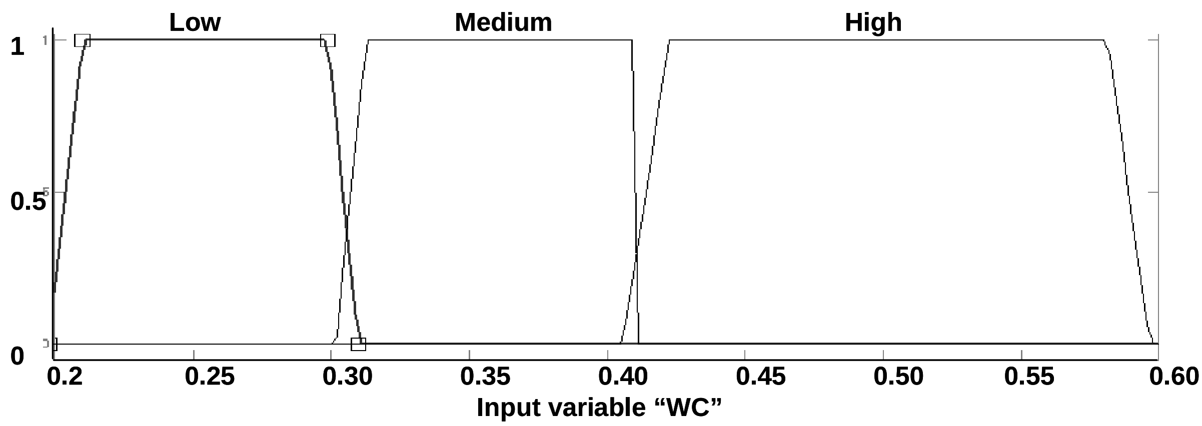


Figure 4.3 Membership functions of input 'WC' (gf.cm/cm^2)

HB was divided into four fuzzy values named as low, medium, moderate and high (Figure: 4.4). All the membership functions were chosen of trapezoidal shapes.

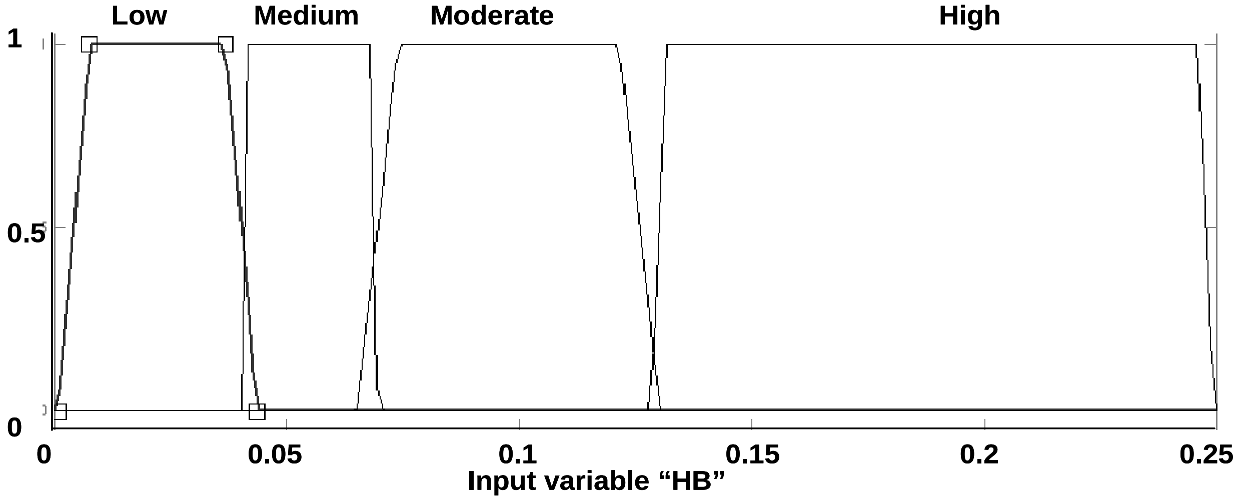


Figure 4.4 Membership functions of input 'HB' (gf.cm/cm)

Step:2 *Fuzzification of output variable (Fluffy):* The sensory scores for "Fluffy" were divided into five fuzzy values at the scale of [0 1] and membership functions are named as most-fluffy, mf 2, mf 3, mf 4 and least-fluffy (Figure 4.5)

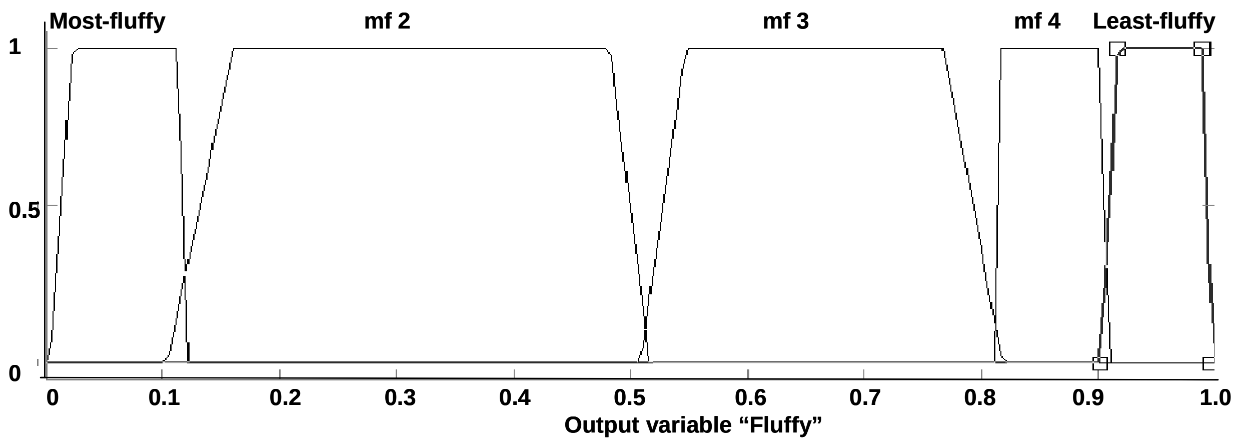


Figure 4.5 Membership functions of output 'Fluffy'

Step: 3 *If-Then rules generation and aggregation of the consequents across the rules:* On the basis of Table 4.2 fuzzy rules were generated. Decisions are based on testing of all the rules which must be combined in such a manner so as to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. The Madmani method is used for aggregating these fuzzy rules and computing outputs from the input values of WC and HB.

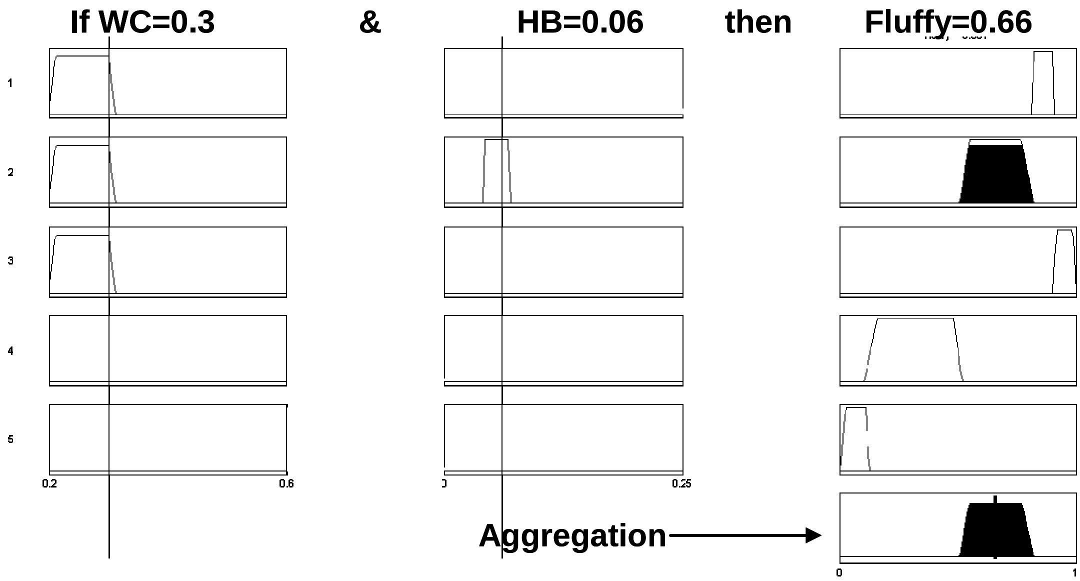


Figure 4.6 If-then rules and aggregation of rules for 'Fluffy'

Step: 4 *Defuzzification of output:* The input of the defuzzification process is a fuzzy set (the aggregated output fuzzy set) and the output is a single number. The defuzzification method we used is the centroid calculation, which returns the centre of the area under the curve.

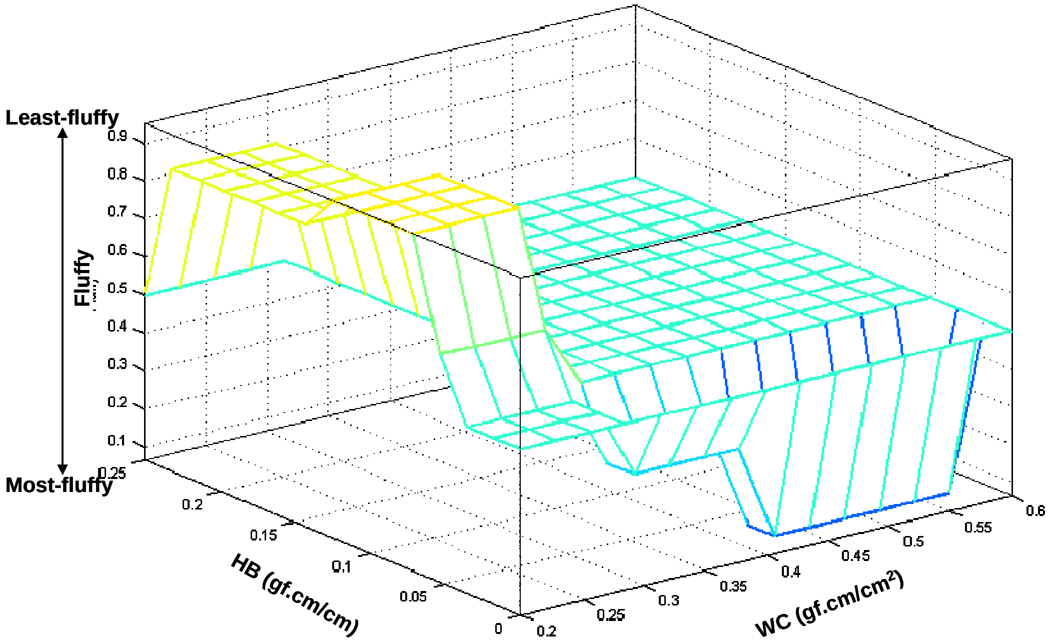


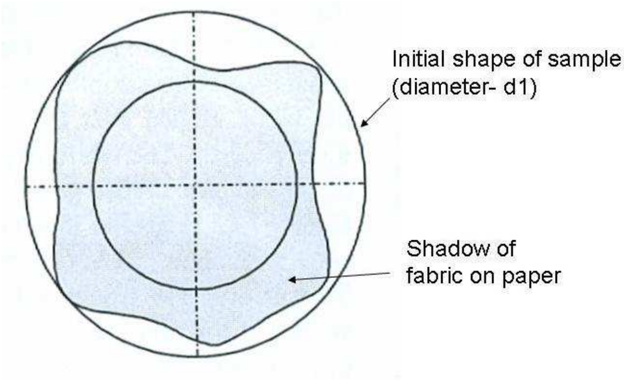
Figure 4.7 Surface viewer of the fuzzy model for the 'Fluffy'

Figure 4.7 shows the surface viewer of the Fuzzy model for Fluffy. A lower Fluffy-score on the z-axis represents more fluffiness of fabric and vice versa. The directional influence of WC and HB on the Fluffiness can be clearly observed. Higher values of WC and lower value HB result in maximum fluffiness of the knitted fabrics. The proposed model gives better understanding of dependency of Fluffiness of knitted fabrics with mechanical parameters WC and HB. Therefore this model can be used to identify how to modify these textile parameters to give better fluffiness.

4.2 Assessment of drapeability of the knitted fabrics:

4.2.1 Correlative between subjective and objective assessment of the knitted textiles:

In chapter:3, 'Drape' was considered as a sensory attribute and the way of evaluation of this attribute is similar to the objective evaluation of drapeability of the fabrics (Figure 4.8). In order to check the relevancy of drape-score given by our panellists, Objective assessment of fabric drapeability was carried out using Drapemeter from Sudemat, France.



(a) (b)

Figure 4.8 Draped fabric during (a) objective and (b) subjective assessments

The drape coefficient (D) can be defined as:-

$$D= (W_{d2}/ W_{d1}) \times 100……(4.2)$$

W_{d2}= weight of paper of shaded area

W_{d1}=weight of paper of diameter d1 i.e. equal to fabric diameter

All measurements were carried out under standard testing conditions, i.e. temperature of 20 ± 2 °C and 65 ± 2 % relative air humidity. In Figure 4.9, the correlation between subjective drape score and drape coefficient measured by instrument is shown.

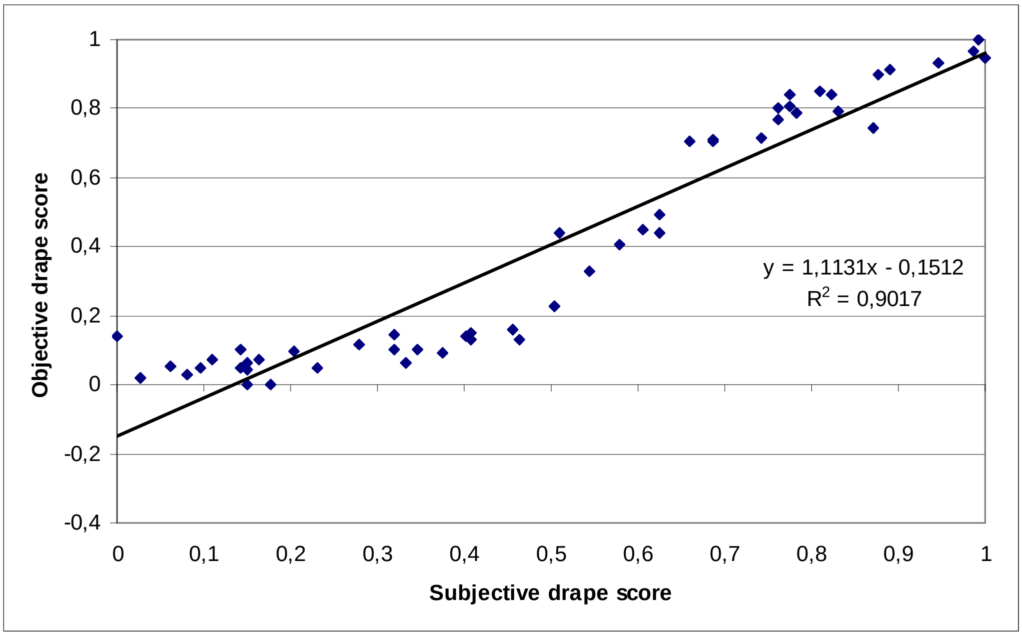


Figure 4.9 Correlation between objective and subjective evaluation of fabric drape

Objective drape coefficient score and subjective score of the fabrics were normalised in the range of [0 1]. We found correlation coefficient of 90 % between objective and subjective score of the drape. This established that the drapeability of the fabrics can be estimated using subjective score.

4.2.2 Fuzzy logic model for predicting the drape-score of a fabric:

In table 4.1, it can be observed that the drape score has strong correlation with G and 2HB, good to strong correlation with B and EMT and poor correlation with HG and RT. The fuzzy logic based model was developed to predict the Drape-score of a fabric using methodology explained above. Figure 4.10 is PCA map of 52 knitted textiles for G and 2HB. First principal component is explaining 80% of the variability in samples

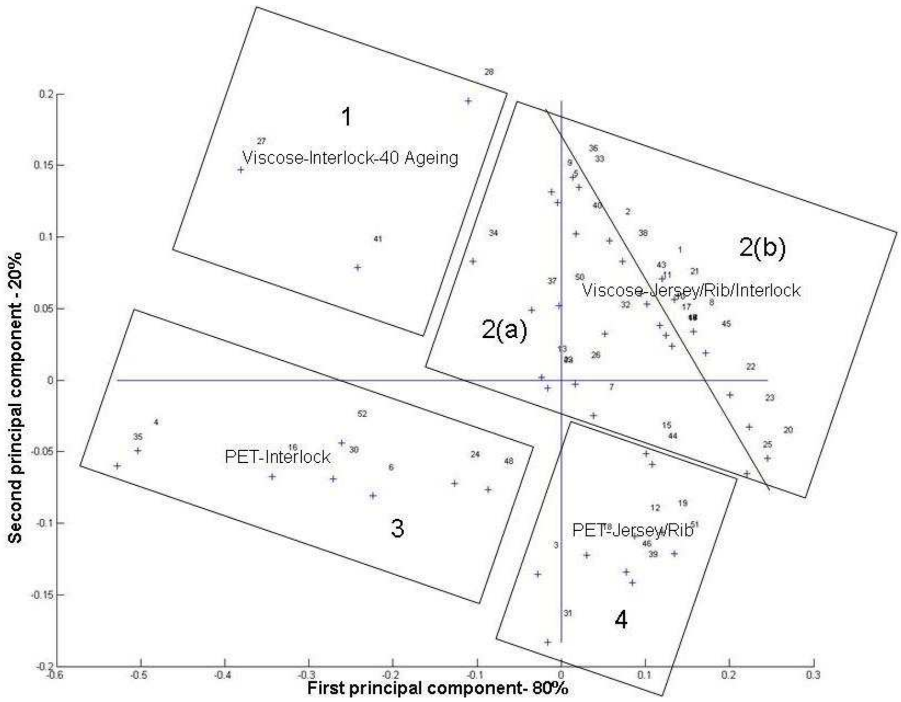


Figure 4.10 PCA map for 52 knitted textiles

We observed the four clusters on this map: - 1) Viscose - interlock fabrics which have gone through 40 wash cycles 2). All other Viscose fabrics other than cluster:1. This cluster was further divided in two sub clusters 2 (a) and 2 (b). 3) All PET interlock fabrics 4) All PET fabrics other than cluster 3. The set of 52 knitted fabrics was divided into the 5 subsets and the following rules given in Table 4.3 were extracted to correlate the G and 2HB with drape score.

Table 4. 3 Rules extracted from the data

Cluster	Rule
1	**If** 0.83≤ G ≤ 0.98 & 0.09 ≤ 2HB≤ 0.13 **then** 0.50 ≤ Drape-score ≤ 0.58
2(a)	**If** 0.42≤ G ≤ 0.65 & 0.01 ≤ 2HB≤ 0.02 **then** 00 ≤ Drape-score ≤ 0.23
2(b)	**If** 0.55≤ G ≤ 0.75 & 0.02 ≤ 2HB≤ 0.07 **then** 0.28 ≤ Drape-score ≤ 0.46

3	**If** 0.66≤ G ≤ 0.94 & 0.12 ≤ 2HB≤ 0.23 **then** 0.76 ≤ Drape-score ≤ 0..89
4	**If** 0.45≤ G ≤ 0.63 & 0.06 ≤ 2HB≤ 0.12 **then** 0.51 ≤ Drape-score ≤ 0.74
Other samples	**If** 0.61≤ G ≤ 0.66 & 0.06≤ 2HB≤ 0.12 **then** 0.76 ≤ Drape-score ≤ 1.00

Figure 4.11 shows the surface viewer of the Fuzzy models for Drape. Lower drape-score on the z-axis represents high drapeability and vice versa. The directional influence of G and 2HB on the Drape-score can be clearly observed in Figure 4.11. Higher values of G and 2HB result in a high drape score i.e. lower drapeability of the knitted fabrics. The proposed model gives better understanding of the dependency of drapeability of knitted fabrics with mechanical parameters G and 2HB. Therefore this model can be used to identify how to modify these textile parameters to give better drape.

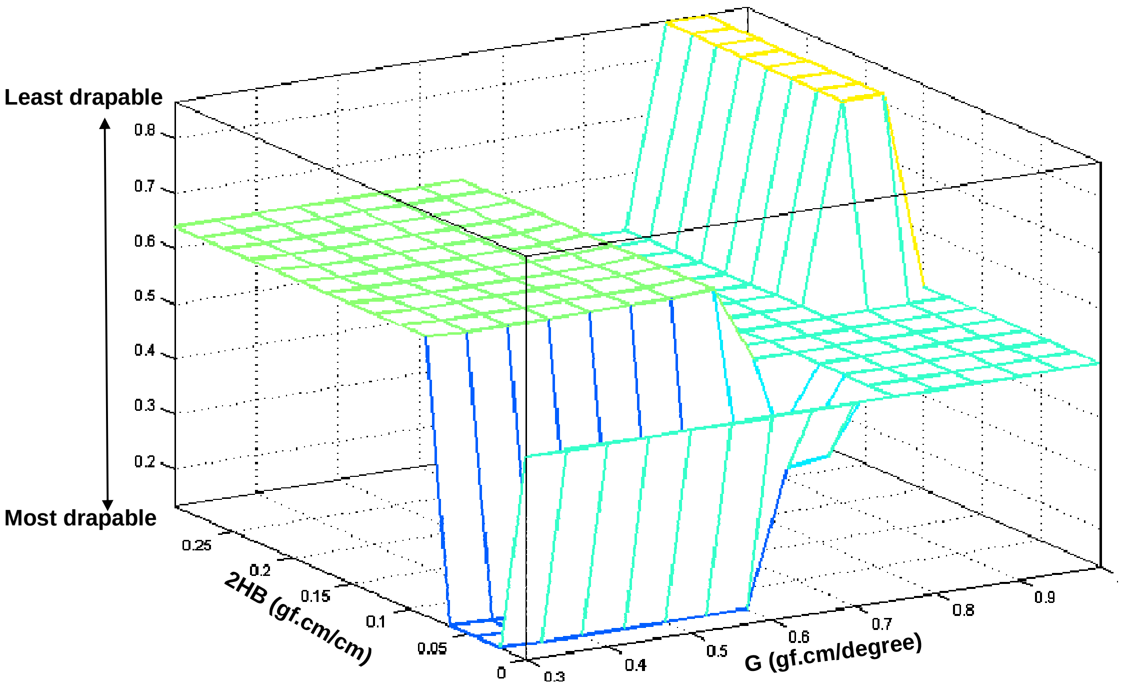


Figure 4.11 Surface viewer of the Fuzzy model for the drape

4.2.3 Surface viewers for all other fuzzy models for knitted fabrics:

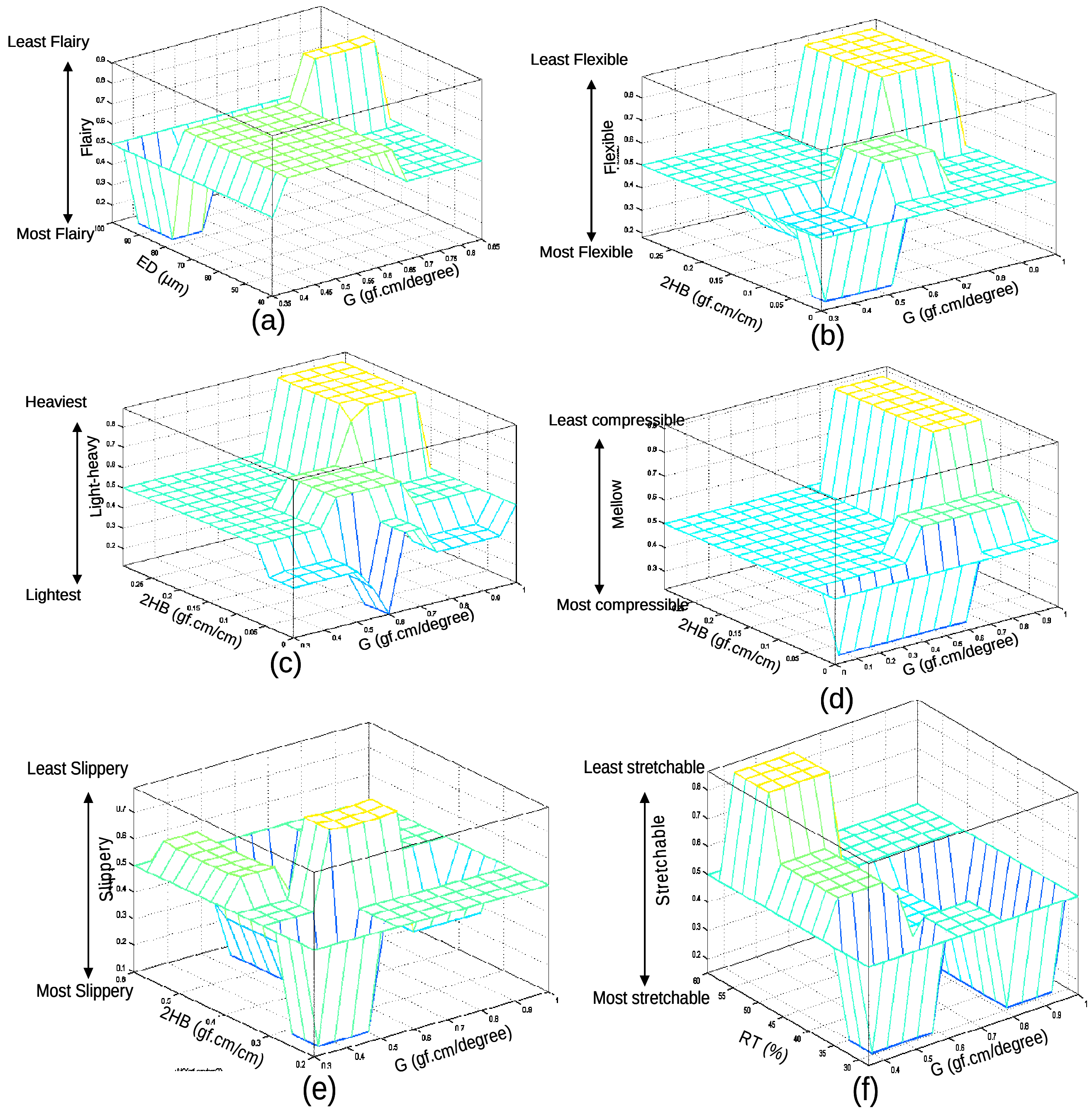
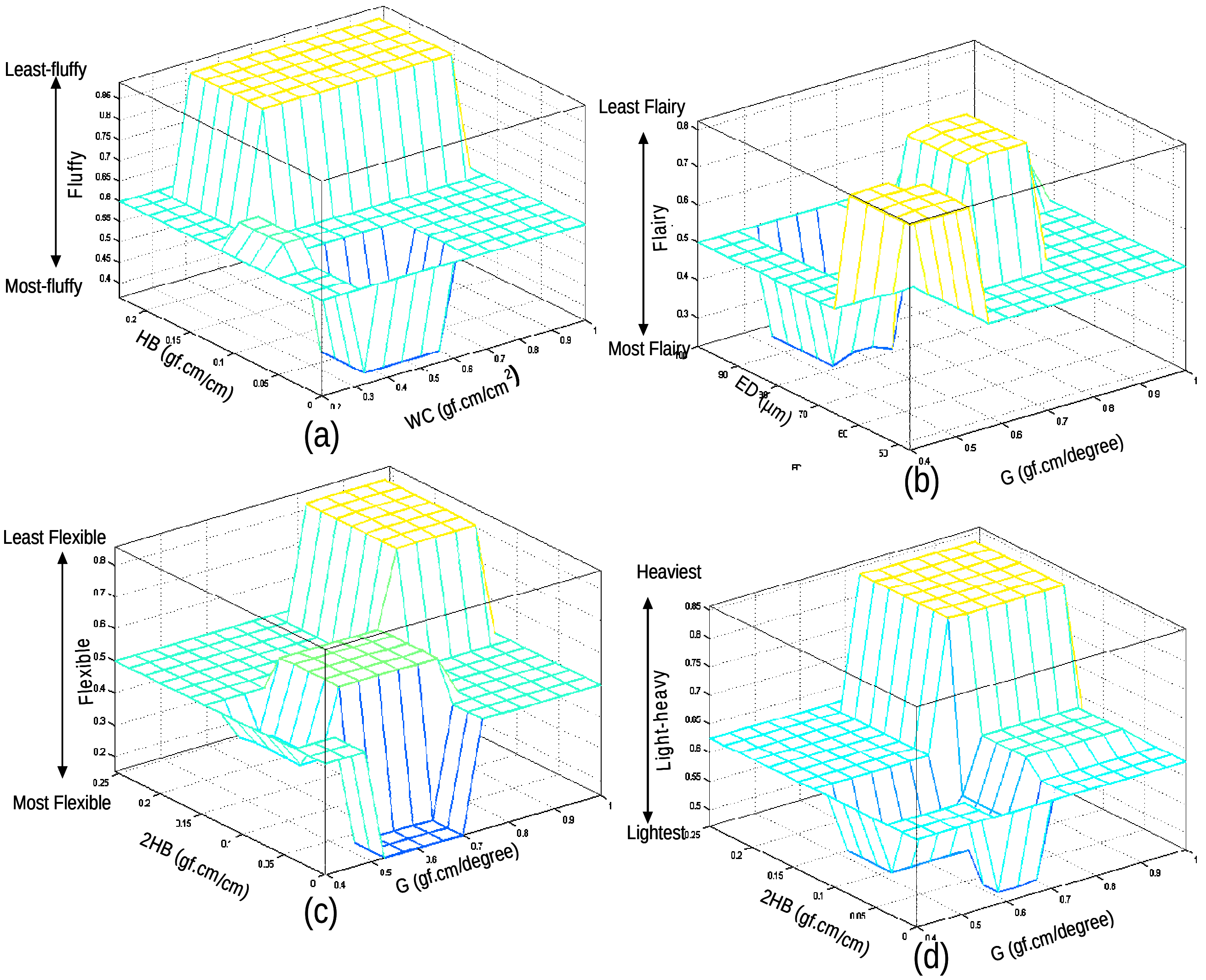


Figure 4.12 Surface viewers of the fuzzy models for sensory attributes of knitted fabrics gone through 1 wash cycle

Figure 4.12 represents the surface viewers for other sensory attributes. It can be noticed that attributes 'Flexible', 'Light-heavy', 'Mellow' and 'Slippery' were found to be correlated with the shear rigidity and bending hysteresis of the knitted fabrics. In general it can be concluded that lower shear rigidity and lower bending hysteresis shows that fabric is flexible, compressible, and slippery. The attribute 'Flairy' was found to be correlated with shear rigidity and elastic deformation: lower shear rigidity and high elastic deformation contribute to more flairiness of the fabrics. We found that stretchability of knitted fabrics depends on shear rigidity and tensile recovery, a lower value of shear rigidity and tensile recovery indicates high stretchability of the fabrics.



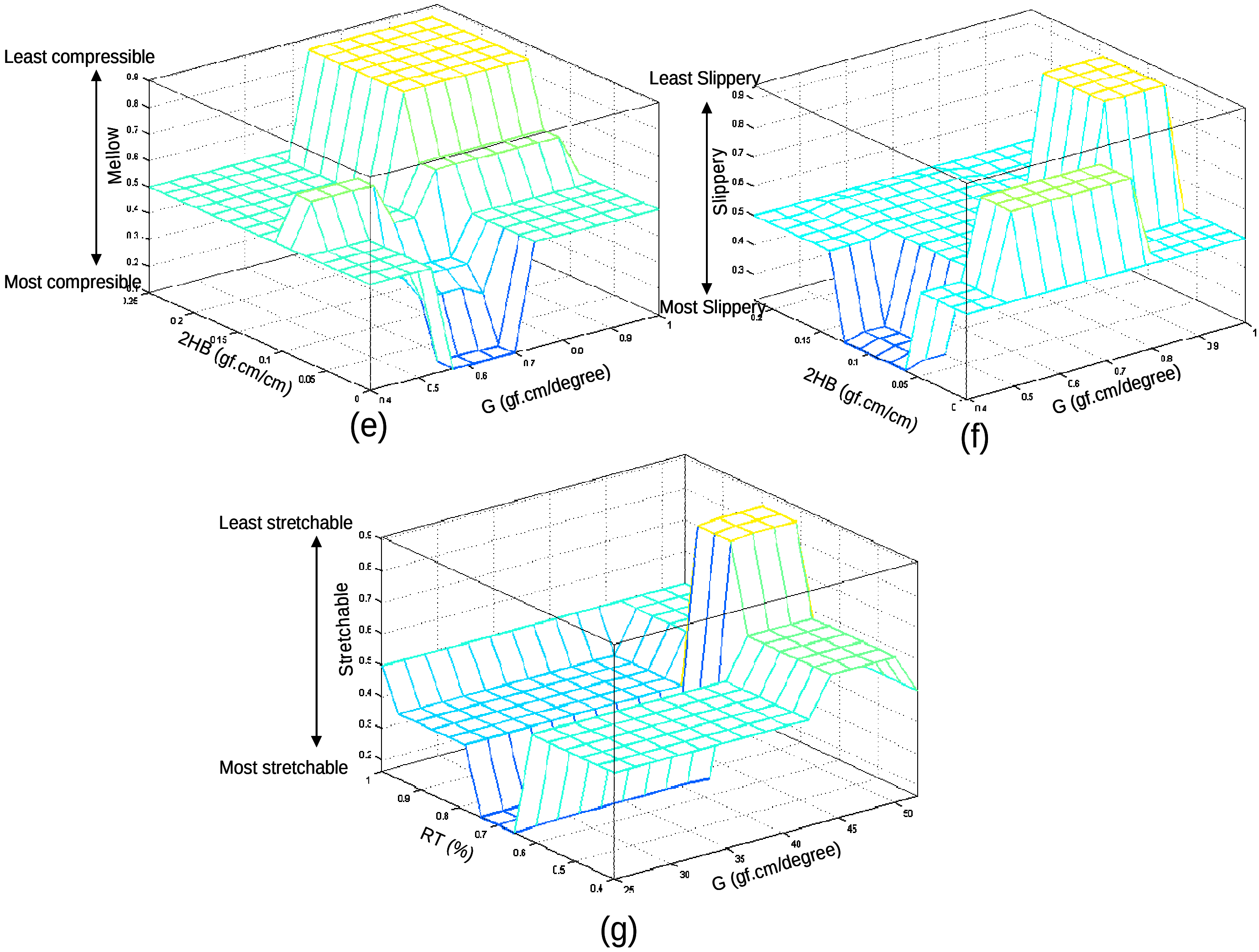


Figure 4.13 Surface viewers of the fuzzy models for sensory attributes of knitted fabrics gone through 40 wash cycles

Figure 4.13 is surface viewers for the sensory attributes of the knitted fabrics, which have gone through 40 wash cycles. It can be observed by comparing figure 4.12 and 4.13 that the correlation between mechanical parameters and sensory attributes is not same for knitted fabrics which have gone through 1 or 40 washing cycles. For example: if we compare figure 4.7 and 4.13 (a), for knitted fabrics, which had gone through 40 wash cycles, a shift of the lower boundary peak for attribute fluffy can be noticed towards lower value of compression energy. This is due to generation of pills and loose fibres on the fabric surface. These loose fibres give a fluffy feel to the fibre and having lower compression energy. The surface profiles of two kind of kniited fabrics (1 or 40 wash cycles) was to be found similar for attributes light-heavy and flexible (figure 4.12 (b), (c) vs. figure 4.13 (c), (d).

4.3 Conclusions:

Shear rigidity and bending hysteresis were found to be most relevant mechanical parameters for predicting the score of most of the sensory attributes of the knitted fabrics. The proposed fuzzy logic model is based on specimen varying in fibre type (cellulosic and synthetic), fibre fineness (micro and regular), knitting structure (jersey, rib and interlock) and the number of wash-ageing cycles that they had gone through (up to 40 wash cycles) with/without the use of the fabric softener. The resulting model can therefore be used for a wide number of knitted fabrics during their wear-cycle for predicting the performance of a garment with respect to the proposed sensory attributes. In order to check the performance of a softener this model can be used as a cost effective and time saving tool.

General Conclusion and perspectives

The softener market will continue to evolve as the demands of the consumer constantly change. Softeners of the future will be impacted by many factors, including the desire for rapid biodegradability, water conservation efforts, raw material costs, new performance benefits, improved freshness, and other consumer needs.

It was found that fibre type (cellulosic or polyester) and fibre fineness are the deciding factors for softener pick up depending upon load condition. This was explained by the competition between different fibre types due to zeta-potential, filtration efficiency and water retention capability of the fabrics. The orders of criticality of these three factors still need to be identified. The results of chapter-1 indicates that softener-pick up is not the same for the fabrics made of micro or regular fibres

This thesis is an overview of the interaction of wash-ageing and use of fabric softener with construction, physical, sensory and surface properties of the textiles. This thesis gives an idea of scope of improvement in softener products with respect to their functionality regarding handle of the fabric.

The influence of ageing on sensory feeling is significant only for viscose fabrics, PET fabrics don't change with ageing cycles. It was found that viscose fabrics loose their drapeability, smoothness, fluffiness and flexibility and significant pilling occurs on the surface of the fabrics. The use of softener significantly changes the sensory feeling of different attributes for both viscose and polyester knitted fabrics. It was investigated that panellists are able to perceive more synthetic feel after treating the fabrics with softener. The use of the fabric softener during 1st wash cycle for viscose fabrics results in more compressible, more drapeable, cooler and smother fabrics. While the use of softener for prolonged washing could contribute mainly to the better stretchability of the viscose fabrics.

The use of fabrics softener during 1^{st} wash-cycle for PET fabrics results more stretchable, more flexible, more drapeable and fabric with more relief. As the influence of 40 wash-cycles on sensory attributes was not found significant for PET fabrics, therefore, the fabric softener remains effective for PET fabrics even after 40^{th} wash cycle. PET fabric which had gone through 40 wash cycles with softener was found to be wrinkle free, smoother but having synthetic feel.

The dimension changes in knitted fabrics due to wash-ageing were found to be significant only for viscose fabrics. These changes occur during the initial 5 wash-cycles, the knitting loops become rounder in shape to achieve their minimum energy stage. Due to high stretchability of rib structure, there was decrease in width constant of the rib fabrics.

The change in dimensional properties of the knitted fabrics result in more significant changes in mechanical properties during the initial wash-ageing than prolonged wash-ageing.

In the case of viscose fabrics there are very significant changes in WC, B, HB, Roughness and Roughness depth. All of these changes occur because of swelling and surface damage due to the severe mechanical action of the washing machine. This implies that ageing deteriorates apparel by making fabrics more stiff, rough and less full. Use of fabric softener diminished the influence of ageing and results in significant changes in EMT, RT, G, and B for both PET and viscose fabrics.

The influence of wash-ageing and the use of fabric softener was also found to be dependent on the knitted structure and fibre fineness. Rib structure shows maximum change in EMT and WC in comparison to jersey and interlock structures during the initial wash cycles. Fabric softener was found to be more effective for interlock structure, this may be due to the fact that interlock is the most stable structure because this structure has more interaction between yarns which provides more area where lubrication may be effective and also results in most uniform deposition of the fabric softener on the fabric surface. The influence of fabric softener was also found to be more effective for micro fibres than regular fibres, with respect to EMT, G, B and WC.

The implementation of the tracking criterion helps to understand what are the most relevant mechanical features that impact on the sensory attributes through the life cycle of knitted fabrics. It was observed that shear rigidity (G) shows a high relevancy (lower value of tracking criterion) with most of the sensory attributes, which implies that it plays most important role in overall handle of the knitted textiles. The model based on soft computing techniques was then developed using sensory attribute with the most relevant mechanical parameters based on the described criterion. The proposed model gives a better understanding of the dependency of the sensory attributes of knitted fabrics with relevant mechanical parameters. Therefore this model can be used to identify how to modify these textile parameters to give better textile-hand during the life cycle of the fabrics.

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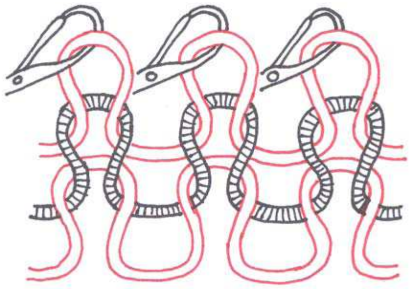
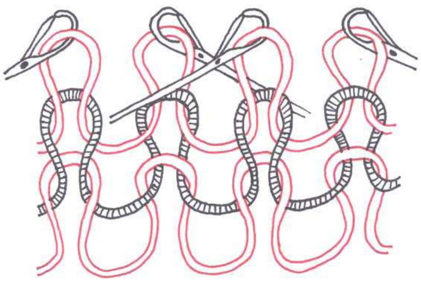
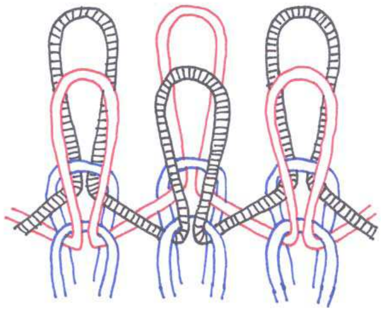
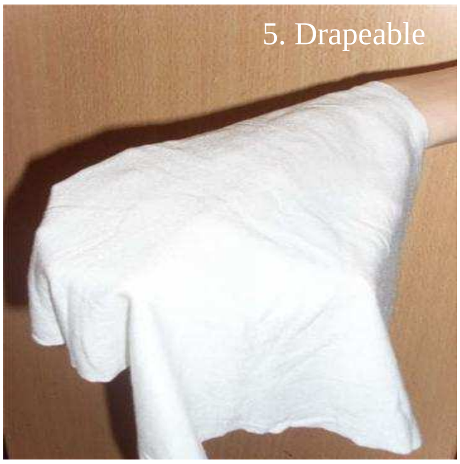
Appendix A Three basic structures of knitted fabrics

Construction	Description	Structure
Jersey	This is the simplest of all knitted structures and is formed by the inter-meshing of a number of loops from side to side and top to bottom. <u>Single jersey fabrics characteristics:</u> • single sided • thin/light-weight • fast and efficient production • edges curl, difficult to handle • partially unstable, stitch distortion <u>End-uses</u>: Tee-shirt, vest…	
1x1 rib	The term "rib" covers a broad range of knitted structures from: 1x1, 2x1, 2x2. The simplest rib fabric is a 1x1 and this is formed using 2 individual beds of needles whereby yarn passes from one bed to the other alternatively. <u>Rib fabric characteristics:</u> • double sided fabric • thick/medium weight • high width stretch/recovery • balanced structure/fairly stable. <u>End-uses</u> :Tee-shirt	

Interlock	This is quite similar in construction to the rib fabric as 1x1 rib is knitted alternately on opposite needles and it requires two knitted courses or traverses to complete one entire knitted row. <u>Interlock fabric characteristics:</u> • double side fabric (same face and reverse) • thick/heavy weight • good width stretch/recovery • balanced structure/very stable <u>End-uses:</u> High quality and winter tee-shirt, vest…	

Appendix B Sensory evaluation of knitted fabrics

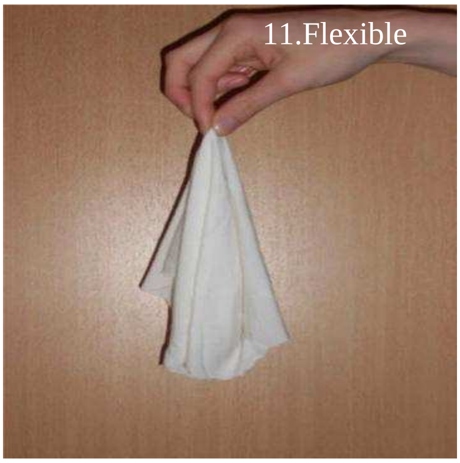


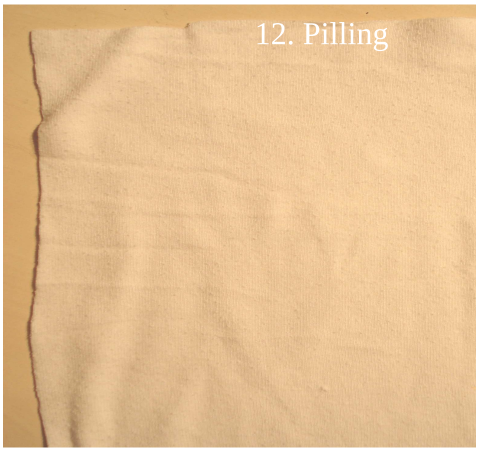

7. Synthetic


8. Wrinkle


9. Light-heavy


10. Flairy


11.Flexible


12. Pilling


13. With relief


14. Greasy

Appendix C Linear correlation between mechanical parameters and sensory attributes

Table: Linear correlation between mechanical parameters:

	EMT	RT	WC	RC	B	HB	G	HG	Ra	Rz	TD	ED
EMT	1	0.22	0.01	0.05	0.29	0.3	0.32	0.19	0	0	0	0
RT		1	0	0	0.08	0	0.13	0.07	0.09	0	0	0
WC			1	0	0	0	0	0	0.1	0	0	0
RC				1	0	0	0	0	0.12	0.1	0.09	0.31
B					1	0.64	0.53	0.16	0	0	0	0
HB						1	0.27	0.15	0	0	0	0
G							1	0.23	0	0	0	0
HG								1	0	0	0	0
Ra									1	0.91	0	0
Rz										1	0	0
TD											1	0.13
ED												1

Table: Linear correlation between mechanical parameters and sensory attributes:

	Fluffy	Stretchable	Slippery	Light-heavy	Flairy	Flexible	Drape	Mellow	With relief	Greasy	Synthetic
EMT	0.12	0.15	0.02	0.26	0.15	0.14	0.25	0.19	0.03	0.01	0.05
RT	0.04	0.29	0.12	0.04	0.026	0.08	0.1	0	0.04	0.01	0
WC	0.19	0.11	0.26	0.04	0.05	0.05	0.14	0	0.014	0.14	0.47
RC	0.06	0.1	0.13	0.04	0.05	0	0	0.01	0.05	0.05	0.02
B	0.11	0.07	0.06	0.31	0.2	0.23	0.22	0.37	0.06	0.11	0.02
HB	0.45	0	0	0.61	0.53	0.44	0.52	0.58	0.14	0.016	0.4
G	0.02	0.27	0.13	0.17	0.1	0.2	0.12	0.16	0	0.12	0
HG	0.02	0.11	0.06	0.05	0.09	0.1	0.11	0.017	0	0.0165	0
Ra	0.01	0.3	0.41	0.014	0.03	0.02	0	0.05	0.05	0.16	0.26
Rz	0.01	0.32	0.36	0.02	0.04	0.01	0	0.06	0.06	0.139	0.27
TD	0.15	0	0.01	0.02	0.07	0.06	0.16	0	0.012	0.11	0.18
ED	0.3	0.09	0.06	0.4	0.42	0.34	0.44	0.27	0.13	0	0.58

Interaction of textile parameters, wash-ageing and use of fabric softener during the laundry with mechanical properties of the knitted fabrics and correlation with textile hand

Abstract: In this thesis, the simultaneous influence of repeated machine laundry and use of the fabric softener on sensory, mechanical and physico-chemical properties of the knitted textiles was investigated. The deposition of softener was characterised by amount of deposition in different load conditions (mixed fibre load and individual fibre load) and level of uniformity of the deposition. The softener deposition was explained by zeta-potential of the fibres and liquid-absorption capability of the knitted fabrics. The non-uniformity of the softener deposition was quantified by image processing method. The sensory evaluation of the fabrics was carried out by a trained panel using pair-comparison method. Furthermore, an intelligent system based on Fuzzy logic for correlating the physical and sensory parameters was developed in order to predict the performance of a knitted fabric which has gone through number of laundry cycles.

Interaction des paramètres textiles et du vieillissement à l'usage des tricots, couplés à l'adjonction d'un assouplissant, avec les propriétés mécaniques et leur corrélation avec le toucher

Résumé : Dans cette thèse, l'influence de lavage répétés et l'utilisation d'assouplissant sur les propriétés sensorielles, mécaniques et physico-chimiques pour la bonneterie ont, a été étudiés Différentes conditions de remplissage de la machine à laver ont été étudiées : soit avec des tricots comportant tous des fibres de même nature, soit avec des tricots de nature différentes. La quantité d'adoucissant déposée sur le textile a été mesurée, l'uniformité du dépôt a été quantifiée par analyse d'image. Le potentiel zéta des fibres et la capacité d'absorption des textiles expliquent les écarts de quantité déposées sur les tricots.

L'évaluation sensorielle des tissus a été réalisée par un groupe de panélistes entrainés en utilisant la méthode de comparaison par paire. En outre, un système intelligent basé sur la logique floue pour corréler les paramètres physiques et sensoriels a été développé afin de prédire les performances d'un tricot aprés un grand nombre de cycles de lavage.

Keywords: Wash-ageing, fabrics-softener, Fuzzy-logic, Textile-hand, Knitted fabrics, Mechanical properties, zeta-potential, wicking

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