Development of a conceptual framework with a smart database for fabric sewability

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Dedicated

To

My Father John McLoughlin (May he rest in peace) and my Mother Doreen McLoughlin and also my son Martin McLoughlin

Not forgetting my beloved Wife Pauline McLoughlin

There comes a time in every bodies life where money, wealth and power mean nothing, the only thing that matters is the people that love you

(M^{c}Loughlin, 2002)

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No Portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institution of learning.

Abstract

Fabric sewability is an important element in garment manufacturing and has a critical impact on the aesthetic qualities and value of a garment. Garment manufacturers who fail to recognise and apply appropriate sewing practices incur huge inefficiencies in resources which can have both social and economic impact. The focus of this research was to bridge the gap between the human and machine interaction by understanding the fabric handle and creating an automated system to minimise sewing defects and maximise production. In doing this, a smart database was developed to predict lower and upper limits for sewing machine settings based on the mechanical and physical properties of the fabrics.

The research further establishes the relationship between the fabric and the performance of the material during the sewing process. A feasibility study was undertaken to generate data on machine settings using woven shirt materials. These lightweight fabrics, with plain weave construction, were chosen as they generally exhibit higher levels of seaming problems during sewing. The relationship between the fabric parameters were examined, by using objective and subjective methods of assessment, to determine the physical and mechanical properties of the material. A technical expert, with extensive years of experience on stitching materials in the apparel industry, was invited to assess the materials and to offer their opinion on the potential sewability and recommend sewing machine parameters to produce a high quality seam.

Based on the outcomes from the feasibility study, the research widened to a representative cohort of fabrics and examined the relationship between the mechanical properties and physical characteristics of the fabric and how they influence seam appearance and seam quality. A team of experts with specialist knowledge referred to as the ‘Sewing Parameter Evaluation Committee’ (SPEC) were invited to handle the materials and offer their advice on the machine settings to reduce seam deformation. Kendall’s coefficient of concordance was used to determine the level of alignment between the experts’ ranking of twenty fabrics and their suitability for a defect free seam. It highlighted that there was little agreement with the ranking of fabrics between experts.

The fabrics were stitched using a standard lockstitch ISU (Integrated Stitching Unit) sewing machine and all the machine settings were adjusted manually. The expert opinions were collated based on their advice to establish the best possible settings to produce a garment with minimal seam deformation. The fabric intelligent technology system (FIT) was created to store the data and generate reports on machine settings for the sewability of the material by combining the validated SPEC recommendations and the fabric mechanical and physical properties. During the final phase of the project, a second set of experts (different from SPEC), were identified to rank the quality of the seams using the American Association of Textile Colourists and Chemists (AATCC) chart for seam deformation. The crux of this work was to develop a conceptual framework for a sewing machine settings database that would benefit the apparel industry by providing a knowledge based system for the optimisation of seam performance, quality and aesthetic appeal.

The outcomes from this study add new knowledge to the body of literature that highlights the significance of fabric sewability in garment manufacturing and the limitations of predictive. The study also contributes to a greater understanding of the behaviour of textile materials during the sewing of garments and the application of machine settings which improve the manufacturing process of sewn seams. The framework underscores the significance of the robust system that reduces seam deformation, increases productivity, and facilitates the overall efficiency of the garment manufacturing process. The implementation of an efficient quality management system (QMS) is vital to the global economy and to the overall well-being of the workforce and this novel framework and system should contribute to the successful implementation of any QMS.

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Chapter 1 INTRODUCTION

1.1. Overview

This chapter presents an overview and introduces the context and purpose of this study. The background to the study is followed by a review of the conceptual framework for the work, the research aims and the organisation of the thesis. Finally, an overview of the machine variables for stitching textile materials is described.

1.2. Preamble

In clothing production, people work under extreme pressures to produce work of acceptable quality to the consumer. They also have to produce garments in large quantities and at the right time. The vast majority of apparel production is still produced manually relying on the experience of fabric handlers and machine operators. Attempts have been made by many researchers to develop systems that would reduce human subjectivity in manufacturing. These include fabric objective measurement tools that predict the mechanical properties of the material by measuring the fabric at small loads. Other methods have included the development of sophisticated systems that automatically adjust presser foot pressure and thread tensions on individual fabrics.

It is right to acknowledge Professor Sueo Kawabata for his contribution as a leading expert in fabric objective measurement systems. The relationships between sewing parameters and fabric parameters have been influential in the development of objective measurement equipment (Kawabata, 1980). The Kawabata Evaluation System (KES) determines the characteristics of the fabric with respect to its parameters and sew-ability performance. These properties are representative of what fabrics are subjected to under normal handling, tailoring and manufacturing conditions. Groups of fabric properties are measured: Tensile, Shear, Bending, Compression, Surface properties and fabric weight. The introduction of sophisticated fabric measurement systems such as the Kawabata Evaluation System and the Fabric Assurance by Sample Testing (FAST) has enabled fabric parameters to be quantified scientifically (Kawabata and Niwa, 1991; Basu, 2002). However, the results from this data are difficult to interpret by an untrained eye and the explanations given about fabric sew-ability have been described by industrialists as difficult to understand (McLoughlin, 2007).

Researchers have studied the behaviour of fabrics during apparel manufacture to develop systems that automatically adjust basic sewing machine settings. Ferriera (1997) developed an on-line control system to optimise seam production during the sewing process. He correlated sewing thread tension, pressure foot forces and needle penetration forces with seam quality to generate information that will allow for better knowledge of seam production. Definitional and practical approaches have sought to explain the factors involved during seam sew-ability (Stylios, 1983; Stylios, 1997; Stylios and Lloyd, 1998). Many of the problems were acknowledged as seam slippage, seam damage, seam grinning, seam cracking and seam pucker, all of which, present difficulties when sewn. Theoretical models have been developed to explain interactions between the needle and bobbin sewing threads (Ferriera et al., 1994a; Ferriera et al., 1994b) and explain that seam balance is a function of the stitch and formation cycles. Stylios and Sotomi (1996) develop methods for optimising sewing machine settings using fuzzy logic in a neural network. They claimed that optimum sewing machine settings were achieved under static and dynamic machine conditions.

However many adjustments can only be performed by hand (Needles Eye, 1996). The use of gauges is necessary to ensure proper adjustment and optimisation of the machine settings. Improper settings can result in sewing problems, poor stitch formation, seam deformation and a general decline in machine performance and seam sewability. It was for this reason that the fabric sew-ability study was developed in order to develop a framework for sewing machine adjustments to ultimately provide production personnel with the knowledge and the skills required to set up equipment quickly and efficiently.

1.3. Conceptual framework

The conceptualisation of this study was built upon a hypothesis facilitating a method for sewing machine settings data using empirical research obtained from this study. An applied approach was used in the work in order to organise the ideas for achieving the research projects purpose. The research was divided into elements to make it manageable and to achieve its aims.

1.4. Research aims

The aims of the research were:

1. To identify and analyse current systems used in fabric parameter analysis and their contribution in determining seam sewability.
2. To ascertain key fabric parameters that affect seam performance, sewability and aesthetics.
3. To evaluate the interaction between advanced sewing machine settings and their impact on seam quality.
4. To synthesise the emerging understanding of sewing machine and fabric interaction into a concept for an electronic database system of empirical machine settings and adjustments that can be implemented in order to optimise the performance of the machine for seam sewability.
5. To model seam behaviour from the stochastic interaction between sewing parameters and fabric parameters allowing refined 3-D CAD apparel avatars.

In order to achieve these aims, it was necessary to understand the fabric properties that were pertinent to this study. The combination of processes, being able to quantify these properties and the subjective factors of adjusting the machine for optimum seam appearance, contributed to the originality of this work.

1.5. Organisation of the thesis

The thesis has been organised into eight chapters. Chapter one introduces the topic of the research aims and gives an overview of the background that led to the research project.

Chapter two presents a review of the key areas underpinning the study. The chapter is presented in sections and presents an overview describing the historical background of objective measurement and scientific approaches to studying sewing machine parameters that affect the operation of the machine. Objective measurement of the mechanical characteristics of fabrics are described and of their impact on stitching the fabric. The industrial literature, derived from the expertise of people in the apparel industry, is discussed in detail helping to create a portrait of the challenges involved in stitching materials. The review also discusses the phenomenon of seam puckering and how various researchers have tried to understand the occurrences and its complexities. The final part of this chapter discusses various modelling techniques that have been developed to aid scientists discover the factors involved in seam puckering and of its effect on production.

Chapter three discusses the machine base settings of how sewing machines respond to being adjusted for different fabrics. This chapter was included because it was essential to explain why adjusting the machine to various levels for good seam performance is fundamental to this work.

Chapter four informs the reader of how the fabric intelligent system was created.

Chapter five describes the pilot study and the methodologies and reasons for creation. This chapter was the most significant part of this thesis as it set the context for the main investigation. This preliminary work was undertaken in order to evaluate the feasibility, time, and cost and of any potential adverse effects that might occur before the main investigation was undertaken. It also helped the study design prior to the performance of the full scale research project.

Chapter six describes the main investigation which was developed from the pilot study.

Chapter seven discusses the results obtained from the experimental work and focuses on the most important factors that were discovered.

Chapter eight discusses the conclusions of this work with particular emphasis on how the aims of this research were achieved.

1.6. Overview of the Sewing variables relating to seam deformation

Stitching fabrics have been described as a complex process due to the number of variables involved in the joining of the product (McLoughlin, 2012). The main variables include:

- machine settings;
- needle and stitching point type;
- type of sewing thread used;
- operator handling;
- fabric physical parameters;

All of these areas are important in producing a quality seam. If one or more of them are incorrect, a poorly sewn and finished garment can be a consequence. Therefore well-organised companies have assessment structures in place in order to minimise production downtime. Garment technologists, quality managers and clothing machine engineers have a contributing role in minimising or eliminating production problems (McLoughlin, 1998; McLoughlin, 1999; McLoughlin, 2000), but in order to eliminate the problems, an understanding of these has first to be achieved.

Fine woven fabrics for example are particularly susceptible to seam pucker caused by structural jamming of the sewing thread within the yarns of the fabric. If the fabric is densely woven near to the practical weaving limit, there may be insufficient spaces to accommodate the sewing thread without distorting the woven yarns. The problem is aggravated if hard twisted yarns or extra fabric finish is used. Stitching along a straight line will distort and stretch the adjacent fabric yarn or yarns. The distress caused to the yarns may produce a puckered seam.

A seam running parallel to the warp direction often tends to pucker more than a seam running parallel to the weft direction. This is due to the warp yarns being subjected to higher tension during the weaving process. The result is a higher compression strain between the yarns in the fabric and the sewing thread in the seam compared to less compression between yarns and sewing thread in the weft direction. A slight change in the design or cutting of the fabric so as to enable the critical fabric seams to be sewn at a 10° bias angle will often reduce this problem. This is due to the sewing thread running at an angle to the warp or weft direction therefore the compression strain between the yarns in the fabric and the sewing thread in the seam is distributed more widely and is therefore significantly reduced.

Sewing machine settings should normally be set as dictated in the machine manual and gauges and a magnifying glass should be used to ensure that the machine is set up perfectly. There are however, circumstances when the sewing machine may be set differently from the manual; when sewing different thickness of seam, difficult sewing operations, such as sewing collars and cuffs on shirts, for which the feeder may need to be tilted to the front to enable the machine to catch the first stitch. As a rule, the industrial standard for setting thread tensions is to have both top and bottom thread tensions as slack as possible whilst producing a well-balanced stitch. Similarly, the presser foot pressure should be set as low as possible. However, if the pressure is too low, there is a loss of control of the fabric and the top and bottom fabric layers may not move together through the sewing stage. If the pressure is set too high, it can cause the machine foot to push the top ply of the fabric thus displacing it from the bottom ply causing “feed pucker”. These fundamental settings are known as “machine optimisation”.

Other factors, which should be addressed, include ensuring that the correct type of feeder and throat plate are used for the fabric. A throat plate with a hole that is too large for the needle causes flagging of the fabric. This is a condition whereby the fabric is pushed into an oversized needle hole by the descending needle. This causes a number of problems, which can include missing stitches due to the fact that the sewing thread loop is malformed inside the machine causing the rotary hook to miss the thread loop. An example of fabric feed pucker on a stitched seam of two plies of fabric is given figure 1.1.

1.6 Discussion summary

Fabric properties differ from batch to batch even with regard to the same style and type of product. Fabrics tested on the Kawabata system can have widely varying results, even from the same batch of fabric.

Figure 1.1: Example of seam pucker on two plies of fabric

In order to generate procedures to prevent a problem that has been highlighted by the objective measurement systems, a thorough understanding of the stitching process and the fabric assembly method needs to be achieved. Also the interaction between the fabric and sewing parameters needs to be clearly understood to identify important relationships that affect the stitching of the material. These relationships are discussed and described from the literature in chapter two.

Chapter 2 LITERATURE REVIEW

2.1. Overview of the chapter

This chapter presents a thorough review of the literature that relates to the aims of the thesis.

The motives for selecting the literature mentioned here was to bring to the reader of this work a holistic perspective on the relationship between the fabric parameters that influence the stitching of the textile fabrics. The importance of understanding these factors is discussed and described in detail particularly with regard to the importance of why this information needs to be acknowledged.

The chapter is presented in sections and presents an overview describing the historical background of objective measurement and scientific approaches to studying sewing machine parameters that affect the operation of the machine. Objective measurement of the mechanical characteristics of fabrics are described and of their impact on stitching the fabric. These included:

- The Kawabata system, a system used mainly in Universities mainly due to its cost and complexity of facilities and cost;
- The Fabric Assurance by Simple Testing (FAST), a system that is simpler to use and easy to install;
- Recent objective measurement systems (FAMOUS) are discussed and explained;

- The industrial literature, derived from the expertise of people in the apparel industry, is discussed in detail helping to create a portrait of the challenges involved in stitching materials. In particular the following methods were identified:

- The differences between subjective and evaluation with examples related to each;

- Research on the impact that machine settings have on seam quality;
- Literature reviewed to ascertain key fabric parameters that affect seam performance, sewability and aesthetics;

- Scientific approaches using sophisticated methods of analysis, electronics and neural networks;
- Manual approaches, setting machines by hand using precision adjustments;

Finally an examination of the literature for modelling seam behaviour from the stochastic interaction between sewing parameters and fabric parameters was undertaken. This would formulate the basis for developing the stitching models bringing all the interactions and relationships between all of the variables together.

2.2. Textile Instability, Garment Aesthetics and Seam Performance

The visual appearance of a product has been described as a critical determinant of consumer response and product success (Bloch 1995).

Similarly, it has also been discussed that, unacceptable products are a significant cost to the manufacturer. Hu and Zhang (1996) in their critical view of an aspect of the Kawabata Evaluation System for Fabric (KES-FB) argued that:

"As textile and clothing products, dictated by modern fashion trends, move through even faster cycles of renovation, Jit and QR are becoming ever more important in the textiles and clothing"

According to Yeung and Taylor (1990) and Yick et al (1995) it has become apparent that, in the international production arena, skills in the industry are being lost or transferred and that the assessment of fabric qualities for production increasingly requires a reliance on transferrable data across manufacturing plants; this assumes an understanding of the data being transferred as well as the ability to enact its meaning. Leaf (2004) comments that the analysis of the relationships between the properties of the components of plain woven fabrics (yarns, sett, yarn crimp) and the mechanical properties of the resultant fabrics has been the subject of many analyses from the 1920's to the present period. Further research by Leaf et al. (1993), Leaf and Sheta (1984) and Leaf and Kandil (1980), describe a consistent approach to the problem that leads to closed form equations for such relationships. These are restricted in application (for example they apply only to fabrics subjected to small deformations), but they have a general interest in which they provide an insight about the form of the relationships among the mechanical properties themselves. As pointed out by Leaf (2002), they also lead to the discovery of relationships among the mechanical properties themselves. Leaf (2004) also stated that:

"The series of papers mentioned above, does not provide a self-contained and unambiguous method for estimating the mechanical properties from a knowledge of yarn properties, fabric sett, and yarn crimp in the fabric. More research is needed in order to deal with this problem".

The foundations on which the analyses are based are the models of plain woven fabric developed by Peirce (1937). Also in his paper (Peirce 1930) "The handle of Cloth as a Measurable Quantity". He establishes the equations that define the phenomenon of the bending length of the material. He develops basic machines that measure and calculate the flexural rigidity of the fabric. Tests are described which have been designed to analyse and reflect the sensations of stiffness and hardness of the fabric and numeric values are awarded to each parameter.

Research carried out at the Swedish Institute for Textile research in the late 1950's and 60's (Shishoo and Choroszy 1990), involved the evaluation of low stress mechanical properties such as bending, buckling, stress, shear and compression in respect of tailor-ability and the investigation of the fabrics when made into garments.

Lindberg et al. (1961) were the first to apply the theory of buckling to textile fabrics in garment technology. Research established the fact that longitudinal fabric compression is a fabric mechanical property that is particularly important during tailoring. Lindberg related this property to fabric formability. Matsuo et al. (1972) at the Toyobo research centre Japan developed test methods and identified parameters that built up a significant collection of fabric samples, which provides an 'Atlas' of fabric hand, combining subjective feel and objective characterisation.

2.3. The Kawabata Evaluation System (KES)

Much of the modern work now used for objective measurement in universities and industry is attributed to Professor Sueo Kawabata of Kyoto University and his associates with the support of the Textile Machine Society of Japan (TMSJ).

Kawabata and Niwa (1991) discuss both the subjective and objective methods of fabric hand and conclude that the benefits of objective measurement over subjective measurement are:

- that objectively evaluated values are not influenced by the individual opinions / preferences of judges;
- fabric hand may be clearly connected with fabric mechanical properties;
- fabric hand data may be recorded by numerical value as well as mechanical measurements on the databank, which is important for the development of new fabrics, for process control in textile manufacturing, for marketing and for sales related stock control of textiles;

The people who buy the fabrics, the consumers and even the fabric processors have a considerable expertise when choosing what type of fabric to wear or buy. The pioneering work by Kawabata has brought about a new approach to this problem with the development of four pieces of equipment and the identification of 18 parameter values that are derived from the test results.

The hysteresis behaviour of the fabric, the bending movement and the compression force are measured in order to determine the fabric resilience and other mechanical properties.

The mechanical properties of the fabric are essential in enabling the objective fingerprint to be produced. The mechanical parameters of the KES system are shown in Table 2.1.

A considerable amount of literature has been published on Kawabata’s work with the HESC (‘Hand Evaluation Standards Committee’) in 1972 and is well documented (Fortress, 1982; Mattina, 1986; House, 1986; Gong 1994). A Sub

Committee of 17 experts from the Textile Machinery Society of Japan (TMSJ) were invited to join the committee.

These represent predominantly the industries of wool, fabric, weaving and finishing and the silk industry. The committee identified the primary hand factors for textile fabrics and these were initially used in the composition of a subjective assessment system.

The factors were described as:

Men’s winter suiting Fabric

- **Koshi – Stiffness:** Stiffness deriving from the bending property. High density fabrics made from springy and elastic yarn usually possesses this feeling strongly
- **Numeri – Smoothness:** A mixed feeling incorporating smoothness and softness; coming from smooth, limber and soft feeling. The fabric woven from cashmere has this feeling.
- **Fukurami – Fullness and Softness:** A feeling associated with bulky, rich and well formed fabrics. (Fukurami means swelling).

Men’s summer suiting fabric

- **Koshi – Stiffness:** Same as Koshi in men’s winter suiting fabric.
- **Shari – Crispness:** A feeling coming from a crisp and rough surface of the fabric. This feeling is brought by hard and highly twisted yarn. This offers a cool feeling. (This word means crisp, dry and sharp sound arisen by rubbing the fabric surface with itself).
- **Hari – Anti-drape stiffness:** Anti-drape stiffness no matter whether the fabric is springy or not. (This word means spread).
- **Fukurami – Fullness and softness:** Same as Fukurami in men’s winter suiting fabric.

Parameter	Description	
Tensile	LT WT RT EMT	Linearity of extension curve Tensile energy Tensile resilience Extension at 500gf/cm Load
Bending	B 2HB	Bending Stiffness Bending Hysteresis
Shearing	G 2HG 2HG5	Shear Stiffness Shear Hysteresis (0.5^0) movement Shear Hysteresis (5^0) movement
Surface	MIU MMD SMD	Coefficient of friction Mean Deviation of MIU Geometrical Roughness
Compression	LC WC RC To Tm	Linearity of compression curve Compression Energy Compression Resilience Thickness at 0.5gf/cm^2 Pressure Thickness at 50gf/cm^2 Pressure
Weight	W	Weight per unit area

'Table 2.1': The mechanical measurements used in the Kawabata Evaluation system (Gong, 1994)

From these primary hand factors, Kawabata produces calculations from which he derives the total hand factor of the fabric. This fabric fingerprint is graphed using a line chart. An example of the data chart developed by Kawabata is given in Appendix 1.

There have been many interpretations of Kawabata's work some of which has been critically appraised. It has been suggested in previous papers Hearle and Amirbayat (1987) that Kawabata uses too many measurements and that fabric predictability, particularly with respect to manufacturing may be quantified using fewer test measurements than was previously thought.

Hearle and Amirbayat explore this by suggesting the use of short cuts to the Kawabata method. This involved a smaller relevant list of parameters and fewer test instruments based, not on new experimental work, but on an examination of data available from Kawabata's existing publications. They deduce that the factors responsible for the listed properties are the fabric structure, (type of weave and geometrical parameters), the yarn properties and the finishing properties. They conclude that the parameters used by Kawabata may be simplified by taking account of the inherent relationships between many of the quantities as influenced by the fabric. Interestingly, they also conclude that in the absence of KES instruments, a limited number of parameters can be measured with ordinary laboratory equipment i.e. the thickness gauge, the balance and the bending length tester, can be used to estimate the fabric hand value of a wide range of men's winter suiting fabric with a good degree of accuracy.

Amirbayat and Alagha (1995) in their paper 'A new approach to fabric assessment' comment upon the fact that many technologists view the Kawabata and FAST instruments as the best tools available for fabric evaluation. However, this work shows how, by means of simple tensile tests, these properties can be estimated without needing any special attachments.

Much has been made of the use of KES instruments in predicting the process-ability of fabrics in sewing. Harwood et al. (1988) discuss the use for the Kawabata system in producing consistency in fabrics for the clothing-manufacturing sector. The paper mentions the fact that dyers and finishers are not fully aware of the ways in which their choice of processing route or processing conditions can affect a fabric's mechanical properties. By using the KES or similar equipment, the way in which mechanical properties vary with the methods used in processing are easily quantified.

There are, however, schools of thought that suggest there is a pitfall developing in that some apparel manufacture and finishers have viewed the KES system as a panacea, which is deemed to be the answer to all the hand and variation problems. This does not seem to be a realistic viewpoint due to the fact that some ground work needs to be done to categorise and understand the measurements.

2.4. Fabric Assurance by Simple Testing (FAST)

The FAST system was principally designed for use in the tailoring and worsted finishing industries. The major advantage of this system is its cost and simplicity of use. The emphasis of the system has been that it should be user friendly and robust enabling fast and accurate measurements to be taken.

FAST works by measuring and interpreting the parameters that have been identified by Scientists at the Commonwealth Scientific Research Organisation (CSIRO) as being critical to fabric appearance, hand and performance during the garment making operation. It comprises of three instruments and one test method. These are classified as:

- FAST-1 Compression Meter;
- FAST-2 Bending Meter;
- FAST-3 Extension Meter;
- FAST-4 Dimensional stability test.

The equipment takes the following measurements:

- tensile properties;
- extension at 3 loads;
- fabric thickness;
- bending length;
- relaxation shrinkage;
- hygral expansion;

Test results can be obtained within one hour and most importantly the equipment is easier to operate than the Kawabata system. It is stated that it takes less than one hour to train unskilled staff to operate the system (Basu, 2002). The only other additional requirement is that the fabric be conditioned prior to being tested.

- FAST1-Compression meter measures the fabric thickness at various loads and measures the surface layer thickness

- FAST-2 Bending Meter measures the fabric bending length according to BS 3556-1961. The bending length is converted into bending rigidity, which is directly related to fabric stiffness. Operator error in aligning the sample is eliminated due to an optical sensor mounted on the machine.

- FAST-3 Extension Meter measures the fabric extension at various loads. The extension is displayed as a percentage with a 0.1% resolution. The bias extension is also measured, and is converted to shear rigidity, which is directly related to fabric looseness. Fabric extensibility is combined with bending rigidity to give fabric formability which is a parameter related to the incidence of “seam pucker”.

- FAST-4 Dimensional stability test is not an instrument but a test method used to calculate the dimensional stability of the fabric. The test requires a laboratory oven and the fabric is subjected to a cycle of drying, wetting and then drying again. After each stage, the fabric’s dimensions in both the warp and weft are measured. The FAST system claimed to give valuable information to the garment maker as to how the dimensions of a fabric will change when exposed to moisture. The test method enables the dimensional stability of the fabric to be split down into two clearly identifiable components, whose cause and effect are quite different.

These components are:

- relaxation shrinkage;
- hygral expansion;

Relaxation shrinkage is defined as “the irreversible change in fabric dimensions (shrinkage or expansion) that occurs when a fabric is wet or exposed to steam. Hygral expansion is the reversible change in the dimension of the fabric that occurs when the moisture content of the fibres is altered.

Another advantage of the system is that it can be linked directly to an IBM compatible PC via the FAST Data Acquisition and analysis program. This program enables the test results to be recorded and fabric “fingerprints” to be printed automatically on a standard computer.

Both KES and FAST systems have been analysed and compared in previous papers (Tester et al. 1991; Minazio, 1995; Bishop, 1996). Correlations between the KES and FAST systems are made and show striking similarities between both types of system.

Figure 2.1: Kawabata Evaluation System (KES)

Figure 2.2: Fabric Assurance by Simple Testing (FAST)

Since its introduction to the industry in 1989, it is claimed that the use of fabric objective measurement has grown rapidly to the point where industry and commerce on opposite sides of the world can communicate in a common language. Many studies have been produced that emphasise how the FAST system can be deployed to help companies by telling them how a fabric will perform prior to production (Postle, 2007; Mahar et al., 2007; Mahar and Postle, 1989; Mahar et al., 2007). The fabric fingerprints can be used for fabric specifications, helping to developing new fabrics, comparing fabric finishes and predicting tailoring performance and final garment appearance. These case studies are representative of situations commonly found in industry.

From the use of the Kawabata system discussed above, its application to the sewing manufacturing sector has also been discussed in many research publications (Leung et al. 2000; Sule and Bardhan, 2000; Matsuo et al. 2000; Sule and Bardhan, 1999; Behera and Shama, 1998; Taylor et al. 1998; Yick et al. 1998). Newly-developed fabrics can be tested prior to release into the market. Preventative procedures can then be implemented at the design stage to ensure that the fabric has properties that will enable its manufacture into garments without too many problems.

The purposes of these testing devices have been described to some extent in chapter two and chapter five. Fabric objective measurement devices have been depicted as a useful tool in enabling the scientific quantification of fabrics (Postle, 2007). A description on how these devices operate is given in chapter seven.

2.5. Other methods of objective evaluation of appearance

Fan et al. (1999) describes garment appearance as one of the most important aspects of garment quality. Aesthetics is a very complicated subject because what one person would define as appealing may not necessarily be another person's view.

Previous studies on objective evaluation were limited to the appraisal of puckering in flat seams. From the 1950's to the 1990's, several instruments were developed to measure the surface contours of seams using photo or displacement sensors (Hebeler and Kolb, 1950; Belser et al. 1993) . However there were problems in the accuracy and reproducibility of these instruments and as a consequence were not widely accepted.

There have been recent attempts in which CCD cameras (Stylios and Sotomi 1993a; 1993b) or laser scanners (Inui and Shibuya, 1992; Park and Kang, 1997; Stylios et al. 1992) were used to capture the image of a seam, and artificial intelligence was applied to establish the relationship between objectively measured parameters and subjective grades from AATCC methods still commonly used today. These cameras were later found less appropriate due to the difficulties with patterned fabrics. The application of the Webber-Fechner law by Kawabata and Niwa (1996) in discovering an almost linear relationship between subjective pucker grade and a physical quantity is a very important contribution, as it improves the accuracy of objective pucker evaluation dramatically. Although much work has been carried out on the objective evaluation of puckering of flat seams, as few garment seams are 100% flat such work cannot directly be applied to evaluate garment seams.

Stylios (2005) publishes a paper in which he describes several new methods of measurement technologies for textiles and clothing. These include 3D measurement of body size and shape, fabric sample testing and a pucker laser measurement system. He also states that:

“Textile materials are of particular interest since they neither behave as solids nor as liquids, i.e. they are said to be limp and they possess viscoelastic properties which enable them to take up any 3D configurations by wrapping or hanging around solid bodies”

The use of objective measurement systems has become more diverse and varied. Barker (2002) in his paper ‘From fabric hand to thermal comfort’ traced the evolution of objective measurement of textile hand and comfort from Peirce through to modern methodology. Special interest is given to the Kawabata Evaluation System towards advancing the state of objective measurement. He remarks that there is value in the measurements given by the KES system when used as a component of comprehensive research designed to explain complex human response to clothing comfort. He concludes that further study should be undertaken in the development of objective measurement systems for garment level situations. The development of manikin technologies as increasingly realistic simulators of human thermo-physiological and even human sensorial response represents an exciting frontier for future research.

Intelligent evaluation and automated objective measurement systems have been developed by researchers that involve low-stress fabric testing by using robotic methods. Potluri and Porat (1996) developed a fully automated fabric test system by using robotics. The advantage of the system was its flexibility to change the test conditions as opposed to the relatively rigid test procedures given by the KES and FAST systems.

- The features of this system consisted of a horizontal robotic arm articulated to having 4 degrees of freedom giving a configuration better suited to manipulating a fabric panel on a horizontal surface.

- The robot has linear and circular path capability, which is required for applying continuous test cycles. Speed and acceleration are programmable which are important for an accurate control of the strain rate.

The researchers claimed that this system has been successfully employed for testing fabrics in the low stress region. Unlike the existing testing systems such as KES and FAST which was primarily developed for fabric hand evaluation, the robotic system was designed to test fabrics under varied conditions. The test conditions such as sample size, strain rate can be changed through the software thus creating the possibility of including fabric testing into an automated clothing environment. An illustration of the robotic test methods is given in figures 2.3 and 2.4 showing all robotic heads used to replicate/replace tests in Kawabata or FAST.

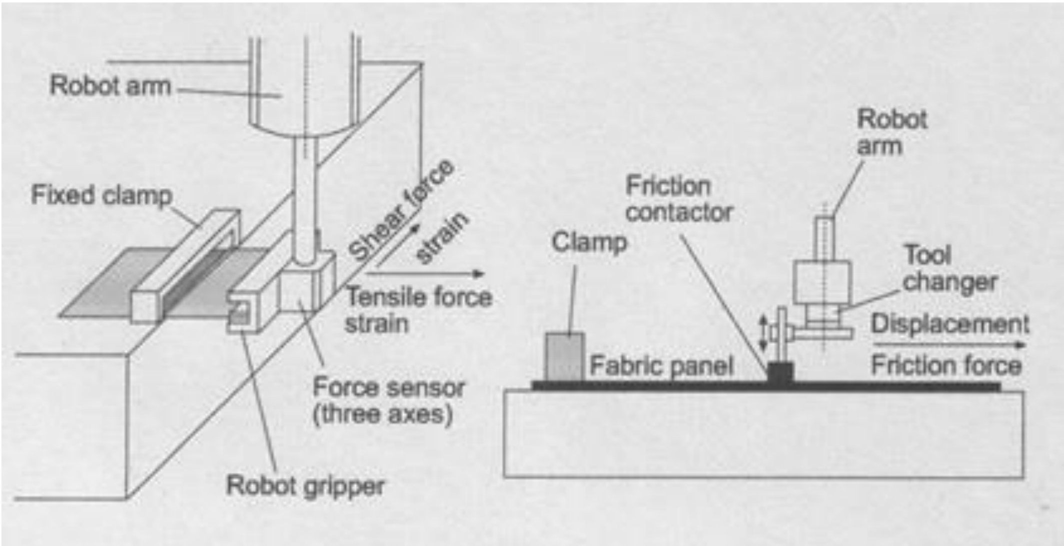

Figure 2.3: Illustration of tensile and frictional tests given by the robotic system (Potluri and Porat, 1996)

Similar methods employed by Panagiotis et al. (2007) develop an intelligent evaluation of fabrics extensibility from using a robotized tensile test. This system is used to perform the tensile test and estimate the extensibility of the samples using neural networking whilst also trying to imitate the human expert estimation. The researchers claimed that the results demonstrate that the system is capable of estimating the extensibility of new fabrics. They also claimed that the work can be integrated in the robotized sewing process with intelligent control where the fabrics extensibility in terms of linguistic values is necessary.

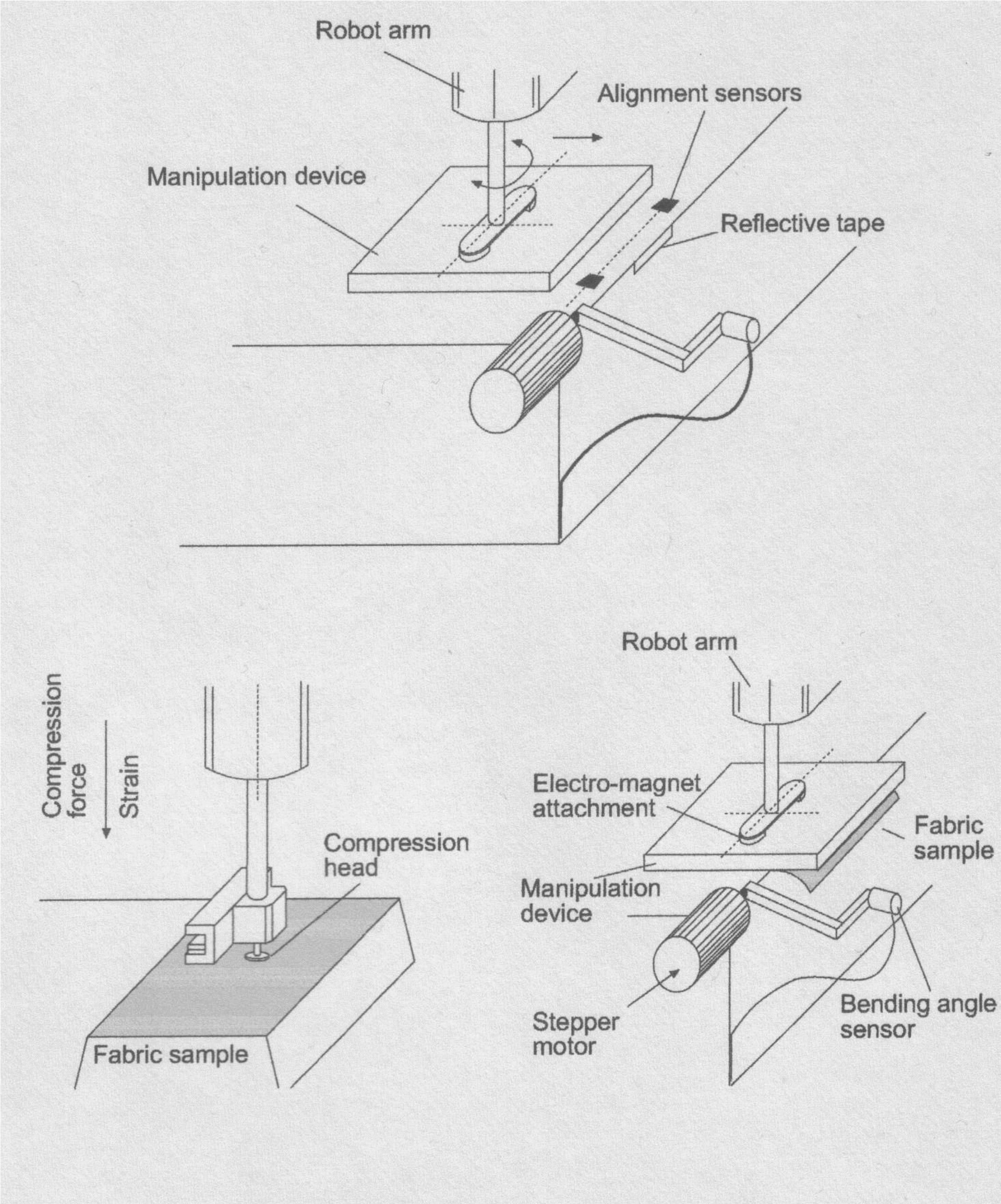

Figure 2.4: Illustration of compression and bending tests given by the robotic system (Potluri and Porat, 1996)

The proposed system initiates a new approach, in which the fabric properties are expressed and used in a way that will facilitate the introduction of artificial intelligence methods into the clothing industry. The future directions of the proposed approach are focused on the bending and shearing fabric tests in relation with the fabric handling automation. They conclude that the observation and the attempt to initiate the human way of testing and evaluating the fabric characteristics should be the guidance of this work. An example of this system is given in figures 2.5, 2.6 and 2.7.

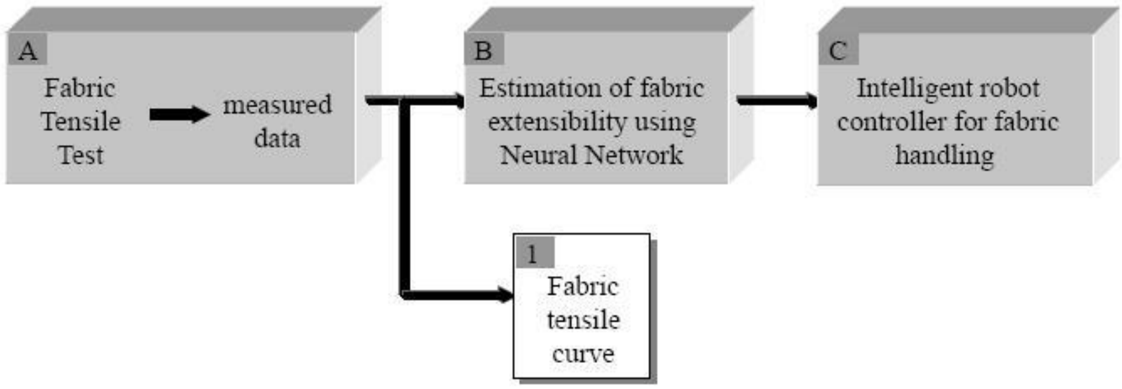

Figure 2.5: Tensile test and intelligent evaluation of measured data (Panagiotis et al. 2006)

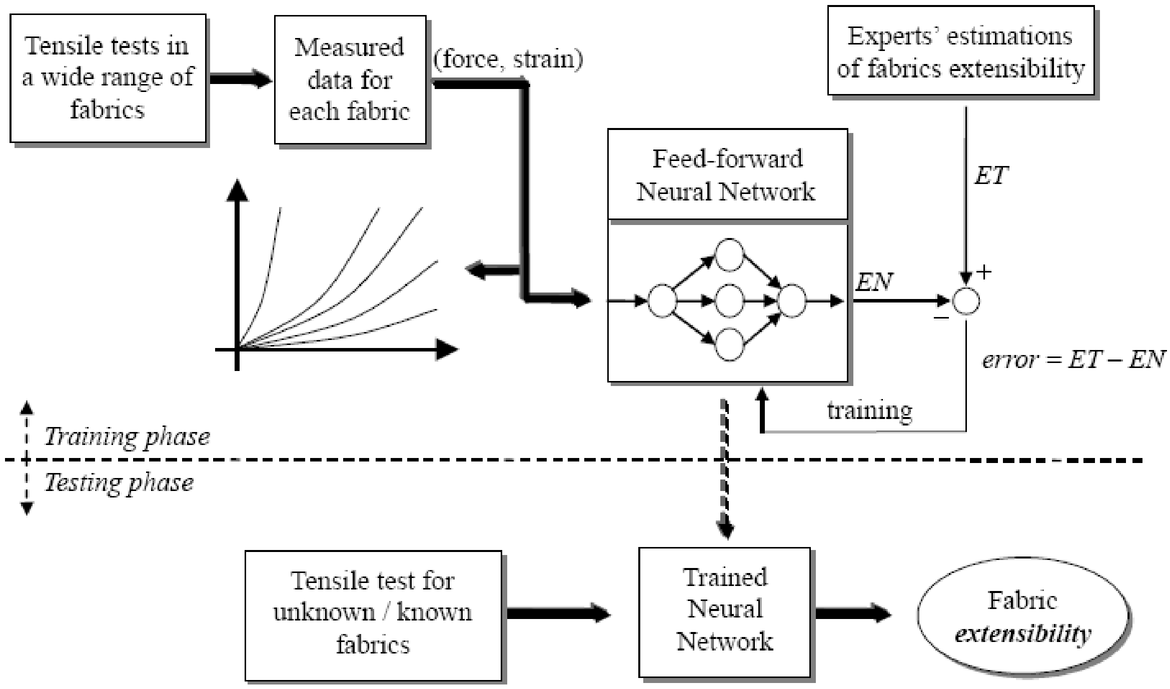

Figure 2.6: Measurement and evaluation of the fabric extensibility (Panagiotis et al. 2007)

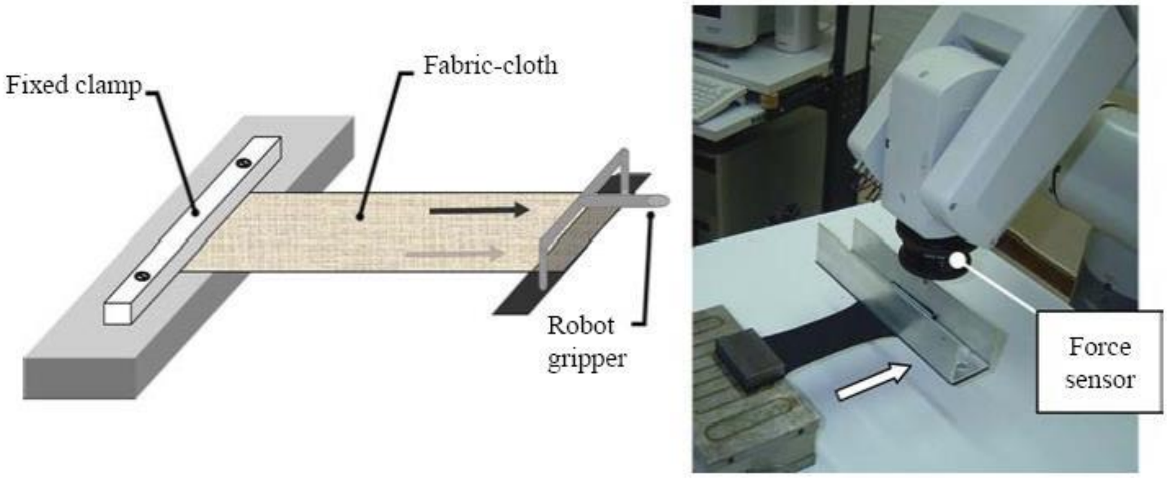

Figure 2.7: Fabric tensile test, extension (Panagiotis et al. 2007)

2.6. Problems associated with objective fabric measurement

Throughout the work reported here, it is generally noted that the Kawabata evaluation system (KES) and FAST (Fabric assurance by simple testing) are regarded as the two major primary devices for the objective evaluation of fabrics and fabric hand. All the papers reviewed and analysed contain references to one or both systems in varying degrees of depth. The general understanding about the current provision of equipment after extensive scientific and industrial use over the last 20 years is that the KES system is regarded as a scientific device for research and the FAST system as a simplified alternative device for industrial use.

Stylios (2005) reports that the results from the KES system are very accurate and the instrument accumulates enough data for a complete test but a sample fabric test takes 1-2 hours to complete. The FAST results are limited to the measured loads only and may not be able to provide sufficient data for complete stress / strain profiles in some fabric samples. Difficulties may have been experienced in the reproducibility of the measurement of both devices due to the need of different sample sizes and the manual handling for each test.

The cost of these systems is another important consideration. The KES equipment is very expensive and out of reach of many SME’s which comprise of most of the textile enterprises. FAST is considerably cheaper on the other hand

and needs less skill to be used. In the case of Kawabata, a great degree of skill is required when placing the samples in devices, in order for the data to be accurate. Also the interpretation of the test results needs to be undertaken with great care to ensure that the data is precise.

2.7. Towards full automation

In the last 3 years, the KES-F system has been made into a fully automated version although it has yet to be fully commercialised (Stylios, 2005). The cost of this system however is set to be even higher than its manual counterpart putting it beyond even more companies and hindering this technology even further.

Stylios (2005) describes another automated system that has recently been developed that could solve this problem. A new concept was established which was developed into a new device for the measurement of limp materials. This device is called FAMOUS (Fabric automatic measurement optimisation universal system).

To fulfil simplicity, all tests are made with one sample only and without the need of human intervention; a new concept of measurement in 2 planes had to be invented; one for tensile, shear and flexural rigidity and another for compression and surface.

This type of device consists of a single piece of apparatus for the measurement of the mechanical properties of a single sample of limp sheet material. This reduces the equipment costs compared to other objective measurement systems that use multiple devices. Another aim of this system is to reduce the time and complexity of making such measurements compared with the existing methods.

To achieve the above aims, the equipment has been designed using state of the art slides, motors and sensors in an ingenious way, which produces motions in six axis and measures property changes in 5 different positions. Figure 2.8 shows a photograph of the equipment which is portable and can be mounted on any work surface.

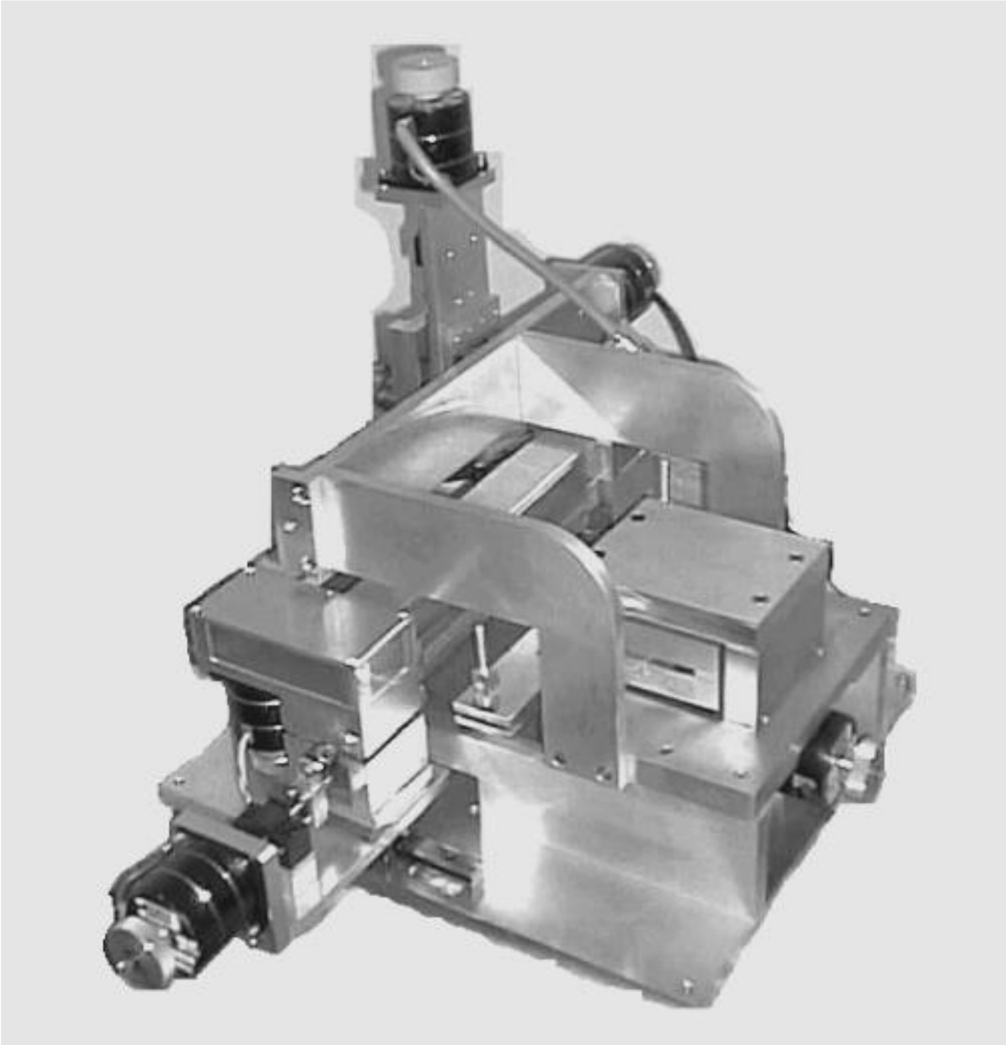

Figure 2.8: The FAMOUS equipment (Stylios, 2005)

2.8. Subjective verses objective evaluation

The application of subjective methods of fabric evaluation is still very widely used in the industry today.

McLaren Miller (1998) investigates lockstitch seam instability in the cross grain construction of woven fabrics. She comments upon the fact that previous research has suggested that the difference between subjective quality and objective quality is that the former is perceived while the latter can be quantified in part from the mechanical properties. It is suggested that by linking these two aspects it is possible that irregularities arising in production may be better controlled.

She describes a situation during a discussion with a production manager at a plant which supplies a UK retail chain, it was stated that:

"It is all very well having handling values for fabric, as numbers, to try to eliminate the pucker problem, but we have to work with what we're given and the turnover in fabric and design is high. We principally rely on the experience of the handlers and in-line assessment to eliminate the problems concerned"

This is supported by McLoughlin and Hayes (2007) who develop a fabric sew-ability system which automatically analyses the results from Kawabata Tests and using this information, successfully generates an automated textual report of the fabric properties. It also produces guidance as to the sew-ability of the material. The system was tested by a team of industrial experts from the apparel industry, the Fabric Sew-ability Panel. Experts from industry were invited to analyse a number of fabrics and render a judgment on their prospective sew-ability. The level of agreement amongst the experts was measured using Kendall's coefficient of concordance and significance testing techniques. Comparisons were then made between the judgment of the experts and the results from the Fabric Sew-ability System; the results confirmed that there was a correlation between the judgments given by the experts and the fabric sew-ability system. During this exercise similar discussions took place between the researchers and the experts. As one expert stated:

"We are not dealing with sheet metal here! Fabrics are flexible structures that have external factors introduced into them during make up. Sewing threads, machine settings and operator handling are all important factors that influence the performance of a fabric during sewing"

The challenge for the future of objective measurement systems seems to be principally that the clothing industry needs to be persuaded that this technology is of benefit to them. It also needs to be used in conjunction with subjective methods. With the will to combine these methods it is likely to further enhance the understanding of sew-ability of fabrics into garments.

2.9. The interaction between sewing machine settings and of their impact on seam quality

Many researchers have investigated the sew-ability and quality of garments using sophisticated technologies (Lojen, 1998; Mallet and Du, 1999; McWaters and Clapp, 1994). Stylios and Sotomi (1996) have been at the forefront of establishing technologies for garment sew-ability and attempting to predict levels of seam pucker using laser and fuzzy logic techniques. Stylios and Sotomi investigate the possibility of developing thinking sewing machines for intelligent garment manufacture. They mention the fact that there is reasonable progress in relating fabric properties to sewing machine settings and stitching quality. There are however, areas that have not been numerically defined because of the complexity of the dynamic interactions between needle, fabric and machine parameters.

Researchers have studied the behaviour of fabrics during apparel manufacture to develop systems that automatically adjust basic sewing machine settings. Ferriera (1997) developed an on-line control system to optimise seam production during the sewing process. He correlated sewing thread tension, presser. foot forces and needle penetration forces with seam quality to generate information that will allow for better knowledge of seam production. Definitional and practical approaches have sought to explain the factors involved during seam sew-ability (Stylios, 1983; Stylios, 1997; Stylios and Lloyd, 1998). Many of the problems were acknowledged as seam slippage, seam damage, seam grinning, seam cracking and seam pucker, all of which, present difficulties when sewn. Theoretical models have been developed to explain interactions between the needle and bobbin sewing threads (Ferriera et al., 1994a; Ferriera et al., 1994b) and explain that seam balance is a function of the stitch and formation cycles. Stylios and Sotomi (1996) develop methods for optimising sewing machine settings using fuzzy logic in a neural network. They claimed that optimum sewing machine settings were achieved under static and dynamic machine conditions.

However many adjustments can only be performed by hand (Needles Eye, 1996). The use of gauges is necessary to ensure proper adjustment and optimisation of the machine settings. Improper settings can result in sewing problems, poor stitch formation, seam deformation and a general decline in machine performance and seam sew-ability. Fabric feeding can be a major cause of seam deformation. Kennon and Hayes (2000) have investigated fabric feed timing on lockstitch sewing machine and conclude that by retarding the feed timing by 25 degrees, the tension in the stitch formation has been reduced therefore reducing seam pucker. Zunic-Lojen and Gotih (2003) analyse the needle bar kinematics with the thread take-up lever on a lockstitch sewing machine by using computer simulation. An image was drawn on the basis of modelling the kinematic simulation of a needle bar with the thread take-up lever and measurements of the thread tension forces on the sewing process.

Much of this state of the art research though important and necessary does not seem to have an impact on the manufacturing shop floor. McLoughlin (2005) comments that:

“The gap between work practice methods and research methods could be seen to be large. Many companies do not have the resources to fund purchase an objective measurement system. In fact many do not know of the existence of such systems at all. It’s apparent that there are major difficulties involved in joining fabrics together at the machine interface by the sewing process” p. 99-100.

There are, however, a number of measures that may be taken in order to help alleviate this problem if not eliminate it completely. These were described as:

- Collating historical machine settings data for each style and fabric sewn;
- Establishing methods for dealing with seam pucker, understanding its causes and steps which may be taken to counter it;
- Giving technicians and production staff greater understanding of the properties associated with a fabric. This includes knowledge of fibres, yarns, yarn twist, frictional properties, shear properties, extensibility and bending rigidity;
- Extending the use of Fabric Objective Measurement systems in fabric manufacturing companies in order to enable warnings of material instability to be given prior to despatch at fabric apparel manufacturing companies;

Further research should be performed and a settings databank may be created to determine optimum sewing conditions for each type of fabric sewn.

The use of low cost instrumentation for machine optimisation should be promoted; such equipment for measuring thread tensions and strain gauges currently exists and is inexpensive to purchase.

2.10. Industrial approach to seaming quality

One aim of the Fabric Objective Measurement (FOM) system was to reduce the incidence of sewing problems on the production floor. But as previously stated, a company is usually unable to exchange the fabric before the end of the order. The major advantage of having tested the fabric on the Kawabata system is that the company is armed with knowledge about the fabric’s characteristics and therefore is in a better position to tackle any production problems associated with the make-up of this fabric. During the history of the Kawabata system there have been many thousands of different types of fabrics tested which have produced many interesting results. The issue of seam pucker for example has been discussed by many authors (Stylios and Sotomi, 1996)

The sew-ability of fabrics at the needlepoint is still classed by some as a ‘Pseudo Science’ and with respect to seam pucker in particular, the reasons for this will be examined in further chapters of this thesis.

When fabrics are made into garments there are many variable factors that need to be taken into account. These variables are dependent upon the type and composition of the fabric to be sewn. There have been many discussions and differences between garment technologists and specialists in the sew-ability of fabrics. This differentiation between experienced professionals has increased the argument for an objective fabric analysis system.

This is verified in the case of a paper written by Felix Robers (1992) on sewing micro-fibre fabrics. He asserted that:

“Problems were practically unknown in shirt and blouse manufacture as the fabrics were mainly of more open weave construction. However, outerwear fabrics tend to feature high warp and weft densities and special finishes, so seam puckering is a common occurrence”.

Similarly sewing raised fabrics can be difficult and micro-fibre fabrics require precise machine set up. However, experience has shown that problems in sewing shirt and blouse fabrics can be just as difficult (Gutermann, 1999). Precise machine settings and handling methods have to be continuously maintained particularly when sewing lighter weight fabrics and fabrics prone to slippage. Micro-fibre fabrics made from polyester or polyamide have lower bending rigidity and are smooth and slippery causing greater handling problems for the operator and more difficulties when feeding the fabric through the machine.

It is very important to point out the fact that even though the KES and FAST systems deliver some useful information on fabric sew-ability, fabrics that have been found to be below acceptable measured limits, will still need to be processed. Therefore a fabric found to have potential sew-ability problems requires a great deal of industrial expertise in order to satisfy this objective. An in-depth knowledge of machine and processing technologies is required for this purpose.

2.11. Other measures affecting seam performance

The stitching of a fabric can be affected by the cutting direction of the material where the number of threads is distinctly high in the warp direction (Zeydan, 2007). This is because weaving machinery is able to weave finer yarns at much greater speeds, imparting higher yarn tensions. This increases the possibility of structural jamming in the fabric (commonly known as inherent pucker), where the sewing thread occupies space between the yarns in the fabric causing yarn displacement. Suda and Nagasaka (1984) investigated the effect of seam on fabric bending rigidity tested in the KES system by varying seam allowances, the number of seams on the same specimen, the type of stitches, seam and sewing thread. They concluded that a seam has distinctive effects on the bending property of a fabric. In another paper (Suda and Nagasaka, 1984), they studied the effect of a seam and hem of a flared skin on the drape profile, by bonding narrow strips of non-woven fabrics at the edge or along the radial direction of circular fabrics. They observed that the bending rigidity of the bonded part increased with the width and/or the number of bonded layers of the non-woven fabric.

Dhingra and Postle (1980) investigated bending properties of fabrics with seams. They used wool woven fabric with 2/2 twill structure. It was found that seam has little effect on fabric shear rigidity and hysteresis, but has a significant effect on bending rigidity under some circumstances.

The drape of a material can have an effect on a stitched seam. Hu et al. (1997) evaluate the effect of seams on fabric drape and conclude that that the drape coefficient increases with seam allowance first, and then decreases with the increase of seam allowance.

The complex evaluation of the quality of a sewing product includes the evaluation of construction of the garment and the pattern, the structure and the properties of the material and also the quality of the seams (Germanova-Krasteva and Petrov, 2007). They examine a seams quality on lightweight materials and define what they call the dominating factors that have an influence on the quality of a seam. Mathematical and flow diagrammatic models are developed (Appendix 2 and Appendix 3) which include an Ishikawa diagram on the influence of a materials properties on the seam. Before this, McLoughlin (1999) writes a paper on a Zero Break Down Strategy adopting a similar method of Ishikawa and Pareto analysis for determining the levels, areas and causes of machine breakdown on a factory floor.

Other factors that affect seam performance are the cover factor of the material and the crimp percentage that binds the fabrics together (McLoughlin, 2013). The tighter the cover factor, then there is a greater possibility that structural jamming can occur as the yarns in the material become more resistant to the sewing thread in the material. This highlights a gap in the literature as very little work has been done in this area regarding the stitching of fabrics.

2.12. Seam Sewing Performance and Stability

The specific area of sewing performance does not appear in the literature until the late 1950’s, which may be attributed to the fact that the stitching of fabrics before that date was comparatively free of sewing difficulty because of much lower sewing speeds.

For several decades many different ways to define and categorise pucker have been introduced. Scott (1951) was one of the first to identify puckering of seams, fusing and needle damage. Since then, many different types of needles and sewing threads have been developed to help improve the sew-ability of seams. Dorkin and Chamberlain (1961) identified five primary causes of puckered seams and classified seam pucker into four groups, inherent pucker, feeding pucker, tension pucker and thread shrinkage pucker. The other variable is pucker induced through the pressure from the presser foot.

Inherent pucker results from the displacement of the fabric yarns from that of the sewing thread. Displaced fabric yarns do not settle into a new position but try to return to their original positions and are prevented from doing so by the sewing thread. The resulting seam distortion is known as structural jamming (Schwartz, 1984; Stylios and Lloyd, 1989; Jin Lian Hu et al., 2006).

An instrument was developed for measuring fabric crinkle resistance and the recovery of fabrics called the Wrinklometer. This instrument employed a photocell connected to a chart recorder which measured the surface contours of the fabric. This instrument was believed to have been used for seam pucker but it was not widely accepted as the instrument was considered to be oversensitive leading to unpredictable results.

One of the most common causes of seam deformation leading to poor aesthetics in a garment is seam pucker. Woven fabrics are particularly prone to seam pucker because of their structure. The interlacing of the warp with the weft yarns in the fabric results in less free space between yarns than for example a knitted fabric.

The problems of seam pucker have been blamed, for years, on the sewing thread properties and the thread manufacturers (Dobilaite and Juciene, 2006). The needle manufacturing companies (and needle sizes), and the fabric manufacturing companies and finishers are also mentioned as a factor. The part that each of these areas have played in causing seam pucker has now been realised and great efforts have been made by the industries to improve garment quality by reducing these causes of pucker.

Achieving a smooth pucker free seam continues to be a central issue in the making up industry. Many researchers have attempted to define the problems of seam pucker by mathematical models that are often complex and difficult to understand by normal industrial standards. Chapter one mentions that most adjustments to a sewing machine can only be performed by hand. Therefore it is sensible and proper that an account be given of the contribution those clothing production personnel make in producing pucker free garments. in addition to this point, clothing manufacturing Companies work closely with sewing thread and sewing needle manufacturing companies who have developed useful literature on areas of best practise for manufacturing quality products. An account of Companies that provide this knowledge is given below:

Guttermans, (1999)**,** discuss how to address seam pucker and highlights 4 main variables as the major cause:

* Feed pucker;
* Fabric yarn displacement (or inherent pucker);
* Tension pucker;
* Stitch density and fabric type;

- Feed Pucker as previously mentioned, occurs when the two plies of fabric are not fed uniformly through the sewing machine. The bottom ply tends to be fed more positively by the feed dogs while the top layer is only clamped by the presser foot. The shortening of one of the fabric layers, usually the bottom one, creates a wavy appearance on one side and results as (what is known) as feed pucker (figure 2.9).

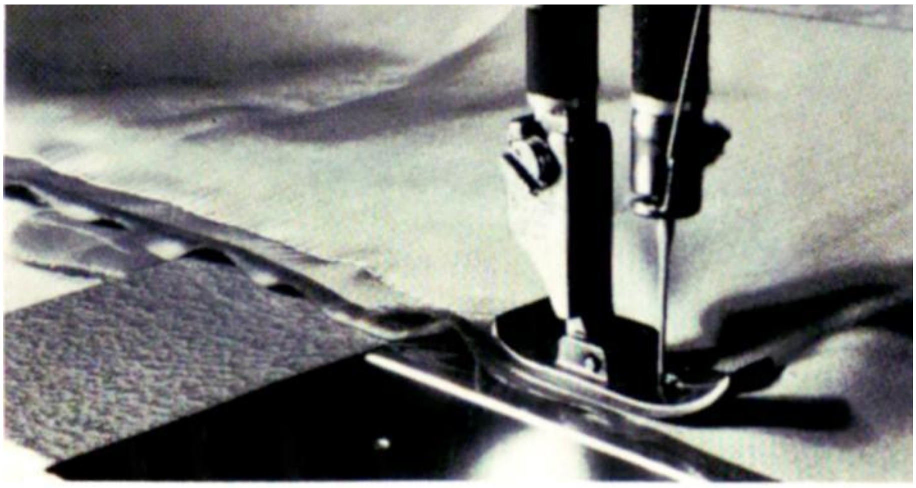

Figure 2.9: Example of feed pucker

Several types of feed mechanisms have been developed in order to help alleviate this problem (Hayes and McLoughlin, 2013).

- Inherent pucker is mentioned as a major cause of seam pucker throughout this thesis. This is described by researchers and industry as the displacement of the warp and weft yarns by the needle penetration and the thread insertion into the fabric. When sewing mainly in warp direction, the warp yarns will be displaced laterally causing an inevitable shortening of length to adjacent yarns. The fabric structure becomes jammed resulting in swelling and puckering of the seam. An example of this is given in figure 2.10.

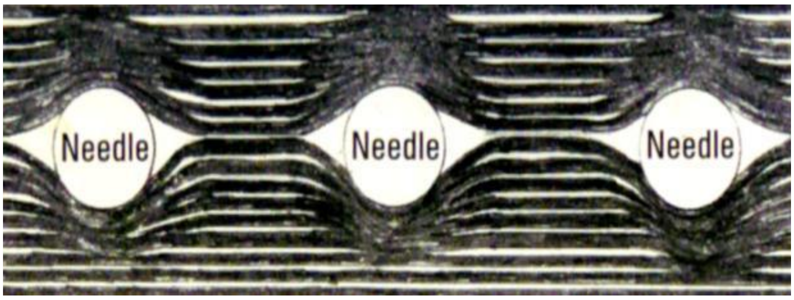

Figure 2.10: Systematic diagram of the warp yarn displaced by the needle

The use of finer needles and finer threads is vital if inherent pucker is to be avoided (figure 2.11).

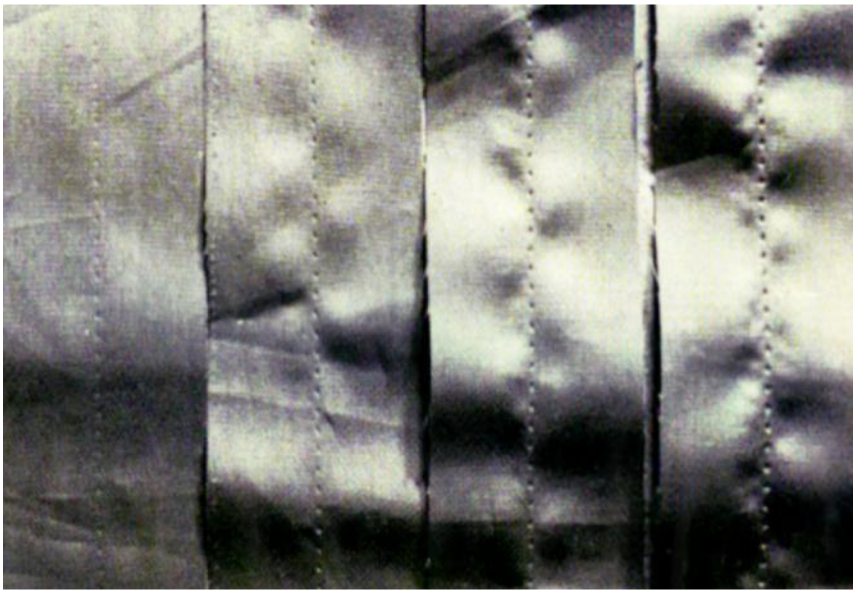

Figure 2.11: Influence of needle size on inherent pucker

Of equal use importance is the use of a throat plate with a needle hole that can accommodate the needle, matching the needle size. This prevents the fabric from being pushed into the needle hole with each penetration of the needle.

It is considered that the finer the needle hole and the diameter of the needle, then the less disruption to the fabric through the penetration of the needle. This produces a flatter seam appearance, but can cause higher needle breakages as the needle can strike the throat plate due to deflection of the needle through the thickness of the fabric.

- Tension Pucker is described by American and Efird (2010) as ‘A thread stitched into a fabric under excessive tension’. The thread will try to recover or return to its original length. This will cause the seam to pucker immediately as the seam comes out from under the presser-foot. They suggest using a thread with a low elongation or high initial modulus to minimize stretching during sewing. They also suggest a thread with good lubricated characteristics that will allow it to be sewn with minimum machine thread tension (figure 2.12).

Figure 2.12: Excessive thread tension

Feed puckering has been described and mentioned in previous and in future chapters. However it is important to mention this again here as different Companies have slightly different suggestions for dealing with it. American and Efird describe this phenomenon as the feeding of the fabric being fed into the machine at slightly different rates. Feed puckering occurs when one of the fabric plies is fed into the seam at a different rate than the other ply or plies. This causes a gathering effect in the over-fed ply. Ply mismatching as shown in figure 2.13, usually occurs when the presser foot holds back on the upper ply as the bottom ply is being fed into the seam at a higher rate by the feed dog. (b) Usually occurs when the operator holds back on the bottom ply and pushes the top ply into the machine so the fabric edges will come out evenly. Many seams observed display both of these conditions, with the first usually contributing to the latter because the sewing operator will attempt to correct for the uneven feeding of the sewing machine.

Figure 2.13: Feed puckering holding back the upper ply

This Company provides a range of solutions to this problem:

- Use the minimum presser foot pressure that will maintain uniform feeding. Make sure the presser foot is clamping the fabric properly both in front and back of the needle. When the feed is up and moving the fabric, the seam should be clamped by the entire bottom surface of the presser foot. This can be checked by inserting a piece of paper under the foot from different angles and observing if the foot is clamping the fabric properly.

- Set the feed dogs at their proper height and check for back-feeding. The feed dog should have the optimum teeth per inch and number of rows of teeth for the operation and fabric being sewn.

- Puckering can sometimes occur if the material is not held down flat as it is being fed through the machine creating a rippled appearance as the plies conform to the feed dog teeth. Usually lightweight wrinkle resistant fabrics should be sewn with feed dogs with 20 - 24 teeth per inch. Medium weight fabrics like men's trousers should be sewn with feed dogs with 14 - 18 teeth per inch. Heavy weight fabrics are usually sewn with feed dogs with 8 - 12 teeth per inch.

- Use the correct presser foot and needle plate for the material and operation being sewn. The needle plate and presser foot should have relatively small needle holes in relation to the needle size being used. As a general rule, the needle hole should be approximately twice the size of the needle. Check to make sure that the needle plate is not bent down at the needle hole.

- Use a low friction presser foot: Teflon coated roller bearing, "feeding foot", etc. Use an "anti-puckering" needle plate with a retaining spring that holds back on the bottom ply to match the top ply.

- Use machines equipped with a needle feed or compound feed mechanism where the needle moves with the feed as the fabric is being sewn. This "pinning" of the plies as they are being fed helps reduce feed puckering.

- Whenever possible, use machines equipped with auxiliary top feeding mechanisms such as: walking foot, puller, top driven roller feed, upper belt feed, etc..

- On machines equipped with differential feed systems, set the differential action to slightly stretch the bottom ply to match the top ply so they are fed evenly into the seam.

- Use automatic machines equipped with material clamping systems that prevent the fabric from moving as it is being sewn.

- Make sure you are using the correct capacity of folders and guides for the fabric being sewn.

- Observe operator handling for proper fabric movement to and through the machine.

- Make sure the pieces are cut properly in the cutting room and the proper seam tolerances have been maintained so the pieces are of equal length before seaming.

- If the plies have different stretch characteristics, position the ply with the greatest amount of stretch against the feed if possible.

During the sewing process, especially joining fabric pieces, uncontrollable changes to the seam area can occur particularly on problematic materials. This can lead to changes in the dimension of the fabric causing distortion in the fabric seam commonly defined as seam pucker.

It is realised from the review of literature outlined above that both working practitioners in industry and academic researchers both agree that these variables are the main cause of many quality problems when sewing garments. Despite so many new techniques and state of the art technologies being developed, this problem has never been fully eradicated.

2.13. Experimentation and modelling for predicting seam sew-ability

The behaviour of fabrics when made into garments has been the subject of many research papers and various attempts have been made to model the various parameters involved. A great deal of effort has been made in modelling and analysing fabric deformation. Most of the work focused on the relationship between the fabric structure and the mechanical properties not on the prediction of the overall shape of fabrics.

Stylios et al. (1995; 1996) developed a series of models for modelling drape and the seaming behaviour of fabrics. In the first paper they develop a technique for modelling the dynamic drape of fabrics on synthetic humans. The second paper involves modelling the dynamic drape in a virtual fashion show.

Similar models have been developed for cloth drape and garment simulation. Ascough (1996) develops a simple finite model for cloth drape simulation. The objective with this model is to simulate the behaviour of a cloth garment as it falls into contact with a human body model from an initial position. The simulation must be sufficiently realistic for the garment designers needs and be carried out quickly enough for the designer to work.

Imaoka (1996) develops three models for garment simulation. These consist of a garment model, a human body model and an environment model. During the development of the models the following rationale was used:

- What is the model or technique trying to do? (Conceptual model)
- What are the underlying equations? (Mathematical model)
- What are the knowns and unknowns? (Posed problem)
- What are the solution techniques? (Implementation)

Figure 2.14 gives an illustration of these models:

Adams et al. (1994) produces a model for protective clothing effects on performance. Their main objective is to understand how protective clothing affects performance and it is necessary to identify those garment properties that potentially affect worker performance and quantify their contributions. They identify the factors that are the causes of negative performance on workers wearing protective clothing. This can be seen in figure 2.15.

Mousazadegan et al. (2012) develop mathematical models for seam pucker analysis and describe these as a novel approach to excluding the influence of human perception.

Researchers have developed models for determining levels of seam pucker in a garment (Stylios and Sotomi, 1993a; 1993b). Hu et al. (2006) presents a method for modelling the seam puckering of multi-layer fabrics by considering the thread shrinkage as well as the seam structure and fabric compression properties. A theoretical investigation and numerical calculation of forces acting on the thread tension puckering were analysed and a seam model to calculate the deformation of a multi-layer seam when threads shrink was developed.

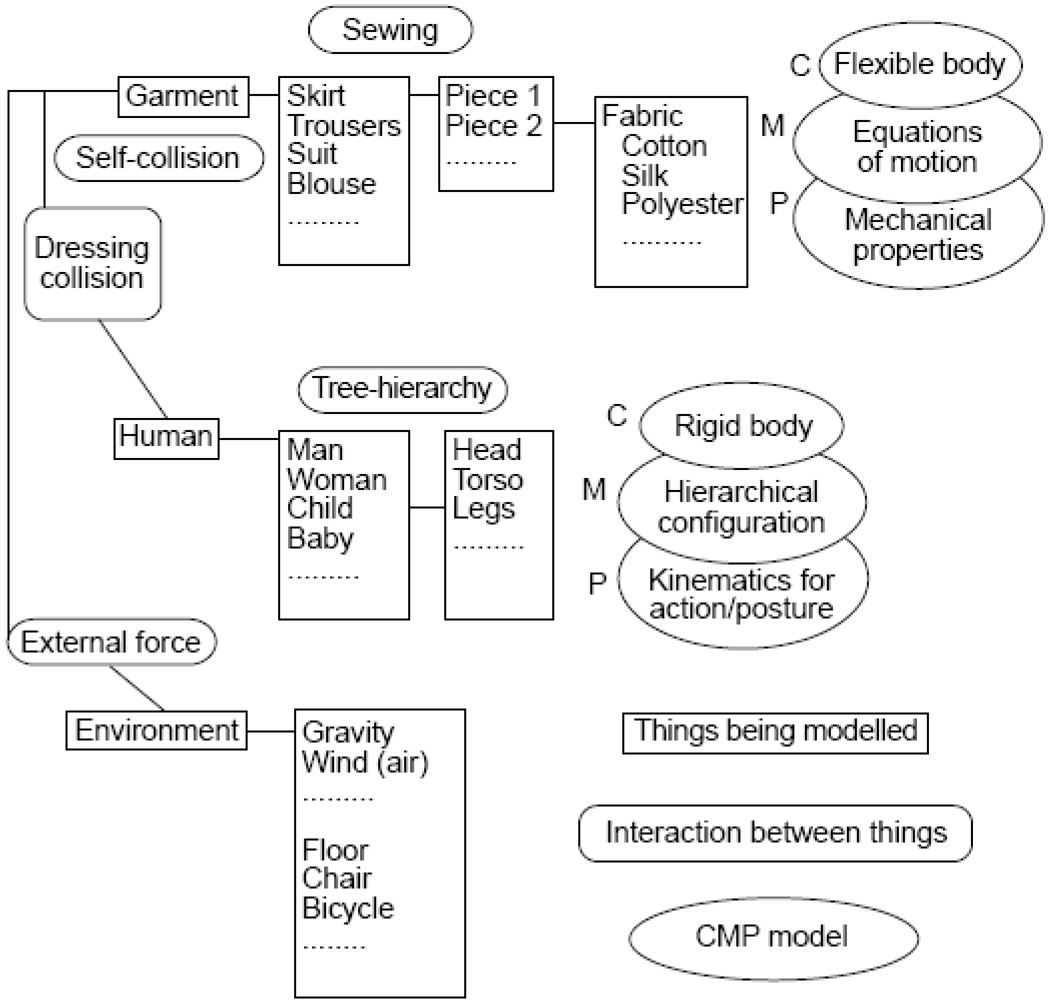

Figure 2.14: An overview of three models for garment simulation

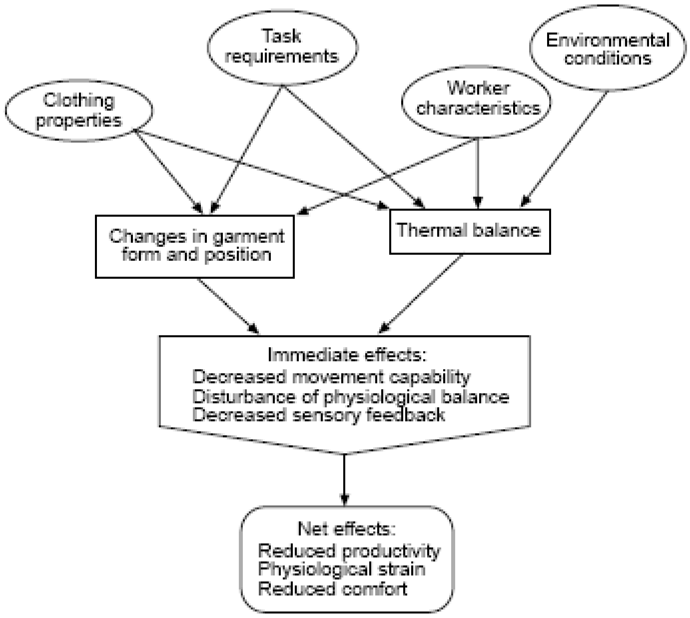

Figure 2.15: Overview model for causes of negative performance effects on workers wearing protective clothing.

2.14. Summary of the key factors on objective and subjective measurement

Key resources from the literature were valuable in setting the scene for this work.

- The prominence of objective measurement was an important part of this research providing an objective assessment on fabric properties;
- The work from Kawabata and Postle, (cited earlier) were pioneers of developing systems to measure fabric properties and draw inferences between these properties and the fabric performance at the sewing machine interface;
- Sophisticated methods were researched on the scientific approaches of measuring the stitching of fabrics. It was deemed appropriate to determine the technicalities of this work in order to ascertain how this work could be used productively in the apparel industry;
- The literature also identified key areas on the stitching of materials bringing both subjective and objective methods together. Mclaren Miller (1998) participated in these arguments quite succinctly;
- The industrial literature describes the problems associated with stitching materials. McLoughlin and Hayes (2007) highlight many of the issues involved.

- The problems identified in the literature were mainly that despite the sophisticated analysis of stitching materials using electronic adjustments of sewing machines, most adjustments are still performed by hand by highly skilled sewing machine engineers;
- Gaps in the literature have been identified on stitching materials particularly shirting materials;

It has been difficult when conducting this review of literature to identify recent work on stitching shirting fabrics. Recent work goes back to 2005 when Namailal et al. (2005) publishes a paper on a study of sewability parameters of different shirting fabrics.

The article provides information on a study which measured the sewability of shirting fabrics of different qualities on the basis of selected basic parameters of cuts and sewn type of garments which are seam puckering, seam efficiency and slippage. Several literature studies which tested sewability of shirting fabrics was considered by this research. The materials and methods used in the study are presented. The article then discusses the findings of the study. The study suggests that seam efficiency decreases with the increase in fabric strength and important factors of seam efficiency include flexural rigidity, areal density and fabric thickness. Another finding suggests that in the case of seam puckering, more or less a reverse trend is observed.

Research by Cheng et al. (1996) used objective measurement of mechanical properties for shirting fabrics. Based on the mechanical parameters, the production and control of some manufacturing problems, such as spreading, cutting, overfeed operation, handling, pressing, and appearance, results in high quality and efficient shirt manufacturing. Shirting fabrics with extensibility less than 1.84 percent tended to cause problems during seam overfeeding. Extensibility greater than 2.53 percent in the warp and/or 4.07 percent in the weft resulted in fabric stretching during spreading and sewing. Fabrics with very high bending rigidity resulted in cutting, sewing, and handling problems. Warp formability was more important than weft formability in shirting manufacturing. Researchers also examined the influence of shear rigidity, relaxation shrinkage, and hygral expansion on shirting manufacturing.

Many researchers have undertaken the difficult task of investigating, identifying and quantifying the vast array of fabric and garment sew-ability problems associated with the makeup of garments. Much of this work has focused only on sophisticated, objective methods of assessment. It has also been discussed that much of this work has concentrated on a relatively limited number of adjustments to a sewing machine as you are limited by what you can achieve by using attachments and devices.

2.15. Identification of research methods used for this study

Choosing the appropriate research methods for this study was an essential process in order to understand and develop the experimental design for this work. Various methods have been developed and introduced to measure the degree of research and its accuracy and competence. Previous studies have based their criteria for selection on the area / topic of research they are doing; which could include socio-economic factors to science based problem solving.

For the purpose of this work, several research methods were considered in order to provide a thorough and systematic methodology. It was important therefore to give a clear and precise account of these approaches with an explanation for choosing the particular techniques.

Research can be applied in many different ways and for the purposes of this study, it was considered appropriate that several different strategies were used in order to fulfil the aims as set out in this work. These are given below:

2.16. Qualitative Analysis

Qualitative methods offer an effective way of describing a population without attempting to quantifiably measure the variables or look to potential relationships between the variables. However it is viewed as being more restrictive in testing a hypothesis because it can be expensive and time consuming (Creswell, 2008).

This method was used to collect the data from the experts on the analysis of the fabrics for sew-ability. The design of a questionnaire was used for this purpose and was based upon a simple method of ticking boxes in ranking the fabrics for sewability. An assessment was made on the human behaviour of the experts and the reasons for that behaviour.

2.17. Quantitative Analysis

Quantitative research is a systematic and empirical investigation of properties, phenomenon and their relationships. It is the collection of numerical data for analysis using statistical and mathematical methods. Statistics derived from quantitative research can be used to establish the existence of associative or casual relationships between variables (Creswell, 2008).

A quantitative approach was employed where numerical data was taken from test instruments and an assessable process undertaken to summarise and compare the information. It was considered that quantitative measures would usefully supplement and extend the statistical methods described in chapter eight.

2.18. Applied research

Applied research refers to a scientific study and research that seeks to solve practical problems (Nills, 2009). Applied research is used to find solutions to everyday glitches, and develop innovative technologies. The applied research method is one of the more practical ways of looking to solve specific issues and difficulties. This approach has a number of attractive features that make it suitable for this study (Bickman and Rog, 2008). These are:

- Stage I of the research process starts with the researcher's development of an understanding of the relevant problem;
- Stage II—developing the research design and plan. This phase involves several decisions and assessments, including selecting a design and proposed data collection strategies;
- Assessing the feasibility of conducting the study within the requisite time frame and with available resources involves analysing a series of situations in the type of design that can be employed;

Every study, whether explicitly or implicitly, is based on a conceptual framework or model that specifies the variables of interest and the expected relationships between them (Bickman and Rog, 2008). In evaluation research, logic models have increased in popularity as mechanisms for outlining and refining the focus of a study (Frechtling, 2007; McLaughlin and Jordan, 2004; Rog, 1994; Rog & Huebner, 1992).

All of the above methods were adapted in order to achieve the research question and satisfy the aims and objectives of this study. The author of this work has also relied for many years on industrial experience, problem solving and trouble shooting.

There is an existing term in industry known as fire-fighting. This term is used to describe situations that occur where a situation is unplanned requiring spontaneous action to solve the problem. Such a problem may involve several machines going down with seam pucker a major cause of machine downtime. This requires immediate and sometimes creative action to resolve the situation. One important method that was used, is an ability known as lateral thinking. This was a major and very important part of this project. A full description is given below:

2.19. Lateral Thinking

Lateral thinking is a means of solving problems through an indirect and creative approach using reasoning that is not immediately obvious and involving ideas that may not be obtainable by using only step by step logic. The term was invented in 1967 by Edward de Bono.

When a problem in manufacturing occurs, the performance of the production line can be affected significantly. Problem solving deals with finding out what caused this problem and then developing ways to fix it quickly and efficiently. The objective is to go back to the situation that was before, in this case, a fully functioning production line. The emphasis in production is one of urgency, ‘wanting things done yesterday’, another common phrase used in industry. Using creative problem solving, one must first solve the problem in an indirect and unconventional manner.

A scenario of lateral thinking in respect of the seam pucker question is given as follows:

A production line is being set up to manufacture high quality ladies skirts and a problem has been encountered in stitching the pleats on the front panel of the garment. The problem is seam pucker and all the machines, ten in total doing the same production operation are exhibiting the same problem. The question is how can this problem be resolved quickly and with minimum disruption to production?

The problem presented here is not uncommon in the clothing industry and where textile materials are concerned, another well coined phrase in the industry is 'The impossible we can do but miracles can take a little longer'!

2.10: Discussion summary

Chapter two has discussed the academic and industrial literature on the complexities and variable factors involved when stitching textile materials.

Chapter three discusses the machine base settings for setting up the sewing machine for stitching materials. This links closely to the literature and provides information not readily available in academic institutions.

Chapter 3 BASE MACHINE SETTINGS

3.1. Overview of the chapter

This chapter gives an overview of the sewing machine settings from basic adjustments to more advanced settings.

Much research has focused only on sophisticated, objective methods for the automation of sewing machine settings for seam sew-ability. These settings have been limited to a small number of basic machine adjustments.

However many adjustments can only be performed by hand (Needles Eye, 1996). The use of gauges is necessary to ensure proper adjustment and optimisation of the machine settings. Improper settings can result in sewing problems including poor stitch formation, seam deformation and a general decline in machine performance and seam sew-ability.

The machine settings used for this experimental work were set by hand by a fully qualified sewing machine engineer with thirty seven years of experience in this field. The machine adjustments used offered the optimum adjustments necessary for the sew-ability of this type of fabric. It was essential therefore, to give a proper account of the settings and adjustments for optimum stitching performance.

3.2. Machine Type

The machine used for the research was a Juki flatbed; drop feed, stitch type 301 (single needle lockstitch, figure 3.1). The lockstitch was selected because the formation of the stitches within the material causes the yarns inside the fabric to be displaced. This phenomenon of displacement often causes seam pucker, a gathering of the material to produce an uneven, crinkled or distorted seam. Examples of the stitching process are given later in this chapter.

Figure 3.1: Juki Single Needle Lockstitch

3.3. Machine Stitching Parameters and Components

Optimum settings are the settings that give the best possible settings on the machine for the fabric to be sewn. These settings are given below:

3.4. Optimum Presser foot Force

The presser foot force should be reduced as much as possible in order to provide an absolute minimum pressure for the fabric to allow for correct feeding of the material without fabric ply slippage. A presser foot adjustment screw located on the top of the machine head adjusts this setting. The pressure of the presser foot for the research was measured using the COATS presser foot measurement device. Once the required pressure was established, a measurement of the presser foot adjusting screw was obtained using a standard measurement rule. An example of this is given in figures 3.2 and 3.3.

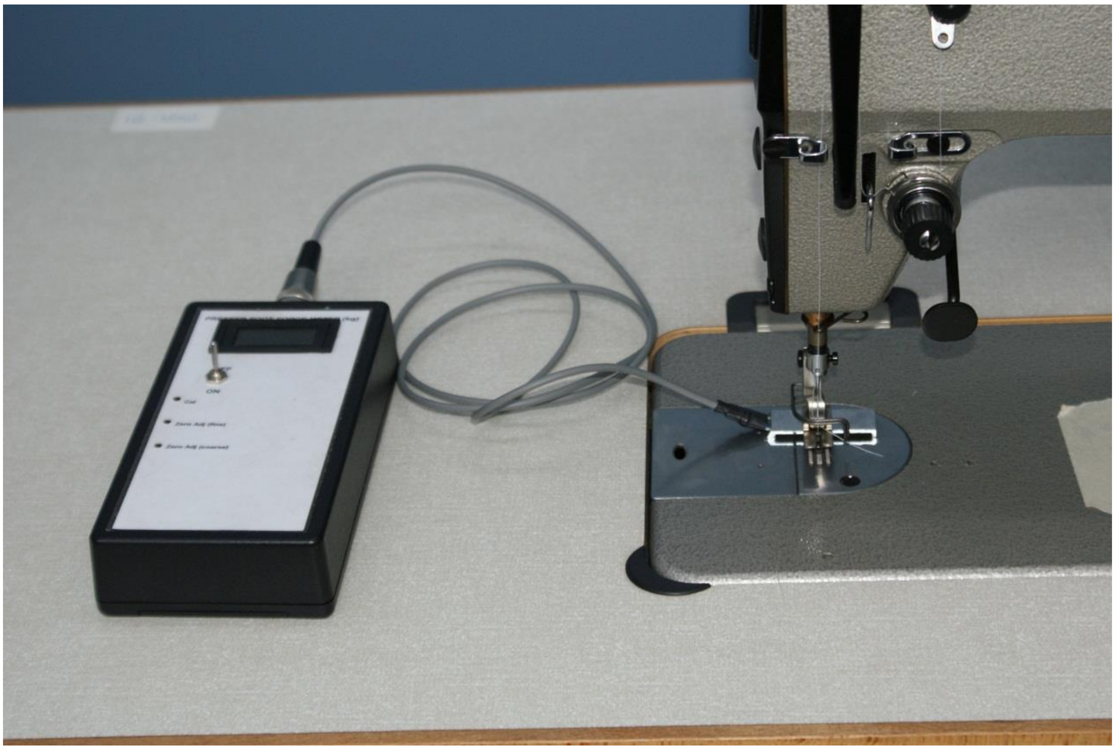

Figure 3.2: Presser foot force measurement gauge

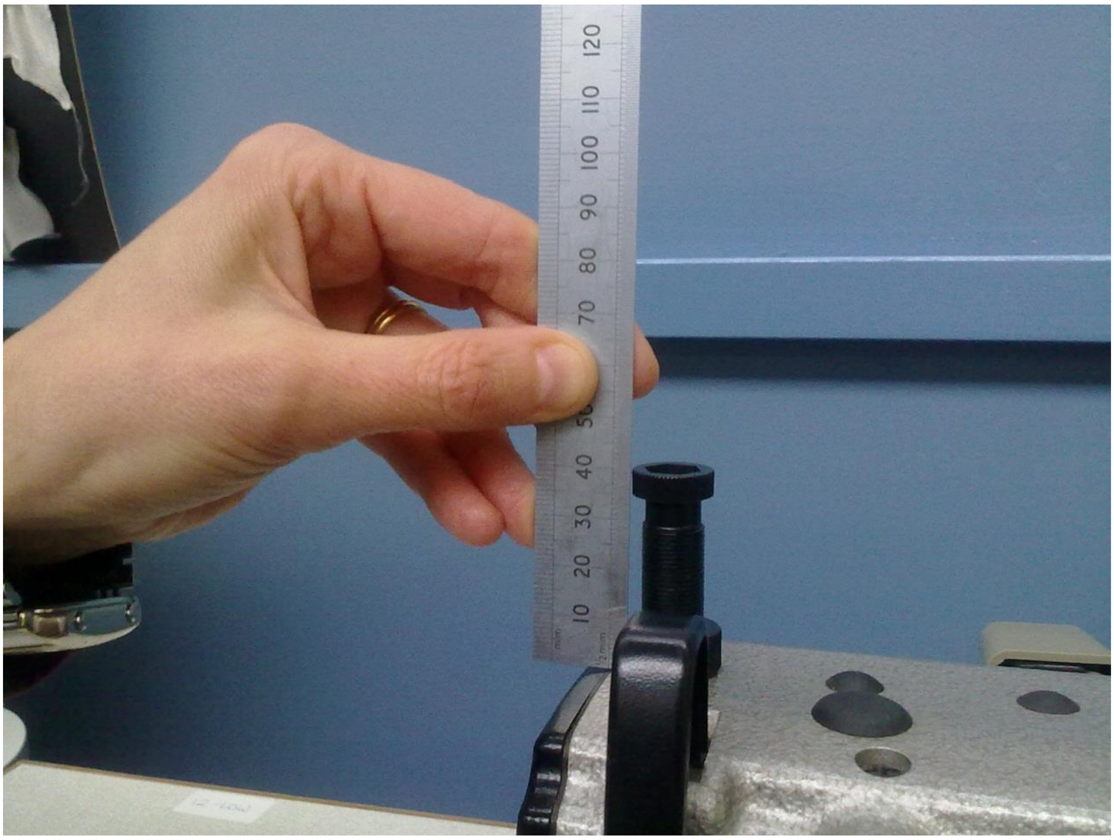

Figure 3.3: Presser foot force measurement adjustment screw

3.5. Optimum Thread Tension setting

The thread tensions should be adjusted to be as slack as possible in order to produce a well-balanced stitch. The thread tension of the static (top thread tension) has the highest set tension and the spool tension is adjusted to be in harmony with the top thread tension. The device used to measure these tensions is the COATS thread tension metering device. An example of this is given in figure 3.4.

Figure 3.4: COATS thread tension metering device

3.6. Behind the faceplate

The components inside the faceplate are key elements in the stitching of the material. These elements are given in figure 3.5. The optimum sewing performance is determined by the harmonious interaction between these components. The advanced machine adjustments are much more complex and require the skill and knowledge of an expert as described above. Modern sewing machines are high-speed precision equipment capable of speeds in excess of 10,000 rpm (Revs per minute) for chain stitch machines and between 5,000 – 6,000 rpm for lockstitch. In order for the lockstitch to produce one stitch, the sewing mechanism must revolve twice; therefore if the top shaft of the machine is turning at 5,000 rpm, the actual sewing mechanism is revolving at 10,000 rpm giving a ratio of 2:1.

3.7. The tension unit

This element is a vital part of the sewing machine as it controls the forming of the stitch. This device is adjusted in accordance with the type of material to be sewn utilising the knowledge and advice from the experts. The settings of this component are described later in this chapter. The device is illustrated in figure 3.6.

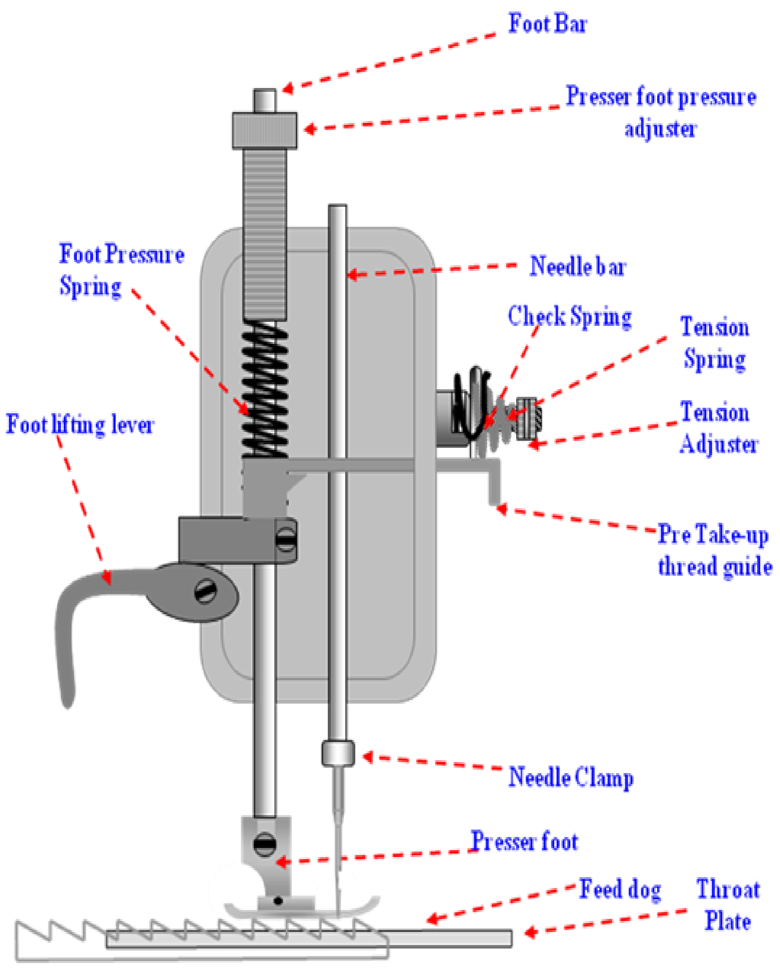

Figure 3.5: Key elements of faceplate components

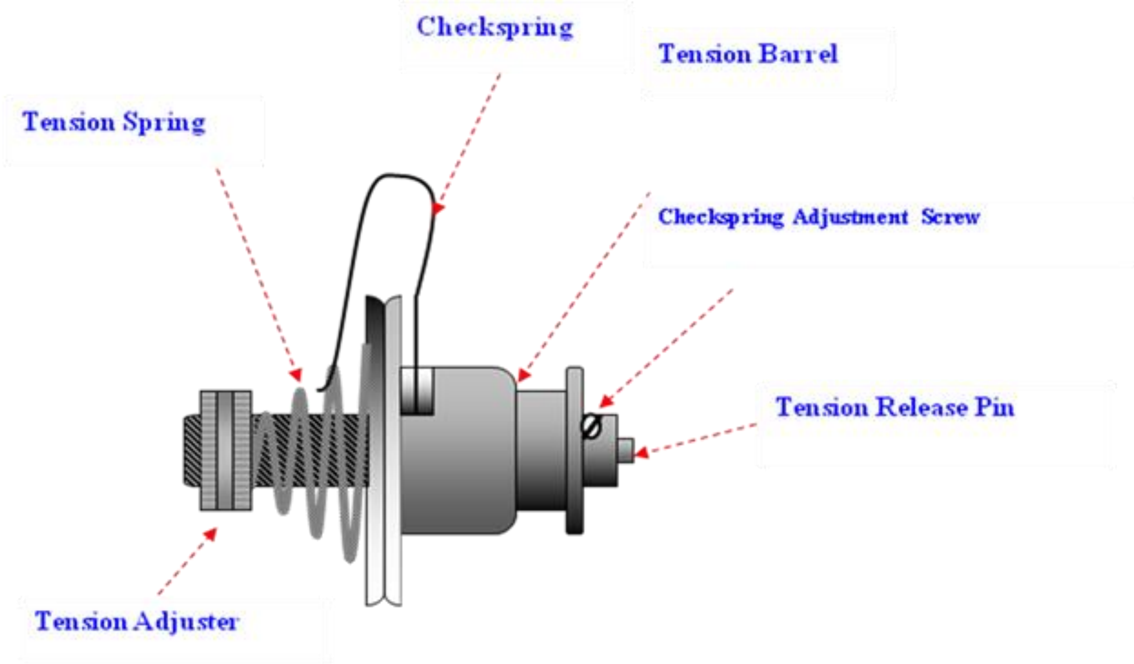

Figure 3.6: The tension unit

3.8. Feeding mechanism / feed dog

The feeding mechanism commonly described as the feed dog, is normally set at one full tooth above the throat plate but there are other adjustments that can be made to the feed dependent upon the material to be sewn and the operation on the area of the garment.

The tilting of the feed for example (figure 3.7) is an adjustment that can have a dramatic impact on how the fabric performs through the machine. There are varied and important reasons for adjusting this setting. One can be when attaching a rigid material to a stretchy material. The difference in the extensibility of the two materials between the presser foot and the feeder causes a deformation of the material on the fabric with the greater extensibility thus causing feed pucker. A typical area of an area on a garment can be when attaching a zip into a trouser where the zip being usually a rigid component and trousers being of a more extensible nature (figures 3.8 – 3.11).

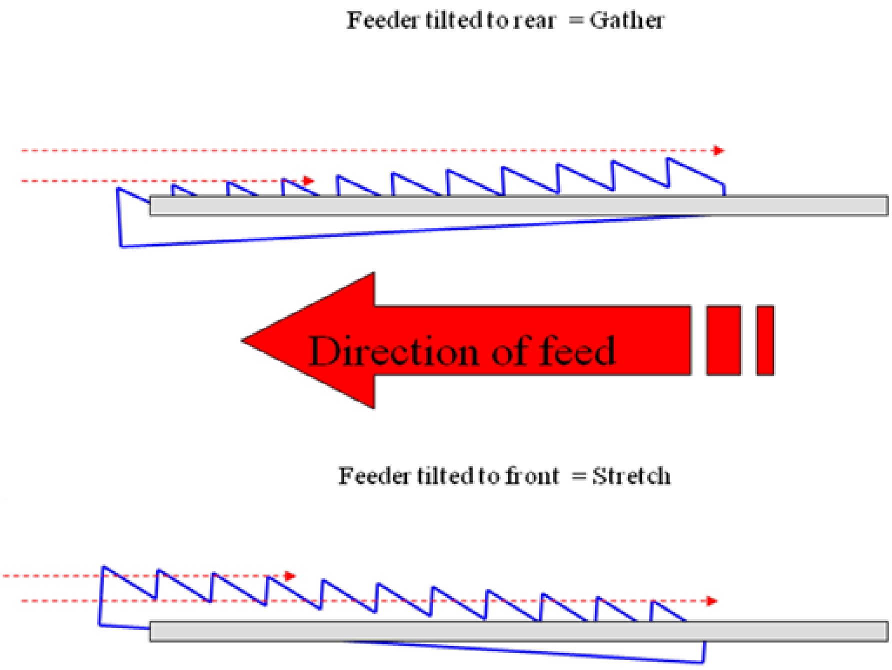

Figure 3.7: Feed tilted to gather and feed tilted to stretch

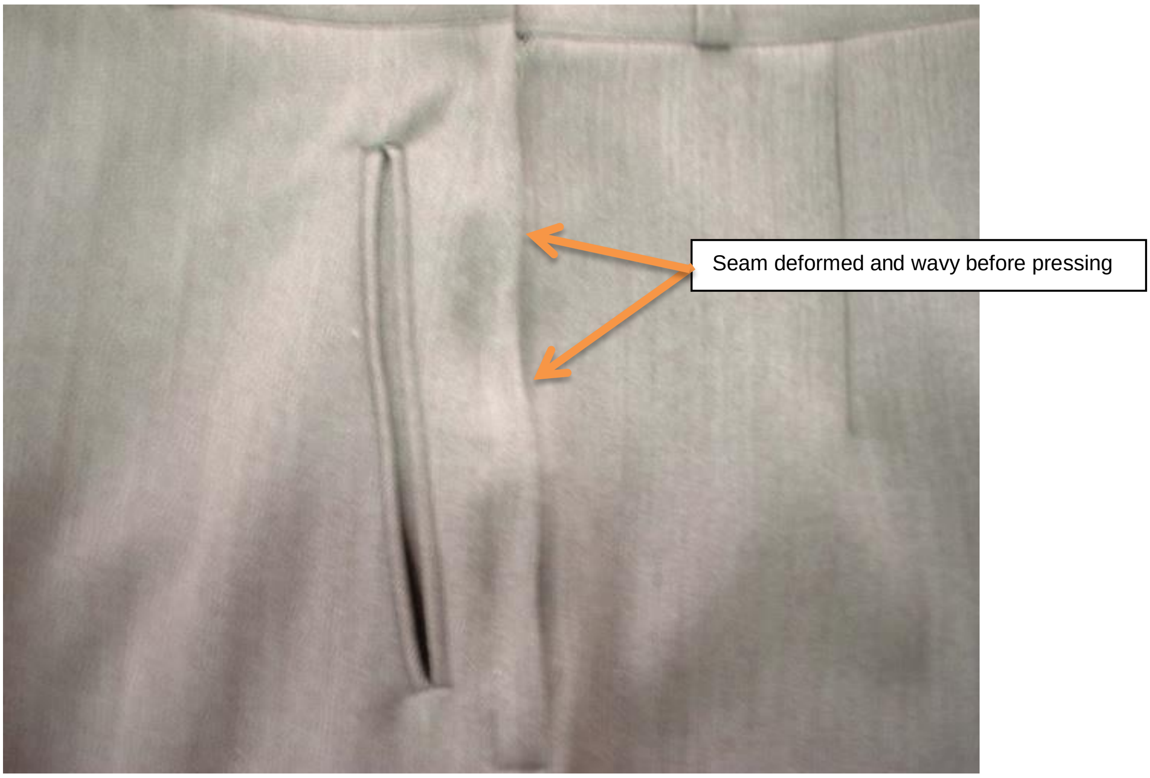

Figure 3.8: Feed pucker in the zip before feed tilt adjustment

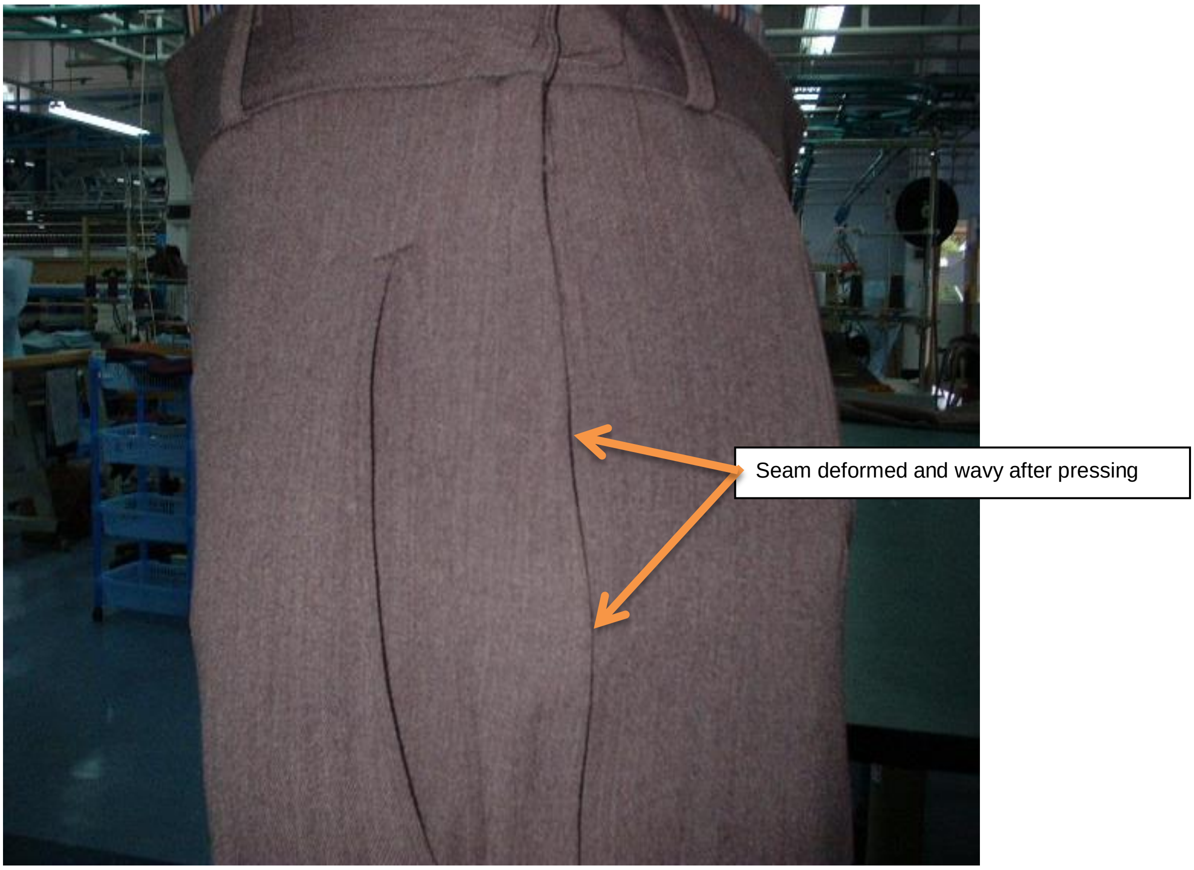

Figure 3.9: Feed pucker on the zip after pressing

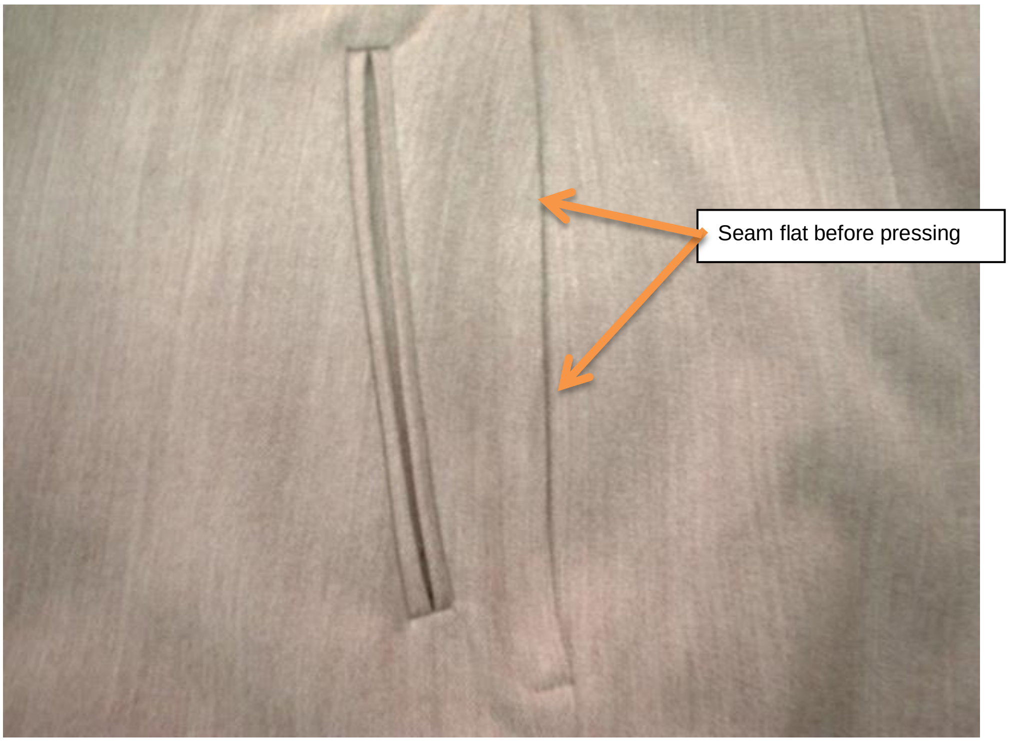

Figure 3.10: Feed pucker reduced by feed tilt

Figure 3.11: Finished garment on the zip after pressing

3.9. Optimum Type and height of the feed dog

The metal feed dog used was a fine-toothed feeder with all the teeth showing above the throat plate when the feeder is at its highest position. This is a feeder especially developed for sewing fine, lightweight fabrics. The height of the feed dog was set in such a way that only the actual teeth were exposed above the stitching plate (Figure 3.12).

3.10. Feed Timing

The correct adjustment of the feed timing is crucial in order to provide the smooth feeding of the material and this has a direct impact upon the formation of the stitch.

Fabric feeding can be a major cause of seam deformation. Kennon and Hayes (2000) investigated the fabric feed timing on a lockstitch sewing machine and concluded that by retarding the feed timing by 25 degrees, the tension in the stitch formation was reduced therefore reducing the effect of seam pucker on the fabric.

Lockstitch machines can employ different feed systems depending on the types of fabric and the sewing operation on the product. The correct timing for the feeder on the drop feed lockstitch machine is when the point of the needle is just about to enter the throat plate hole, the teeth of the feed should be level with the top of the throat plate. An example of the feeding timing setting is given in figure 3.12 and the adjustment for the feed timing is shown in 3.13.

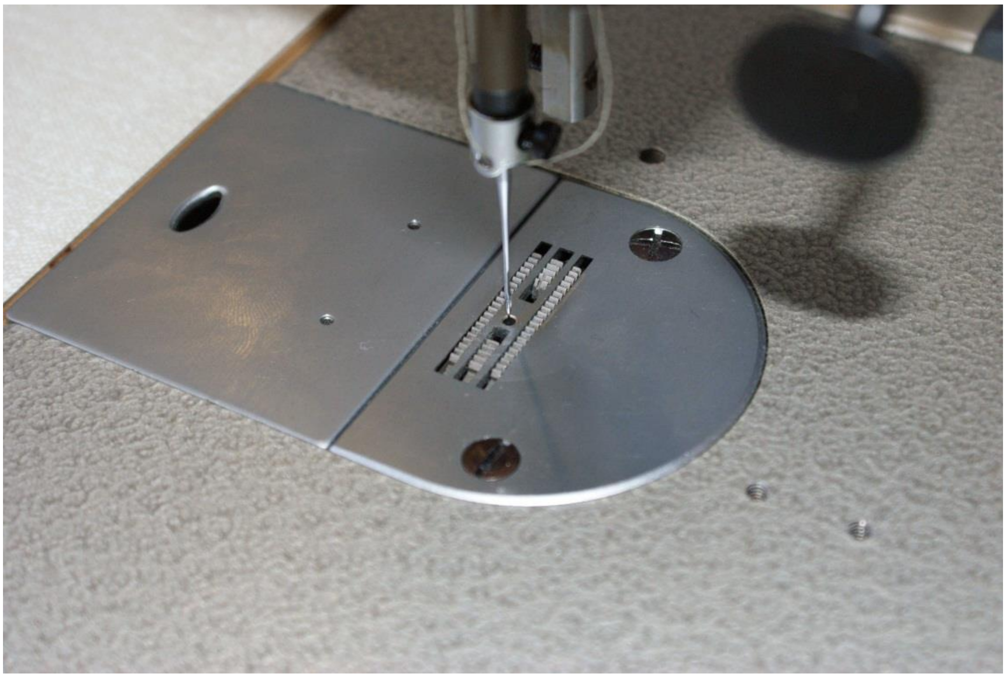

Figure 3.12: Feed timing setting

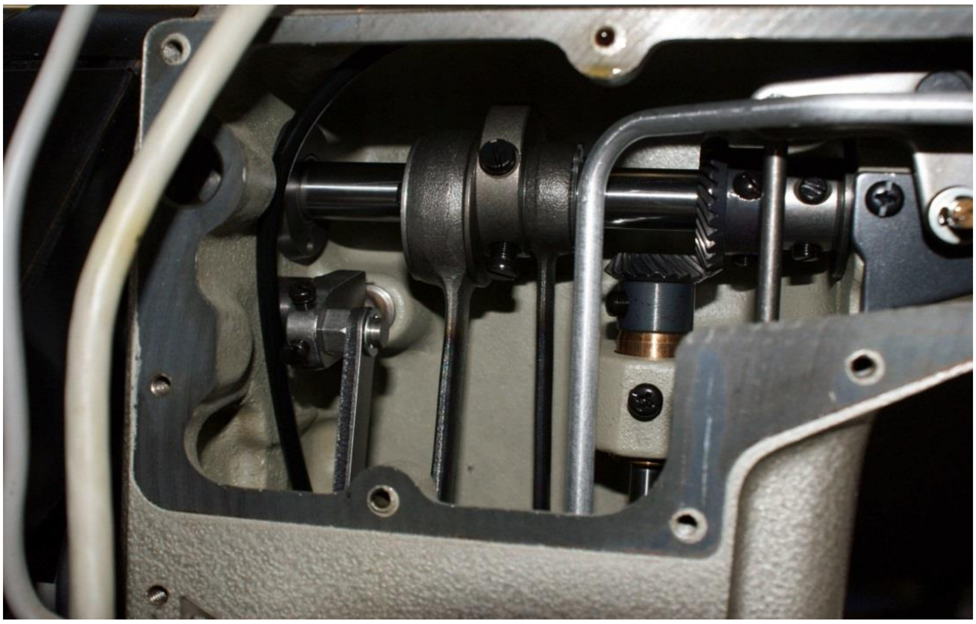

Figure 3.13: Feed-timing adjustment on an eccentric inside the machine

3.11. The floating presser foot

One setting that is little known about is the floating of the presser foot usually done in exceptional circumstances if all other settings have failed to produce the desired quality. The presser foot (figure 3.14) is adjusted to leave a small gap between the presser food and throat plate when the feed dog is at its lowest position. The space between the gap can vary depending upon the thickness and composition of the material.

The reasons for performing this adjustment is that the surface of the presser foot skims the surface of the material enabling less pressure on the material whilst still maintaining adequate pressure to feed the fabric. The frictional forces on the fabric are also reduced. It is a very delicate adjustment and should only be performed by a highly skilled engineer.

3.12. Machine timing and setting

The machine timings have to be set correctly in order for the machine to sew correctly and consistently and for good quality to be maintained.

The hook point is the part that picks up the sewing thread from the needle and it is a highly precision part of the sewing machine revolving at speeds in excess of 10,000 rpm. An example of this component is given in figure 3.15.

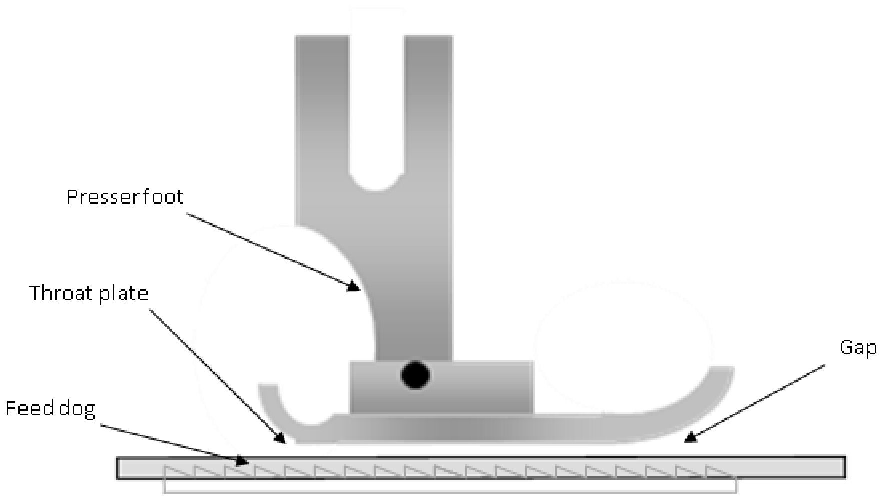

Figure 3.14: Gap between the bottom of the presser foot and throat plate

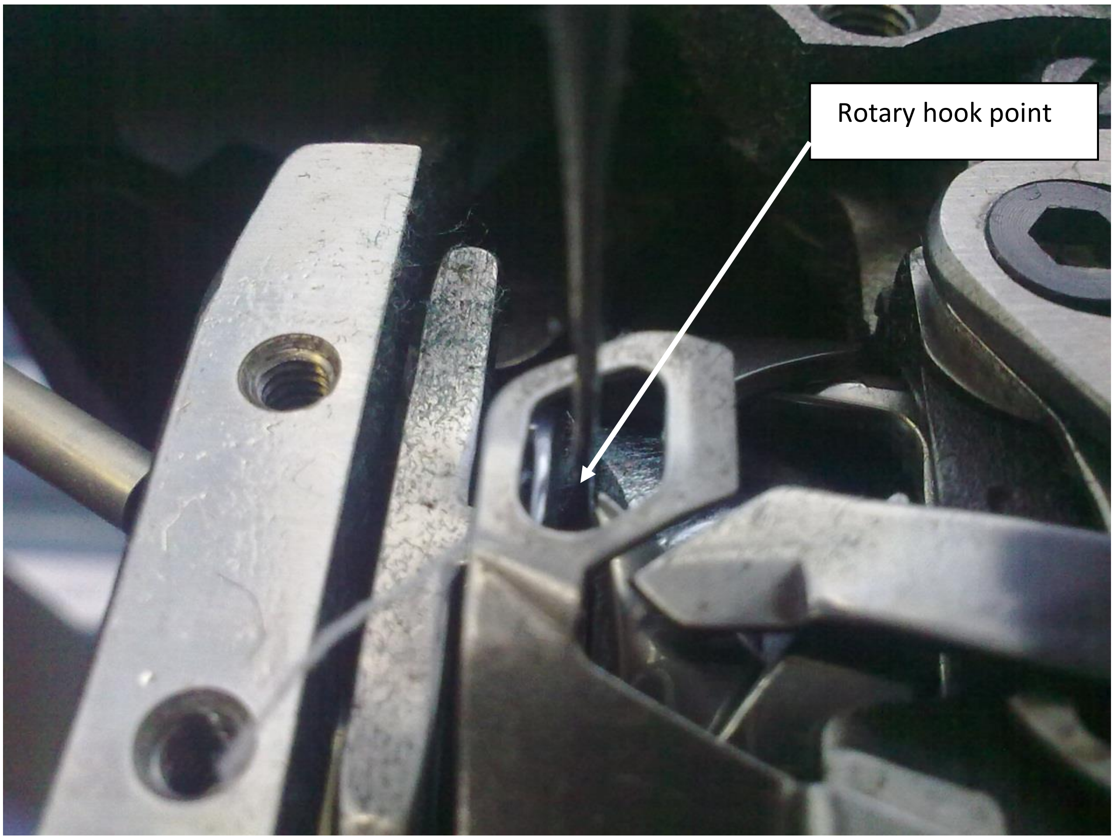

Figure 3.15: Example of rotary hook point on the machine

3.13. Advanced Machine Settings

Advanced sewing machine settings consist of settings that can only be made by hand either by using gauges or a subjective estimation by the engineer making the adjustment on the machine. Examples of these alterations are given below.

3.14. Adjustment of the Check Spring

The check spring is a very important part of the sewing machine and plays a fundamental role in stitch formation. This adjustment needs to be made under sewing conditions with fabric under the machine. The most common setting of the check spring is to set it so that the spring is between the hours of ten to and quarter to on a 24-hour clock (figure 3.16).

The check spring setting has a direct relationship with the sewing mechanism and must be set as follows:

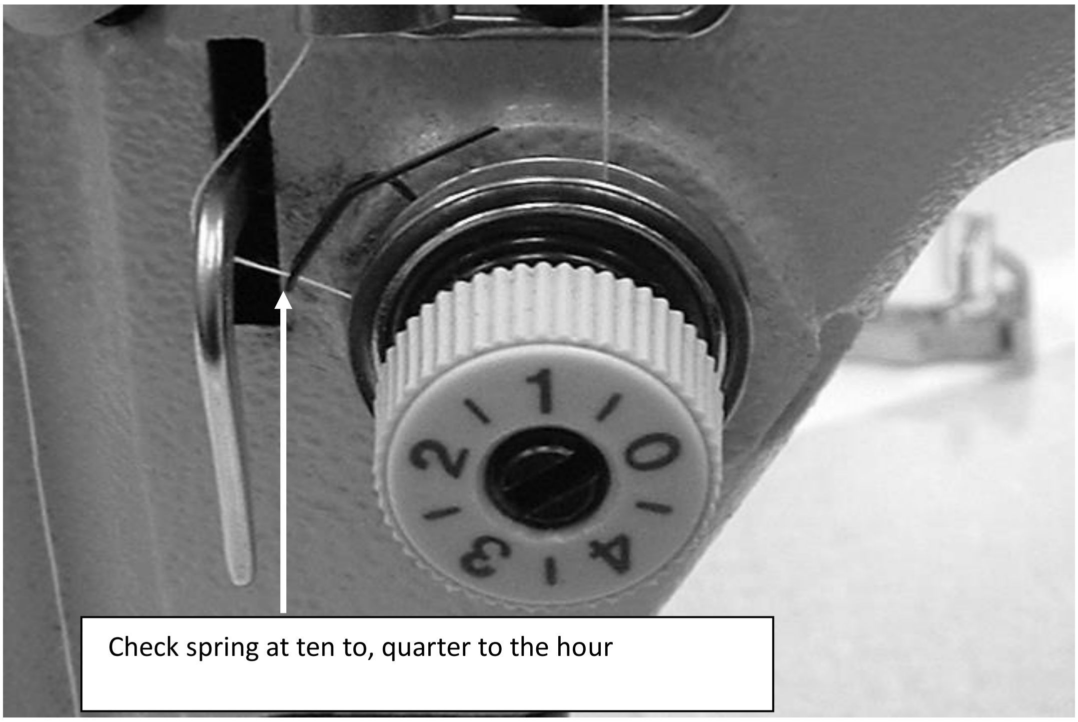

Figure 3.16: Check spring set between ten and quarter to the hour

- **Correct Setting: -** When the sewing mechanism has transported the sewing thread around the hook and down to the six o'clock position (figure 3.17), the check spring should wink or move from its stop position.

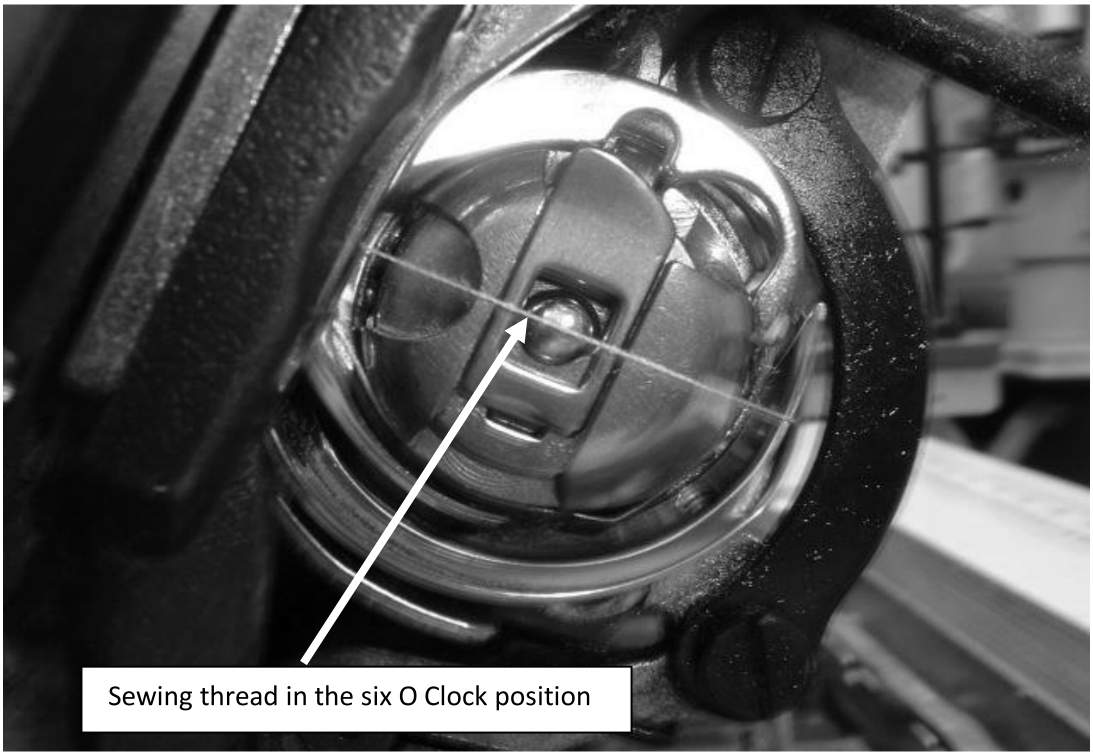

Figure 3.17: Sewing thread in the six O-Clock

When the sewing mechanism picks up the sewing thread; the thread is transported down and around the hook and base to form the stitch. At some point of its formation, the thread reaches what is termed its six o'clock position and at this position is subjected to the highest amount of strain. It is at this point that the thread needs as much support as possible. Therefore, the main function of the check spring is to provide a means of reducing the strain of the sewing thread at critical points of sewing. The example of this is given in figure 3.18.

If the setting is incorrect, loosen screw and turn the entire tension assembly until this condition is obtained. It may be necessary to sew a few inches between adjustments to get an accurate setting. More information on the check spring and its setting for the methodology is given in chapter 6.

Figure 3.18: Check spring (2) should wink (move) when thread is at the Six O -Clock position

The lockstitch (type 301) is the commonest of all the stitch types of all the machines used in the clothing industry. It is often referred to as a double lockstitch due to the way it locks together inside the material. This stitch type is formed by the interlacing of a needle thread supply with the bobbin thread supply underneath the machine bed. These stitches are very secure, as a break in one stitch will not cause the seam to completely unravel although it will compromise the overall seam performance. Figures 3.19 to 3.24 demonstrate the formation of the single needle lockstitch:

3.15. Examples of acceptable and none acceptable stitch formation

As previously mentioned, the top thread tension and bobbin tension on a lockstitch machine should be set as slack as possible in order to form a good quality stitch. The bobbin thread should be wound with a low tension to enable the thread to be interlaced more easily with the top tension thread into the centre of the fabric. The definitions of acceptable and unacceptable stitch qualities are given in figures 3.25 – 3.27.

3.16. Optimum Needle Point and Size

The needlepoint is the most important component of the sewing machine due to the fact it is the carrier and deliverer of the sewing thread to the sewing mechanism. If it is not changed regularly it can be responsible for major quality problems. It is also subject to the most abuse of all the machine parts as it penetrates the material at speeds of five to six thousand times per minute for Lockstitch and eight to ten thousand times per minute in chain-stitches. The friction caused by the penetration of the needle into the fabric causes extreme needle heating with temperatures in excess of 250^{o} C (Schmetz, 2000).

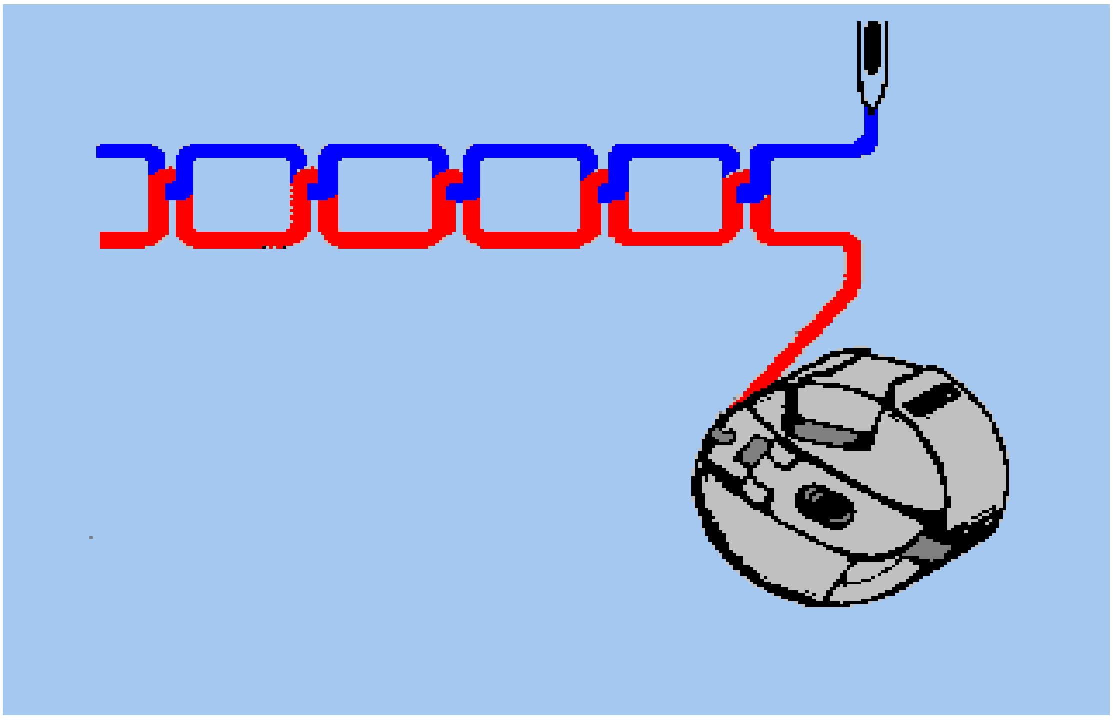

Figure 3.19: Operation 1 - Ready to form the stitch

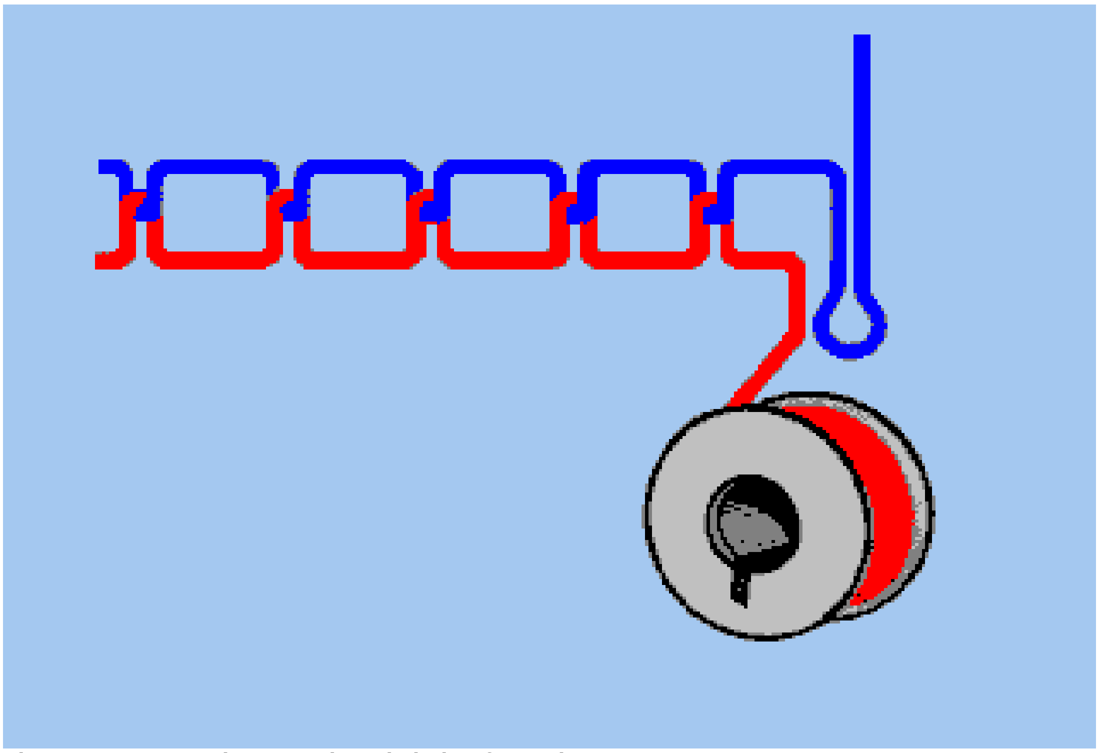

Figure 3.20: Operation 2 – A loop is being formed

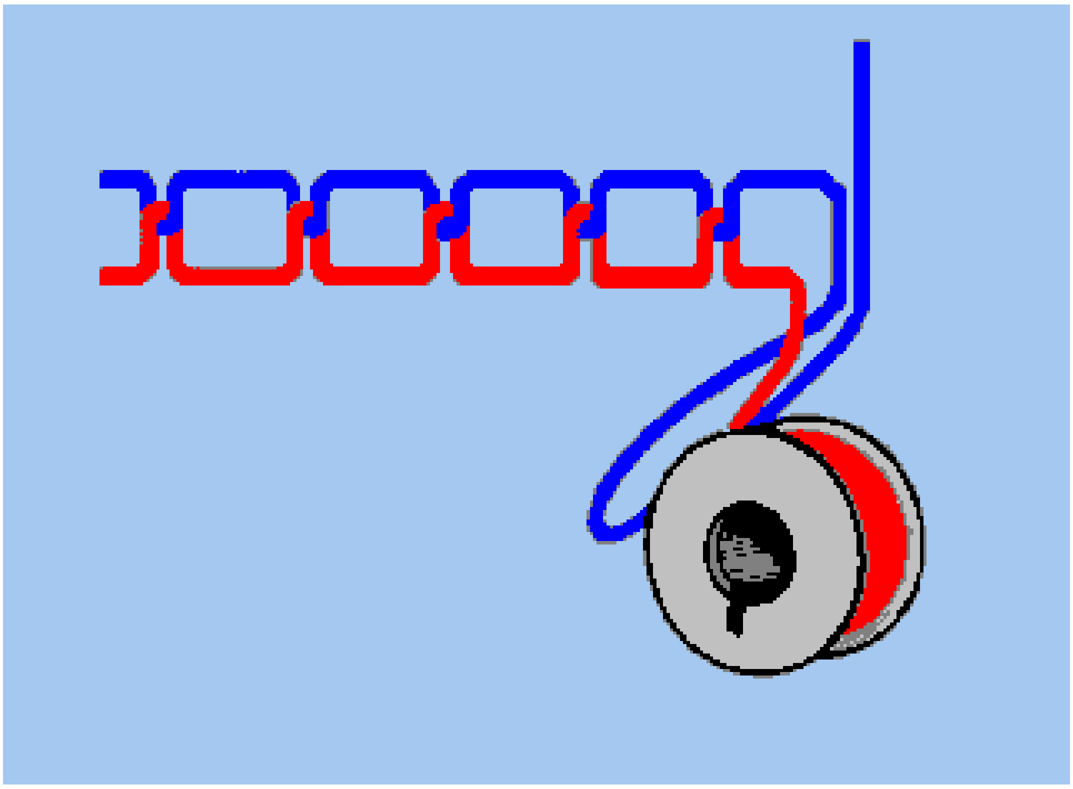

Figure 3.21: Operation 3 – Thread is picked up by the sewing hook

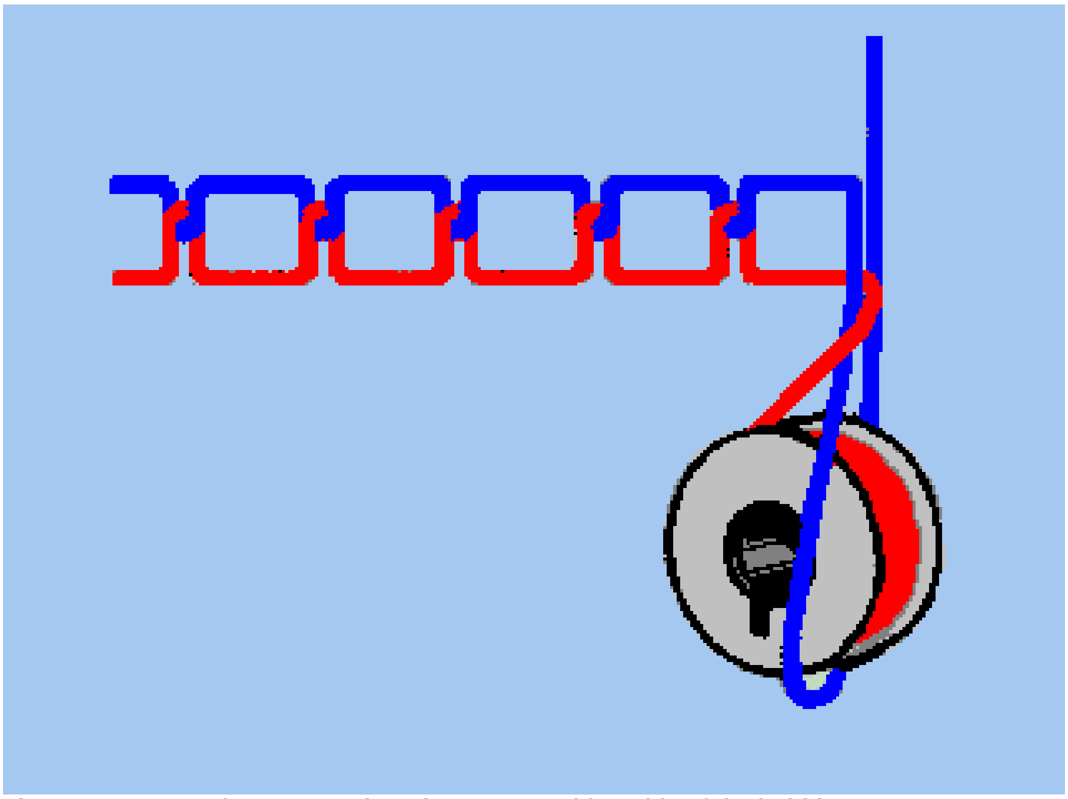

Figure 3.22: Operation 4 – Top thread passes on either side of the bobbin

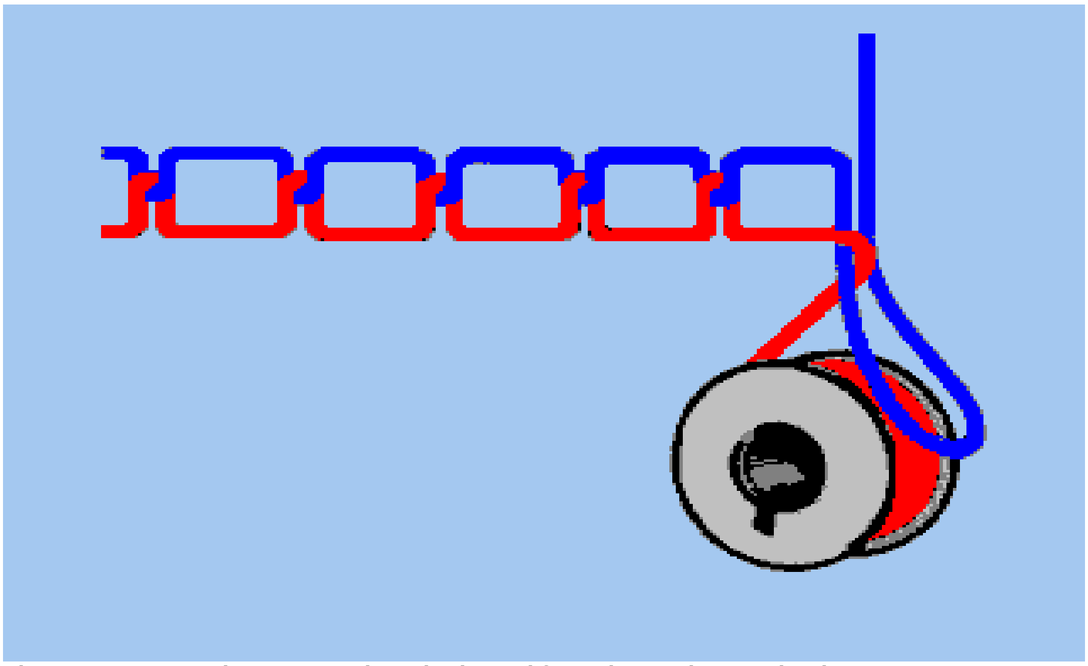

Figure 3.23: Operation 5 – Top thread released from the sewing mechanism

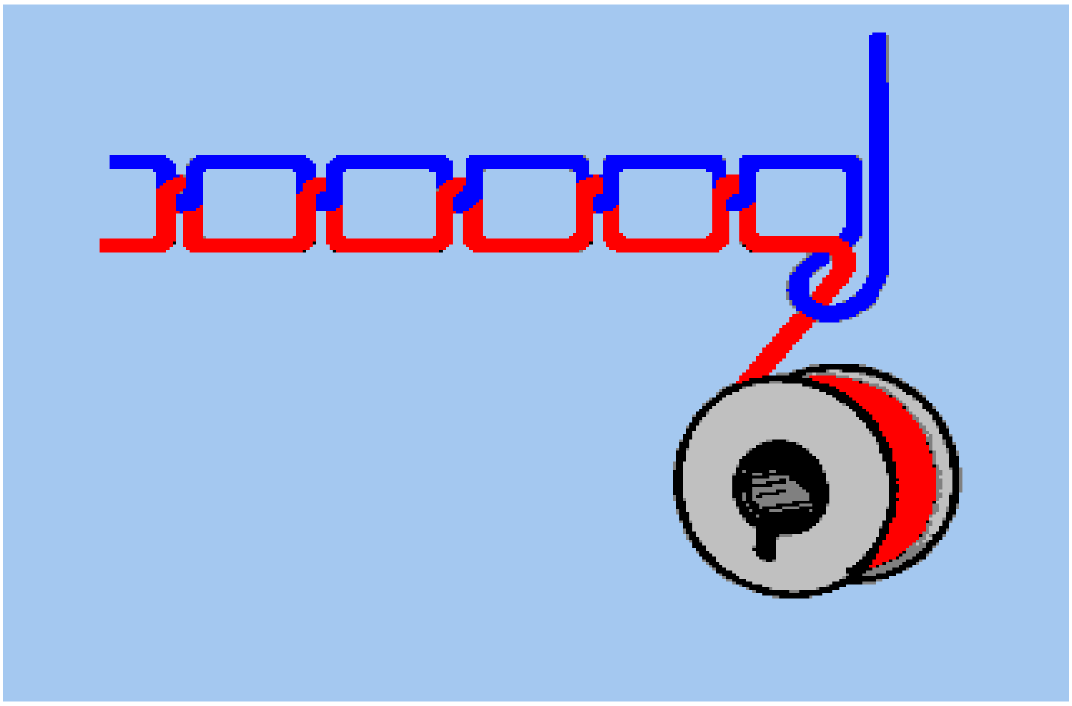

Figure 3.24: - Operation 6 – Top thread by take-up into the centre of the fabric

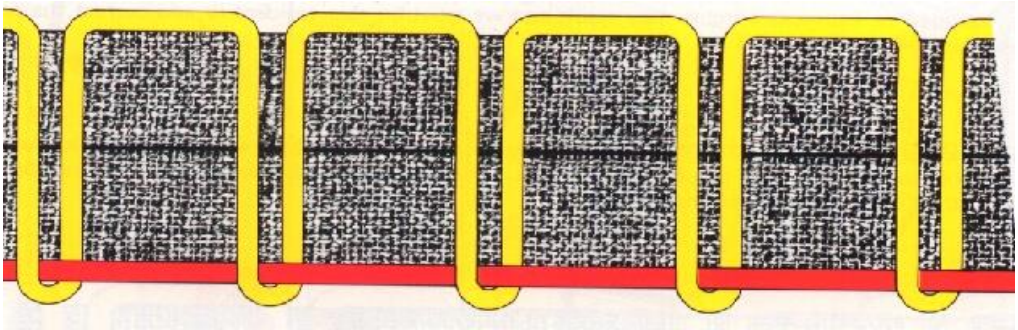

Figure 3.25: Stitch slack underneath caused by top thread tension too slack and bobbin thread tension too tight.

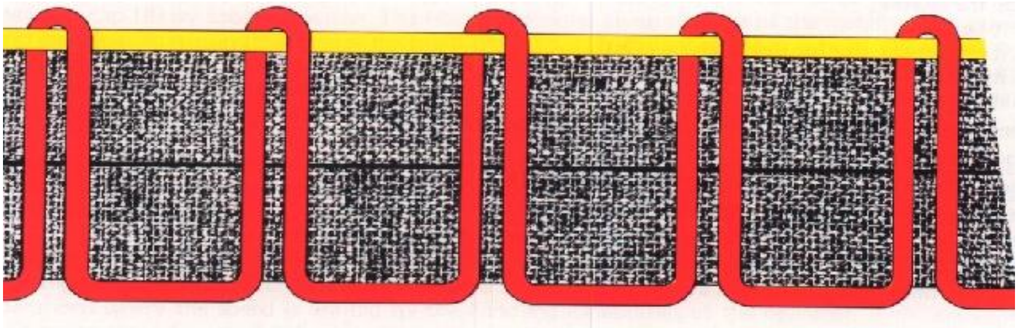

Figure 3.26: Stitch slack on top caused by the bobbin tension too slack and the top thread tension too tight.

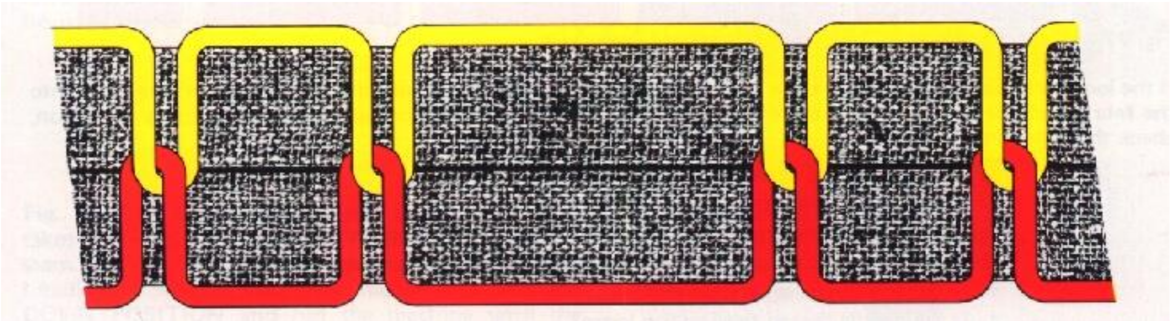

Figure 3.27: Stitch formed correctly with both threads interlaced in the centre of the material.

The Factors considered when choosing the needle were:

- Fabric Type
- Fabric Density
- Fabric Composition
- The Type of Machine
- The Type of Sewing Thread
- Fabric Thickness

The needle chosen was a Schmetz size 80 (0.8 mm) acute round point needle (SPI). This type of point was chosen because the steeper point helps to minimise the surface area of penetration causing less displacement of the yarns in the fabric. This type of needlepoint is commonly used on fine fabrics where yarn displacement is more acute. An example of this needlepoint can be seen in figure 3.28 compared to a normal round point in figure 3.29.

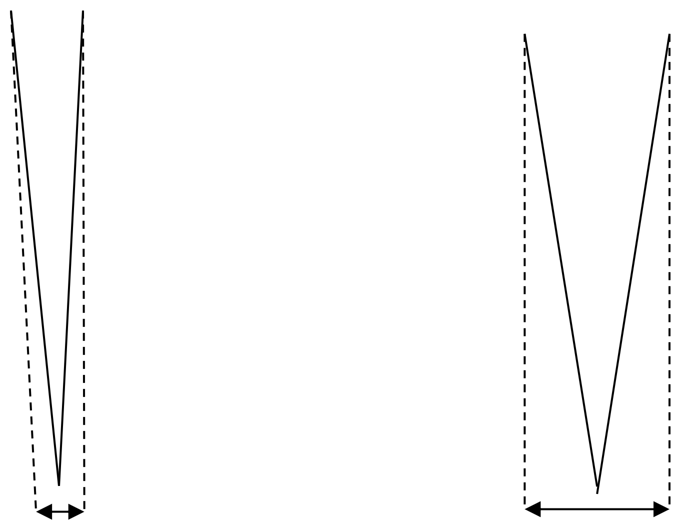

Figure 3.28: Example of acute RP (left)

Figure 3.29: Example of normal RP (right)

The most important aspect of needle design is the needle-point because it has to penetrate the fabric minimising the damage to the material. It is also most diverse part of the needle due to the many different type of points used. These needle-points are designed for sewing on many different fabric types and Seams. An Example of needlepoint designs and the component parts of the needle can be seen in figure 3.30 below.

A smaller diameter needle reduces the mechanical forces exerted on the yarns. Needle diameters can range in thickness from size 50’s (0.50 mm) in excess of 150’s (1.50 mm).

The component parts of the needle are:

- Butt
- Shank
- Shoulder

- Blade
- Long Groove
- Short Groove
- Needle Eye
- Scarf
- Needle Point
- Needle Tip

When fabrics are stitched together, the impact from the needle as it penetrates the fabric can cause buckling and distortion on the yarns and the fibres. The mechanical strain on the yarns increases if the needle is damaged (Figure 3.31) thereby causing the fibres to rupture thus reducing the seam strength significantly. The following factors need to be taken into account in order to help avoid this problem.

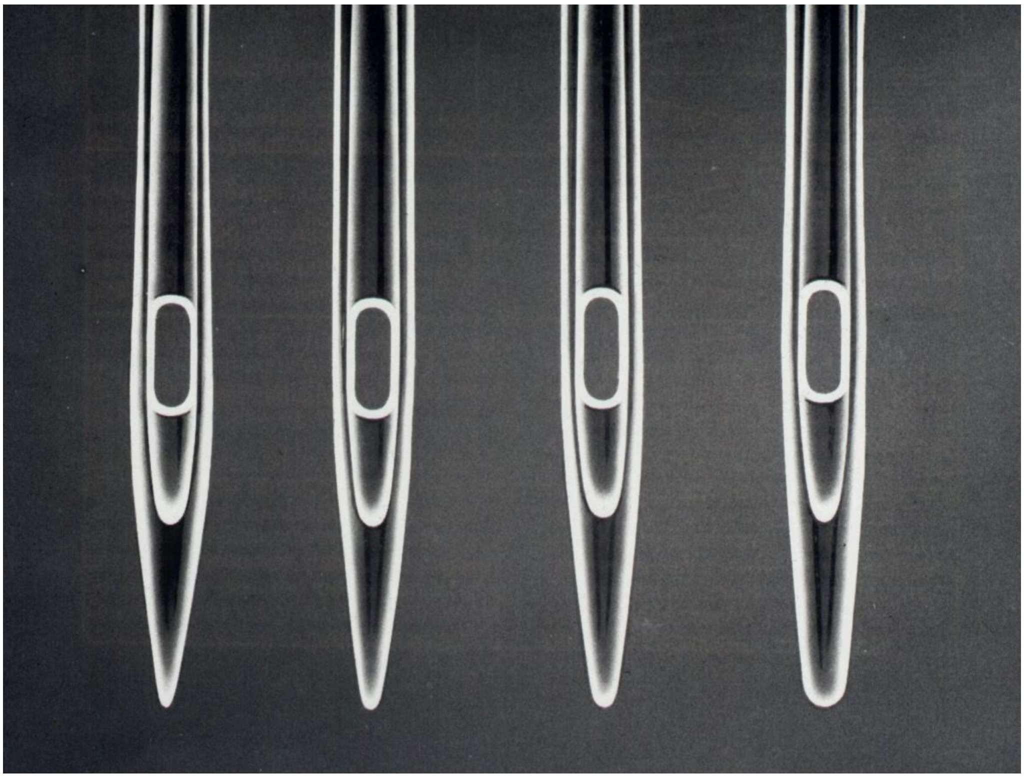

Figure 3.30: Examples of Needlepoint Types, from right to left, acute round point, round point, light ballpoint, heavy ballpoint.

- Use a needle with a smaller diameter for the fabric and seam being sewn;
- Adapt the opening of the sewing plate to fit the needle size;
- Use a sewing thread with the correct diameter for the needle eye;

- Use the correct needle point for the type of fabric you are sewing;
- Consider whether the type of seam that you are using to construct the garment could be changed or use multiple seaming in order to divide the strain;
- Some needle types have a short groove that runs from the scarf of the needle up to the shoulder.
- The grooves, which are channelled into the blade, are designed as a protective channel for the sewing thread.
- The shank is what fits into the needle bar of the machine.
- The point and the tip are the first point of contact with the fabric.
- The needle eye is threaded with the sewing thread.
- The scarf is the flattened part of the needle so designed to enable the sewing mechanism (in the case of a lockstitch, the sewing hook) to pick up a loop of the sewing thread and thus form a stitch.

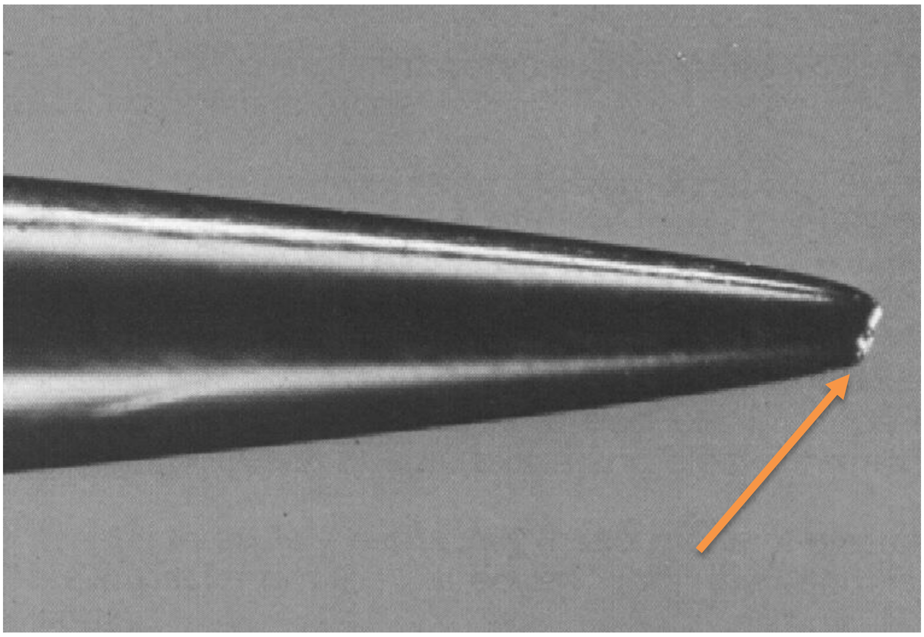

Figure 3.31: Needlepoint Damaged

Diagrams for needle component parts are given in Figures 3.32 and 3.33. The threading of the needle for the lockstitch machine can be seen in figure 3.34.

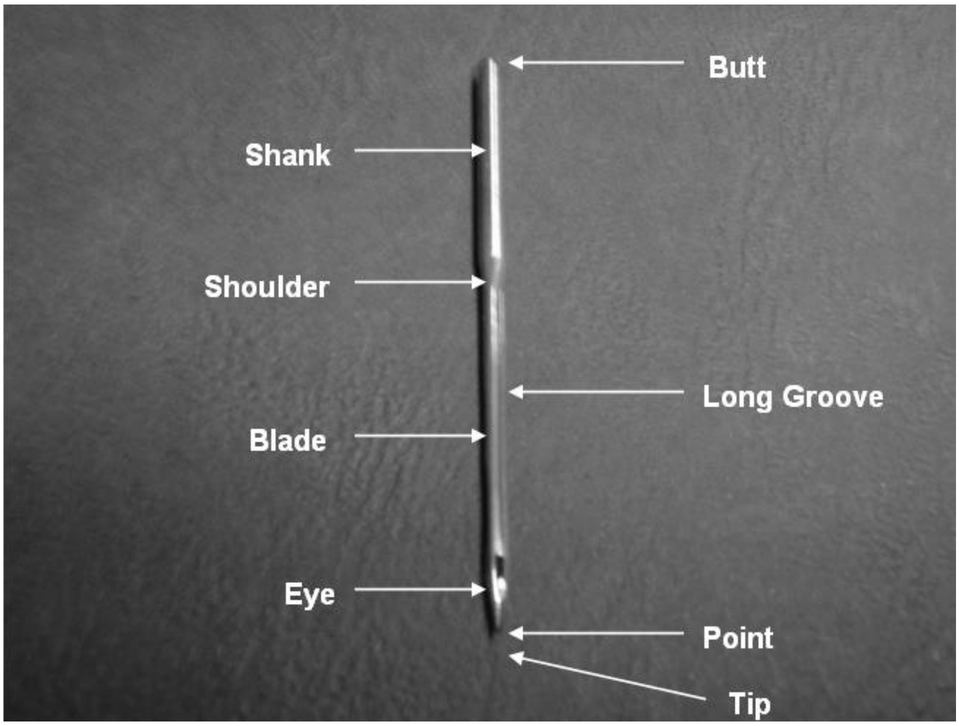

Figure 3.32: Needle component parts

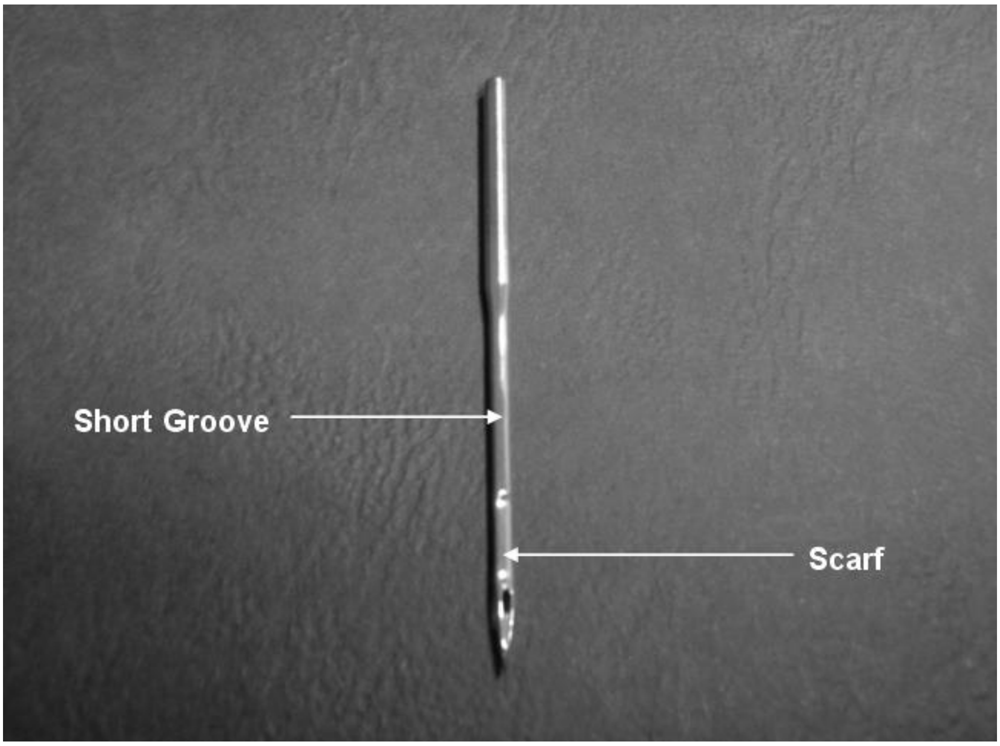

Figure 3.33: Needle component parts

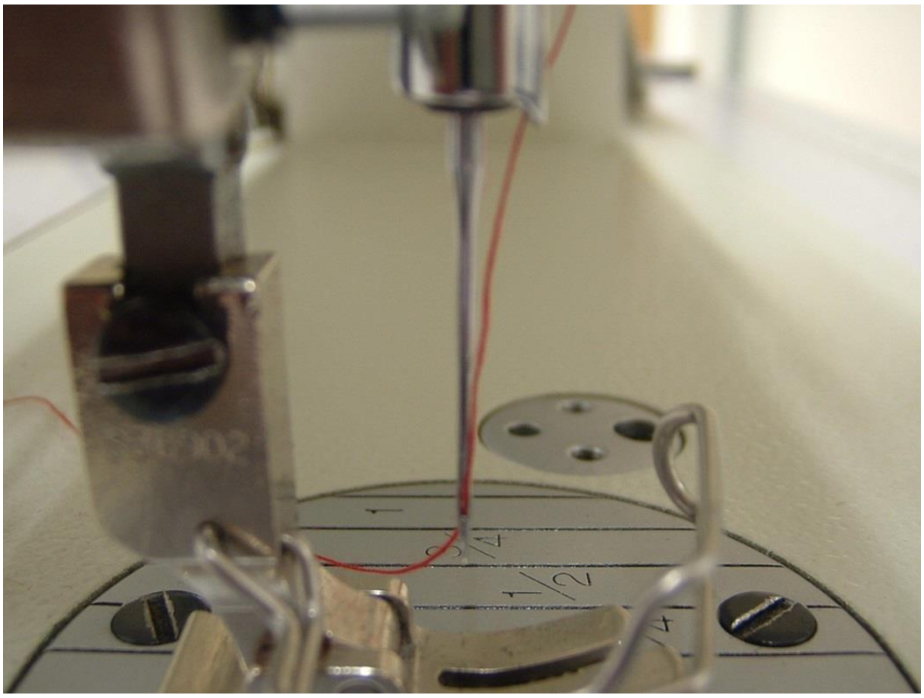

Figure 3.34: The needle is threaded with the sewing thread left to right.

3.17 Discussion summary

Experience has shown that sewing machines do not perform always the same despite the fact that they may be the same make and model. Even machines that are produced off the same production line may have slim and minor tolerances in the engineering that can have a slightly different effect on stitching the fabric.

The information described above has been written in order to inform the reader of this work, the variable factors that can have an effect on the quality of the seam. Needles, machine settings, sewing threads and operator handling are all important factors that have a significant bearing on sewing the material.

Manufacturers of machine equipment have learned that by understanding about fabrics and production, many types of different machines have been developed with different methods of feeding fabrics.

Many hundreds of needle point types exist from stitching leather to silk materials. These components and of their significance when sewing materials together are discussed later in this thesis;

Chapter 4 DEVELOPMENT OF THE FABRIC INTELLIGENT TECHNOLOGHY (FIT)

4.1. The FIT System

The FIT system was developed to simplify the process of containing and analysing the data from both the Kawabata and the FAST systems and to generate a fabric fingerprint and a fabric-mapping model. The system also provides expert guidance on the sewing machine settings for the sew-ability of the material. The program focuses on the stitching of the fabric, particularly with respect to seam pucker and overfeeding difficulties which relate to seam deformation. Therefore it was necessary to identify the parameters from the Kawabata and FAST calculations that identify the fabric aspects that contribute to these phenomena. These were identified from the literature as:

A) Fabric Extensibility
B) Fabric Bending Stiffness / Rigidity
C) Fabric Shear Properties

(Gong, 1994)

The system is designed to generate succinct sewability reports. A report produced from the parameter map or fingerprint gives an account of potential problems that can occur and preventative measures that can be taken to minimize disruption to production. These measures are innovative and add new knowledge to the literature. They provide an entirely new approach to enhancing knowledge by analysing the relationships between the textile and fabric properties, giving informed advice on generating a sewing machine setting and an adjustment regime for stitching the fabric.

An example of the analysis software for the Kawabata and FAST systems is given in figures 4.1 and 4.2:

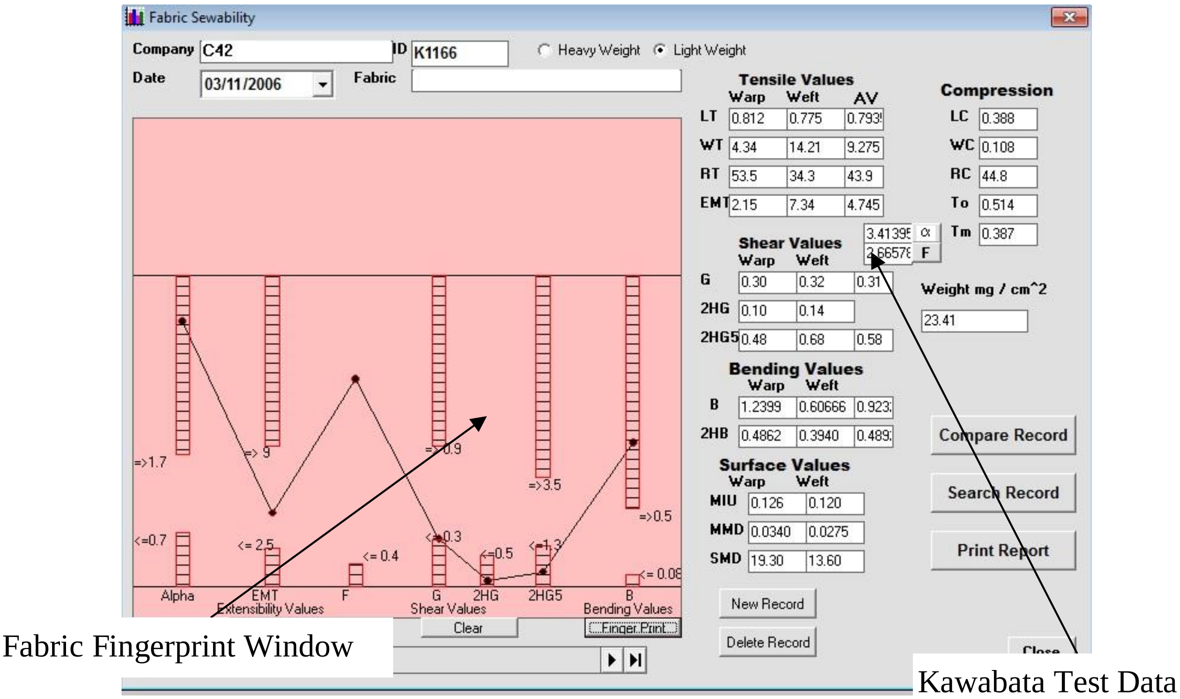

Figure 4.1: Analysis tool for Kawabata in the FIT system

The software is a distributable software product that can be loaded on to any PC running a Windows platform.

The FIT program analyses the average values for both the KAWABATA and FAST systems. For the KAWABATA system, the values analysed are:

- **Tensile properties**
  - LT – Linearity %
  - WT – Tensile Energy – gm.cm / cm^2
  - RT – Resilience - %
  - EMT – Extensibility %

- **Bending properties**
  - B = Bending Rigidity - $gf.cm^2$ / cm
  - 2HB = Bending Hysteresis

- **Shearing properties**
  - G = Shear Stiffness - gm / cm
  - 2HG = Hysteresis at Ø = 0.5°
  - 2HG5 = Hysteresis at = Ø = 5°

- **Alpha properties [α]**
  - The difference between two matching parts of fabric – Warp / Weft

- **Fabric formability**
  - A measure of the ability of the fabric to absorb compression in its own plane without buckling

For the FAST system the properties analysed are:

- **FAST – 1 Compression Metre**
  - Measures the thickness of fabric under two fixed loads

- **FAST – 2 Bending Metre**
  - Measuring the stiffness / flexibility of a fabric

- **FAST – 3 Extension Metre**
  - Measures the amount (in percent) that a fabric will stretch under 3 fixed loadings

Diagnostic forms are produced when clicking on it activates the “Average Value” text box. An example of a diagnostic form is given in Figure 5.3.

The text can be edited in the data window if the explanation needs to be modified.

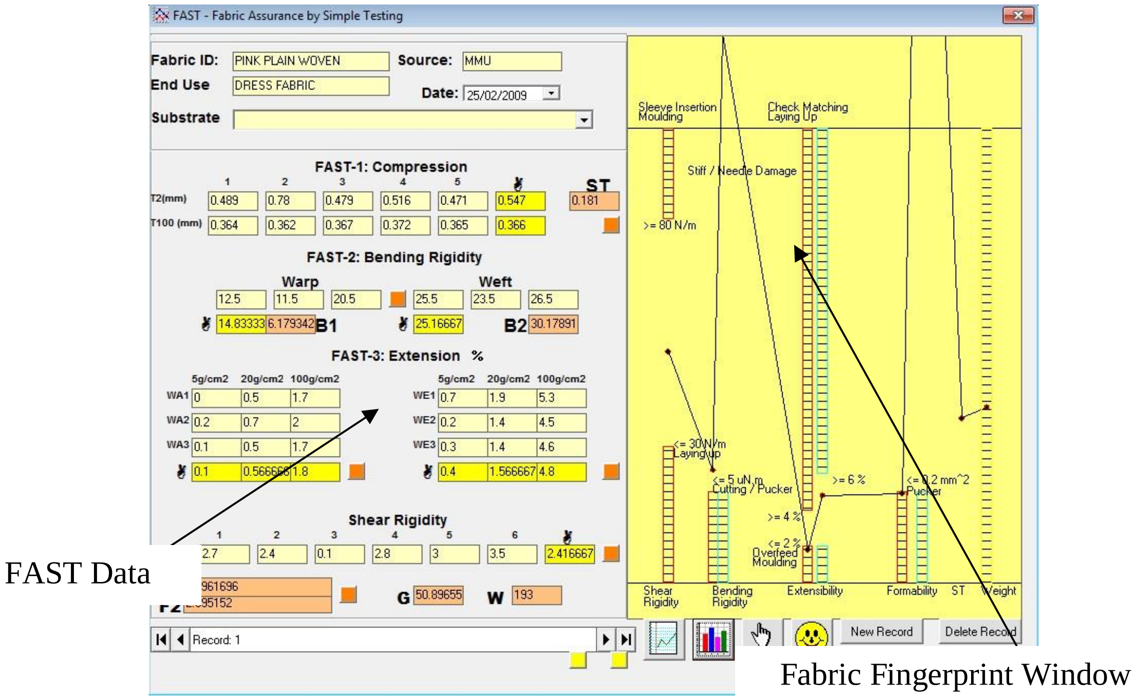

Figure 4.2: Analysis tool for FAST in the FIT system

The red-laddered areas indicate the potential problem areas and are marked with the high and low values accordingly. The spaces between the ladders are determined as the comfort zones of acceptable fabric performance and tolerance of sew-ability. If fabric values are within these spaces, it is predicted that the fabric will present few problems during or after sewing.

4.2. Report Generation

The report can be generated in two ways. The first method is by clicking on the “Print Report” button where a message box is generated that asks the user if they want to generate the report. If “Yes” is clicked upon the report is generated in Microsoft Word (Figure 4.3).

The second method is by clicking on the text box that contains the value that the user wants to examine. This produces a diagnostic window and an explanation of that parameter is given (Figure 4.4).

COATS LTD

CUSTOMER: Stocks Clothing

FABRIC : MOYCASHEL

END USE :

DATE : 10.10.00

CONTACT :

OUR REF : K1166

Operation	Stitch type	Stitch rating per 3cm	Stitch type	Point Style	Needle thread	Under thread

Comments

Very low extensibility (e.g. less than 2.5% can cause overfeeding difficulty in warp and weft directions during making up. This value indicates that the fabric may be prone to over feeding difficulties. Seam pucker could also occur due to the fact that the insertion of the sewing thread, causes a compression strain too high for the fabric to contain without pucker.

Shear properties measure the inter-yarn friction and indicate the ease of fabric movement. If the values are low i.e. less than 0.3 then although it indicates that this is good for drape, comfort and handle, difficulties may occur in laying, cutting and making up due to the ease of fabric distortion. Sewing of long seams and pattern matching can be particularly difficult. Seam puckering may also occur as the extensibility in the bias direction is high.

Bending properties are mainly affected by the inter-fibre and inter-yarn forces in a fabric. This value is relatively high for bending stiffness and may affect fabric handle and drapeability and can result in needle damage.

Figure 4.3: Reporting system generated in Microsoft Word

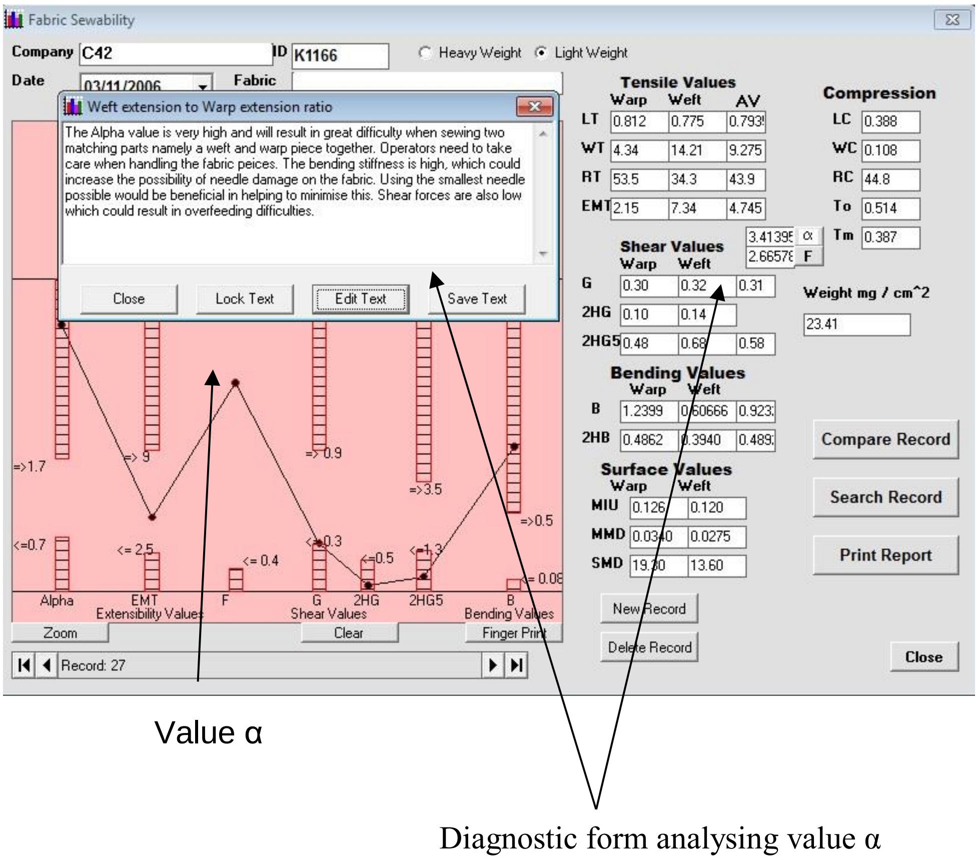

Figure 4.4: KES analysis, diagnostic form analysing value alpha

4.3. Fabric Parameter Mapping

The FAST tool also contains a fabric parameter mapping model function that produces a map of the physical properties of the fabric. These properties include:

A. Warp ends/cm
B. Weft picks/cm
C. Warp and weft tex
D. Crimp percentage – warp and weft
E. Crimp ratio – warp and weft
F. Actual and Theoretical area density
G. Warp and weft cover factor
H. Fabric weight

The fabric mapping technique allows the option of being able to visually compare the properties of fabrics with respect to their physical quantities. It also enables the possibility of being able quantify fabrics into specific groups and by being able to do this, recommend specific sewing machine adjustments and settings that will facilitate efficient and accurate sew-ability of the material.

4.4. Discussion summary

The KES data values that are analysed by the FIT system have been obtained from the Guidelines for KES-FB Test Results (Standard Test Conditions) and from COATS Sewing Threads Ltd. The FAST data values have been taken from the FAST technical data and from the literature. The explanations for each data value are triggered by thresholds that have been determined from work done by Marks and Spencer and from the University of Manchester. A smart database has been incorporated into this system which has been titled 'FIT as a guide line for stitching shirting fabrics'. It is this system that is used for the pilot study and for the main methodology.

Chapter 5 PILOT STUDY

5.1. Methodology

Shirting fabrics were chosen for the investigation due to their lightweight nature, relatively dense construction and fibre composition making them more prone to seam pucker. The chosen materials are plain-woven. Plain-woven fabrics are more prone to seam puckering due to the higher density of warp and weft yarns, which cause higher values of their shear properties (Pavlinic et al., 2006).

Six fabrics were chosen randomly from a batch of thirty samples. These were selected using a lottery system whereby all the fabrics were numbered and the numbers drawn from a hat. This was to ensure impartially during this research.

The Pilot study consisted of the following eight steps:

1. One expert in sewn product technology to subjectively analyse the fabrics and to comment and recommend sewing machine settings to ensure good seam quality.
2. The fabrics deconstructed and the data from their physical parameters recorded.
3. The fabric mechanical parameters tested on the FAST system.
4. Sewing experiments undertaken on the material and adjustments made to ensure a fully flat seam on the fabric.
5. Comparing the sewing information given by the expert to the final settings on the machine.
6. The results from the sewing experiments evaluated through the America Association of Textiles, Chemists and Colorists (AATCC), seam pucker charts.
7. The data from the physical, mechanical and sewing experiments entered into the FIT system.
8. The FIT system to analyse the physical parameters, the mechanical parameters and the sewing experiments to produce expert advice on the sew-ability of the material both by report generation and the generation of a sewing machine settings model

5.2. Step one - Trial Expert (SPEC 1)

SPEC 1 was chosen to undertake the pilot study for a specific reason. This expert was the only professional to have specialist knowledge of objective fabric measurement, particularly the Kawabata system and also a thorough awareness and expertise in the handling and sewing of fabrics. Having worked for COATS sewing threads for 20 years prior to joining Matalan Ltd as manufacturing manager, this individual had developed the reports to industry for fabric handle tested by the KES system. The résumé of this expert is given in appendix 4.

The expert was asked to examine the six fabrics according to methods “A” and “B”. Method “A” was chosen for the fabric parameters that influence the sew-ability of the material (Postle, 2007). Method “B” was selected to gain information from the expert on the best settings to set the sewing machine to sew the material. The first assessment for method “A” used two approaches consisting of a blind evaluation where the expert could handle the fabric’s without seeing them and secondly, a visual appraisal where the expert could view the fabrics and handle them. The reason for adopting the blind approach was that visual perception could influence a person’s judgement. It was also to determine how accurate the expert’s judgements were in predicting the end use of the fabric (Crilly et al., 2004, McLoughlin and Cashman, 2010). The criterion for “A” and “B” are given below:

5.2.1. Method A

Handle values:

1. Softness of handle
2. Stiffness of handle
3. Limpness
4. Extensibility

The reasons for choosing these characteristics for method ‘A’ was that in normal sewing environments, these properties of materials are analysed subconsciously by a technician prior to setting the sewing machine. An explanation of these properties is given below.

Softness of handle: Can cause overfeeding by the machine. The presser foot sinking into the fabric thus pushing the top ply forward can cause this phenomenon. The result is an overlap of fabric from the top ply over the under ply causing the two lengths of fabric to be unequal.

Stiffness of handle: Generally does not cause many problems during garment making but will feel stiffer and can be prone to needle damage.

Limpness of a fabric: The opposite of stiffness, which can cause problems in a number of areas particularly cutting as the fabrics distort easily. In the case of sew-ability, the fabrics can be particularly susceptible to seam puck due to their low of formability causing the yarns in the fabric to be distorted by the forces of the needle and sewing thread within the seam (Postle, 2007). This causes structural jamming of the sewing thread and the yarns within the fabric.

Fabric Extensibility: Low extensibility can lead to difficulties in producing overfed seams and problems with moulding garments into three dimensional shapes. Also potential problems with seam pucker both with low and high extensibility, the fabrics maybe distorted during sewing and more difficult to handle.

5.2.2. Method B

Sew-ability

- How will the fabric perform at the needlepoint?
- What sewing machine settings do you recommend for this fabric? This will include, needle selection, sewing thread selection, tension and presser foot settings and advance machine settings for difficult to sew fabrics

On conclusion of the evaluation by the expert, the conditions for the machine settings and adjustments were recommended by the expert to be:

1. A size 70 Schmetz needle, acute round point described in chapter 3
2. Polyester core spun sewing thread size 180,s – this is a very fine thread meaning neat seams and high strength to mass ratio

3. The optimum presser foot tension i.e. As light as possible to produce the feeding of the material without ply slippage – this was recommended to be 35 Newtons (N)
4. The optimum sewing thread tension adjustment, i.e. to produce a well-balanced stitch – this was recommended to be 125g for static tension and 12g for bobbin tension
5. A fine toothed feeder part number with the appropriate throat plate with diameter needle hole of 1mm.
6. The feeder should be set at one full tooth above the throat plate
7. Check-spring set at between 10 to and quarter to the hour

The expert commented that a major importance of objective measurement systems, particularly Kawabata, were that the data generated by them was used to backup or prove a subjective assessment given to the company by the expert. In other words the data obtained from objective testing was used to confirm the information given to the company by the expert. This provided a useful and interesting analogy of the potential use of objective measurement for an early warning system on fabric sew-ability.

5.3. Step Two – Physical parameters

The fabric variables of six shirting materials were determined by analysing their physical parameters. These consisted of:

1. Warp ends/cm
2. Weft picks/cm
3. Warp and weft tex
4. Crimp percentage – warp and weft
5. Crimp ratio – warp and weft
6. Warp and weft cover factor
7. Fabric weight

The data was entered into the FIT system and a fabric parameter map was produced for each fabric.

5.4. Step three - Mechanical parameters

The mechanical properties of the fabrics were tested using the FAST system. The mechanical measurements on the FAST system were:

1. FAST 1 – Surface thickness
2. FAST 2 – Bending rigidity
3. FAST 3 – Extensibility

- **FAST-1 Compression tester and surface thickness**

Fast-1 comprises of a compression metre, which measures the fabric at two predetermined loads. The principle of this measurement is highlighted below in figure 5.1. The pressure is controlled by adding weights to a measuring cup on the machine (figure 5.2). Five measurements are taken and an average is calculated. From these two measurements the surface thickness is calculated which is given by the equation:

$$ST = T2 - T100$$

Where:

ST = Surface thickness in mm

T2 = Average thickness at 2gfcm^{-2}

T100 = Average thickness at 100 gfcm^{-2}

The surface thickness of the fabric can influence the frictional forces of the material during sewing, which can have an impact on seam slippage and overfeeding difficulties.

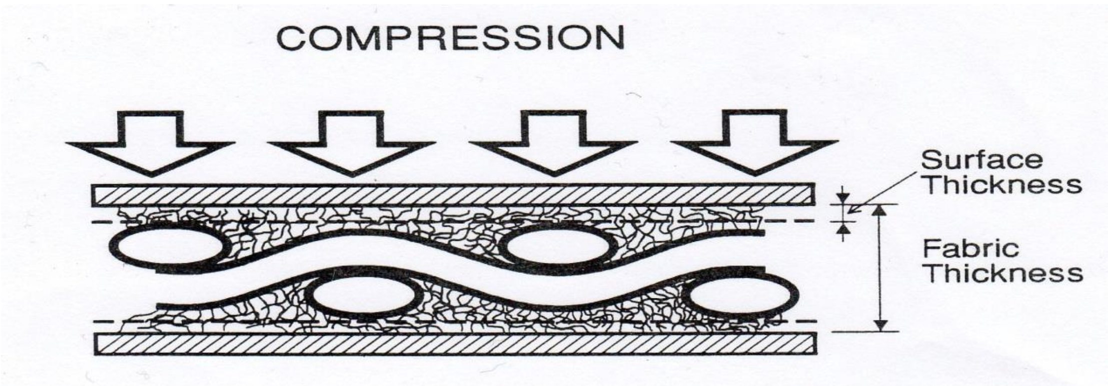

Figure 5.1: Compression and surface thickness of the fabric (FAST, 1989)

- **FAST-2 Bending stiffness / rigidity**

This device is a bending metre, which measures the bending length of the fabric in millimetres. From this measurement, the bending rigidity is also calculated. With this instrument, a cantilever principle is used described by the British Standard method (BS: 3356, 1961). This instrument uses a photocell to detect the edge of the fabric thus making the instrument simpler to use than detecting the edge by eye.

Figure 5.2: FAST-1 – Surface thickness tester measurement testing device

This enables a more accurate reading to be taken and the values of the bending lengths are read directly from a display on the instrument. Examples of the bending principle and the device are given in figures 5.3 and 5.4.

Three samples from the warp and the weft are measured and an average for both parameters is produced in millimetres. The bending rigidity is calculated from these average bending lengths and is given by the equation:

$$BR_{\mu Nm} = \text{Fabric Weight} \times (\text{Bending Length})^{3} \times 9.81 \times 10^{-6}$$

The bending stiffness is a particularly important with regard to the formability of the fabric. A stiffer material is unlikely to pucker due to having a great resistance to the forces from the sewing needle and the sewing thread.

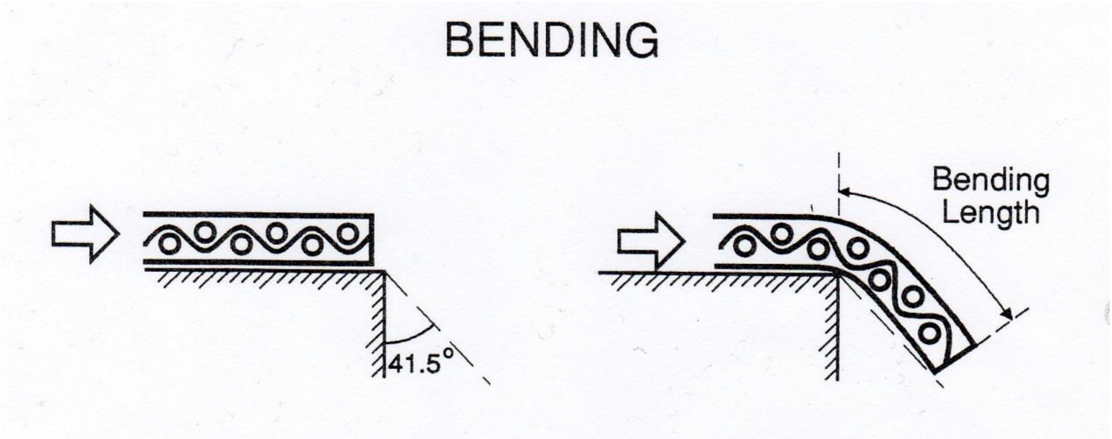

Figure 5.3: Bending stiffness of fabric (FAST, 1989)

- **FAST-3 Extensibility**

FAST-3 is an extension metre, which operates as a simple lever principle by removing weights from a counter-balancing beam. The fabric is measured at three different loads, thereby simulating the kind of deformation the fabric is likely to undergo during garment manufacture. The extensibility can, in theory, be measured at any angle to the warp or weft threads. In practise, it is normal to measure the extensibility in only the warp, weft and bias directions. Examples of the extensibility test and metre is given in figures 5.5 and 5.6.

- **Derived properties**

Some properties produced by FAST are not measured directly by the instruments but are calculated using a combination of values from different FAST instruments and mathematical constants. These properties are described as derived properties due to the fact that they are not measured by one instrument.

Figure 5.4: FAST 2 – Bending stiffness tester

Bending rigidity described earlier is a derived property because in addition to bending length, fabric weight is brought into the equation.

5.5. Formability and shear rigidity

Other derived properties are formability (figures 5.7 and 5.8) and shear rigidity (figures 5.9 and 5.10). Formability is a very important property in fabric stability and is described as “A measure of the ability of a fabric to absorb compression in its own plane without buckling”. This compression is imposed upon the fabric by a combination of thread size, needle size, thread tension and stitch rate. A fabric that buckles easily under these forces will produce puckered seams. A combination of sewing machine settings combined with careful selection of the sewing thread and needle can help significantly reduce this problem.

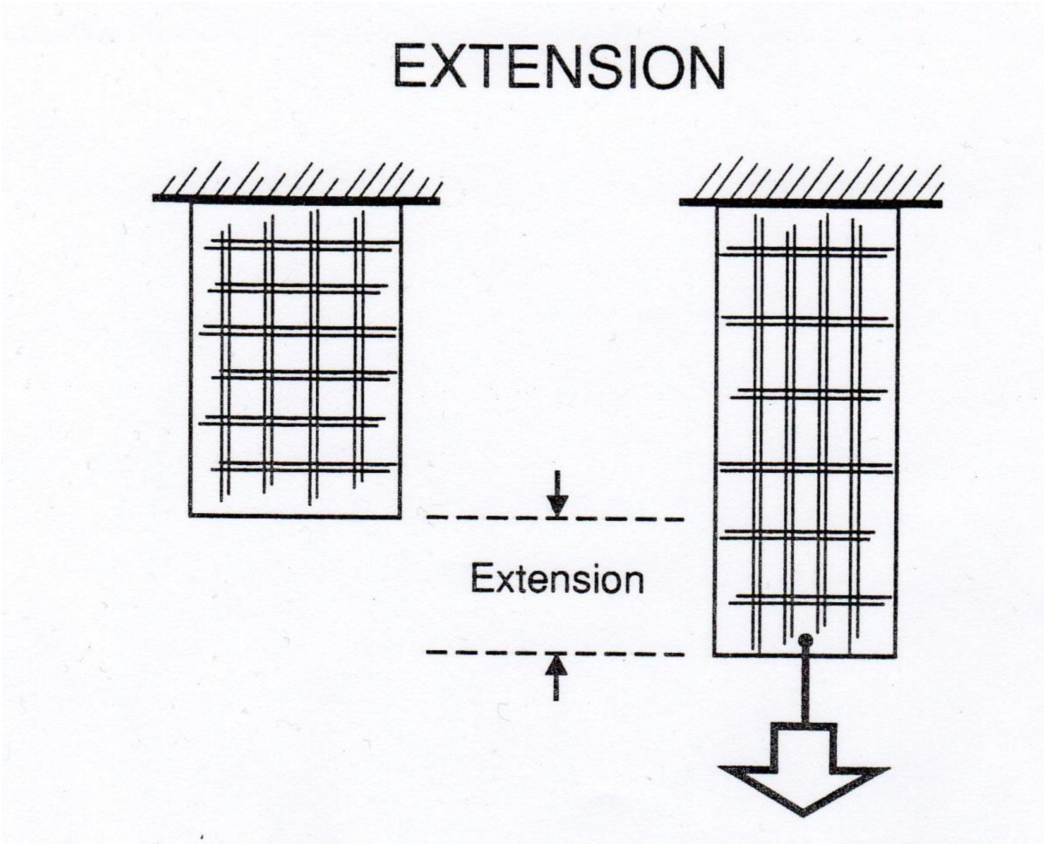

Figure 5.5: Extensibility of fabric (FAST, 1989)

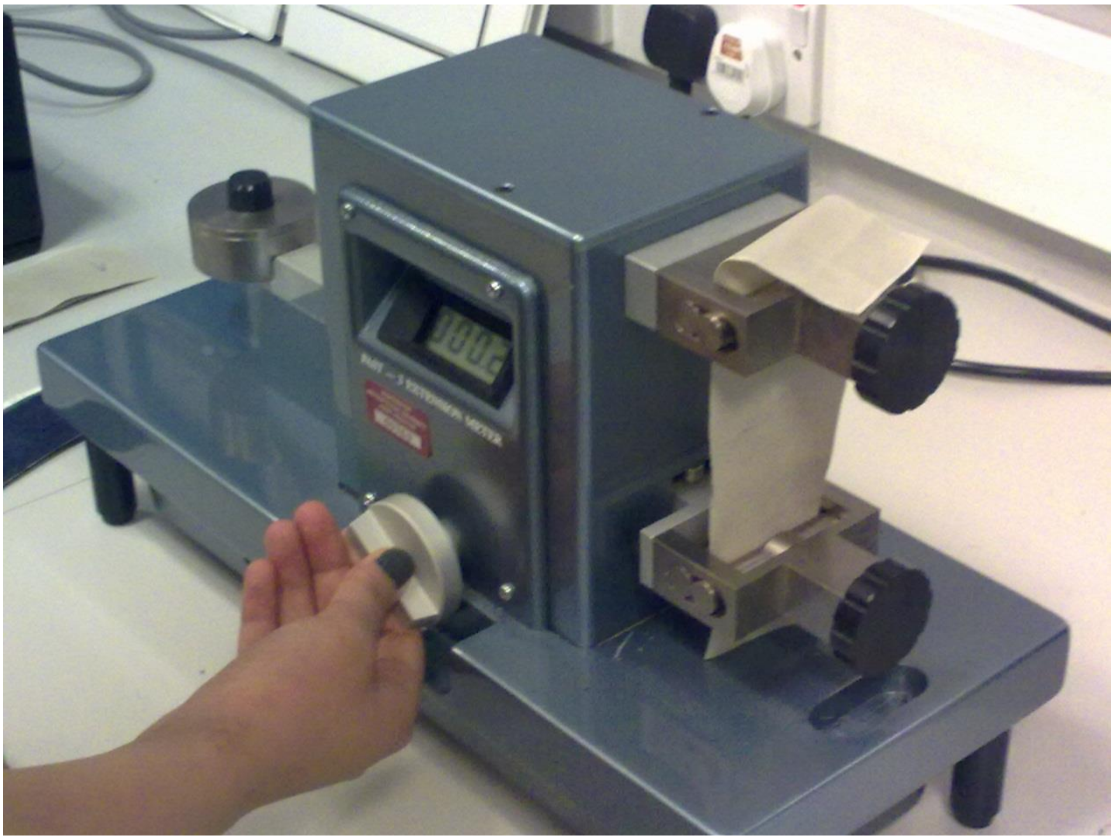

Figure 5.6: FAST 3 – Extensibility tester

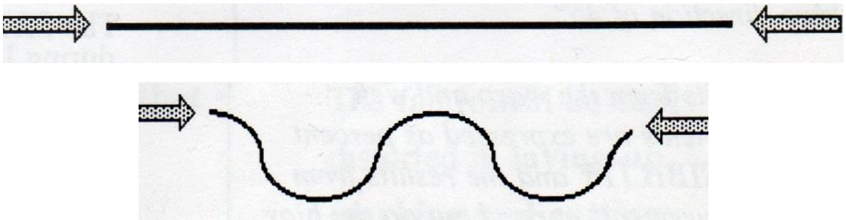

Figure 5.7: Fabric formability (FAST, 1989)

The equation for formability (F) is given as:

$$F_{mm}^{2} = (E_{20} - E_{5}) \times B$$

Where: E_{20} = extensibility at 20g force

E_{5} = extensibility at 5g force

B = bending rigidity

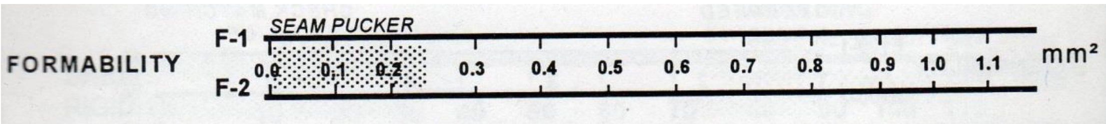

Figure 5.8: Fabric formability scale (FAST, 1989)

- **Shear rigidity (G)**

Shear Rigidity is a measure of the ease with which a fabric can be distorted in a trellising action and is calculated from the bias extensibility measured on FAST-3.

Low shear rigidity indicates that the fabric will be easily distorted in laying-up, marking and cutting.

High shear rigidity indicates that the fabric will be difficult to form into smooth three-dimensional shapes causing problems in moulding and the insertion of sleeves. The drape of the material can also be affected.

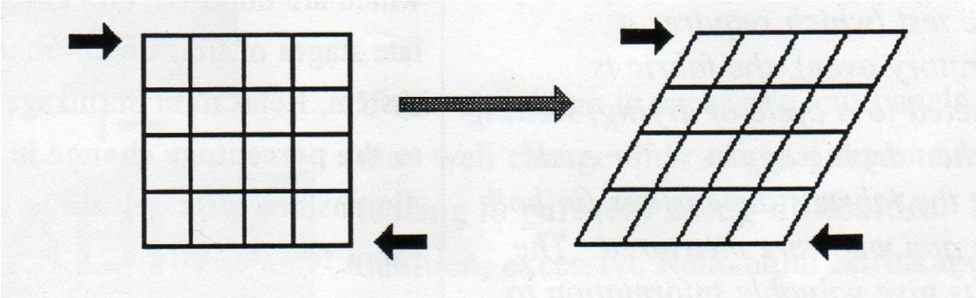

Figure 5.9: Shear Rigidity (FAST, 1989)

The equation of shear rigidity is given as:

$$G_{Nm}^{-1} = 123 / EB5$$

Where G = Shear rigidity

EB5 = Bias extension %

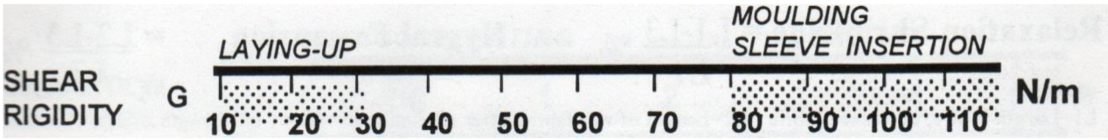

Figure 5.10: Shear rigidity scale (FAST, 1989)

The results from the FAST tests were entered into the FIT software system (chapter 4). The FIT system was developed to contain and analyse the data and to generate expert guidance on the sew-ability of the material by modeling the seam behaviour. The system is able to produce automated reports from the objective test data to ease the task of interpreting the results from FAST.

5.6. Step four - Sewing experimental work

The fabric strips from which the sewing samples were prepared were 50 centimetres long and 5 centimetres in width and were stitched in the warp direction (figure 5.11). Bertoldi and Munden, (1974) offered examples of seam widths and lengths on sewing suiting fabrics. It was considered desirable that this measurement be adopted; as the length of the seam was comparable with similar lengths used in industry for seaming garments and enabled the

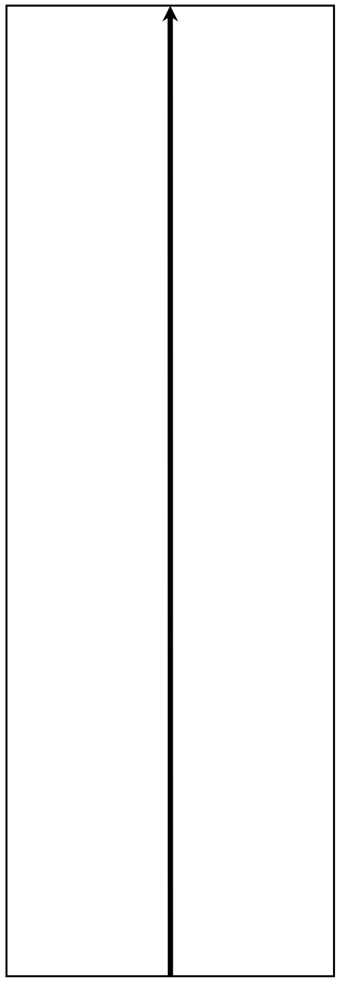

Figure 5.11: Samples cut in the warp direction (5x21 cm)

machine to reach its maximum speed for stitching. The sewing experiments were performed using the Juki machine (figure 5.12) as described in chapter 3. The samples were fed through a guide as shown, which ensured that the seam was straight, and consistent. The guide also allowed a reproducible sewing procedure because the strips were allowed to feed freely through the machine.

1. Spare strips of fabric were used initially to set the machine to achieve the flattest seam possible. The initial settings were adjusted to those recommended by SPEC 1.

2. The machine adjustments were slightly modified to those given by the expert to give a flatter seam.

Figure 5.12: Strips of material fed through the machine

3. The number of samples used was determined by the amount of adjustments needed to produce a flat seam. This required the skill and expertise of the engineer setting the machine.

4. The samples were sewn without any handling of the material in order to allow the fabric to move freely with no interference by human contact.

5. Once a flat seam was achieved, 3 samples for each fabric were sewn for evaluation using the AATCC seam pucker chart making 18 samples in total.

5.7. Step 5 - Assessment of the fabrics using the AATCC charts

The American Association of Textiles, Chemists and Colourists (AATCC), the seam pucker evaluation chart ranges from a value of 1 for bad seam pucker, to a value of 5 indicating no seam pucker. This chart is the standard assessment as used by academics and industry worldwide.

Three independent experts in seam and sewn product analysis were invited to evaluate the quality of the seams. One expert at a time would view each fabric x

3 specimens for each material. One sample at a time was placed in the light-box (figure 5.13). The light box has a daylight fluorescent tube (product number TL 84 to light up the interior of the box. The expert was asked to face away from the viewing area thus not being able to see the samples. The samples were presented individually. And the expert was then asked to turn to view a specimen and give a verdict on the level of seam pucker. Each expert was given 5 seconds for their evaluation, timed on a stopwatch and the results from each expert were recorded into a table (table 5.1).

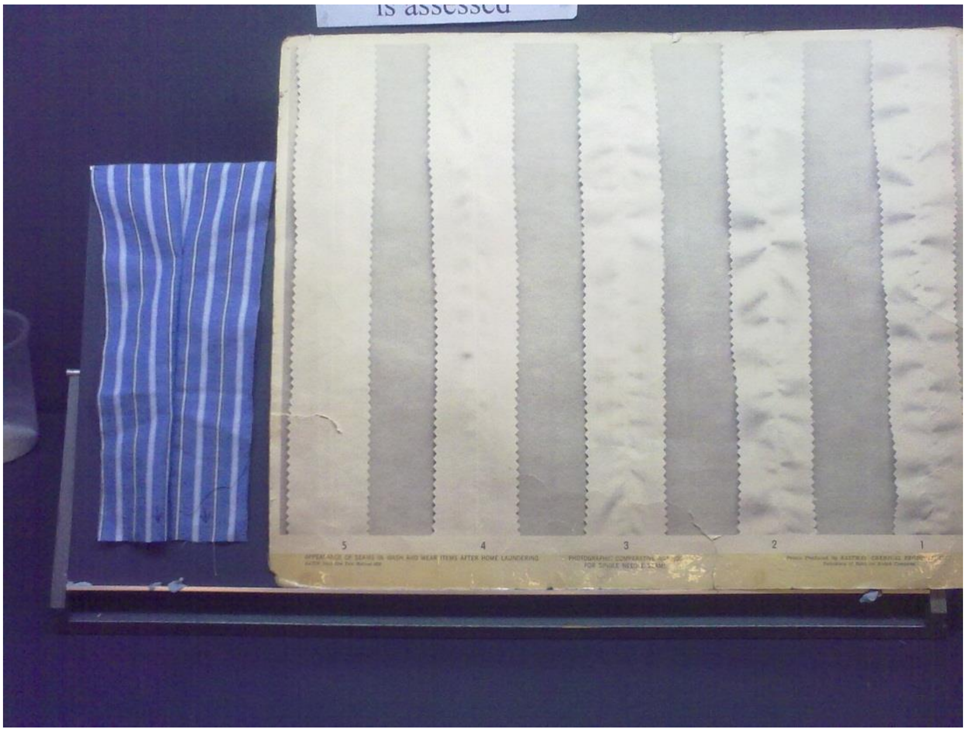

Figure 5.13: Light box with AATCC seam pucker chart

Fabric 1 - 50 % Cotton 50 % Polyester

	S_1	S_2	S_3	Median
AATCC Grade				

Table 5.1: AATCC Seam pucker evaluation chart for one of the fabrics

5.8. Results from the pilot study, trial expert (SPEC 1)

This expert identified correctly that all the fabrics assessed during the blind test were for an end use in shirting. He also identified correctly that fabric 1 was a blend of cotton and polyester though he was unsure about the blend composition. The time taken with this expert was nearly 3 hours due to the fact that a very thorough handling assessment was undertaken. The fabrics were slightly deconstructed by hand, which meant separating the yarns from the material down to picking apart the fibres from the yarns.

From his analysis of the fabrics, they were ranked from 1 to 6 on which material offered the worst to best results for sewing according to criterion A and B described in above. The fabrics were ranked as follows (table 5.2):

Fabric	**1**	**2**	**3**	**4**	**5**	**6**
$S^{!}$	**1**	**4**	**3**	**5**	**2**	**6**

Table 5.2: Results of rankings for the six fabrics

Interestingly, fabric 1 ranked at number 1 is highlighted by the expert to be the most difficult to sew, is the polyester / cotton material and this he predicted would give the worst results for seam pucker. He predicted that it would be hardest to sew in the weft direction with a strong possibility of structural jamming in both the warp and the weft direction.

The fabric ranked at number 6 was predicted by the expert to be the best for sew-ability and the best fabric for handle. The other materials were assessed to be of little difference in their sew-ability.

5.9. Physical and mechanical analysis

Two different methods of assessing the properties of the six shirting fabrics were used to measure the variables of each fabric parameter, the physical and mechanical parameters. Each method has indicated that from the variables selected, there are strong similarities between all the fabrics in terms of their physical properties and also very close similarities between the mechanical characteristics of the material. The data from the physical parameters are presented in table 5.3 below.

It can be seen from table 5.3 that there are very close similarities between the ends and picks density of the fabrics and the yarn-tex. The fabric weights are also very closely related to each other, the exception being the cotton / polyester fabric which is significantly lighter than the other fabrics. Also the ends per cm in this material are greater in number than all the other fabrics with both warp and weft Tex values correspondingly lower.

The fabric maps produced indicate that there are close similarities of all the other parameters measured. These are presented in figures 5.15 – 5.20.

	F1	F2 100%	F3	F4 100%	F5 100%	F6 100%			
	50 % Cotton / 50% polyester	Cotton	100% Cotton	Cotton	Cotton	Cotton	Mean	Median	Mode
Ends/cm	48	44	44	44	44	44	44.6	44	44
Picks/cm	30	30	30	30	30	30	30	30	30
Warp tex	14	15.9	14.9	15.4	15.6	15.8	15.3	15.4	15.4
Weft tex	14.7	16.5	16.8	17	17.3	16.8	16.6	16.8	16.8
Warp crimp %	9.5	8.7	8.5	9.4	8.5	8.8	8.9	8.8	8.5
Weft crimp %	9.3	11	11.5	13.6	12.5	13.4	11.8	11.8	11.8
Crimp ratio - warp	1.095	1.087	1.085	1.094	1.085	1.088	1.089	1.088	1.085
Crimp ratio - weft	1.093	1.11	1.115	1.136	1.125	1.134	1.11883	1.11883	1.11883
Warp area density gm^{-2}	67.17	69.42	65.5	67.69	68.65	69.51	67.99	67.99	67.99
Weft area density gm^{-2}	44.06	49.48	50.41	50.95	51.9	50.38	49.53	50.38	50.38
Warp cover factor	17.5	16.82	16.29	16.51	16.69	16.76	16.7617	16.76	16.76
Weft cover factor	10.99	11.56	11.64	11.59	11.17	11.54	11.415	11.54	11.54
Fabric weight sq/m	110	116	115	116	115	115	114.5	115	115

Table 5.3: **Physical measurements of the 6 fabrics taken from the pilot study**

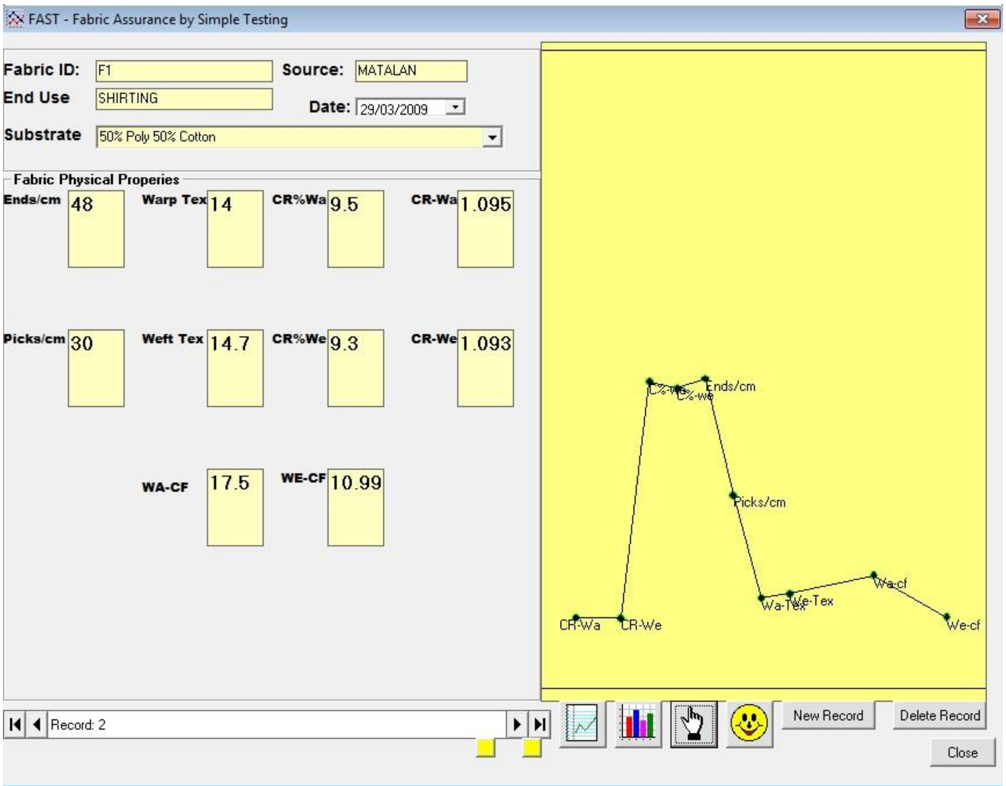

Figure 5.14: Fabric parameter map for fabric 1 from the pilot study

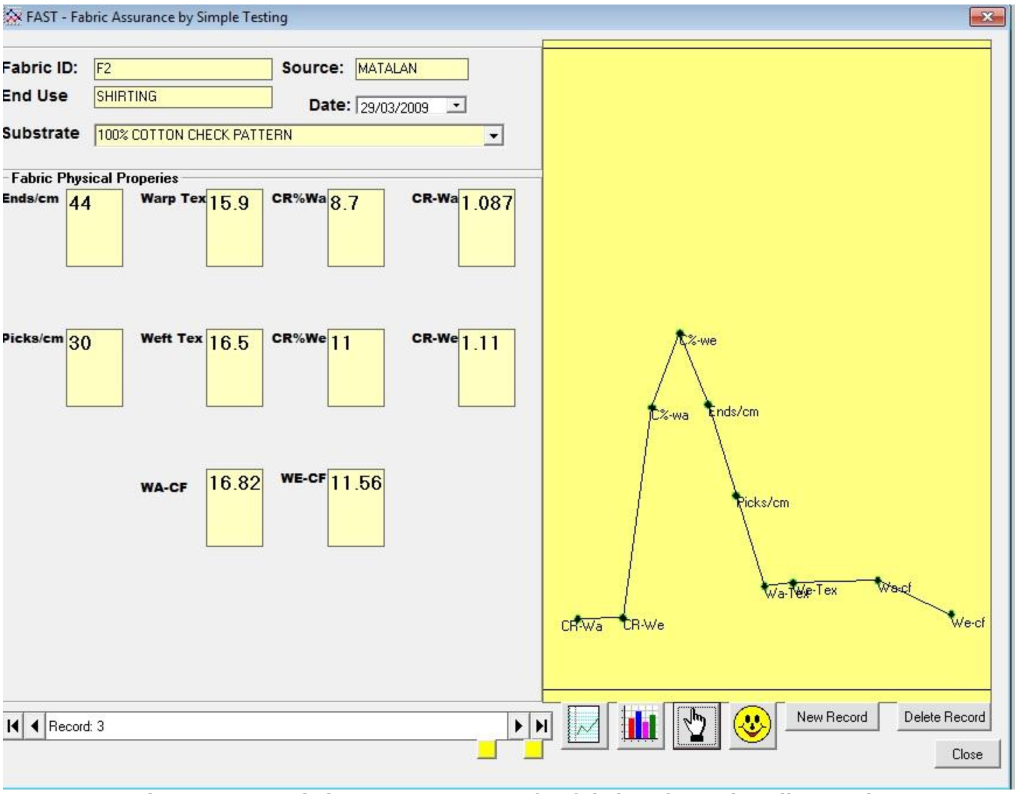

Figure 5.15: Fabric parameter map for fabric 2 from the pilot study

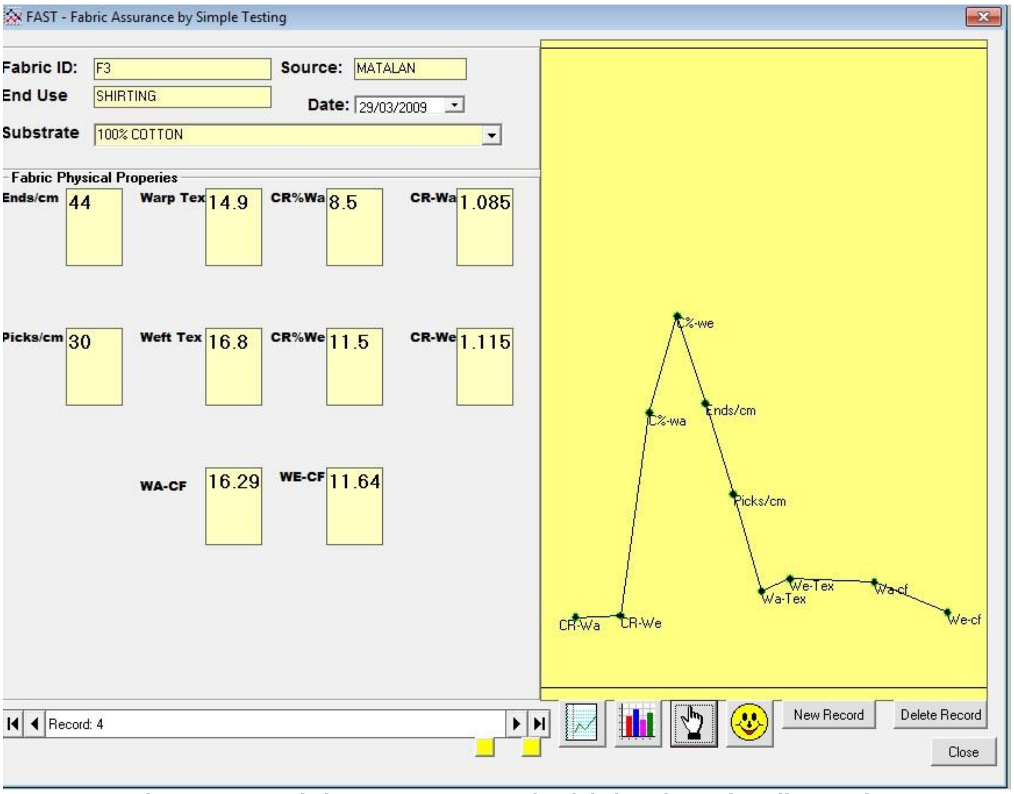

Figure 5.16: Fabric parameter map for fabric 3 from the pilot study

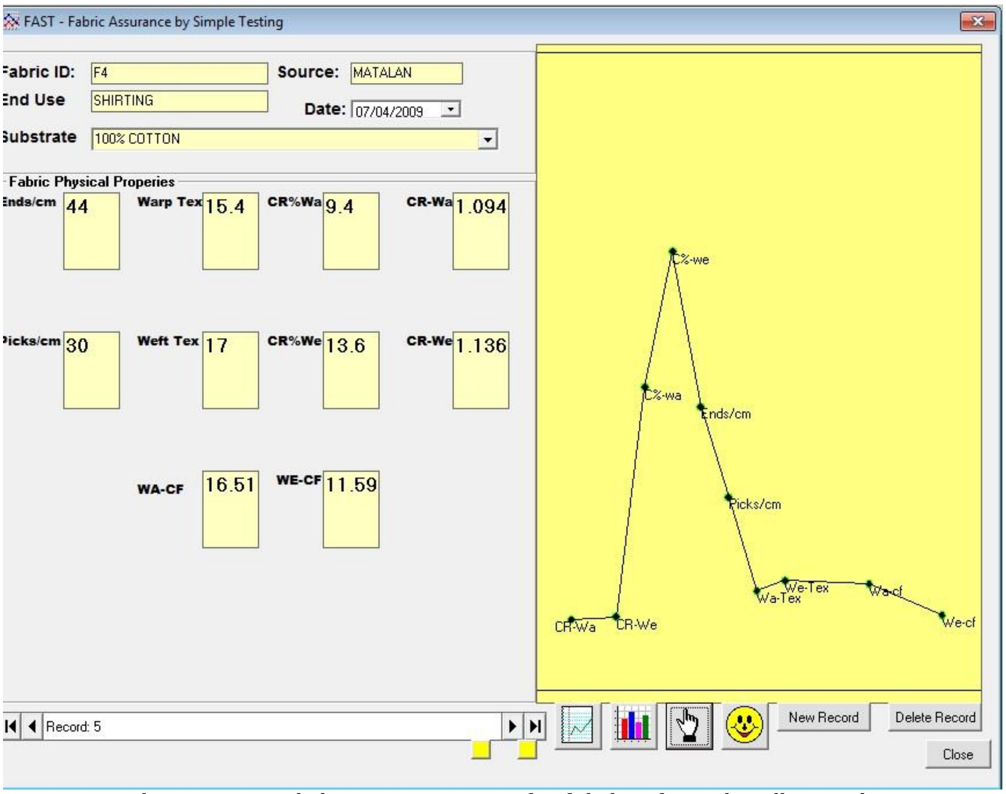

Figure 5.17: Fabric parameter map for fabric 4 from the pilot study

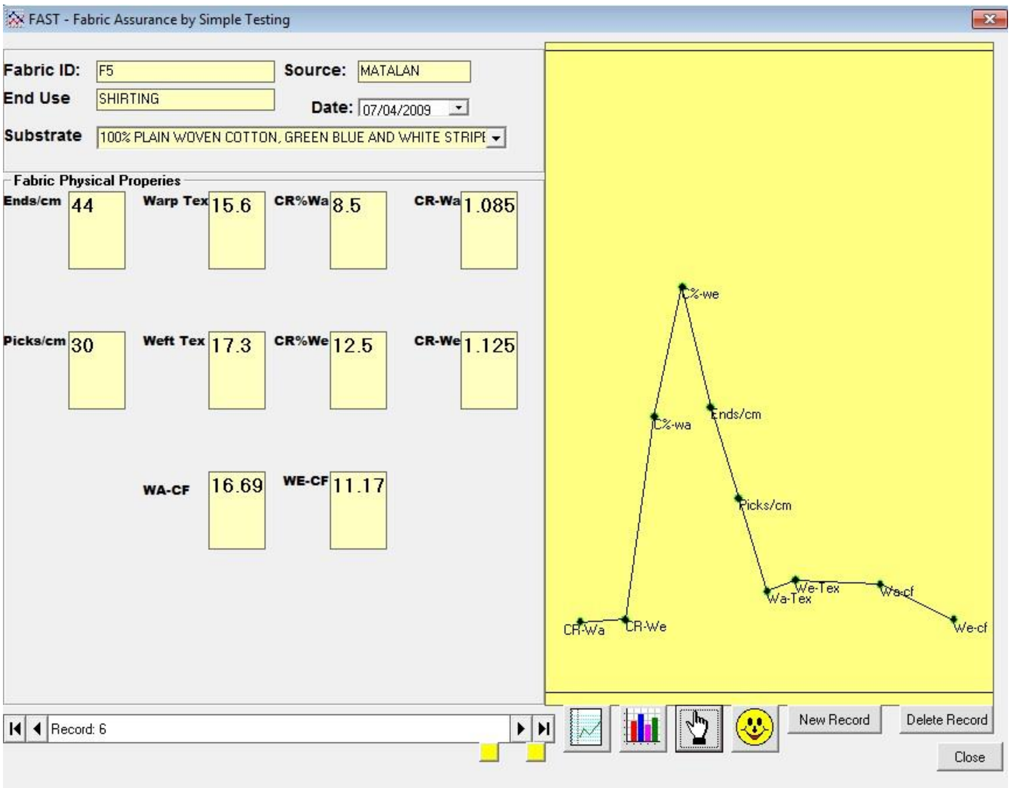

Figure 5.18: Fabric parameter map for fabric 5 from the pilot study

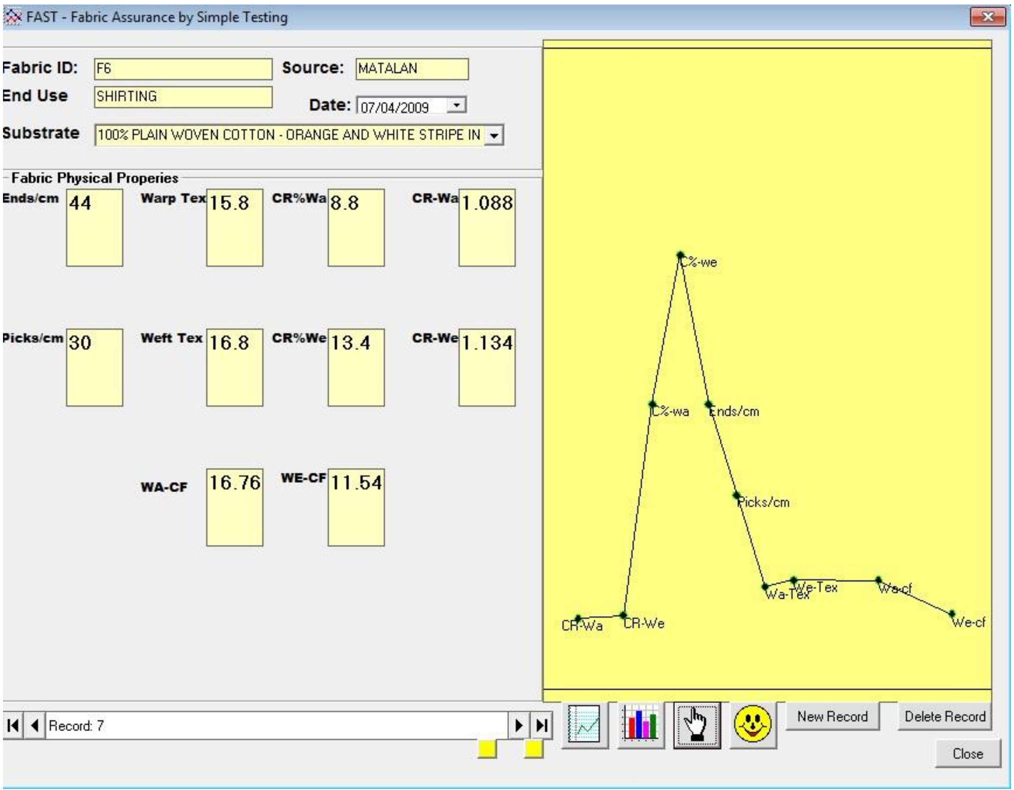

Figure 5.19: Fabric parameter mapping for fabric 6 from the pilot study

The tests undertaken on the FAST system indicate some interesting similarities between numbers of fabric parameters. Figure 5.8 offers an example of the relationship between the bending rigidity and the formability of the fabric. A low bending rigidity indicates a low formability. The formability of the material is a derived property, calculated by using the values obtained from both the FAST-2 and FAST-3 instruments. It can be defined in terms as “A measure of the ability of a fabric to absorb compression in its own plane without buckling”. (Postle, 2007). This type of compressive state is imposed upon the fabric by a combination of thread size, needle size, thread tension and stitch rate. A fabric that buckles easily is more prone to seam pucker than a fabric with stiffer composition. The values obtained from all the FAST tests are shown in figures 5.21 – 5.26.

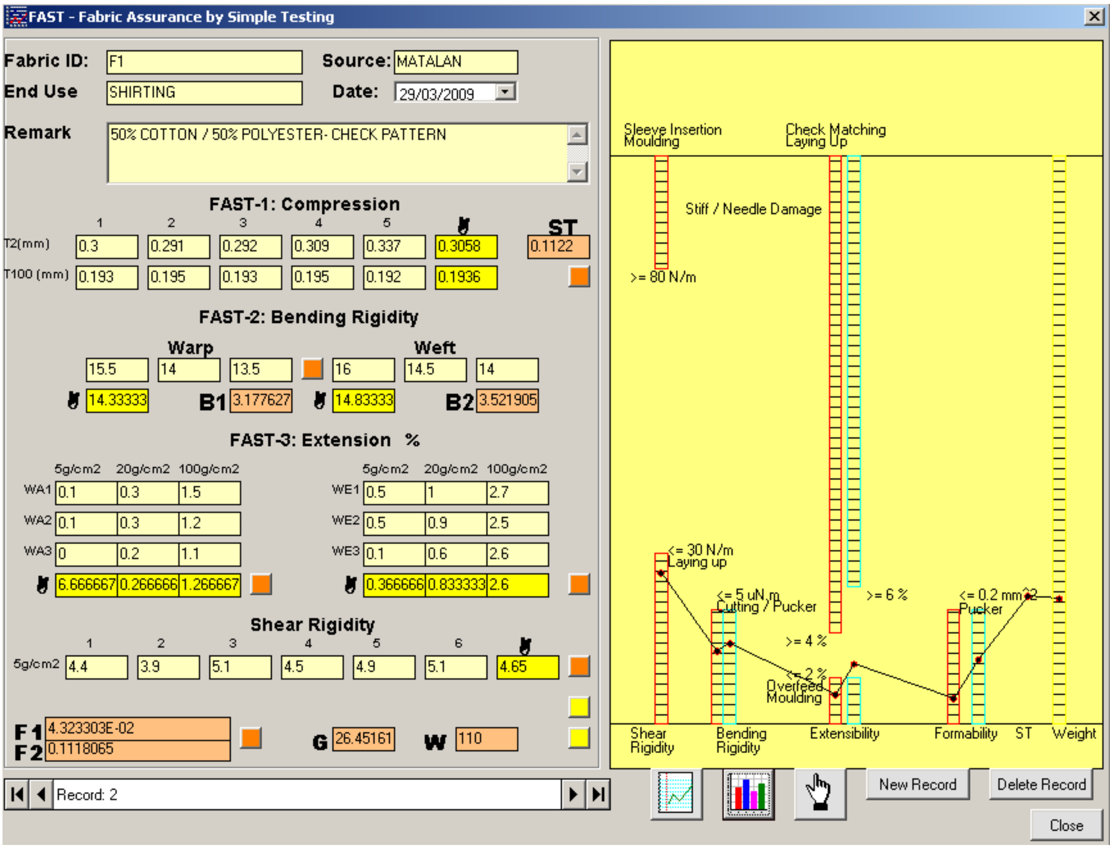

Figure 5.20: FAST data and fingerprint from fabric 1 from the pilot study

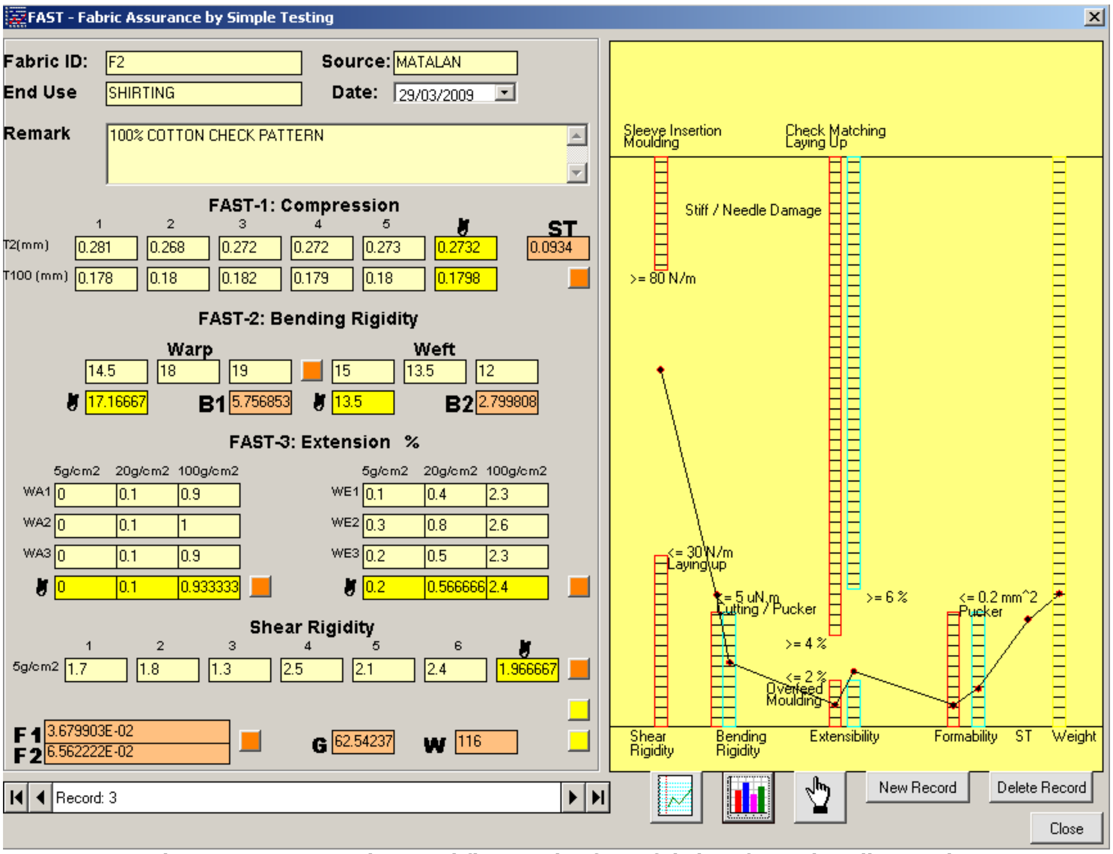

Figure 5.21: FAST data and fingerprint from fabric 2 from the pilot study

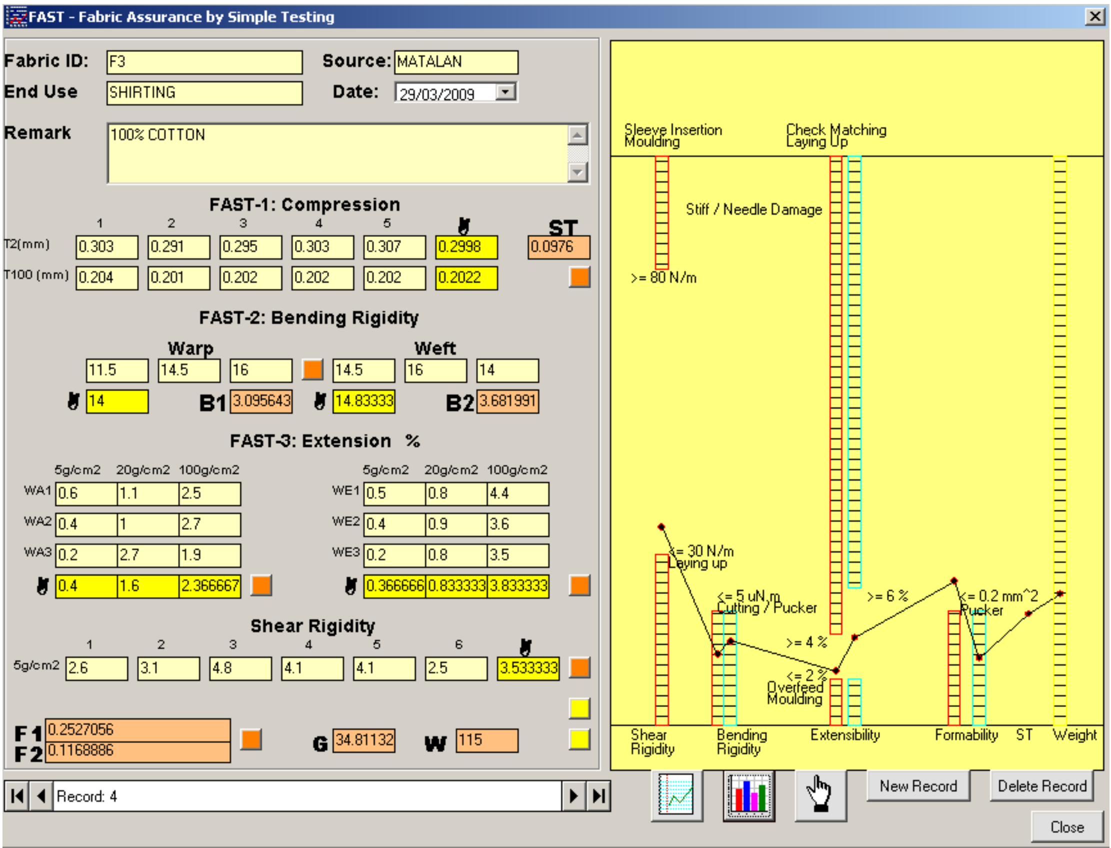

Figure 5.22: FAST data and fingerprint from fabric 3 from the pilot study

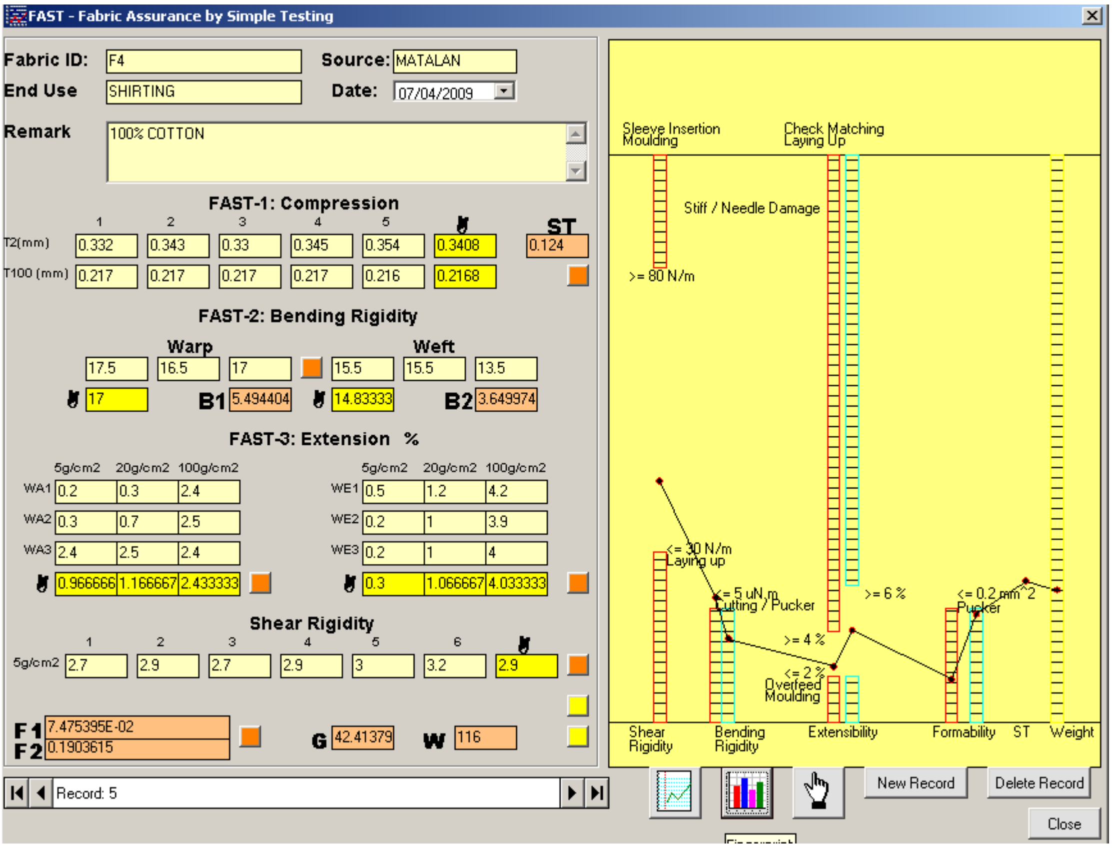

Figure 5.23: FAST data and fingerprint from fabric 4 from the pilot study

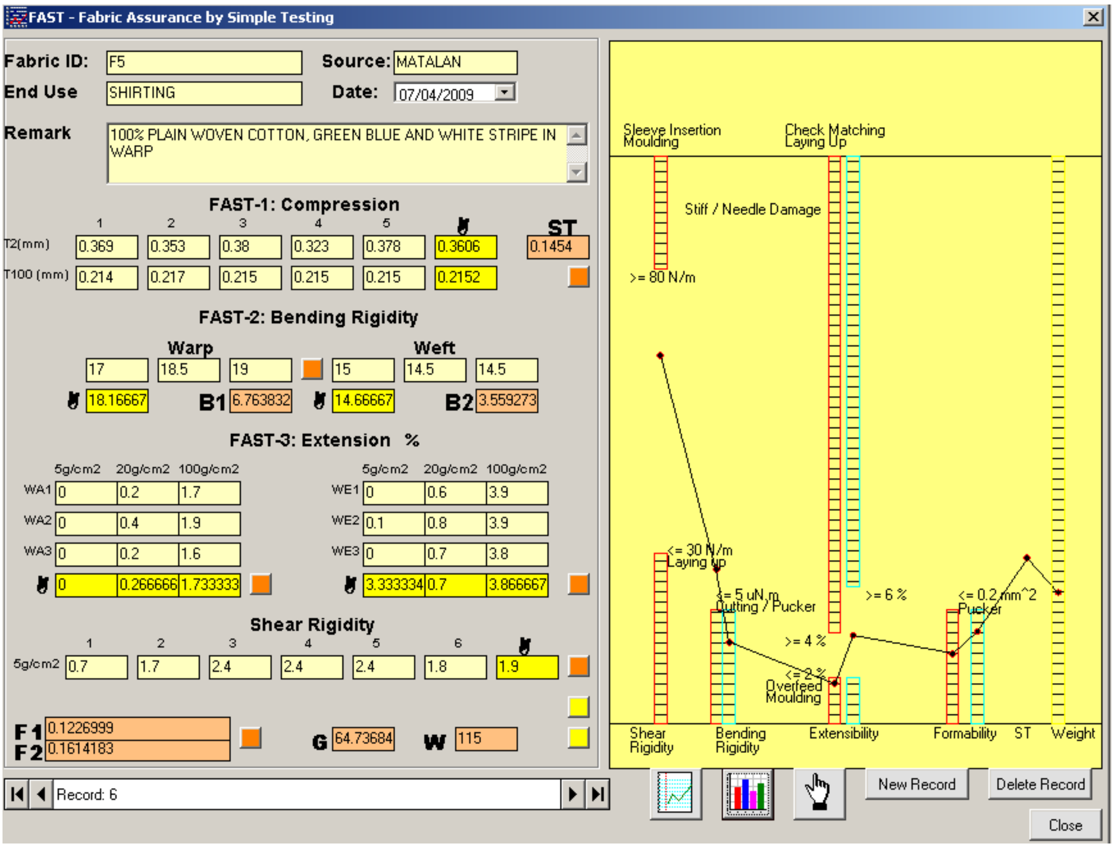

Figure 5.24: FAST data and fingerprint from fabric 5 from the pilot study

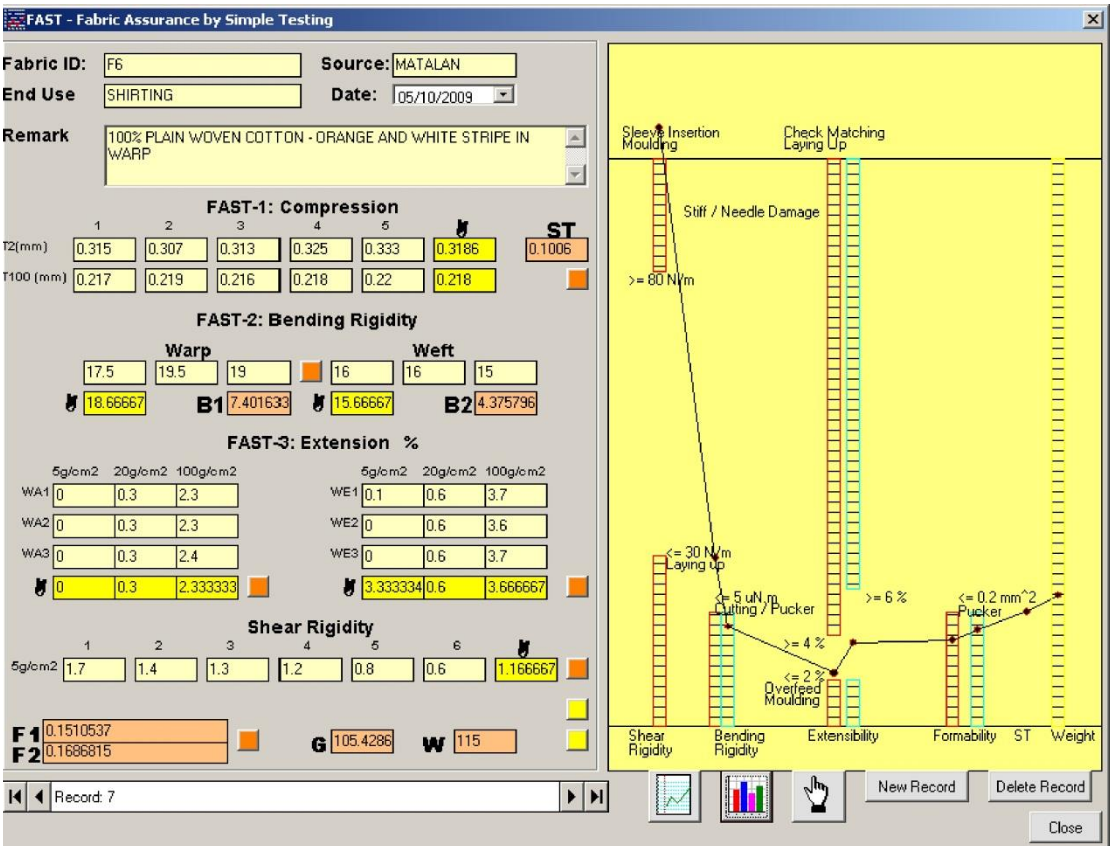

Figure 5.25: FAST data and fingerprint from fabric 6 from the pilot study

Figures 5.22 to 5.25 indicate that the shear rigidity is within the comfort zones of the FIT system, the exceptions being fabric F1 and fabric F6 where the values are noticeably lower and higher respectively. Lower shear rigidity means that the fabric will be easily distorted in laying-up, marking and cutting. Higher shear rigidity indicates that the fabric will be difficult to form into three-dimensional shapes, causing problems in moulding and sleeve insertion. Drape may also be affected.

5.10. Summary of the tweaked sewing machine settings

The sewing machine settings used for the experiments were initially adjusted in accordance with the recommendations given by expert SPEC 1. Sample specimens were sewn (figure 5.27) and evaluated for seam flatness and pucker and were found to be slightly deformed. The machine was then further adjusted (tweaked) in order to produce the flattest seam possible. The final machine settings are given in table 5.4.

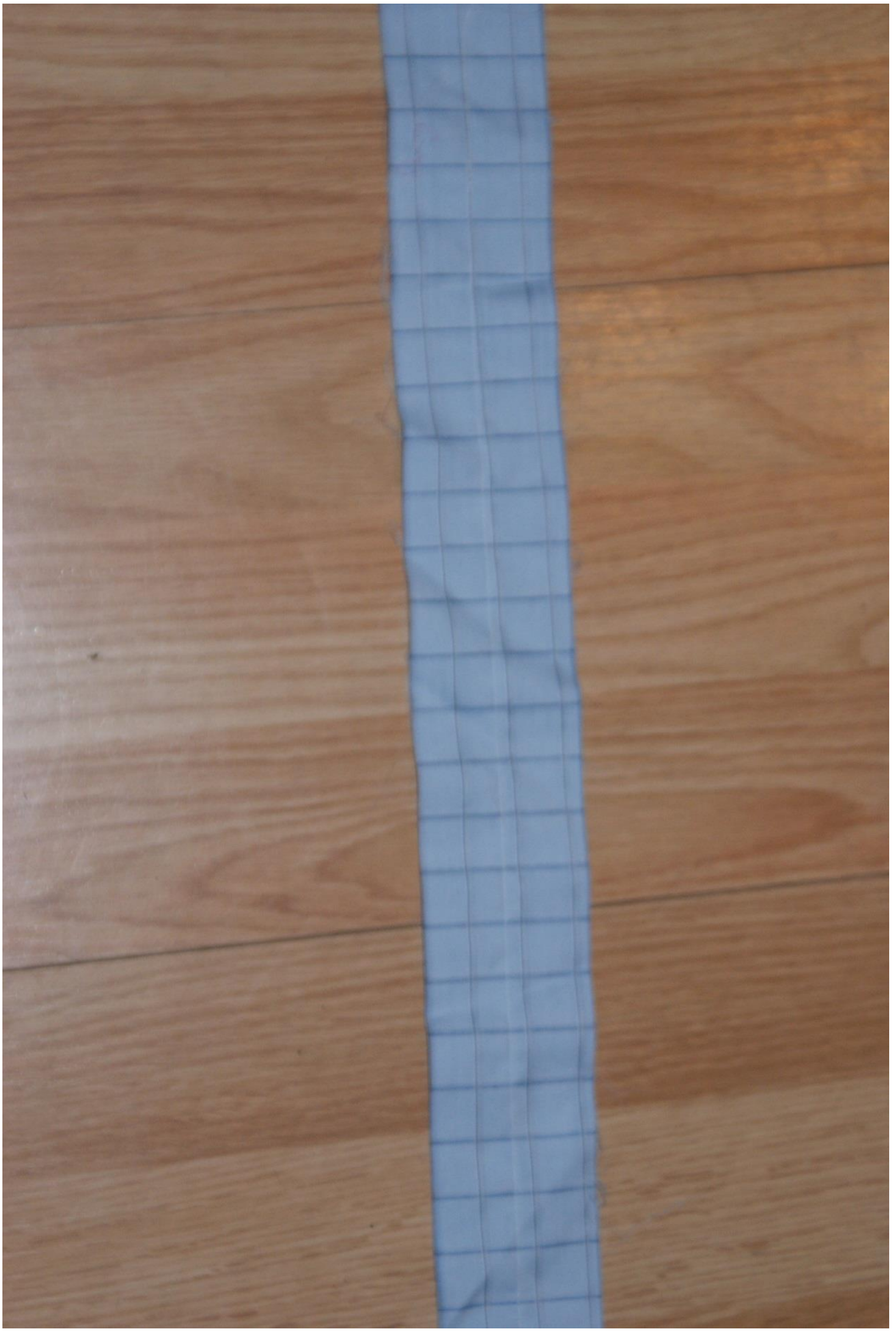

Figure 5.26: Specimen from fabric 1 from machine settings given by SPEC 1

Variable		Setting
A	Presser foot force	24 N
B	Feed dog	Fine tooth feeder, (All teeth showing above the throat plate 1mm)
C	Machine speed	4000 stitches / min
D	Stitch density	5 s.p.cm
E	Needle thread tension	1.07 N
F	Bobbin thread tension	0.12
G	Sewing Thread	150's Polyester core spun
H	Needle size / point type	70's Schmetz SPI
I	Check spring	Set to wink when the sewing thread is in the six O clock positing on the sewing hook

Table 5.4: Sewing machine parameters set for the experimental work

Sewing thread tensions were measured using a pencil thread tension measurement device (figure 5.28). These instruments are low cost technology and can be purchased for a few pounds. Presser foot force was measured in millimetres and converted to 'Newtons' (figure 5.29). These measurements are derived from measurements the presser foot force measurement gauge (figure 3.4, chapter 3). Hence the force given of 24 'Newton's' in table 5.4 equates to 4.2 cm from a standard measurement rule.

5.11. Results from the AATCC analysis

The individual results from the AATCC seam pucker charts by each expert are given in the tables below:

	s1	s2	s3	**Median**	**Mode**
fabric 1	4	4	4	4	4
fabric 2	5	5	5	5	5
fabric 3	5	4	5	5	5
fabric 4	4	4	5	4	4
fabric 5	5	5	5	5	5
fabric 6	5	5	5	5	5

Table 5.5: AATCC results given by expert 1

Figure 5.27: Pencil sewing thread tension measurement device

The fabric generally ranked as the lowest for seam flatness is fabric one, which is the 50% Polyester and 50% Cotton material. But this fabric seam according to the experts that assessed the materials would be ranked a pass in industry.

	s1	s2	s3	**Median**	**Mode**
fabric 1	5	4	4	4	4
fabric 2	5	4	4	4	4
fabric 3	4	4	5	4	4
fabric 4	5	5	5	5	5
fabric 5	5	5	5	5	5
fabric 6	5	5	5	5	5

Table 5.6: AATCC results given by expert 2

	s1	s2	s3	**Median**	**Mode**
fabric 1	4	3	4	4	4
fabric 2	5	3	4	4	4
fabric 3	4	5	5	5	5
fabric 4	4	4	4	4	4
fabric 5	5	4	4	4	4
fabric 6	4	5	4	4	4

Table 5.7: AATCC results given by expert 3

As described earlier, all of the materials were sewn at the maximum sewing machine speed with the fabric allowed to feed freely through the machine. The subjective analysis given by the assessments against the AATCC charts indicate that the seams show a good degree of seam flatness and would be acceptable in production.

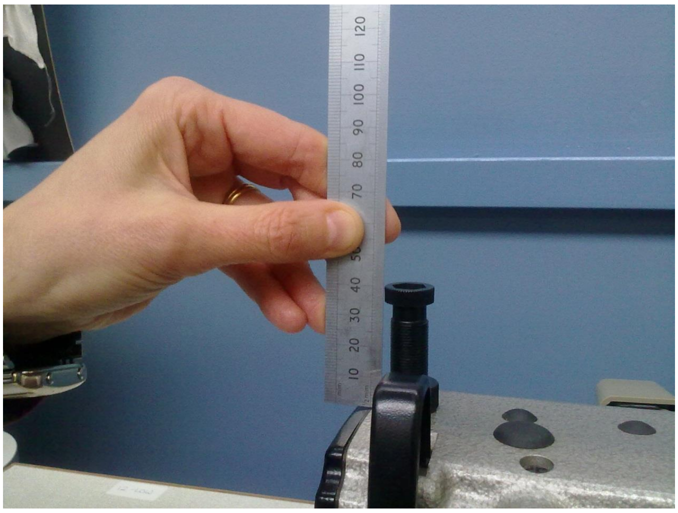

Figure 5.28: Presser foot screw adjustment measured with a standard measurement rule

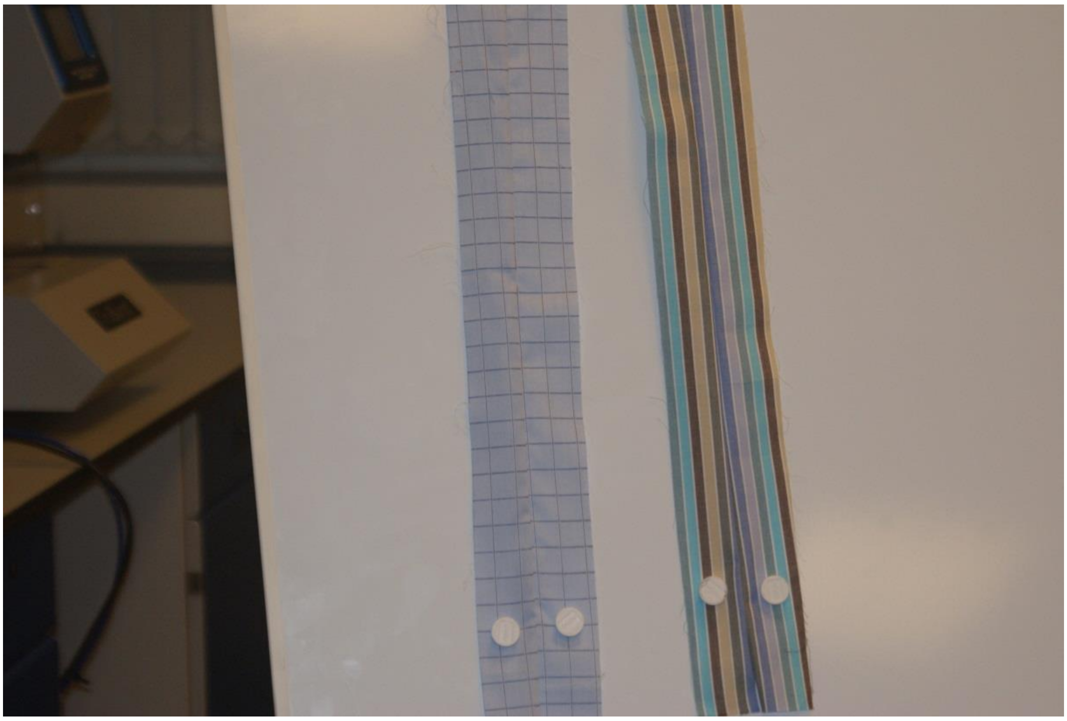

Figure 5.29: The seams of fabric 1 (50% polyester, 50% cotton) and fabric 2 (100% cotton)

5.12. Comparison of sewn seams to the FAST test results

The FAST test results for fabric 1 (figure 5.21) indicates low shear rigidity and this result seems possible as it can be seen from the diagram below that there are gaps in the fabric structure. This would allow the yarns to move (shear) across each other. The FAST explanations for this value mean that there may be problems with the laying up and cutting the fabric.

The FAST results for bending rigidity and formability indicate mainly low values for all the six fabrics and these values point towards the possibility of seam pucker, seam buckling and distortion. The sewn results do not agree with FAST for these six materials. The AATCC grades given by the experts confirm that flat seams achieved on the fabrics are acceptable in the flatness of the seam. This contradicts the FAST data. The subjective measurements support the literature on subjective fabric handle (chapter 2, pg 40) *“That fabric handle in production is based upon the judgement and experience of fabric handlers”.*

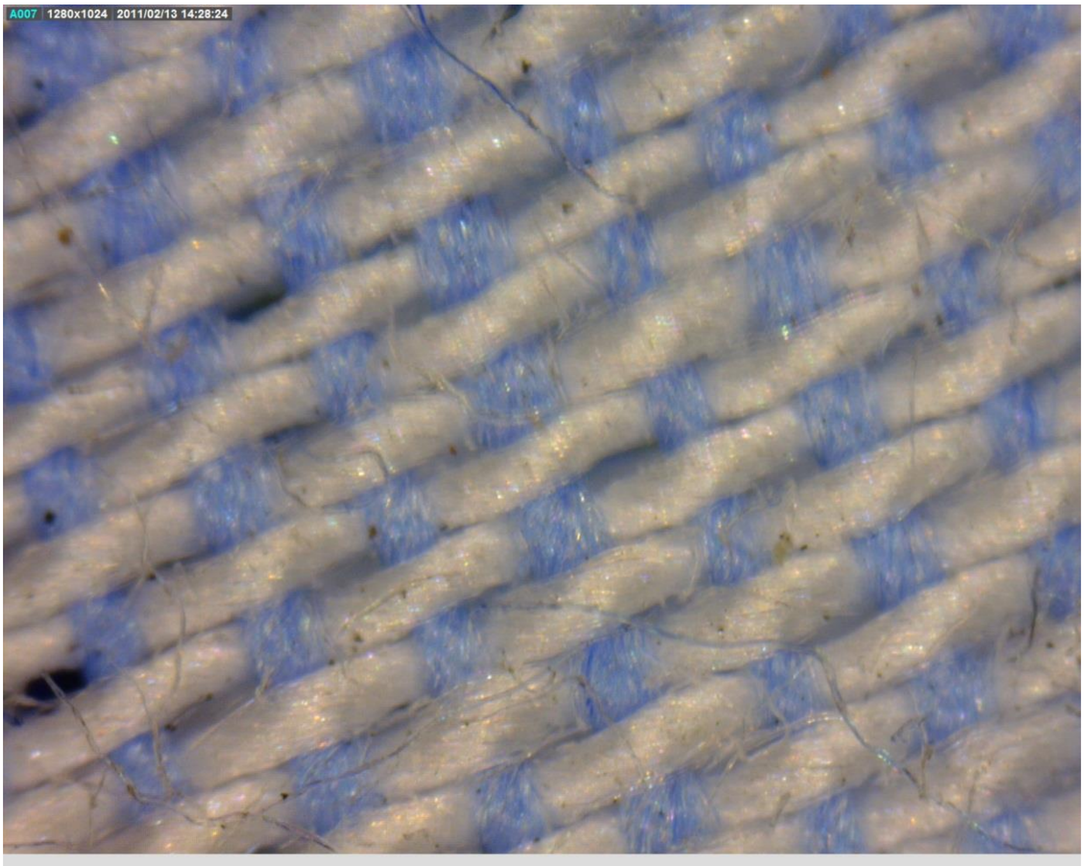

Figure 5.30: Fabric 1 showing gaps in the fabric structure

The FAST test results may be considered by some to be an objective barometer for the sew-ability of the fabric. However, it became apparent during this pilot study that the physical parameters are equally important to the quality of the seam.

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5.13. Comparison of sewn seams to the physical parameters

The most important parameters have been determined as:

- Composition of the material
- Fabric structure
- Fabric weight
- Ends and picks / cm
- Tex
- Crimp %
- Cover factor

Fabric 1 (50% polyester / 50% cotton) has the lowest weight of all the fabrics and has the highest number of ends per cm. This material also has the highest cover-factor in the warp direction. This fabric does exhibit greater seam distortion and indicates the least resistance to the forces of the sewing thread and forces from needle penetration. The AATCC analysis also grades this fabric marginally lower than the other shirting fabrics.

All of the materials were sewn using the same machine settings for each material. The sewing thread tension and presser foot were adjusted for optimisation for the fabric. These adjustments could not be set any better as any further slackening of the tension for example would result in the deterioration of the stitch (going slack). Any further reducing of the presser foot force would result in the possibility of ply slippage. These adjustments eliminated the possibilities of stitch pucker or feed pucker. Therefore, any pucker still present on the seam is likely to be (inherent pucker) structural jamming (figure 7.32). This is where the sewing thread displaces the yarns in the material. It can be seen from the figure 7.33 that the sewing thread has a greater diameter than the yarns of the fabric. This will undoubtedly cause some displacement and distortion of the seam, affecting the seam flatness.

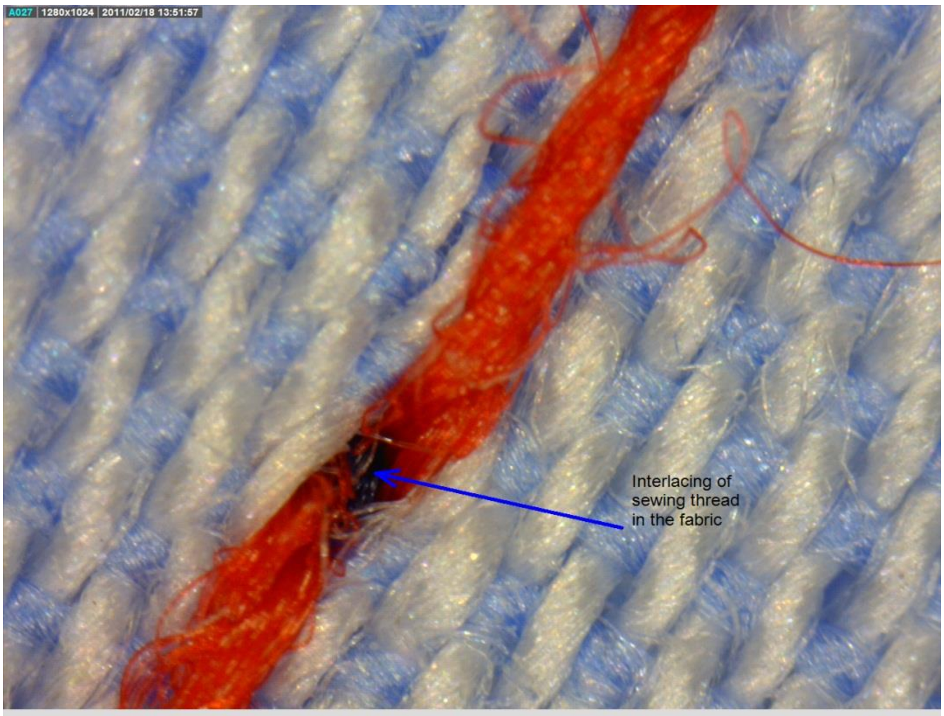

Figure 5.31: Interlacing of the sewing thread in the fabric

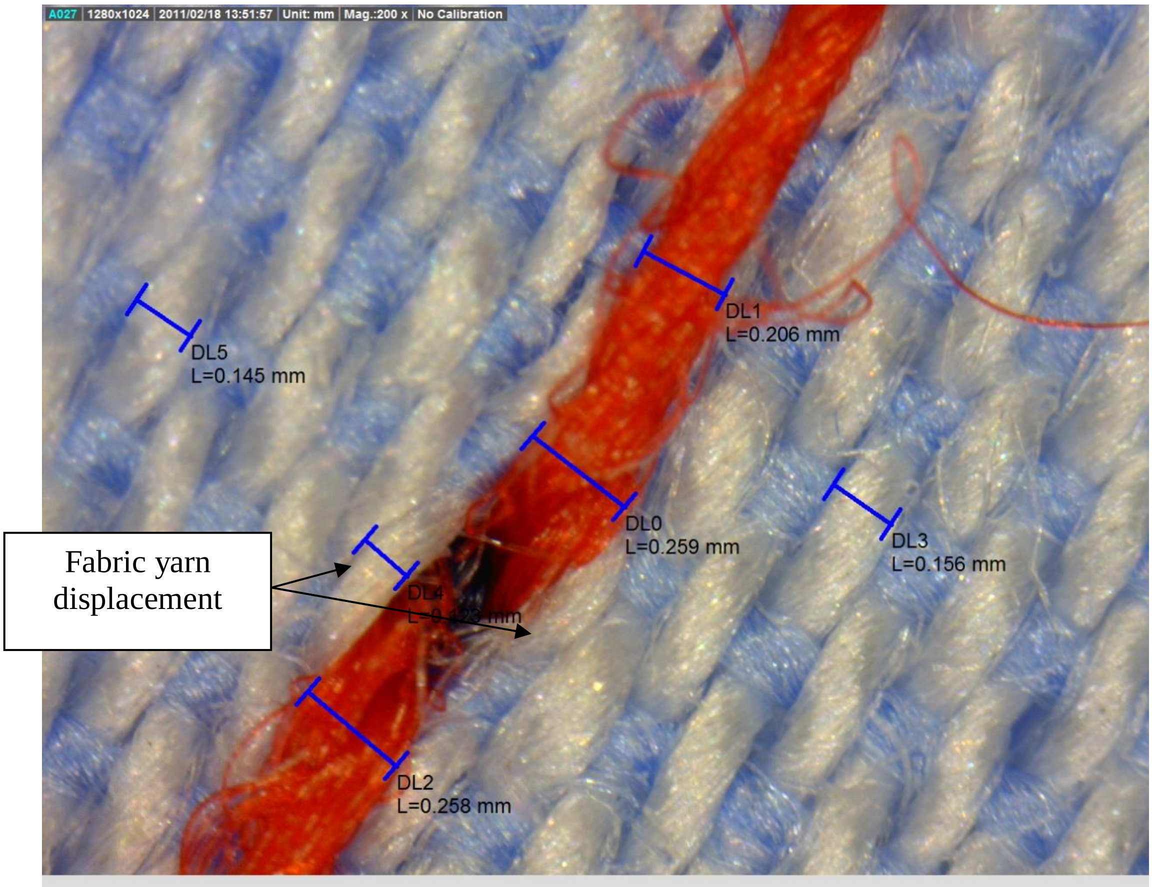

Figure 5.32: Width of the sewing thread compared to width of the yarn

3 points across the sewing thread and fabric yarn have been taken and the mean taken from these measurements. These are given in table 5.8 below.

				Mean
Sewing Thread	0.206 mm	0.259 mm	0.258 mm	0.241 mm
Fabric Yarn	0.123 mm	0.146 mm	0.145 mm	0.138 mm

Table 5.8: Yarn sewing thread diameter measurements

Using a high performance USB camera, it can be clearly seen that yarns of the fabric are being displaced by the sewing thread at the interlacing point where the needle has penetrated the material. The yarn with the smallest diameter is the one most displaced by the sewing thread. This camera device has proved to be an essential aid in identifying the physical properties of the material.

5.14. Model of physical properties and reporting functions

There are many correlations between fabric parameters and the ones considered to be the most important here are given below in figure 5.34. The reasons for choosing these parameters have been explained above. Another factor to consider is that the sewing thread shown in figure 5.33 is the best thread available for sewing this type of material. However it can quite easily be seen under microscopic conditions that the thread shows quite a high degree of yarn hairiness on the face of the fabric. It seems probable that this condition is also present inside the fabric creating greater fabric distortion.

The algorithm developed for the FIT system to generate the reports is based upon the physical properties of the six fabrics and not on the FAST test data. This is because the results from the sewing experiments do not support the FAST test results.

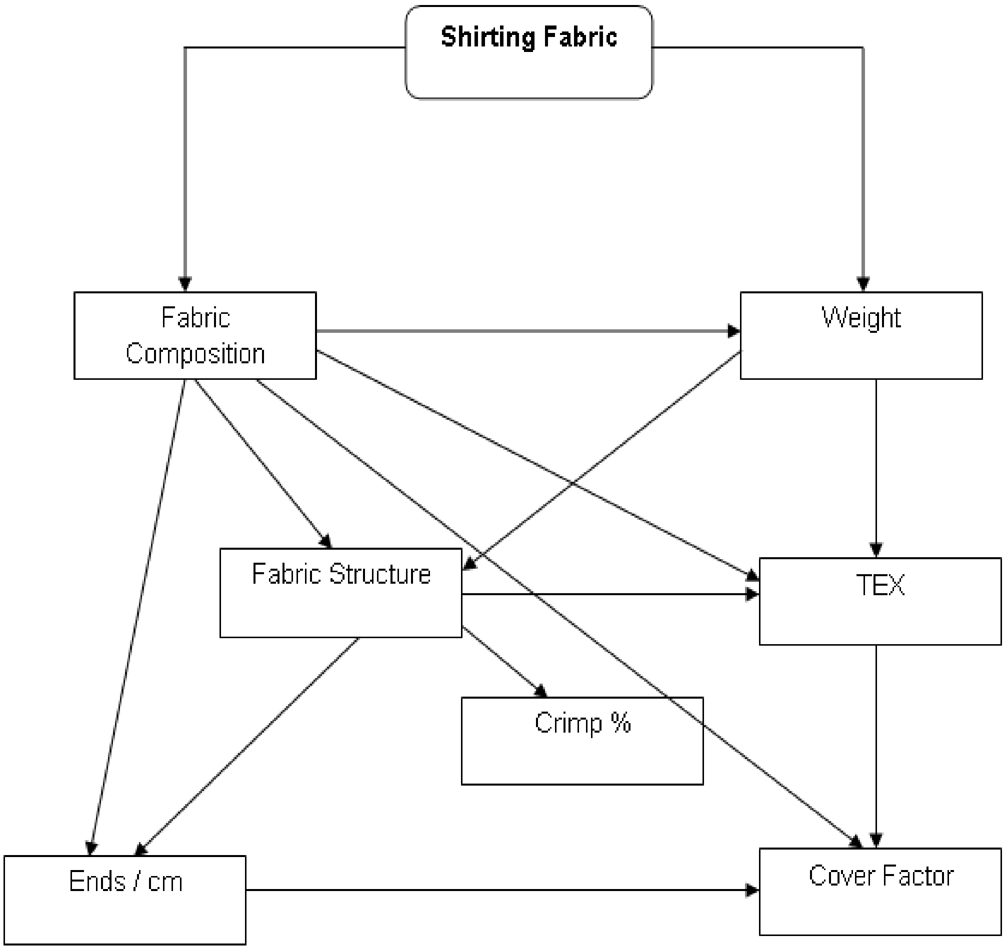

Figure 5.33: Model of fabric physical properties for fabric sew-ability

5.15. Discussion summary

The pilot study was essential in providing information to be used for developing the methods and techniques necessary to be used for the main investigation. However there were some factors that did not work as well as expected and these are as follows:

- The blind subjective evaluation proved to be an interesting assessment of fabric handle. However the process was lengthy so it was decided to abandon this method and focus on visual evaluation for the main study.
- Time taken with this expert was approximately 3 hours, which was an excessive period so it was deemed appropriate to reduce this due to time restrictions.
- The AATCC charts used for the seam flatness assessment were based upon seams after fabrics have been laundered. The sewn samples were not laundered prior to assessment.

Fabric properties, fabric density and processing are all factors that can have an outcome on the sewing of the material. Cotton fabrics in particular are subject to humid conditions, which create moisture in the fabric causing them to swell. This makes them more difficult to process through the sewing machine due to the fabric being thicker.

The connection between the fabric parameters and sewing parameters is often complex and difficult to comprehend on the production floor. There exists a void between the knowledge of sewing fabrics in practise and of the understanding the properties of the fabrics themselves. This research has been undertaken in order to simplify the understanding of this relationship and by increasing and adding to the knowledge of why and how fabrics behave unpredictably, can enable professionals within the industry to react more efficiently to problems that occur. There exists a void however between the knowledge of sewing fabrics in practise and of the understanding the properties of the fabrics themselves.

Many skilled and very knowledgeable people have not had the opportunity to do formal, recognised training at a College or University. They have relied upon on the job training, which has focused more upon how you do things in practice but have not learned much of the theoretical knowledge underpinning sewn product technology. A typical example of this is that many people within the industry do not know or understand the importance of stitch numbering systems when developing garment specifications.

As explained in chapter two, the introduction of sophisticated fabric measurement systems such as the Kawabata Evaluation System and the Fabric Assurance by Sample Testing (FAST) has enabled fabric parameters to be quantified more scientifically (Kawabata and Niwa, 1991; Basu, 2002). However, the results from this data are difficult to interpret by an untrained eye and the explanations given about fabric sew-ability have been described by industrialists as difficult to understand (McLoughlin, 2005). By being able to translate the scientific information derived from the objective assessment to the fabric handlers on the production floor would enable a better understanding about fabrics before being manufactured into garments thus making them more effective in solving production problems.

Chapter 6 DESCRIPTION OF METHODS AND TECHNIQUES FOR THE MAIN STUDY

6.1. Discussion

Research has been undertaken in copious areas of stitching fabrics together (Yuen et al, 2009; Tarafder et al. 2005, Kurt and Walter, 2006). The literature discussed in chapter two highlights work that describes futuristic techniques for stitching materials by textile scientists. It has also been mentioned that most machine adjustments can only be made by hand. The work described here provides a redoubtable argument for a simplification of adjusting machines from a human perspective.

The chapter discusses the methods used for the main investigation and of their importance for developing the concept for a smart stitching databank for sewing machine adjustments. The chapter also proposes the notion that the sew-ability of the material can be predicted prior to stitching the fabric and how objective and subjective methods can be used in harmony together.

The judgement from the experts provided useful information necessary to build the algorithmic models for this work. The purpose was to develop a conceptual framework for a databank of base sewing machine settings for apparel fabrics.

In order to achieve the aim, the objectives of the research were to:

- Determine the physical measurements of the fabrics;
- Conduct sewing experiments on fabrics from the “FAST” system;
- Establish the accuracy of the sewing results compared to the “FAST” data;
- Compare the objective test results with subjective assessment from an expert panel;

- Ascertain the accuracy of the “FIT” system with current reporting methodology.

In order to achieve the objectives, the following experimental work was carried out. Both objective and subjective measurement used enabled this goal to be achieved as shown in figure 6.1.

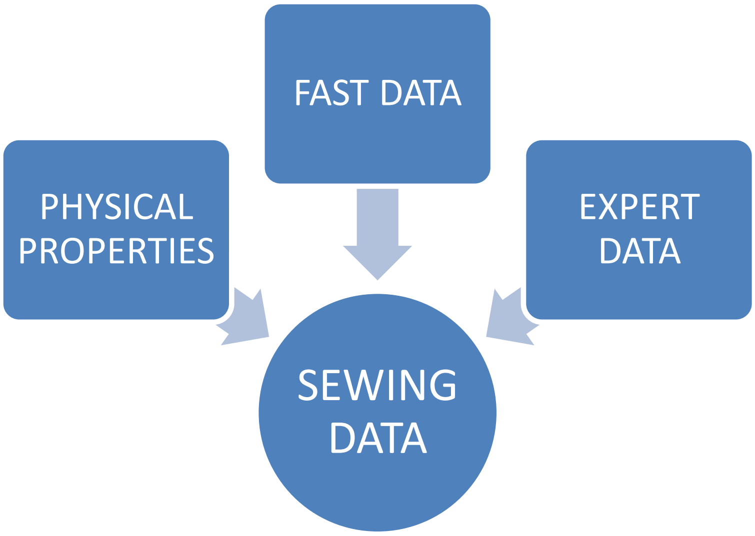

Figure 6.1: Fabric sew-ability for subjective and objective assessment

The physical data and FAST data provided a valuable insight into the properties of the materials which included the deconstruction of the materials and analysing their mechanical propertes.

However, as mentioned above, most adjustments on machines that stitch fabric can only be adusted by hand and this requires considerable skill by the engineer. Therefore expert opinion was researched in order to provide as much information as possible. The significance of the committee was to:

- Extend the pilot study on a wider range of fabrics to broaden the scope of the research using more expert opinion;
- The experts to advise on fabric properties that may create proplems during stitching that cannot be obtained objectively;
- The experts to recommend machine settings for stitching the materials to an acceptable quality standard;

It is important to mention that this knowledge from the experts can only be acquired from many years of industrial experience. From the knowledge given by the expert team, a model was established for creating a holistic view of devlopmental procedures for this work. This model is given in figure 6.2.

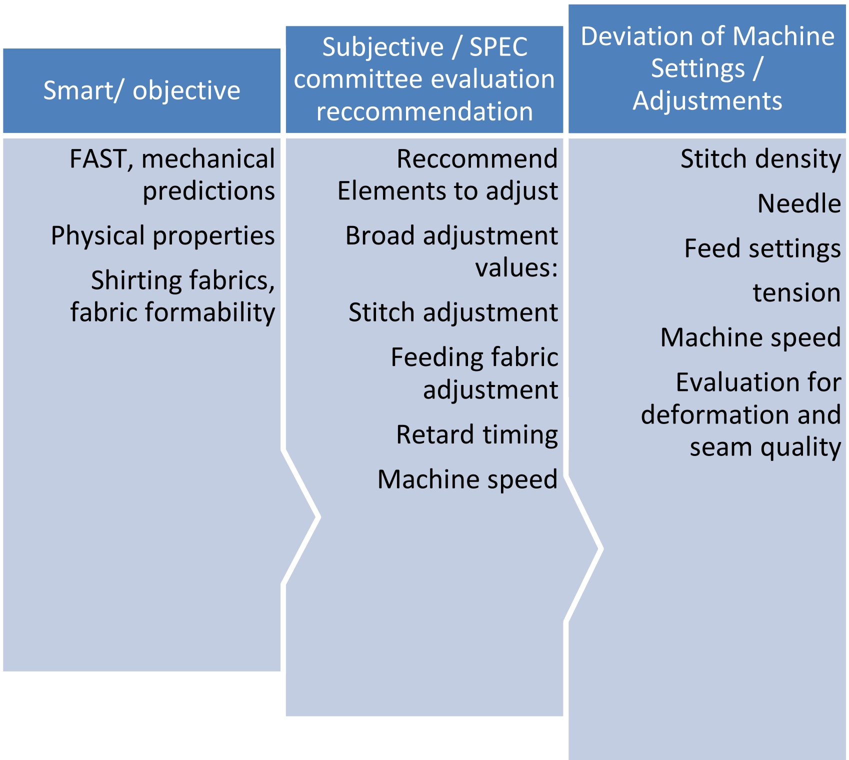

Figure 6.2: Representative model for development of the methodology

6.2. The importance of the Pilot study

Pilot studies are common in the examination of textile materials (Ong et al. 2014.; Shaikh and Nasir 2013; Mangalapally et al 2011; and Ku et al.). As described in chapter 5, the pilot study was undertaken in order to assess the feasibility of the techniques to be used for the main investigation. The information from the expert (SPEC 1) provided an important contribution to this work due to his extensive knowledge of objective measurement and his industrial experience. He was the only individual of all the experts with this knowledge. This experience was acquired through many years in the clothing manufacturing industry and with a major leading sewing thread manufacturing company.

It was decided after the pilot to proceed with a similar methodology for the main investigation, the exception being the blind evaluation. This method was deemed useful. However, this technique was not used for the main investigation as it was decided that it would be too lengthy to complete successfully. This was due to the greater number of experts and fabrics used. It is also important to mention in the next chapter that the experts are referred to mainly as judges. Hence judges and experts are one and the same.

6.3. The sewing parameter evaluation committee (SPEC)

The sewing parameter evaluation committee were selected for their expertise in the handling and sewing materials. In the pilot study, one expert was selected for his extensive knowledge of both objective measurements and the sew-ability of materials at the needlepoint. The experts had extensive knowledge in the repair and maintenance of the sewing machine and wide-ranging experience in trouble shooting problems on garment quality and performance. The experience of all ten experts is given in appendix 5. Members of the SPEC committee are given in figure 6.3.

6.3.1. The organisation of the committee

There is no doubt that the hand judgement of fabric is one of the important factors of fabric properties and is still widely used in industry (Kawabata, 1980). Expert opinion was an essential part of this research work as it valued the contribution of a wide range of opinions for the sewability of textile materials. Expert opinion has been used for evaluating the performance of textile fabrics for many years (Sharhabi, et al. 2013; Jaouachi et al. 2010; and Gong, 1995). These expert opinions have been mostly concerned with fabric assessment and calculation. The methods presented below involve experts with practical and industrial experience in the stitching of fabrics. They are specialists in the stitching of materials and adjusting the sewing machines to achieve the highest quality of seam.

The importance of facilitating a robust and credible technique for developing the framework for the machine settings database was founded upon the opinions given by the Sewing Parameter Evaluation Committee.

Figure 6.3: Members of the sewing parameter evaluation committee

The experts were classified into two categories namely experts in factories and also as senior people now in retailing. The experts in factories are the frontline professionals that are responsible for the production and quality of the product and have used this hand judgement to control the property of their merchandise every day. The retailer on the other hand would select a fabric by hand in order to select a good clothing material according to the feeling and experience when purchasing the garments from the manufacturer.

Where industrial methods are used in the production of apparel, the sense of touch has not been replaced by robotic methods or by objective methods of assessment. Subjective expressions are commonly used like ‘stiff’, ‘soft’ and limp etc. to describe the properties of the material. It is possible that these subjective assessments can lead to confusion between fabric handlers. It was identified by Kawabata (1980) that these expressions were not classified or defined and that professionals had some different conception about the feeling of each of these expressions.

It is for this principle reason that the sewing parameter evaluation committee (SPEC) was formed to assess fabrics for their handle and sew-ability and to prove or disprove the hypothesis outlined at the beginning of this chapter.

The function of the committee's activities was a simple methodology to:

(1) Judge and rank the fabrics according to their perfection / imperfection for seaming deformation

(2) Suggest and recommend suitable sewing machine settings in order to provide the optimum adjustments for fabric sew-ability

These people have many years of experience in the maintenance, trouble shooting and repair of clothing and ancillary machinery. All are experts in seam distortion problems, reducing seam pucker, ply slippage, seam buckling and general seam performance. The experts were invited to handle the twenty fabrics and render their judgement on the sew-ability of each material. The fabrics were ranked from 1 to 20 from 1 being the worst to sew to 20 being the best. The experts were also asked to give their opinion on the sewing machine settings required to give the best results for preeminent quality of seam. The results for the handle of the fabrics are given in table 7.2 in chapter 9.

Each analysis from an expert lasted for approximately two hours and consisted of a thorough handling of all the materials and guidance to their stitch-ability and sewing machine adjustments. This information was recorded on a data sheet (appendix 6)

The results are contained and explained in chapter nine.

6.4. Measuring the levels of agreement between the experts

The levels of agreement between the experts were measured, adapted from Kendall's Coefficient of Concordance 'W' (Leaf, 1987) where the values range between 0 and 1. If all the rankings are the same meaning complete agreement then 'W' would equal 1. If the rankings between the judges differ significantly, then 'W' will be closer to Zero. This equation is given in equation 6.1 and the ranking is discussed in chapter nine.

$$W = \frac{12S}{r^2 n(n-1)(n+1)}$$

$$\text{Where } S = \sum_{i=1}^{n} (r_i - \overline{r})^2$$

Equation 6.1: Kendal’s Equations of Coefficient of concordance

S = the sum of the squares of the deviations
r = the number of judges

r = the mean of the rank -sums
n = the number of fabrics used in the study

$$W = 0.3779$$

6.5. Fabric deconstruction and FAST testing

The fabric deconstruction and FAST testing were carried out in accordance with the pilot study. A pilot study of two-plied lock-stitched seams was deemed appropriate in order to determine the outcome for the “FAST” test data. Twenty commercial fabric types were chosen that had been tested on the “FAST” system. All the fabrics were used to manufacture men’s and women’s SHIRTING garments.

Due to the Limitation of fabric quantities, lengths of fabric for the sewing experiments were limited to the warp direction only.

The fabric sett of each fabric was determined using a piece glass and counting needle over a light source in accordance with British Standards BS 2862:1972(85). The sample specimens were conditioned in a standard atmosphere for testing textiles for a period of 24 hours prior to the sewing experiments.

The mean percentage yarn crimp was measured for the ends and picks of each sample, using the methods laid down in BS 2865:1984(101) and BS 2863:1984(102). The values were calculated in order to determine if a relationship would exist between the yarn crimp and the results of the seaming process. It was recognised that while crimp was measured in the warp and weft directions, planned seaming was in the warp direction only (McLoughlin, 2012).

The sewing tests were performed under conditions as close as possible to commercial conditions. A Juki lock-stitch (model DB2-B755-403A) was used in these experiments. The machine was a fully programmable ISU (integrated stitch unit) from the F-40 operating panel. A four legged, drop feed, feed dog was set at the recommended height of 1.00mm above the throat plate for medium weight materials. At this height all of the teeth are visible above the throat plate in order to provide an evenly distributed feeding action on the fabric.

The machine used a rotary hook mechanism comprising of a top thread (needle thread) and a bobbin thread (bottom thread). The stitch was formed by the interlacing of these two threads. Element 1 lists the principle elements of stitch formation. Previous work undertaken by Bertoli and Munden highlighted the effect of machine variables during the lockstitch process and identified them as constant variables. The variables used in this research had to be changed for each piece of fabric. A technique known as “machine optimisation” was used to set the machine for the sewing tests. Optimisation is when the stitch tension and presser foot settings are set as light as possible in order to sufficiently sew the material without ply slippage. The stitch forming elements are given in Element 1.

- **<u>Sewing threads</u>**

The sewing thread used was Coats EPIC staple core-spun polyester commonly used in industry for the application of the chosen seams as well as the variety of fibre types named by Coats (1999). The density of the thread was measured and found to be 240dtex. Each of the cones carried 5000 metres of thread and gave an even delivery from the machine stand spindles i.e. there was no over-delivery of thread during the sewing process; over-delivery of thread to the take-up and sewing mechanism may result in snagging of the thread during seaming. Coats

(1999) stated that: "(the cones) – give trouble-free delivery at intermittent or continuous high speeds and this, combined with their long length capacity, makes them ideal for use on Class 300 lockstitch".

ELEMENT 1

Needle thread tension unit
Check spring
Take up lever
Needle bar
Feed system (fittings)
Rotary sewing hook and base

The sewing thread tensions for each fabric were measured using the electronic "Coats M82000-000 Thread Tension Metre" and the "Tajima A321 thread tension pencil gauge". The Tajima pencil gauge was relatively inexpensive costing only a few pounds. The reason for using both these gauges was to compare the readings between the two instruments in order to measure the variation between them. It was decided that if the variation was minimal, then the "Tajima pencil gauge" may be a useful tool to companies in setting thread tensions objectively and accurately. Examples of these tension units are given in figures 6.4 and 6.5.

In order to try and determine the accuracy, ten measurements were taken from the upper thread tension of the lockstitch machine by both instruments.

The results from these tests are given in chapter nine (tables 7.1 and 7.2).

6.6. Investigation for the guide line of sewing machine base settings

A machine base setting is the starting point for adjusting the machine to the fabric to be stitched. The experts gave recommendations for the settings of the sewing machine which were initially used to set the machine as a starting point for sewing each material. Each fabric was stitched in the warp direction on two plies of material at one centimetre in from the edge of the fabric. The material was placed in a guide (figure 8.6) to give accuracy to the stitching and to ensure that the plies of material were level and even. The fabric was fed uniformly through the machine with no operator handling in order to assess any ply slippage that might occur. If the seam showed any sign of seam pucker or deformation, the settings were refined in order to achieve the flattest seam possible. The fabric strips were cut at 51 centimetres in length by 5 centimetres wide and were stitched at the maximum speed of the machine at 4000 stitches per minute. This is representative of the speed that machinists would be sewing at on a production line in manufacturing. The objective was to make the conditions of sewing as demonstrative as possible to the industry. After each machine adjustment, the setting was recorded as in the pilot study. For example the adjustment of the pressure could be measured electronically (figure 6.7) and then the adjustment screw measured for its length. In this case 24 Newtons, was recorded as 42 mm in the length of adjustment on the presser foot adjusting screw (figure 6.8).

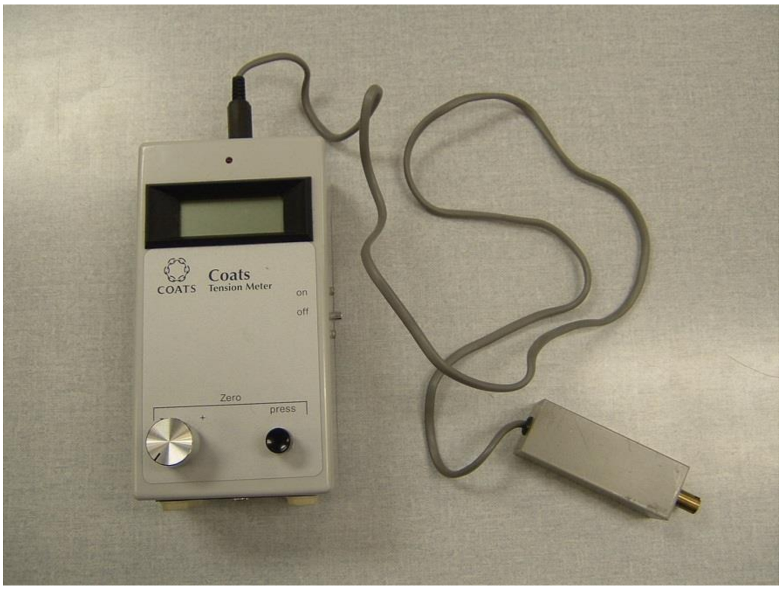

Figure 6.4: COATS M82000-000 thread tension metre

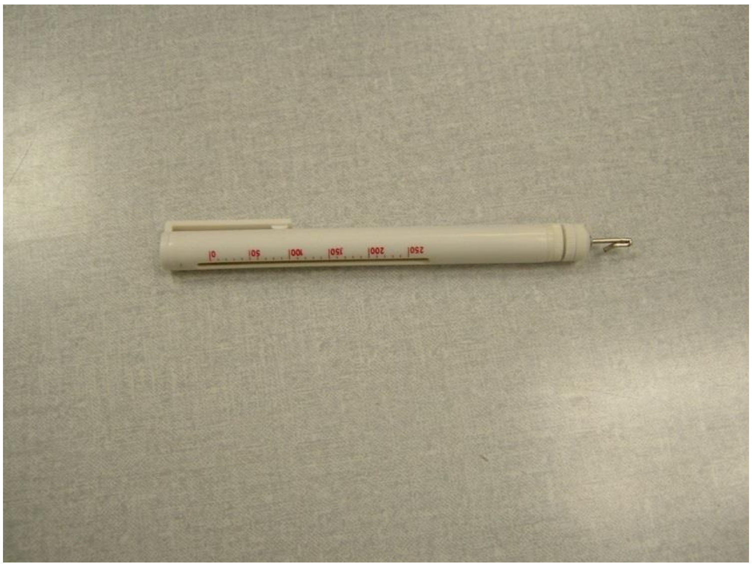

Figure 6.5: Tajima pencil thread measurement gauge

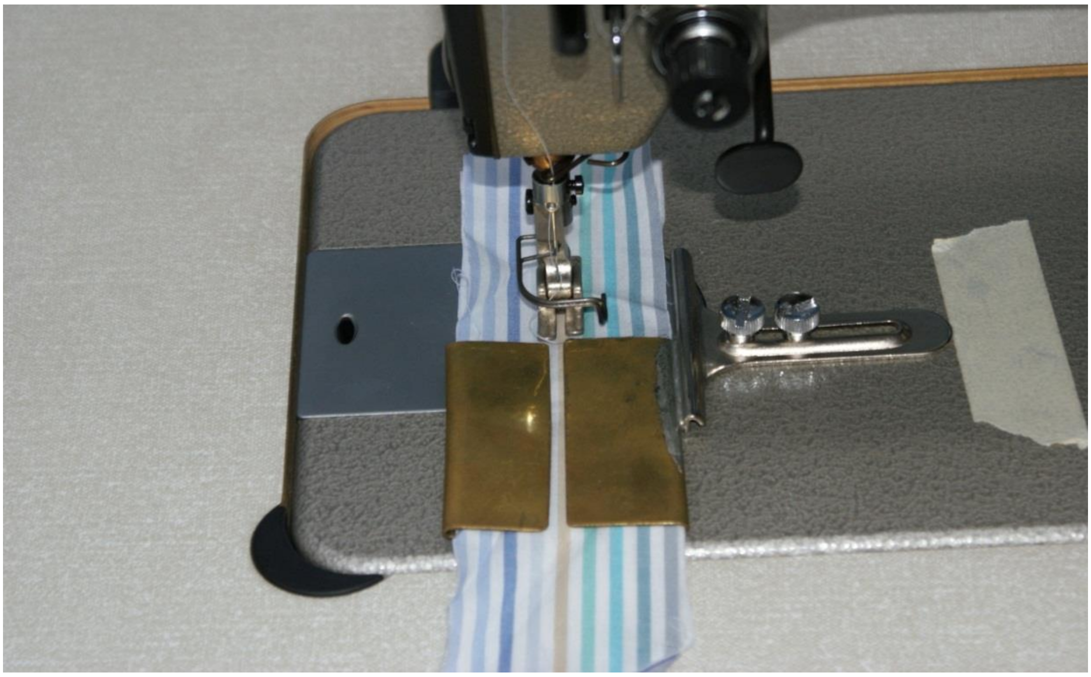

Figure 6.6: Plies of material fed through the machine

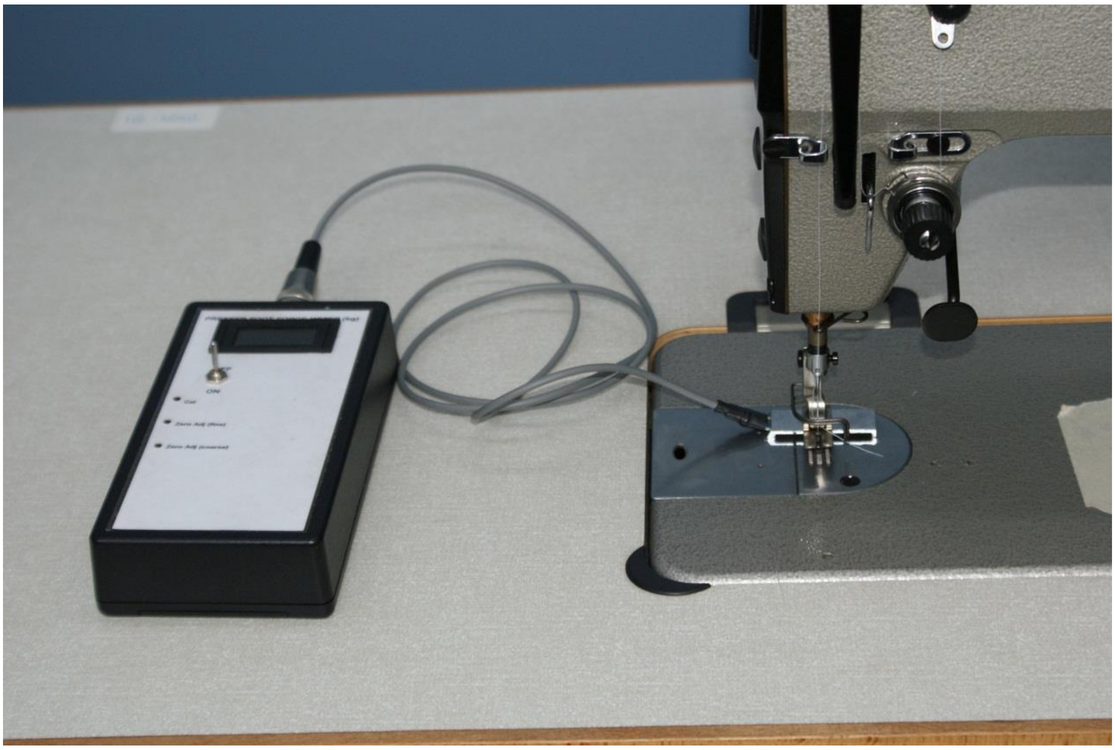

Figure 6.7: Presser foot pressure measured electronically

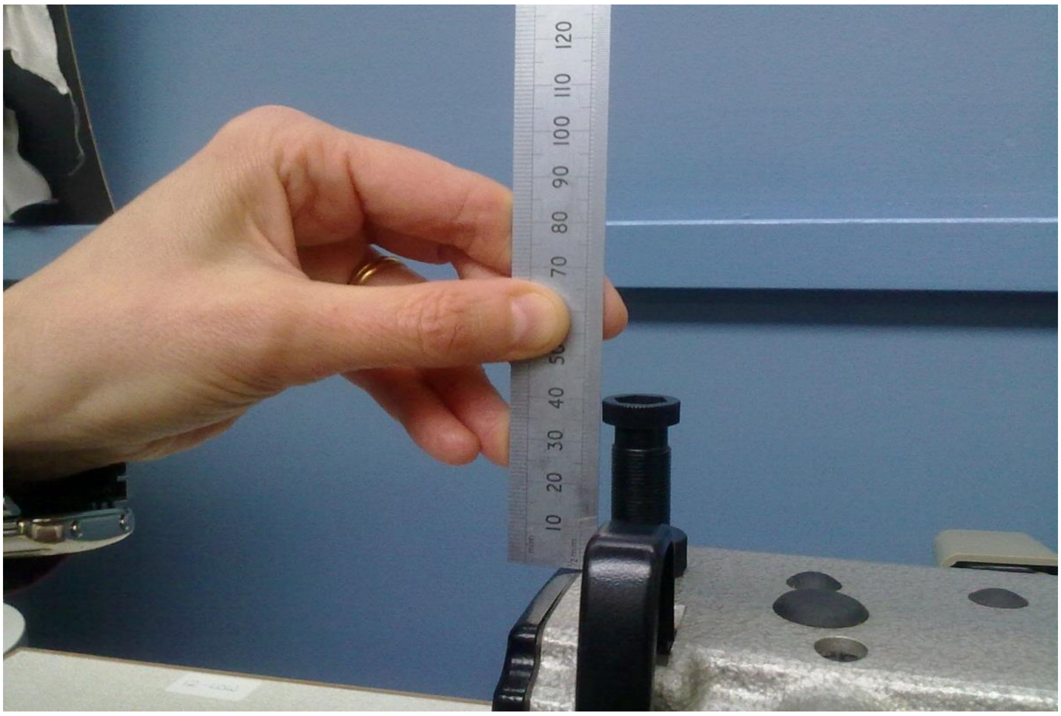

Figure 6.8: Measuring the length of the presser foot adjusting screw using a standard 6 inch rule

The experts did their best to provide a thorough analysis of handling the materials and rendering their judgement on the potential sew-ability of the material. It became evident throughout this process that it was more difficult for the experts to distinguish the differences between the handle of all the fabrics due to slight variances. With regards to recommending the sewing machine setting, all of the experts were in close agreement in endorsing the sewing machine settings. The collective recommendations from the experts are given in table 7.4.

As mentioned above, the sewing machine was initially set according to the experts recommendations based upon their experience of sewing materials. This was termed by the author as the absolute base setting and used as the first starting point for sewing all the twenty materials. After each fabric was sewn, a visual assessment was made to the quality of the seam. If any distortion or deformation was visible, the machine was adjusted by hand in order to achieve the flattest seam possible. Table 7.5 shows the adjustments for the 20 materials, which differ from those of the experts. These are often called in industry, the ‘tweaked settings’ as the increments of the adjustment are very slightly changed.

6.7. AATCC Examination of the materials

The fabrics were examined by experts using the American Association of Textile Colourists and Chemists (AATCC charts). The experts differed from those from the SPEC committee and a brief description of each expert is given in appendix 7. The experts graded the fabrics from 1 to 5 where:

1 = a distortion free seam to 5 being the most deformed.

Where the pilot study involved 3 observations from each fabric and the mean taken for each sample, only one observation was undertaken from the 20 fabrics. This was due to the greater population of the fabrics meaning it would take a great deal of time to complete. The results from the objective observations are given in chapter nine.

6.8. The fabric intelligent technology System (FIT)

The information from the physical and mechanical properties of the fabrics was inputted into the FIT system and an algorithm was developed for material sew-ability. The data gained from this algorithm was programmed into the FIT software in order to provide the stitch-ability information for all of these shirting fabrics.

6.9. Discussion summary

The pilot study proved to be useful in providing information to be for developing the methods and techniques necessary for the main investigation. However there were some factors that were amended:

- The blind subjective evaluation was not used due to the time factors with each expert and the greater population of fabrics
- Time taken with each expert was approximately 2 hours and access to the experts was difficult to organise.
- Data recording was a challenge due to time restraints.
- Many restrictions from the pilot study also applied to the main investigation.

The expert opinion proved to be useful in setting the machine at a base setting starting point. Chapter 7 discusses the results from the main study and a full discussion is provided.

Chapter 7 RESULTS AND DISCUSSION

7.1. Results from the main study

Chapter eight dealt with the investigation into the sew-ability of 20 shirting fabrics which are commercially used in the market. Subjective and objective methods of investigation were used in their assessment.

Subjective analysis from experts was utilised to give their judgement on the sewing machine adjustments for each fabric material. Objective measurement was used to gain an insight into mechanical properties of the material. The physical parameters of the fabrics were also ascertained through deconstruction.

The motivation of the work was to develop an original 'smart' framework for a machine settings databank that could be applied to stitch any type of fabric.

The fabrics were stitched on a single needle lockstitch initially using the guidance given by the experts on fabric performance through the machine and the adjustments were then enhanced in order to perfect the flatness of the seam.

As mentioned in chapter 8, a second panel of experts were employed, increasing more objectivity for this research, by assessing the flatness of the sewn seams by using the American Association of Textile Chemists and Colourists (AATCC) scale.

The resultant data was then entered into the FIT system which formulated the algorithm model given in figure two. This would enable the databank to generate textural reports for fabrics on the sewing machine settings to be used.

A thorough literature survey on objective measurement systems revealed that although the systems were being used commercially in the assessment of fabric hand, manual handling methods are still, by far, the best means of providing information from the subjective data to the recipient.

Further literature showed that adjusting the machines manually and by eye still provides best results and that this is the only reliable method to ensure acceptable seam quality. Therefore a novel way of determining sewing machine settings based upon the established physical parameters of the fabrics is proposed in this chapter.

7.2. Results from the SPEC committee

Table 7.1 provides the results from the subjective assessments given by the 'Sewing Parameter Evaluation Committee'. Fabric 1 figures prominently at 20 as the material less likely to give problems during the sewing process. There are other fabrics that rank quite highly, fabrics 13, 15 and 18 show some agreement between the experts. However the longer the analysis went on it became clearer that there is less and less agreement.

Kendall's Coefficient of concordance (as described in the methodology) was used to measure the levels of agreement between the experts. The value of 'W' 0.3777 gives a strong indication that there is little agreement between the committee on which fabrics will perform satisfactorily at the needle point. All of the experts where of a similar opinion that there are close similarities between the materials handled, but the longer the assessment progressed the more confusion there was from each person. The standard deviation of fabric 20 shows the lowest measure of distribution between the mean with fabric 16 being the second lowest. This also gives reinforcement to the view that these two fabrics show the most agreement from the experts.

The testimony given by the SPEC member is a representative example from information given by the other SPEC members. Each expert provided similar information.

The data from the physical and mechanical parameters are provided in tables 7.2 and 7.3 and the FAST terminology is described below. These are:

- ST = Surface Thickness in millimetres
- B1 = Warp Bending Rigidity in micro newton metres
- B2 = Weft Bending Rigidity in micro newton metres
- EXT1 = Warp Extension in percentage
- EXT2 = Weft Extension in percentage

- F1 = Warp Formability
- F2 = Weft Formability

The handling of fabrics by the expert panel closely emulates what happens in a clothing production factory. As previously mentioned and indicated from table 7.1, the longer the assessment went on, the ability of the panel to grade the materials became more challenging. One expert mentioned that handling all of these materials and trying to predict the sew-ability was like ‘pulling rabbits from a hat’. The only way of accurately predicting the stitching of the materials was to put them under the machine and sew them.

Information from the literature in chapter two outlined the fact that most of fabric assessment with regards to sew-ability came from the experience from the fabric handlers. These included garment technicians, supervisors and clothing machine engineers. Objective measurement was developed as an aid to removing as much as possible subjective evaluation. Several questions emerged however, in how useful is this evaluation of mechanical fabric parameters and do they help in preventing sew-ability and seaming problems?

These factors have been explored by measuring the mechanical properties of the fabrics and then by stitching them. Another question was how important are the physical parameters in the stitching of the materials and what areas are of particular significance? The answers to these questions are presented henceforth.

r	n	S	rbar		W	W'	F	k1	k2		F crit												Probability F Dist
9	20	20339	95		**0.37759**	0.37758	4.85302	19	150		1.9												1.81567E-08
		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20		
	Judge 1	20	14	8	5	7	9	15	12	11	4	3	1	16	17	18	13	2	19	6	10		
	Judge 2	20	4	1	6	19	18	8	7	5	10	14	3	17	13	9	15	2	12	16	11		
	Judge 3	20	3	2	5	17	16	13	15	7	4	12	6	8	9	19	18	1	10	14	11		
	Judge 4	19	4	2	17	3	9	11	12	8	20	1	7	13	10	18	16	15	6	5	14		
	Judge 5	17	12	5	4	16	15	6	8	10	18	2	1	14	7	19	13	3	20	9	11		
	Judge 6	14	6	4	2	18	12	10	11	5	16	17	8	9	19	15	13	1	20	3	7		
	Judge 7	18	7	5	8	20	6	14	15	9	10	1	2	13	17	11	12	3	19	4	16		
	Judge 8	20	13	3	7	19	18	14	12	15	9	2	5	16	17	10	11	1	8	4	6		
	Judge 9	16	18	20	13	1	2	3	19	5	17	14	11	10	8	9	15	12	7	4	6		
	STDEV	2.167	5.4	5.81187	4.7199	7.5	5.5902	4.1	3.7	3.4	5.98	6.7	3.44	3.3	4.61	4.44	2.1794	5.24669	6	4.8	3.5		
	Rank-Sums	164	81	50	67	120	105	94	111	75	108	66	44	116	117	128	126	40	121	65	92		
42	RBAR	94.5	95	94.5	94.5	94.5	94.5	94.5	95	95	94.5	95	94.5	95	94.5	94.5	94.5	94.5	95	95	95		
	Rbar =	69.5	-14	-44.5	-27.5	25.5	10.5	-0.5	17	-20	13.5	-29	-51	22	22.5	33.5	31.5	-54.5	27	-30	-3	0	
	SQUARED	4830	182	1980.25	756.25	650.25	110.25	0.25	272	380	182	812	2550	462	506	1122	992.25	2970.25	702	870	6.3		

Table .7.1: The verdicts from the judges on ranking the sew-ability of the 20 fabrics

	Seam App	P / F / F (N)	FEED	M / SPEED	S/D	N / T / T (N)	B / T / T (N)	SEWING THREAD	NEEDLE SIZE	POINT TYPE	CHECK SPRING
Fabric 1	Flat	1.1	1 Full tooth	4000	5 /cm	1.4	0.11	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 2	Flat	1.1	1 Full tooth	4000	5 / cm	1.4	0.11	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 3	Flat	1.1	1 Full tooth	4000	4 / cm	1.4	0.13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 4	Flat	1.1	H/TOOTH	4000	5 / cm	1.4	0.13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 5	Flat	1.2	H/TOOTH	4000	5 / cm	1.4	0.13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 6	Flat	1.2	H/TOOTH	4000	5 / cm	1.4	0.13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 7	Flat	1.1	H/TOOTH	4000	5 / cm	1.4	0.12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 8	Flat	0.9	H/TOOTH	4000	5 / cm	1.5	0.12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 9	Flat	1.1	1 Full tooth	4000	5 / cm	1.5	0.12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 10	Flat	1.1	1 Full tooth	4000	4 / cm	1.5	0.14	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 11	Flat	0.8	H/TOOTH	4000	5 / cm	1.5	0.13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 12	Flat	0.8	1 Full tooth	4000	4 / cm	1.5	0.12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 13	Flat	1	H/TOOTH	4000	4 / cm	1.5	0.12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 14	Flat	1	1 Full tooth	4000	5 / cm	1.5	0.13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 15	Flat	1	H/TOOTH	4000	5 / cm	1.5	0.13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 16	Flat	1.1	H/TOOTH	4000	5 / cm	1.5	0.14	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 17	Flat	1.1	1 Full tooth	4000	5 / cm	1.4	0.14	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 18	Flat	1.1	H/TOOTH	4000	5 / cm	1.4	0.12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 19	Flat	1.1	H/TOOTH	4000	5 / cm	1.5	0.12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 20	Flat	1.1	H/TOOTH	4000	5 / cm	1.4	0.12	150ss poly/poly	70	Acute RP	SET TO WINK

Table 7.2: Physical measurements of the 20 fabrics from the main study

FABRIC	ST mm	B1 µNm	B2 µNm	EXT1 %	EXT2 %	G N/m	F1	F2
1	0.13	2.77	2.21	3.93	2.6	36.53	0.144	0.00752
2	0.1	7.66	4.004	0.63	7.93	103	0.00695	0.335
3	0.3	4.73	7.01	0.53	7.66	47.3	0.00214	0.937
4	0.095	5.62	1.66	2.8	2.33	55.48	0.178	0.00453
5	0.09	5.58	2.78	1.8	1.86	73.8	0.00875	0.00378
6	0.09	3.72	1.26	2.06	2.4	139	0.00845	0.00286
7	0.12	3.73	0.78	3.6	2.8	36.35	0.203	0.00322
8	0.1	2.28	1.14	3.73	2.03	95.84	0.0088	0.00286
9	0.096	5.49	1.72	0.6	7.8	68.97	0.00124	0.144
10	0.13	3.81	1.77	2.8	3.06	31.27	0.146	0.00845
11	0.26	10.55	1.48	1.76	2.93	31.27	0.215	0.00673
12	0.14	1.89	0.89	3.13	17	29.63	0.00731	0.23
13	0.14	2.41	0.81	3.33	3.6	31.008	0.00984	0.00351
14	0.18	5.1	2.34	2.63	2.83	35.82	0.15	0.00639
15	0.19	3.31	1.48	4.13	4.36	15	0.225	0.117
16	0.11	4.53	1.93	2.03	1.2	45.55	0.00926	0.021
17	0.14	3.84	1.88	2.83	19.3	38.23	0.139	0.56
18	0.15	5.42	1.89	2.13	3.3	51.97	0.11	0.00687
19	0.09	5.02	2	2.46	2.73	76.87	0.136	0.00592
20	0.12	7.01	2.22	2.26	2.73	68.33	0.158	0.00656
X Bar	**0.13855**	**4.7235**	**2.0627**	**2.4585**	**5.02**	**55.5609**	**0.093337**	**0.12066**
σ	**0.056**	**2.04**	**1.37**	**1.061**	**4.91**	**30.4**	**0.084**	**0.24**

Table 7.3: Mechanical Properties measured on FAST of the shirting fabrics from the main study

7.3. Results from the physical and mechanical data

Tables 7.2 and 7.3 present the results from the physical properties and mechanical properties of the fabrics. It is common sense to assume that the physical properties are closely interlinked to the mechanical properties of the materials. There are certain characteristics from the fabrics that are particularly influential on the seam performance and flatness of the seam. One of these physical properties is the cover-factor. This is how close the yarns are packed together in the fabric. The higher the cover factor then the closer the yarns is packed together. This can mean that the closer the yarns are packed, then the more strain is placed upon the sewing thread by the compression from the yarns of the fabric. From table 7.2, it can be seen that fabric 1 has a warp cover factor of 12.4. Four out of the 10 experts of the SPEC panel ranked this fabric as being the best to sew. The other 6 experts also gave this material a high ranking. An example of this fabric is given in figure 7.1. The results from the parameter maps and the fabric fingerprints from the FAST data are presented below.

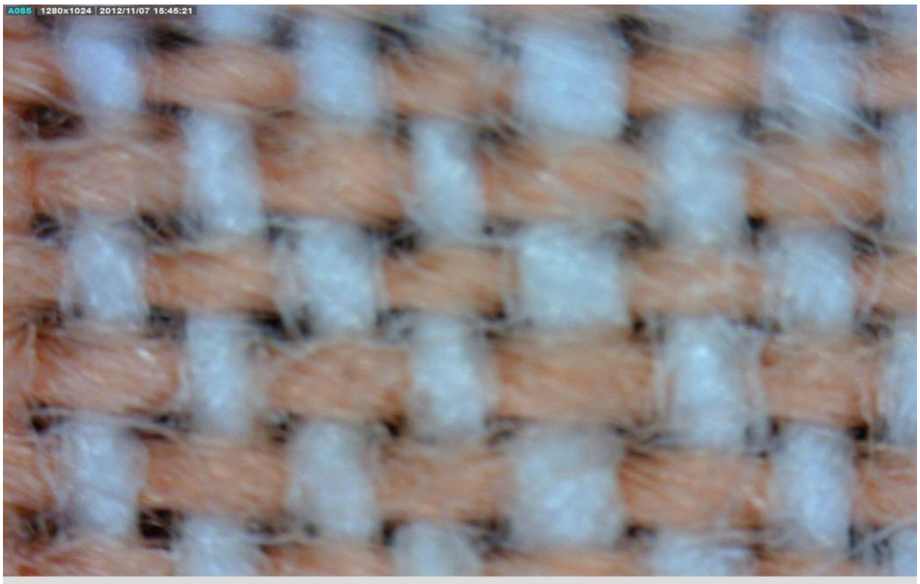

Figure 7.1: Fabric 1 with a warp cover-factor of 12.4

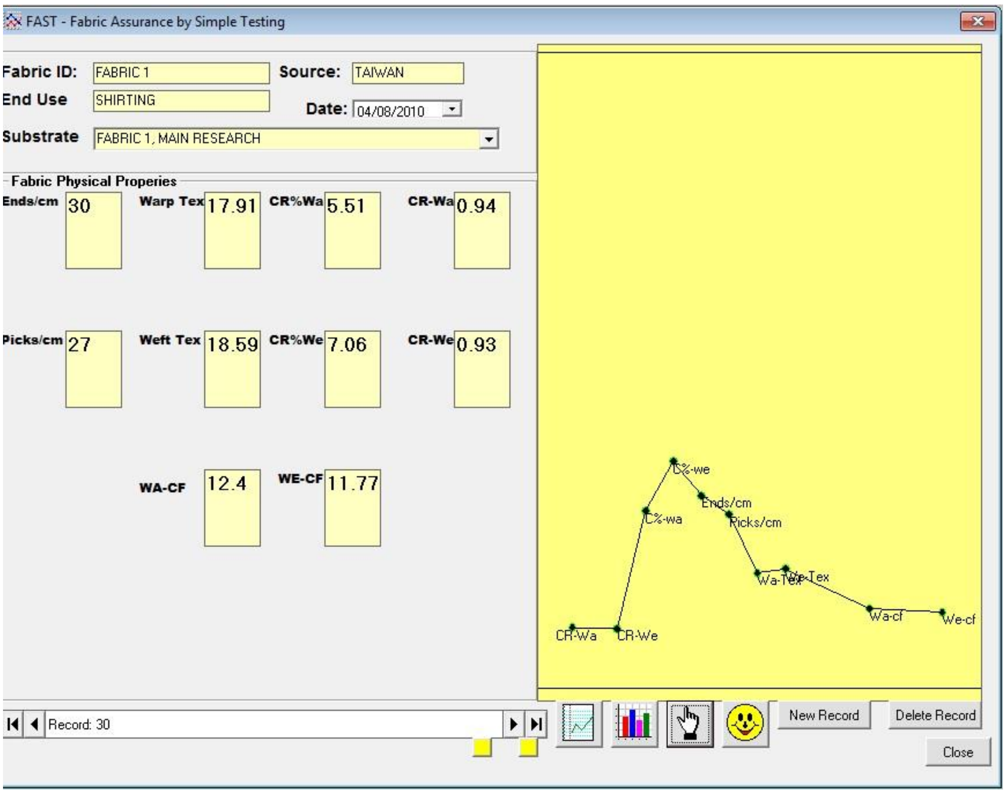

Figure 7.2: Fabric parameter map for fabric 1

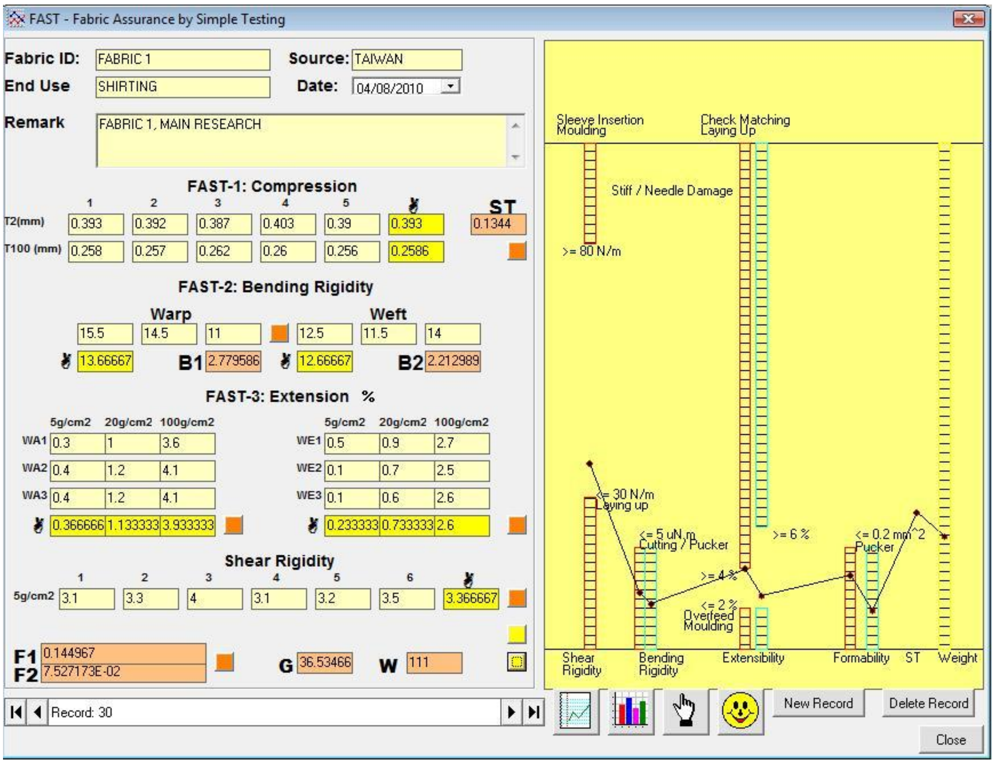

Figure 7.3: Fabric fingerprint for fabric 1

Generally, this fabric exhibits good characteristics. However it can be seen that potential problems have been highlighted from the bending rigidity which influences the formability of the fabric. This may cause the fabric to buckle more due to the forces from the needle and the sewing thread inside the material. This indicates that seam pucker is a distinct possibility but if one examines the photograph in figure 7.1, it can be plainly seen that there are significant gaps between the yarns in the fabric. Therefore the yarns are more likely to accommodate the sewing thread helping to reduce and eliminate this problem.

Fabric 2 has a mixed review of expert opinion, in that 4 experts give this material a score above 10, whilst the other 6 are giving a ranking below 10. An example of this material is given in figure 7.4 and the fabric parameter and fingerprint are given in figures 7.5 and 7.6.

Fabric 3 ranks very low in terms of the sew-ability of the fabric from all the experts a part from judge 9 who gave it a top mark for best to sew of 20. The weight of this fabric is also the heaviest of all the materials. The cover factor in this fabric can be considered low particularly in the warp direction. The fabric and parameters is given in figures 7.7 – 7.9.

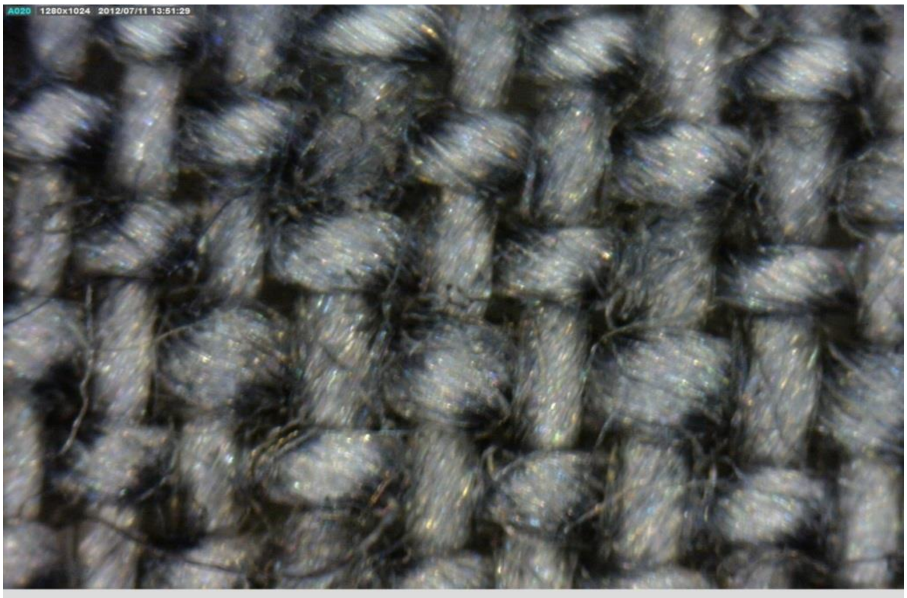

Figure 7.4: Fabric 2 with a warp cover-factor of 14.27

Figure 7.5: Fabric parameter map for fabric 2

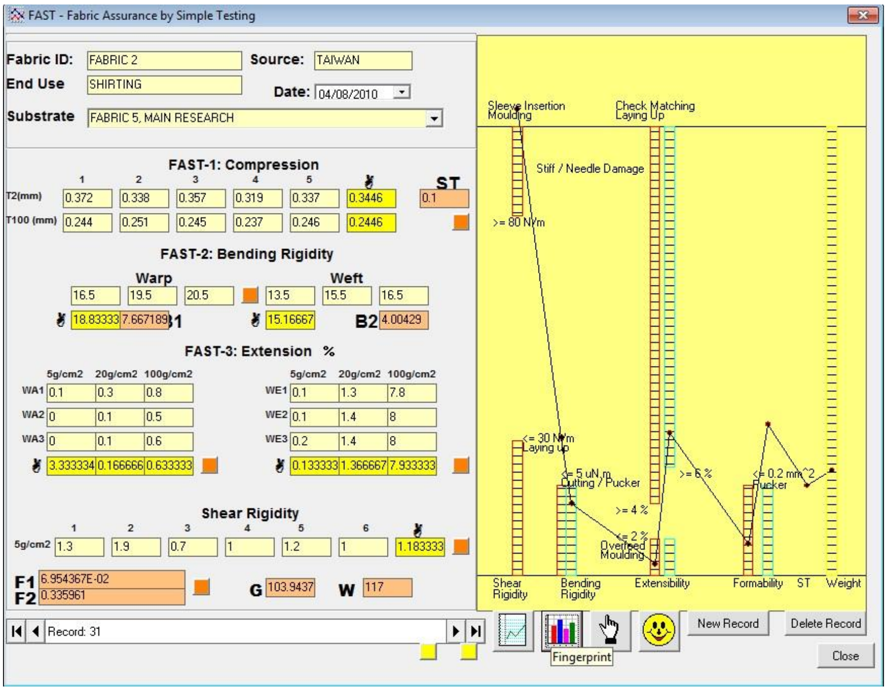

Figure 7.6: Fabric fingerprint for fabric 2

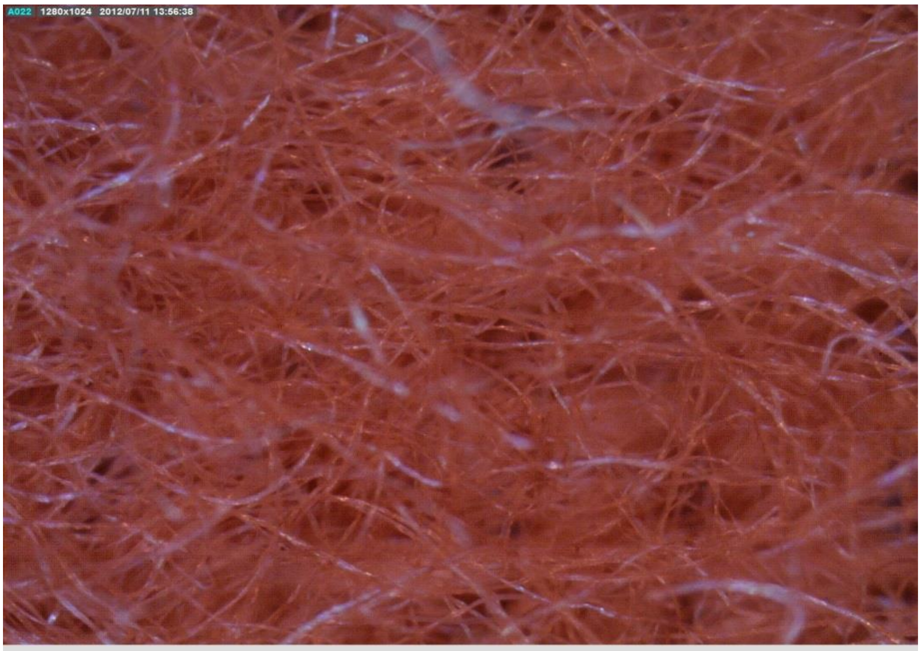

Figure 7.7: Fabric 3 with a cover factor of 9.87

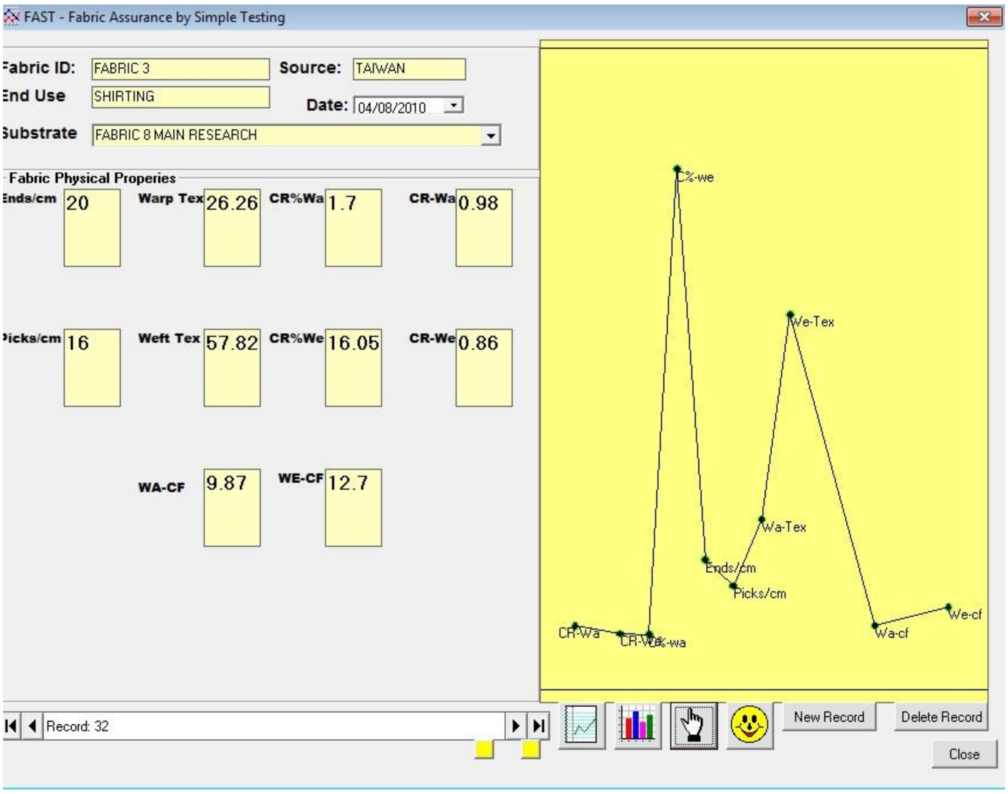

Figure 7.8: Fabric parameter map for fabric 3

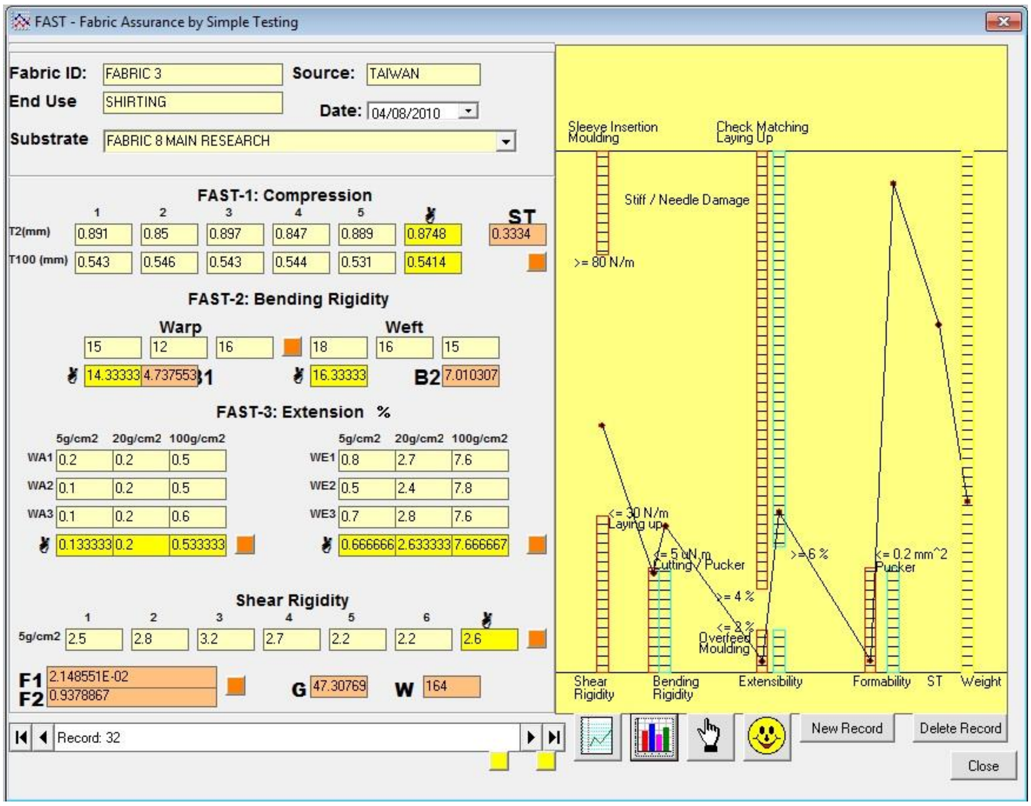

Figure 7.9: Fabric fingerprint for fabric 3

Figure 9.9 highlights the volatility of this fabric particularly in the areas of extensibility and formability. The yarns of the fabric are difficult to see due to the brushed nature of the fibres in the material.

Fabric 4: shows some contradiction between the judges with 7 judges ranking the fabric low in terms of sew-ability. Judge 4 and Judge 9 rank the fabric quite high with 17 and 13 respectively. The cover factor of 15.52 is higher than the other fabrics mentioned above. Illustrations are given in figures 7.10 – 7.12.

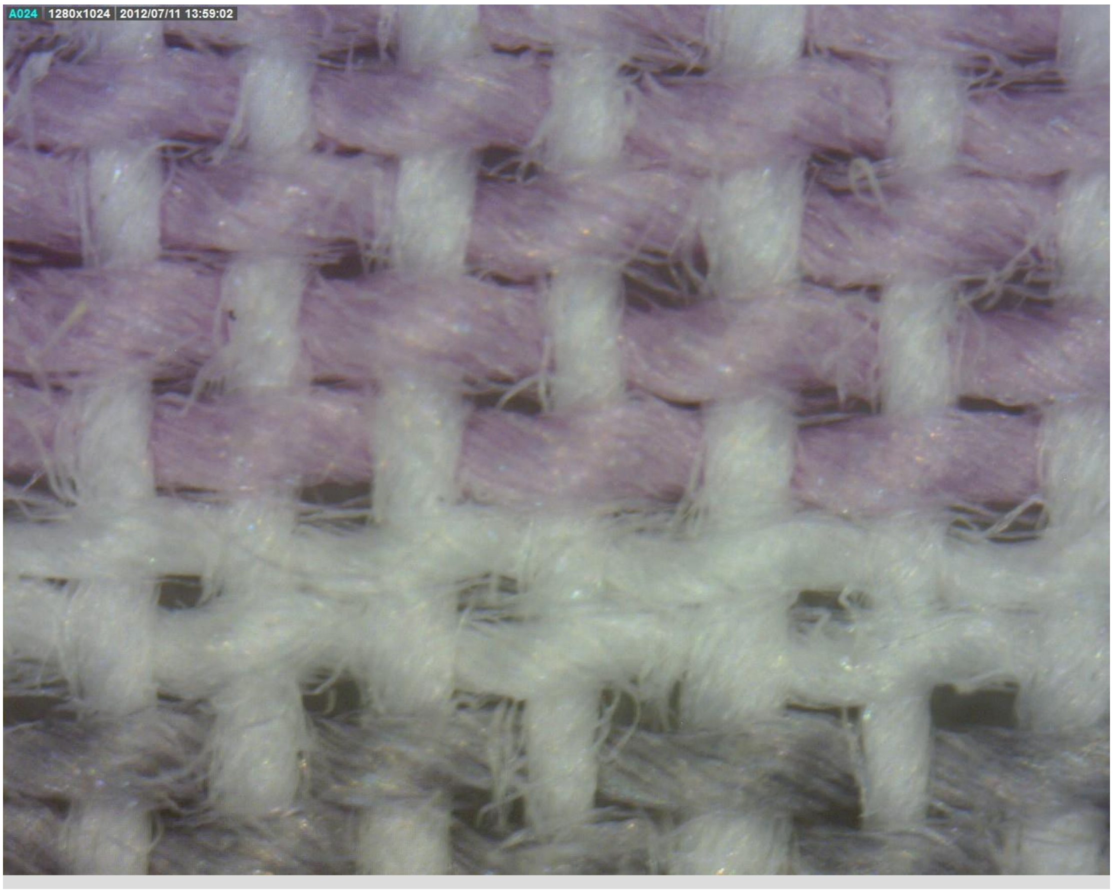

Figure 7.10: Fabric 4 with a cover factor of 15.5

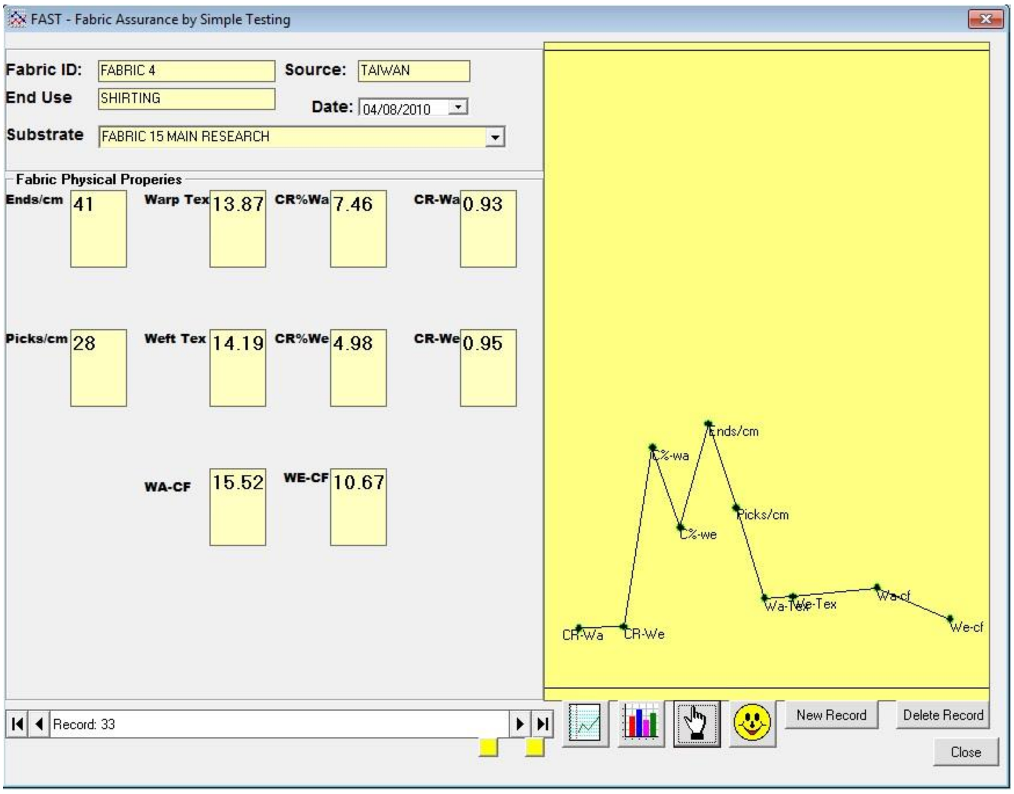

Figure 7.11: Fabric parameter map for fabric 4

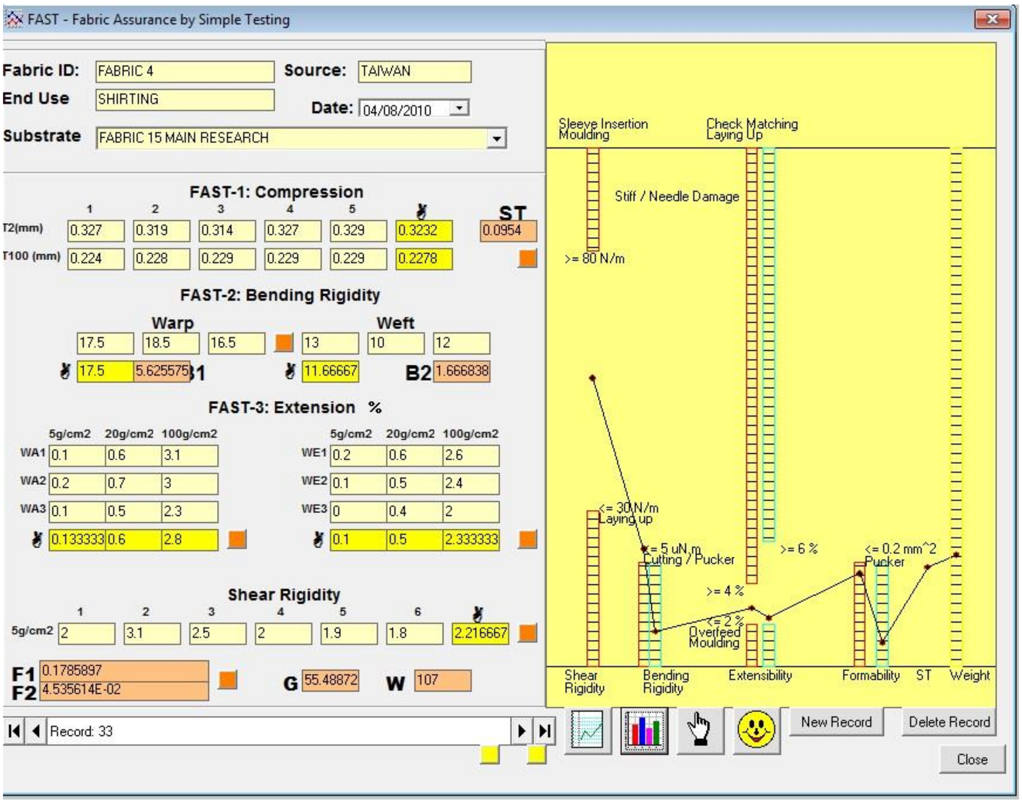

Figure 7.12: Fabric fingerprint for fabric 4

Fabric 5: Ranks highly amongst judges as being a fabric for stitching without many problems. The weight of the fabric at 129 gm $^{-2}$ is one of the heaviest and the cover factor is 21.76 making it one of the highest (Figures 7.13 – 7.15).

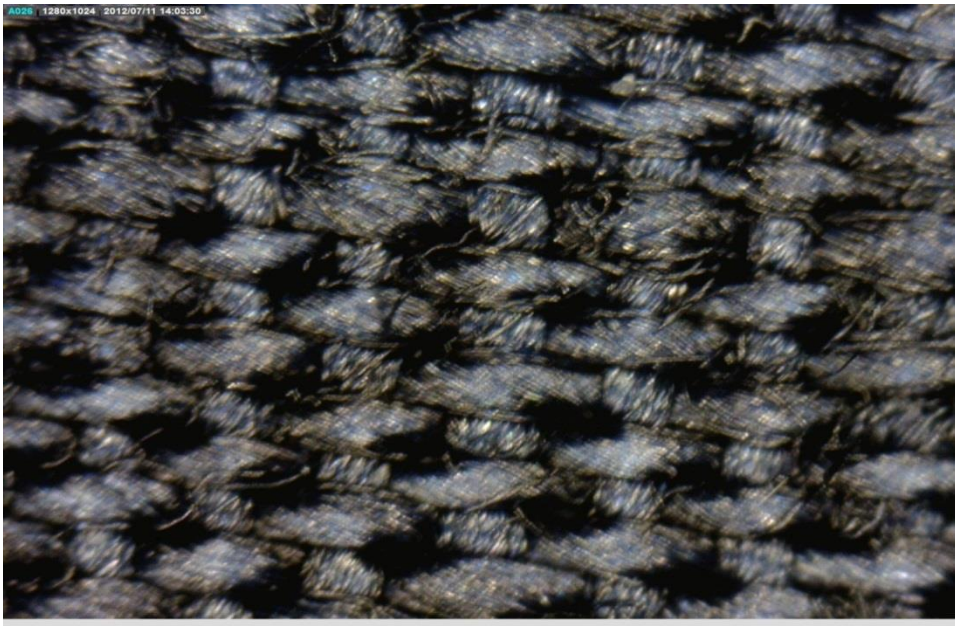

Figure 7.13: Fabric 5 with a cover factor of 21.76

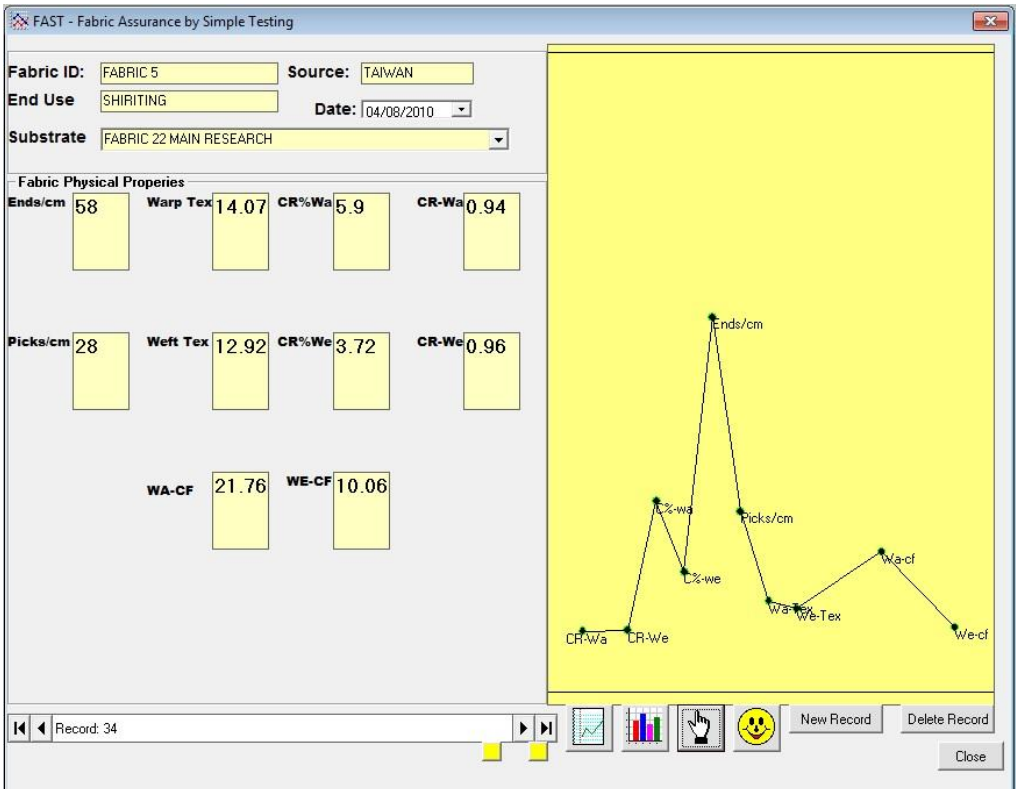

Figure 7.14: Fabric parameter map for fabric 5

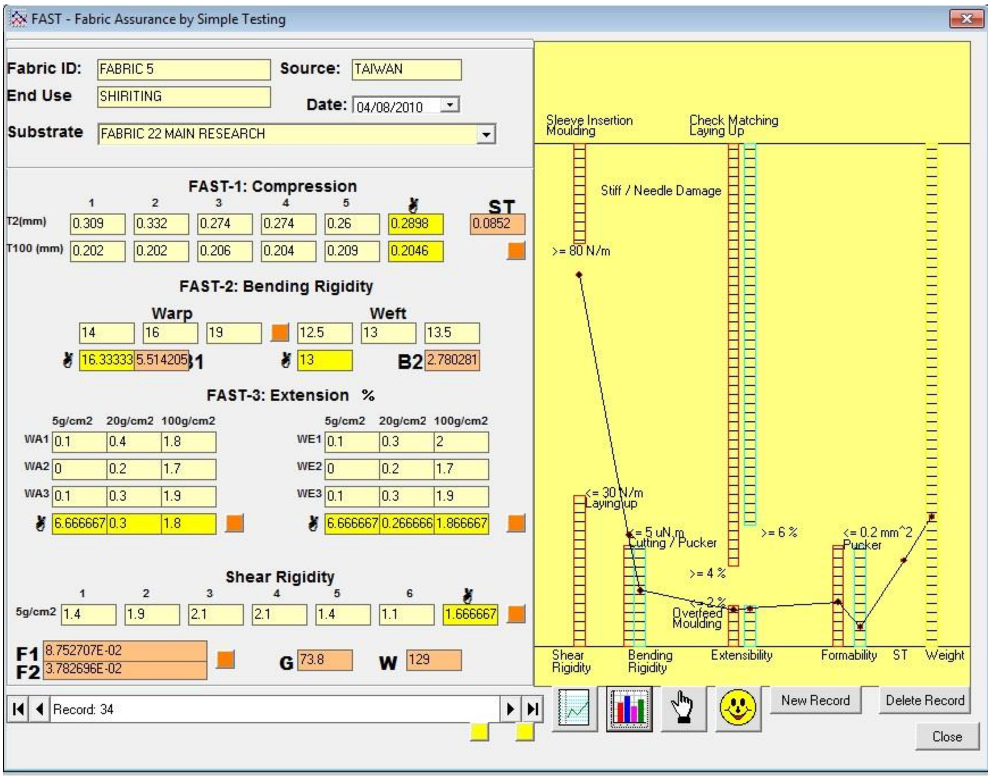

Figure 7.15: Fabric fingerprint for fabric 5

The results from the FAST analysis predict that this fabric will perform poorly regarding seam pucker with its diagnostic on low bending rigidity and formability, also with borderline extensibility. Many of the experts however have indicated that this fabric will perform well during stitching.

Fabric 6: Is given a mixed review with 5 judges giving the fabric high score (above 10) and 4 judges with a score below 10. This material also scores high on weight (similar to fabric 5) and also scores high on its cover factor and ends per cm.

This fabric is also a 100% cotton plain woven fabric like all the materials discussed here. Figures 7.16 – 7.18 give the parameters of these fabrics.

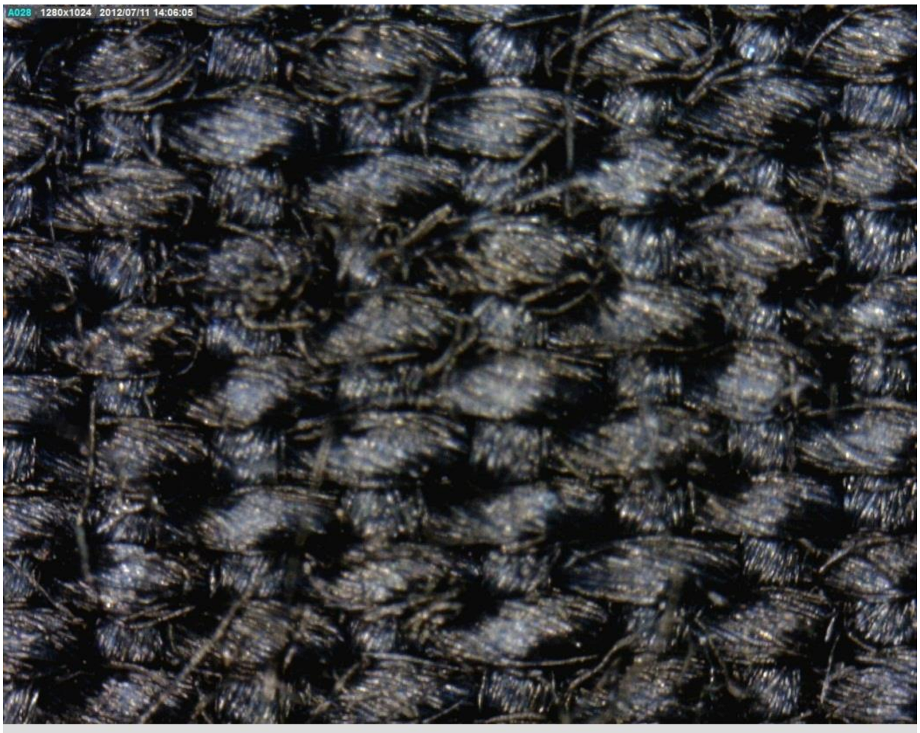

Figure 7.16: Fabric with a cover factor of 21.4

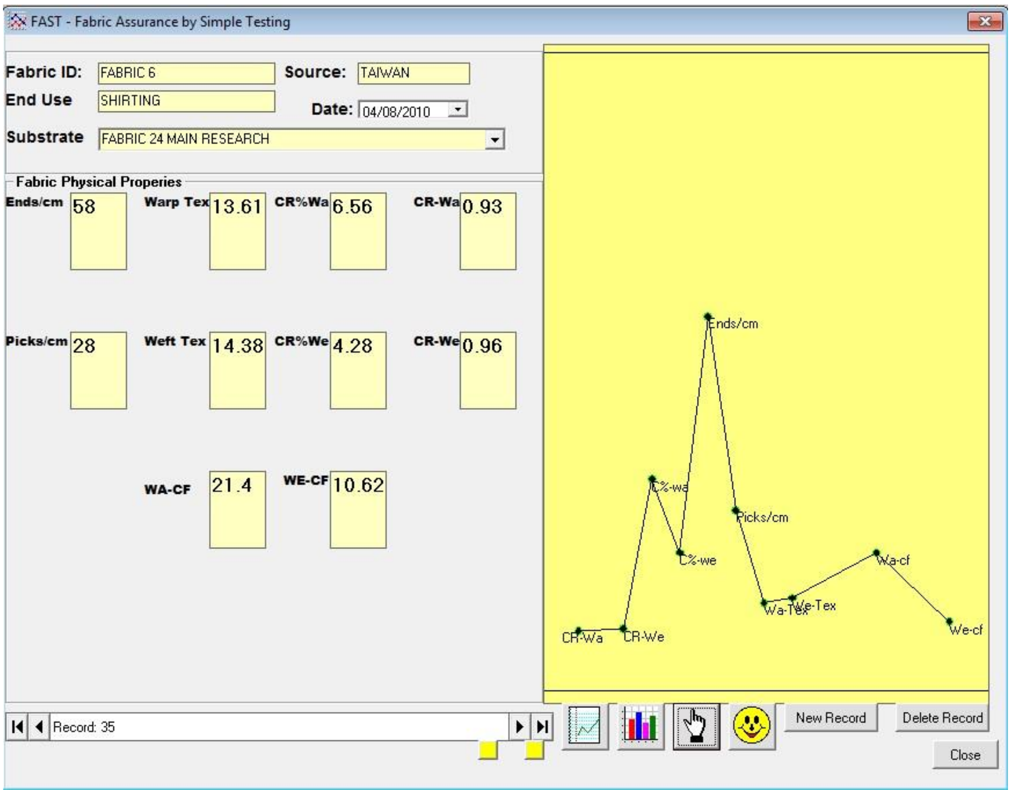

Figure 7.17: Fabric parameter map for fabric 6

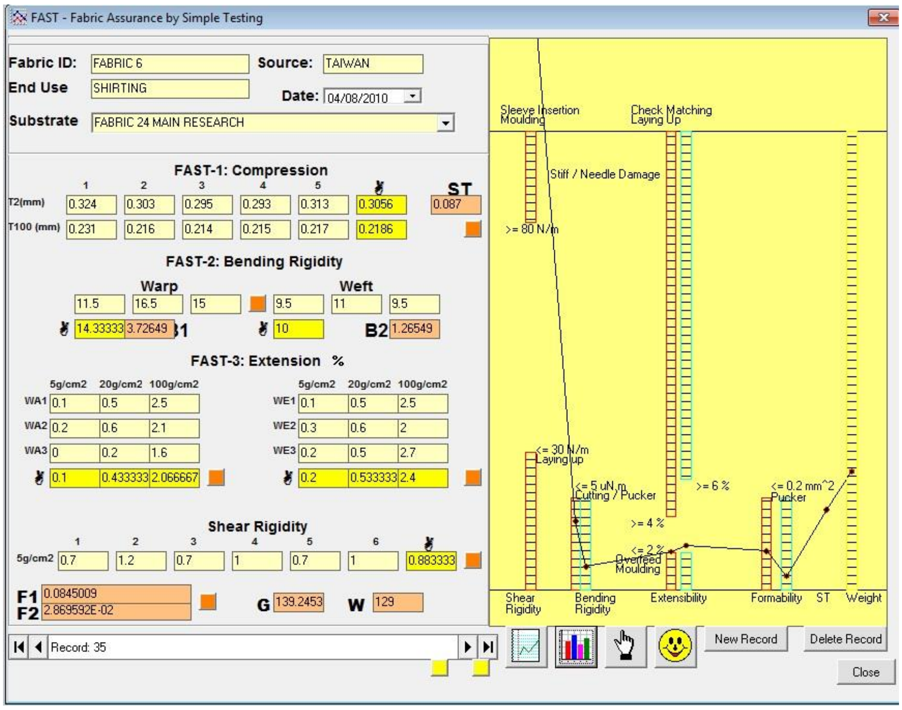

Figure 7.18: Fabric fingerprint for fabric 6

Fabric 7: Fabric seven is given a positive review with the six of the judges ranking the material above 10. The weight of the fabric is one of the lightest and the cover factor is 14.83. The FAST testing has indicated that the shear results of the fabric are acceptable. But it can also be seen from the mechanical properties, that there are potential problems with seam pucker due to their low bending and formability ratios. As previously stated, shirting fabrics are particularly susceptible to seam distortion due to their lightweight construction. With careful scientific analysis, a picture of stitching fabrics to the required quality standards can be achieved by nurturing people and by developing the skills required, enabling them to diagnose problems quickly and efficiently. Examples of fabric 7 are highlighted in figures 7.19 – 7.21.

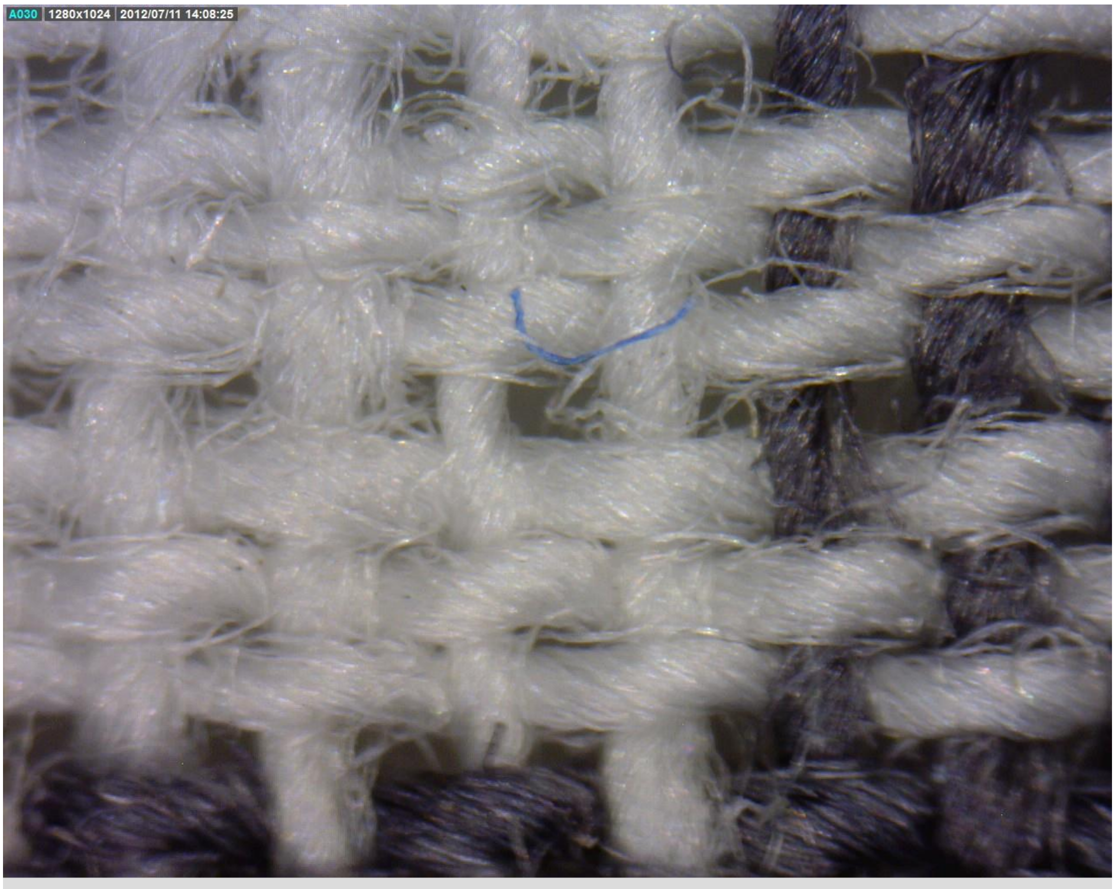

Figure 7.19: Fabric 7 with a cover factor of 14.83

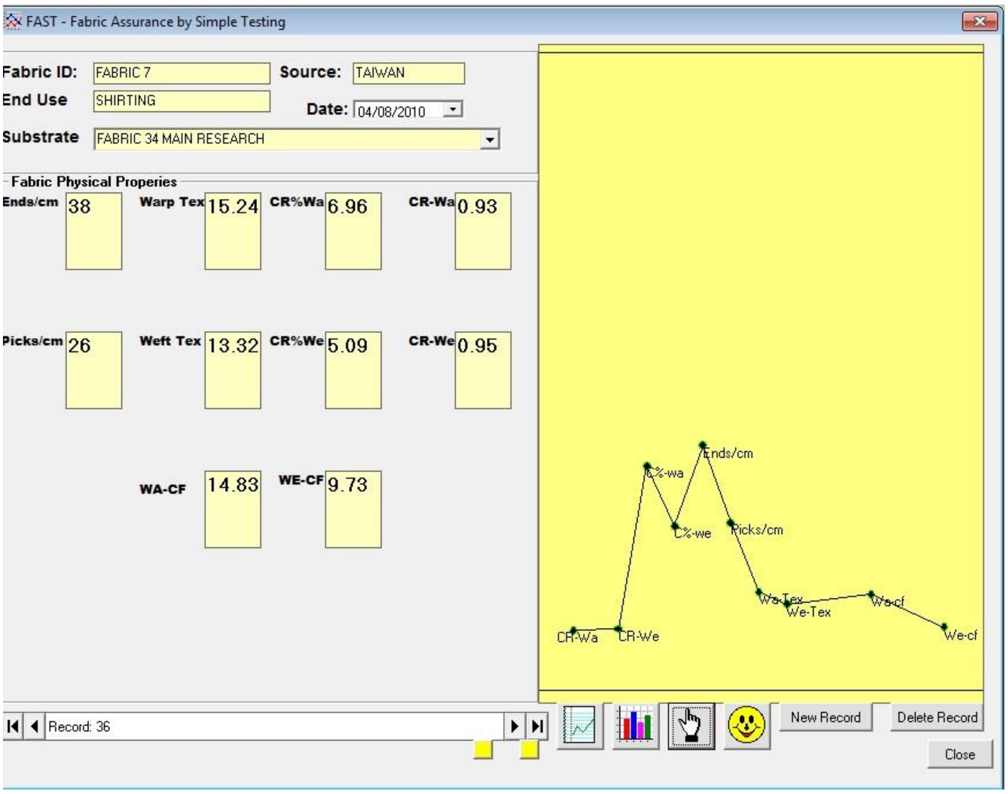

Figure 7.20: Fabric parameter map for fabric 7

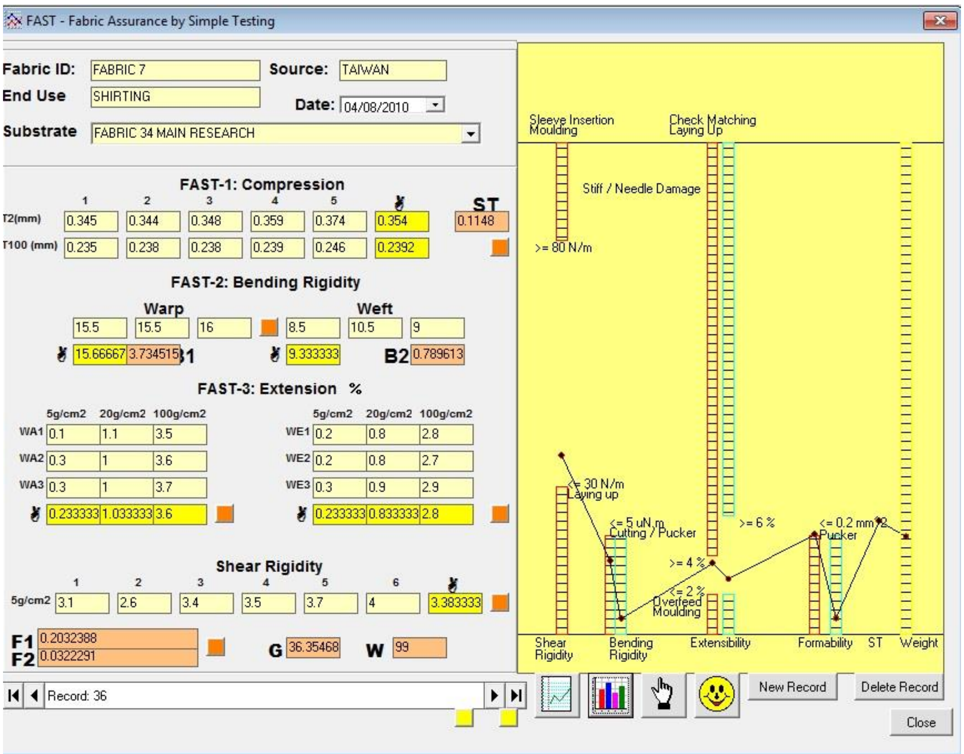

Figure 7.21: Fabric fingerprint for fabric 7

Fabric 8: Is also given a positive review by most judges as a fabric with a good stitching performance. The fabric is also lightweight compared to many of the other fabrics and it also exhibits a middle of the range cover factor similar to that of fabric 7. The outcome of fabric 8 is given in figures 7.22 – 7.24.

Fabric 9: Fabric 9 has been described by most of the experts as being a particularly difficult fabric to stitch. Only 3 gave the fabric a score above 10. The others gave the fabric a low ranking of values mostly below 5. The fabric has a weight of 121 gm^{-2} making it one of the heaviest fabrics described here and has a cover factor of 13.99 with ends per cm of 32.67. An example of this fabric is given figures 7.25 – 7.27.

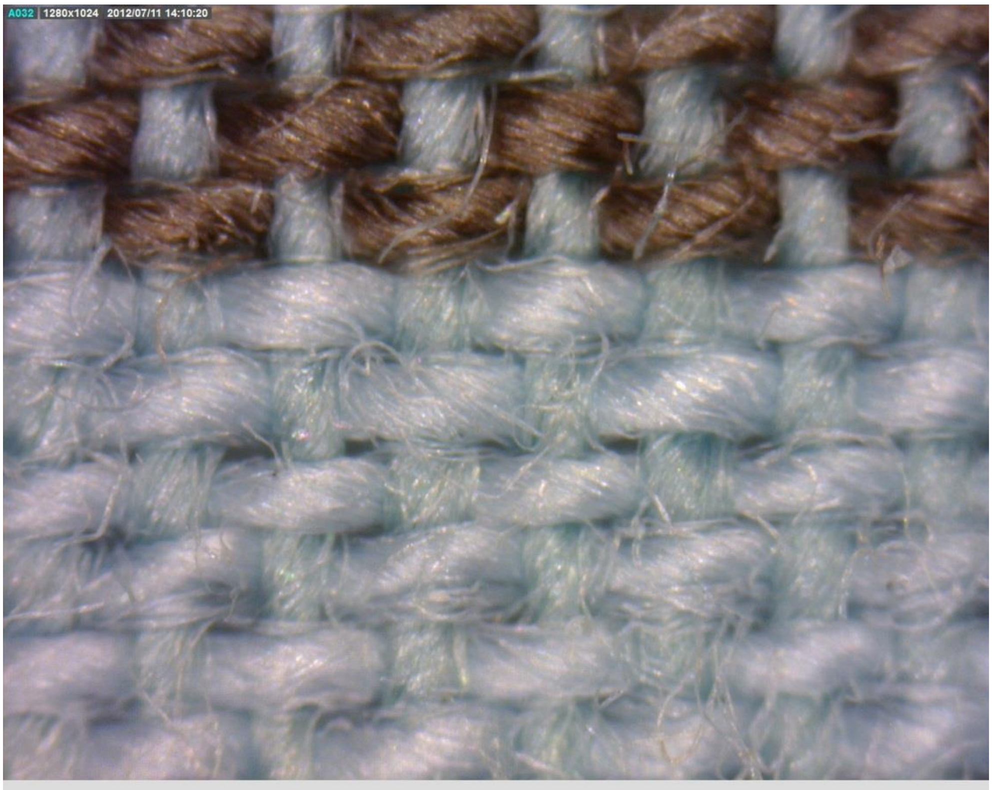

Figure 7.22: Fabric 8 with a cover factor of 14.57

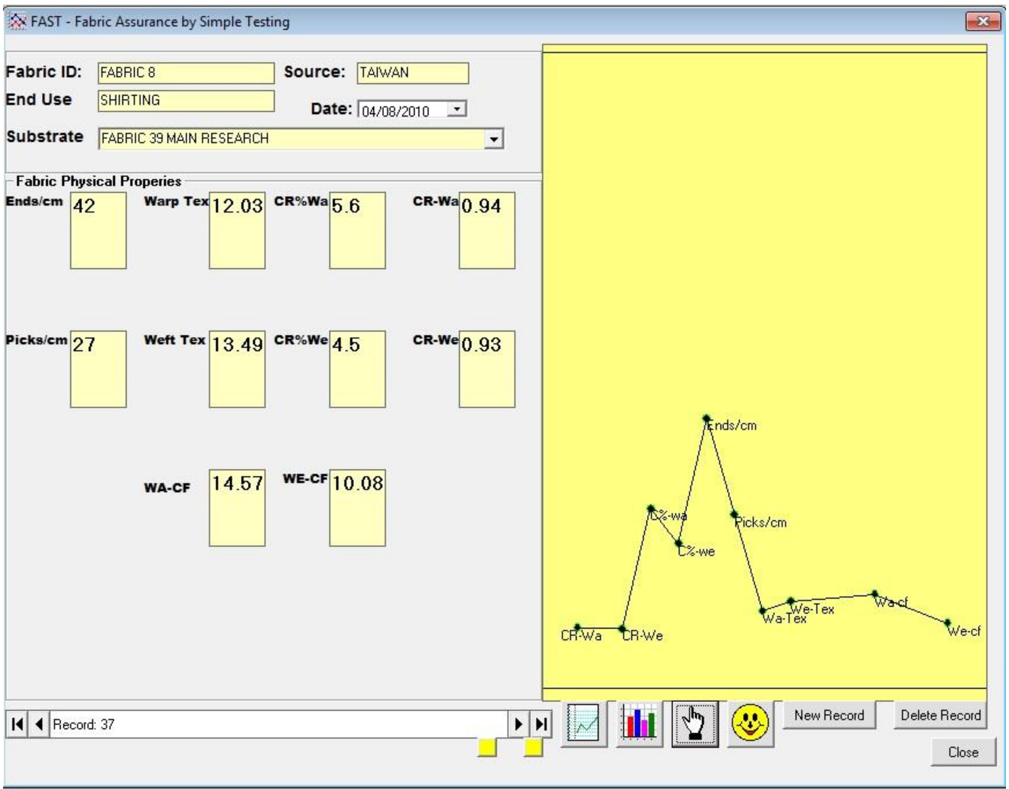

Figure 7.23: Fabric parameter map for figure 8

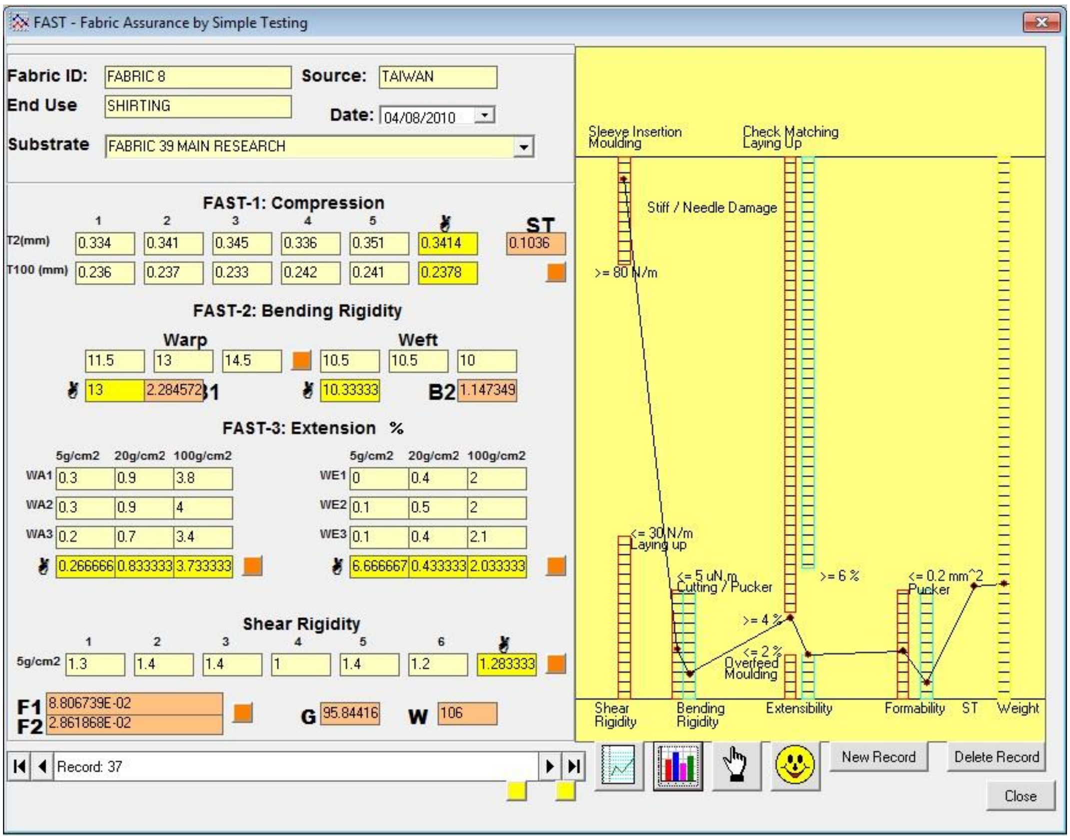

Figure 7.24: Fabric fingerprint for fabric 8

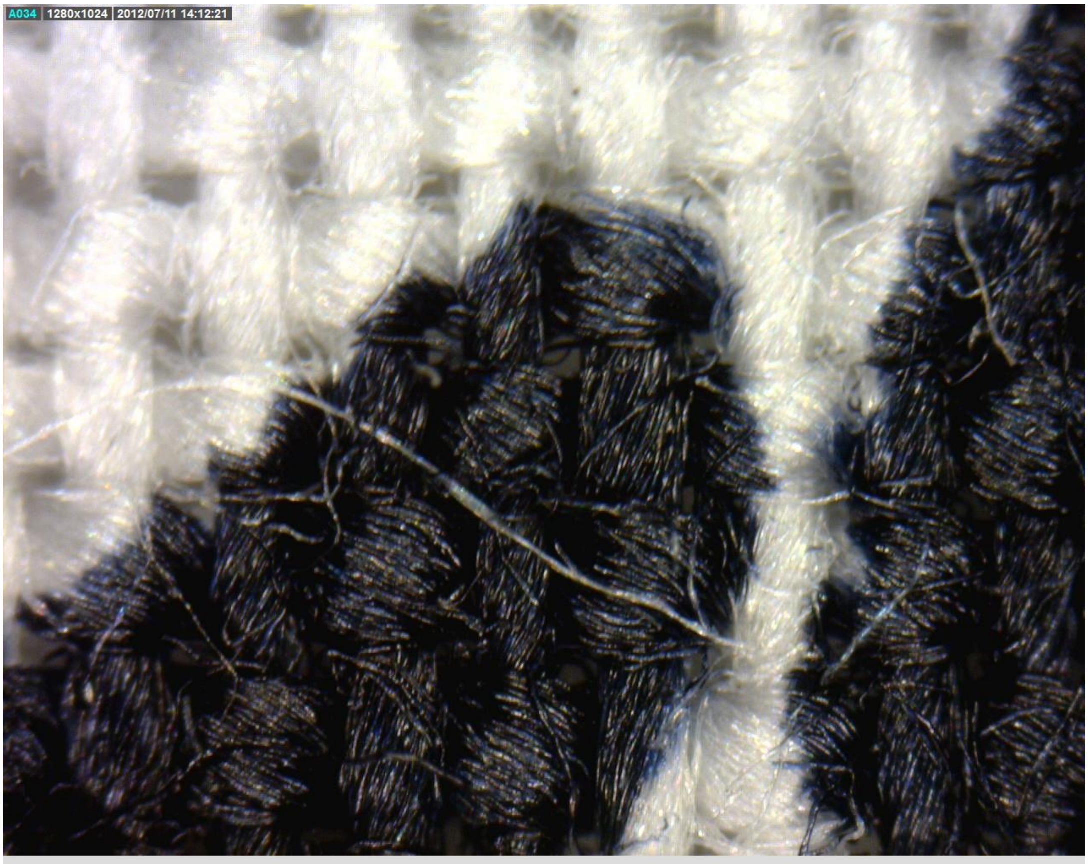

Figure 7.25: Fabric 9 with a cover factor of 13.99

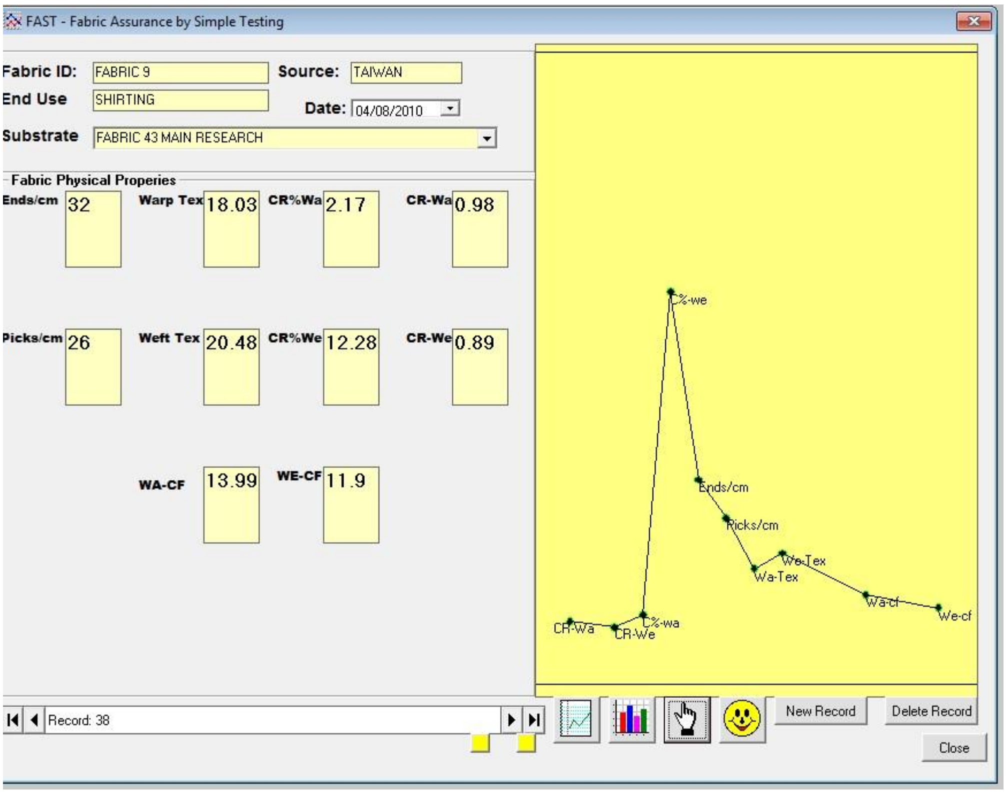

Figure 7.26: Fabric parameter map for fabric 9

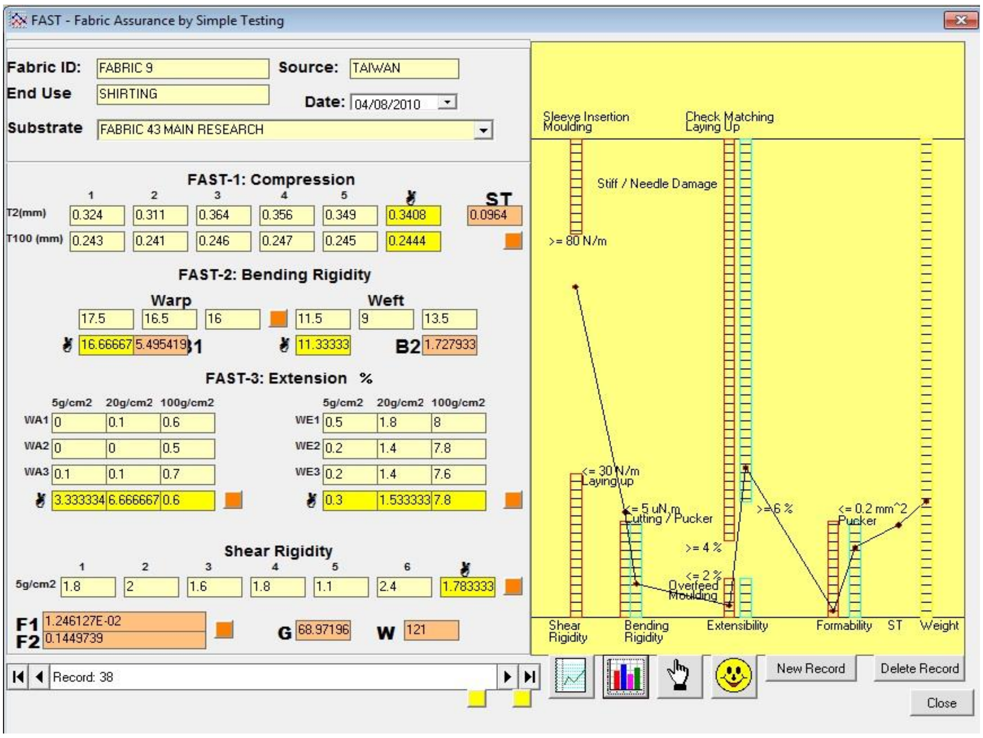

Figure 7.27: Fabric fingerprint for fabric 9

Fabric 10: Has been given a good rating by six experts from 10, to a 20 from judge 4 as being the best to stitch. The fabric indicates a relatively low weight and a low cover factor. The warp ends is also one of the lowest of all the fabrics. These are given in figures 7.28 - 7.30.

Figure 7.28: Fabric 10 with a cover factor of 11.39

From the mechanical data generated by the FAST testing, it can be seen that both the bending rigidity and formability are outside the comfort zones for trouble free stitching. Lower values indicate that a fabric is in more distress from buckling and distortion. It is important to add however, that the parameters of the material are entwined and dependent upon each other; therefore it is important to point out that it is not necessarily the case that a fabric will perform badly at the needle point just based on the mechanical factors alone. There are many other influences that can affect the outcome of a flat seam of a product.

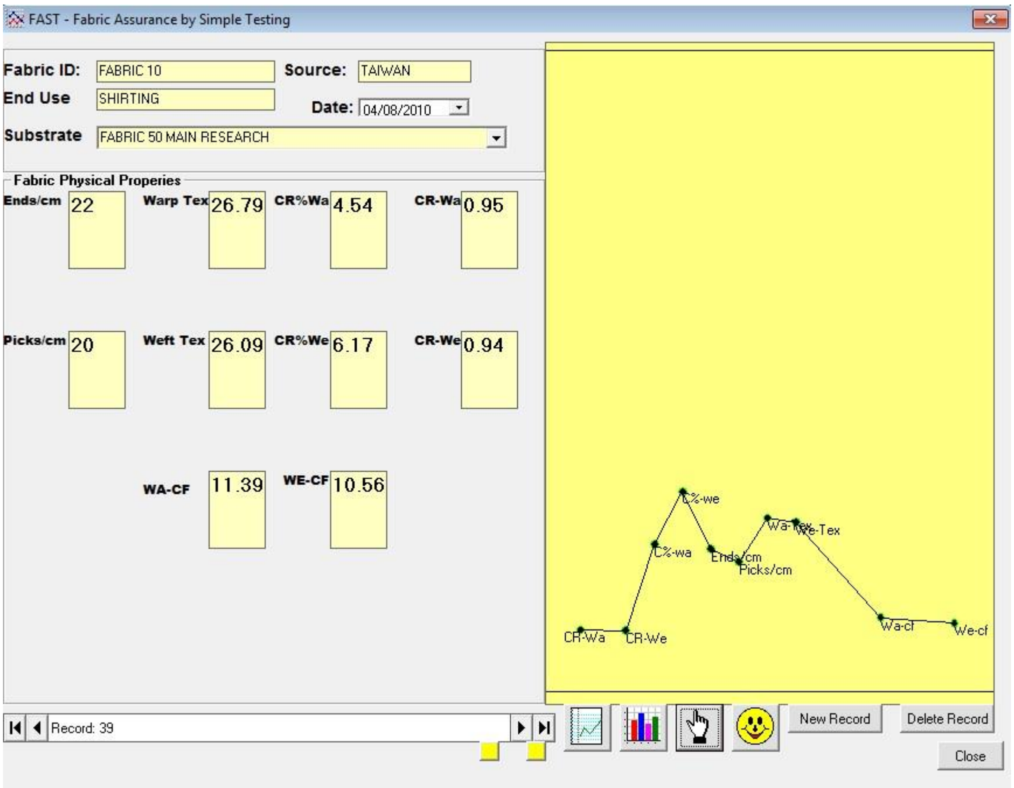

Figure 7.29: Fabric parameter map for fabric 10

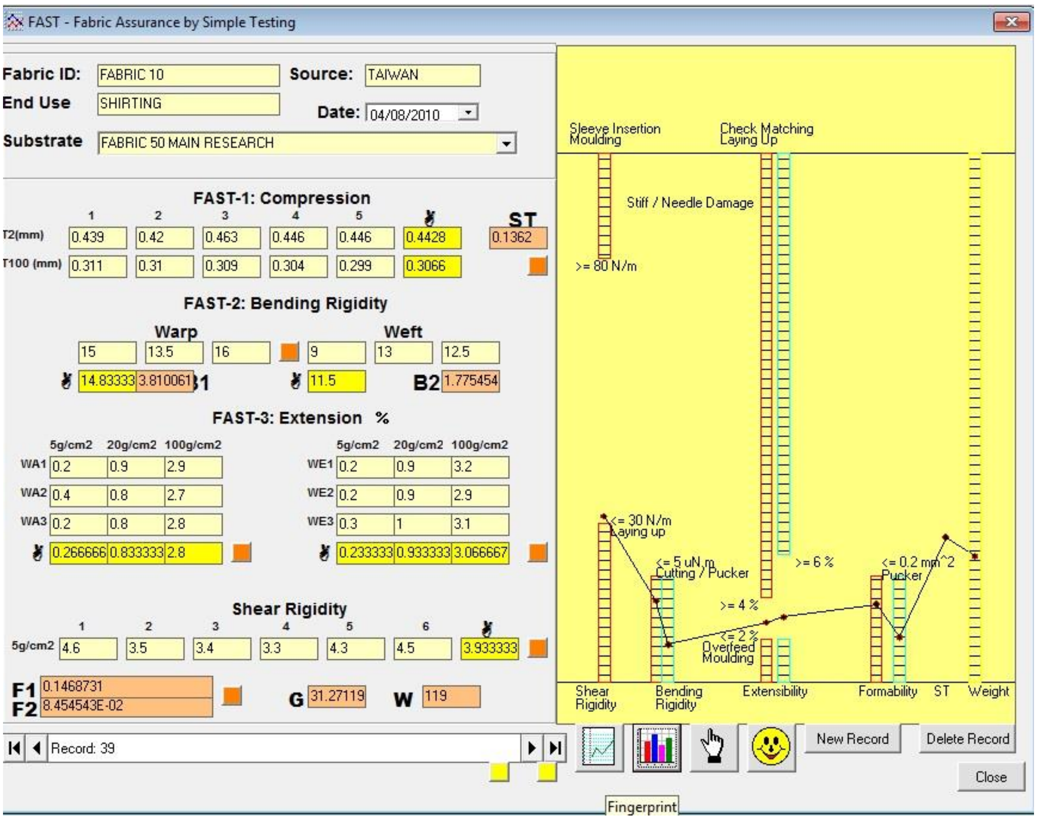

Figure 7.30: Fabric finger print for fabric 10

Fabric 11: Fabric 11 has a weight the same as fabric 10 but has a slightly higher cover factor. The fabric (figure 7.30) shows greater gaps between the yarns than that for fabric 10 (figure 7.27) but it can also be seen from the data in table 7.2 that the yarns are less in diameter. This is indicated by the end count and the Tex. The experts have mixed reviews on this material with 4 judges ranking it above 10 with the other 6 giving it a very low score. Examples are given in figures 7.31 – 7.33.

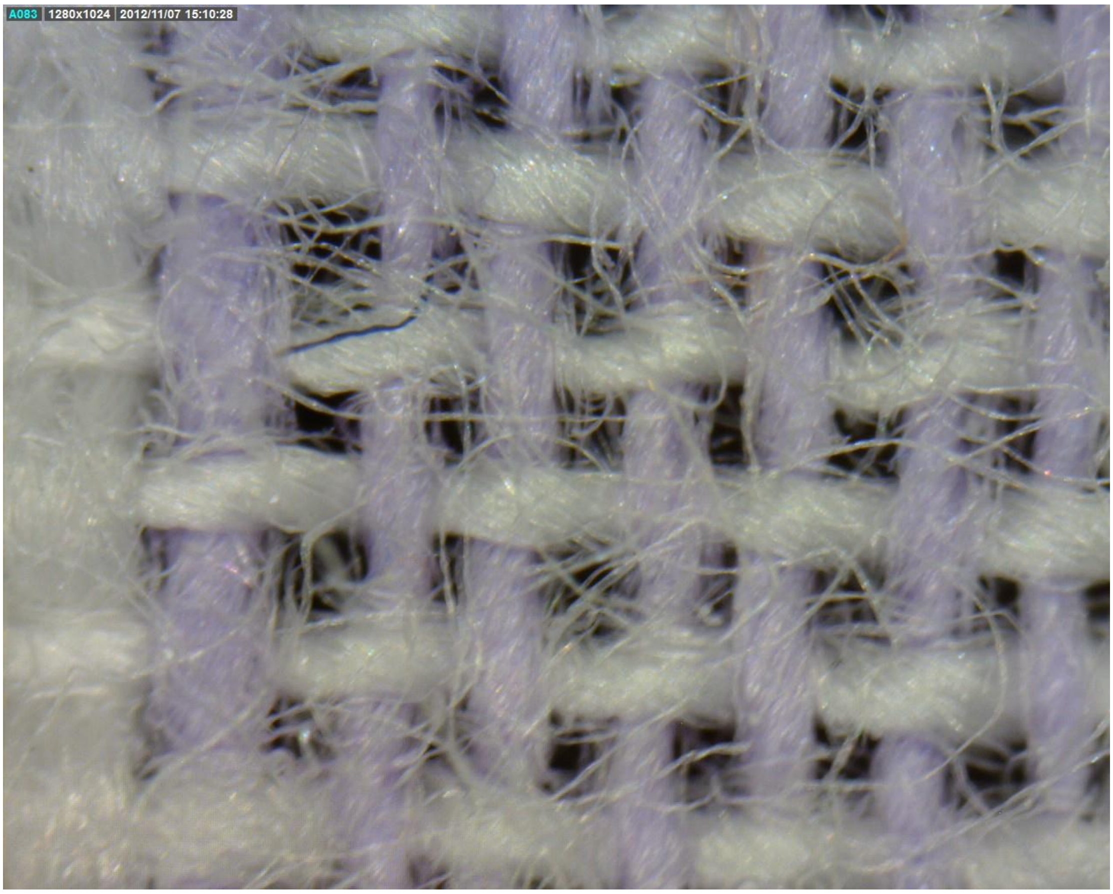

Figure 7.31: Fabric 11 with cover factor or 14.79

It is important to note that the results from the FAST testing have indicated that this fabric will perform well during sewing in the warp direction. All of the possible manufacturing problems for stitching the material are within the comfort zones as specified on the chart.

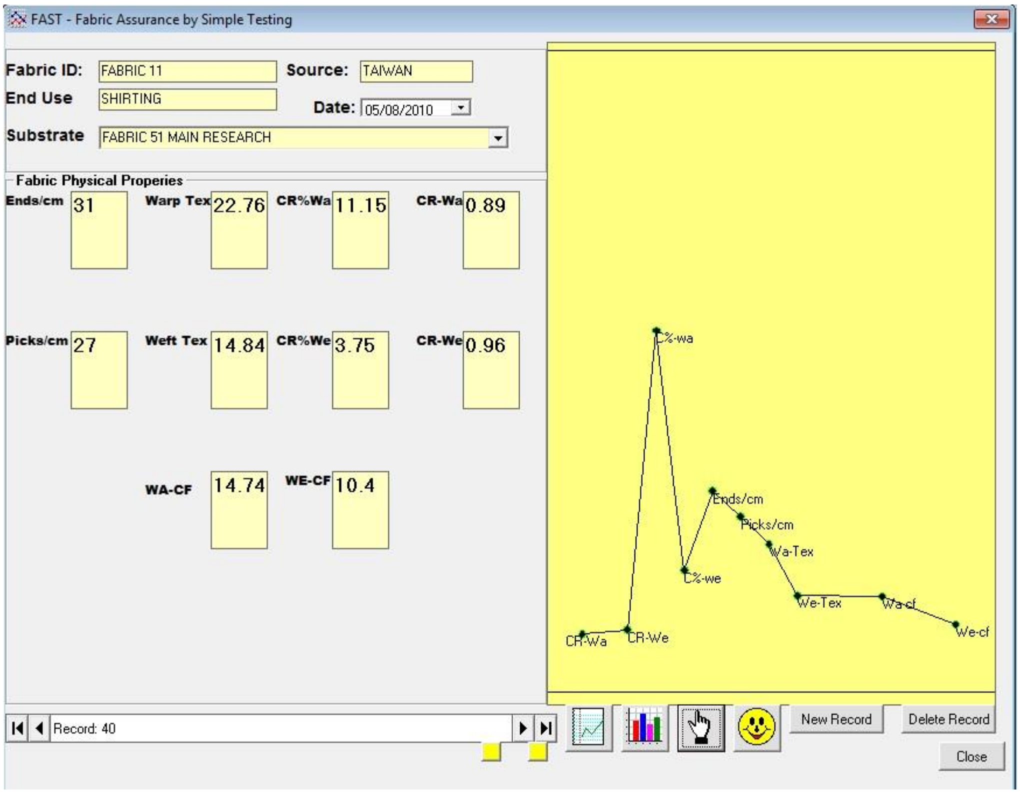

Figure 7.32: Fabric parameter map for fabric 11

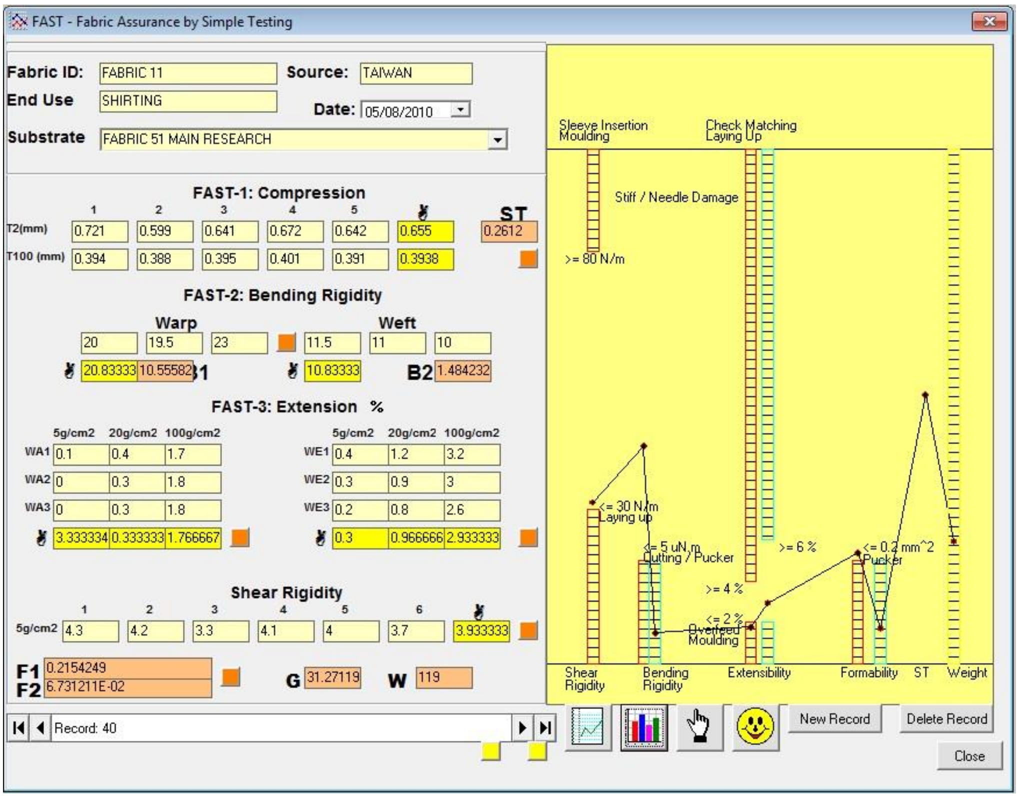

Figure 7.33: Fabric fingerprint for fabric 11

Fabric 12: This material is one of two with a fibre content of 97% cotton and 3% spandex. The fabric has been ranked by 4 judges as having good properties for stitching. However, 6 have given the fabric a low ranking with one giving the material a score of 1 (the most difficult to sew). Some of the physical properties of the material are very similar to those earlier described. However, this material differs significantly to these in the mechanical properties of the material. The material indicates very high extensibility in the weft direction.

The crimp percentage is also very high placing it off the scale on the fabric parameter map. It is relevant to mention that a number of judges did comment upon the fact of the fabric being highly extensible of the possible consequences of a potential problem during stitching. This fabric is given in figures 7.34 - 7.36.

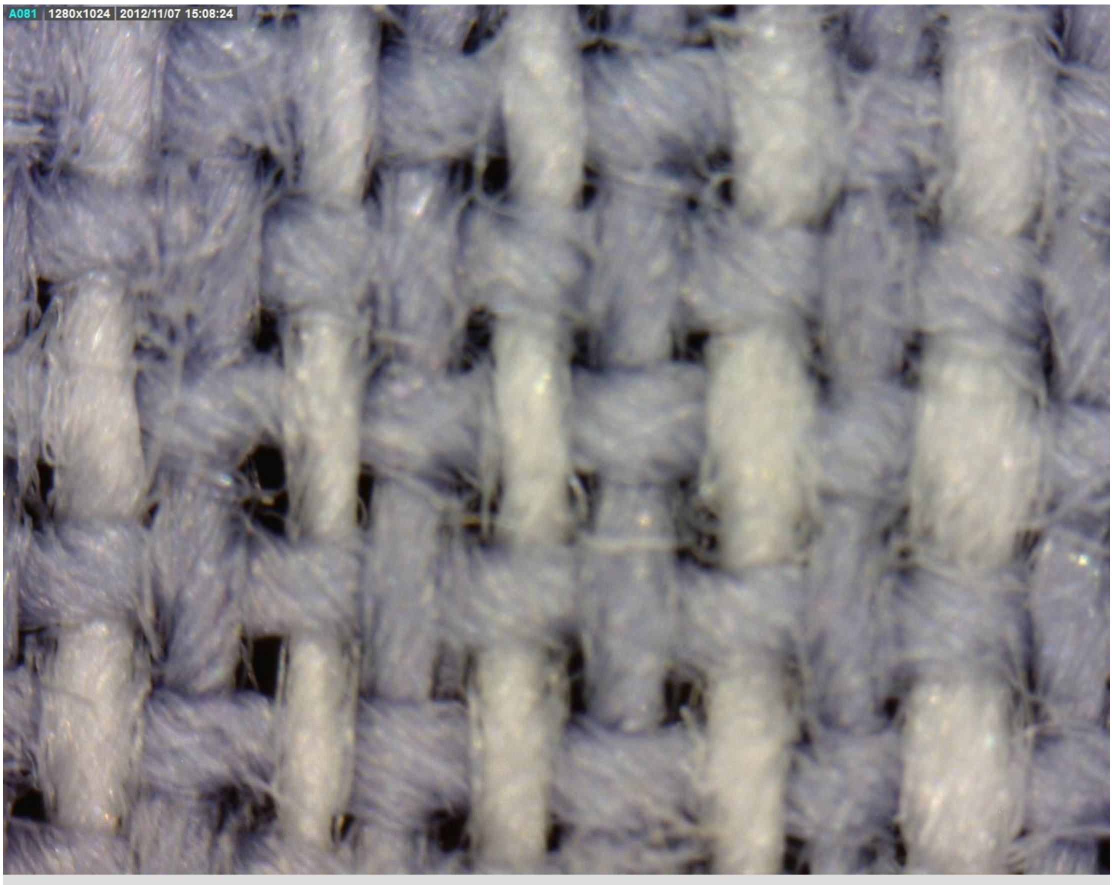

Figure 7.34: Fabric 12 with a cover factor of 14.31

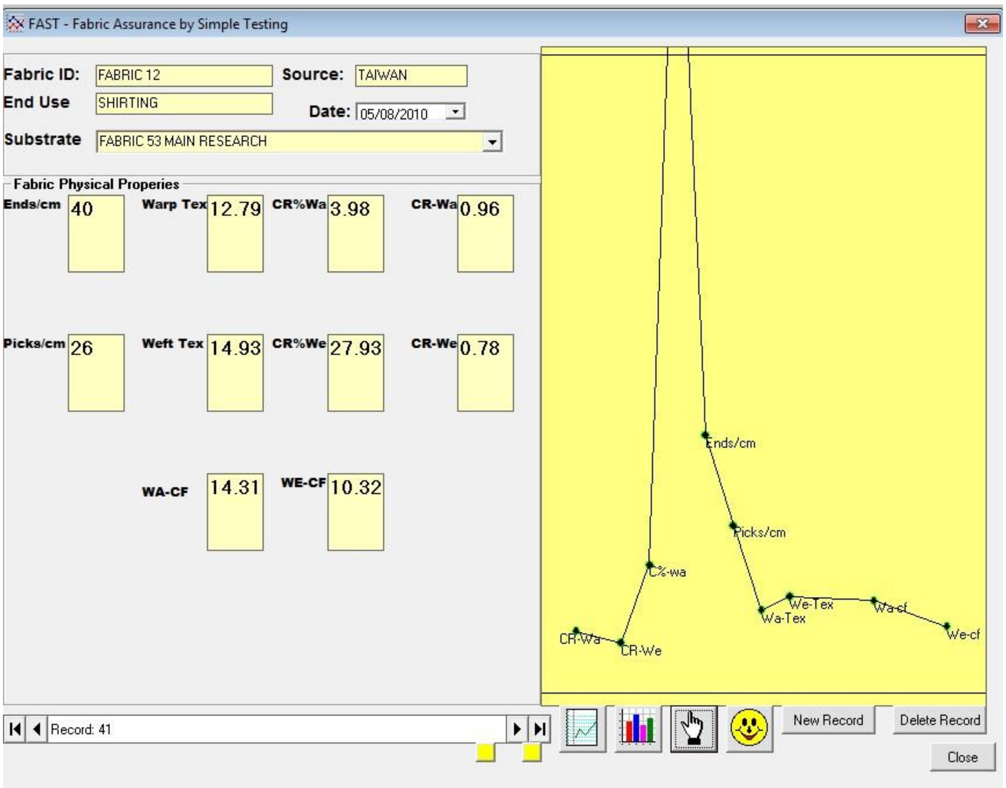

Figure 7.35: Fabric parameter map for fabric 12

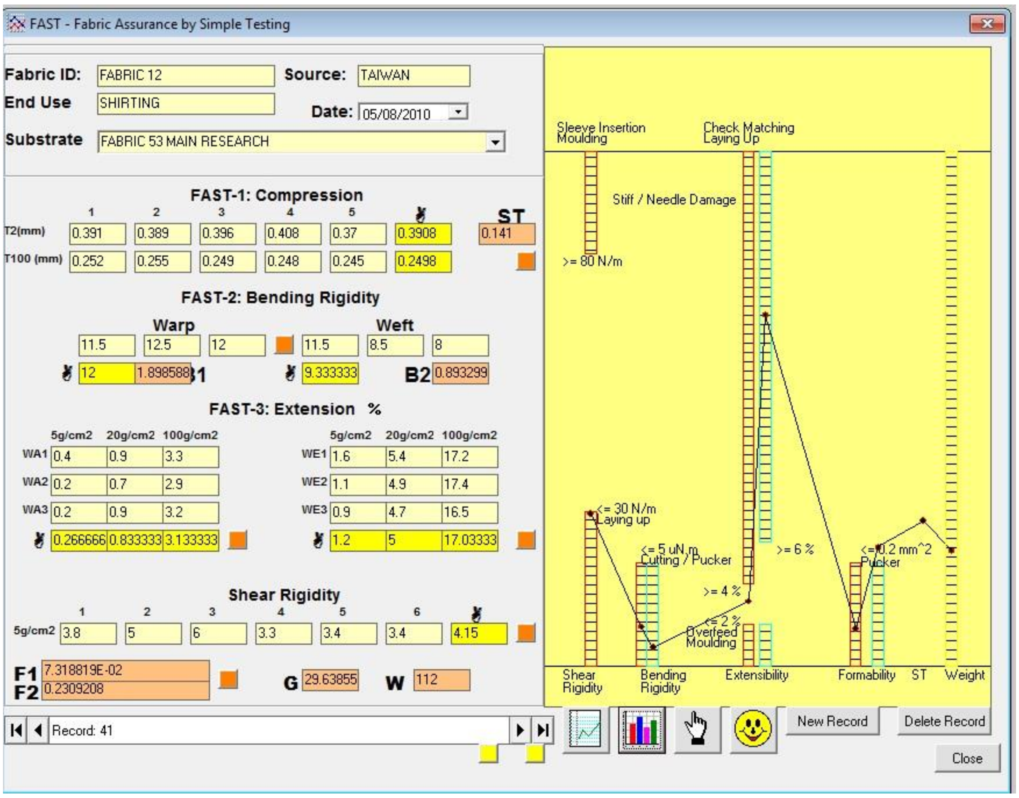

Figure 7.36: Fabric fingerprint for fabric 12

Fabric 13: This material also figures prominently as a fabric for good stitch-ability with 7 judges giving the fabric a score from 10 up to 17. The cover factor of 12.4 is also relatively low.

Figure 7.37: Fabric 13 with a cover factor of 12.4

The mechanical properties indicate that there will be some problems regarding potential seam pucker as the bending rigidity and formability of this fabric are low and in the danger zones of the FIT system.

A factor that needs to be mentioned at this stage is that although these values are low, this does not necessarily mean that the fabric will perform badly at the needle point. Before and since these machines where invented, the process of manufacturing fabric into the product has always been done through the skills and expertise of the technologists and machinists employed on the factory floor. This point applies to all the fabrics discussed here. The fabrics and properties are given in figures 7.38 and 7.39.

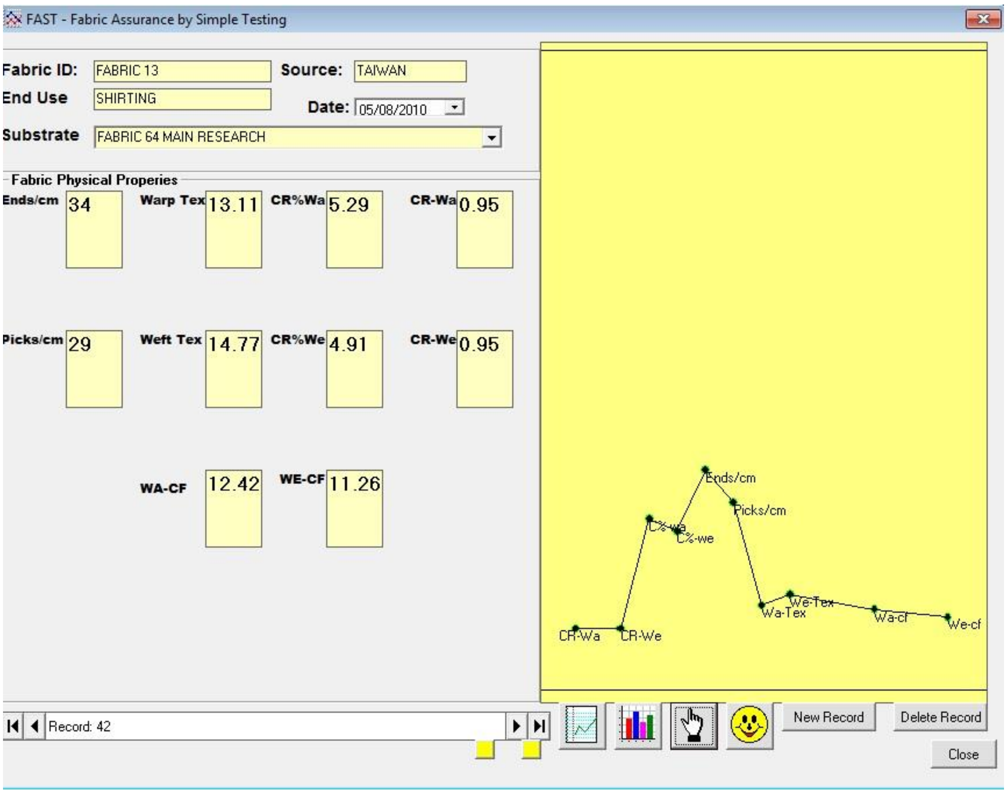

Figure 7.38: Fabric parameter map for fabric 13

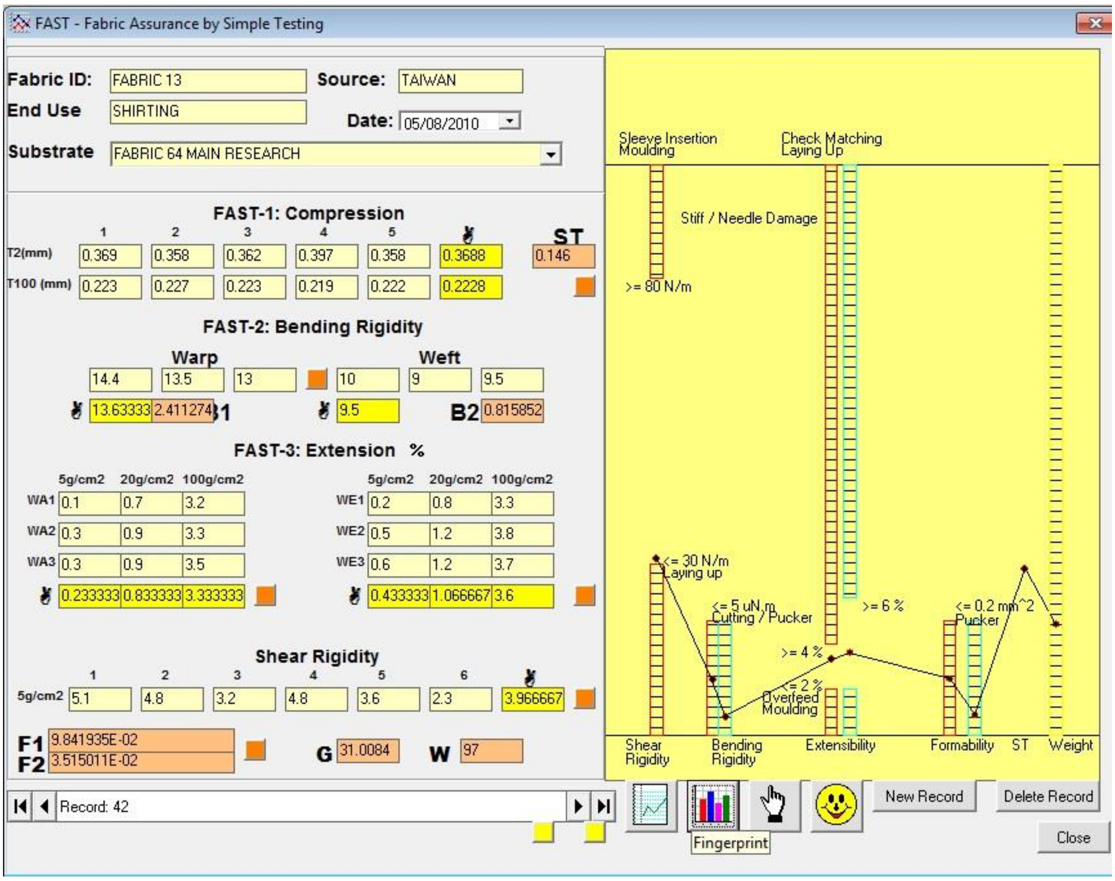

Figure 7.39: Fabric fingerprint for fabric 13

Fabric 14: This fabric is also given a positive review by most judges giving the material scores above 10 with only 3 giving scores below. The fabric has a higher cover factor than that of fabric 13 with a value of 17.35.

Extensibility for both warp and weft lye comfortably within the comfort zones on the chart but the bending rigidity and formability of the material are well embedded in the danger areas particularly in the weft direction. The bending rigidity for the warp lies just on the borderline for the bending rigidity.

The illustrations for this material with the parameter map and fabric fingerprint is given in figures 7.40 – 7.42.

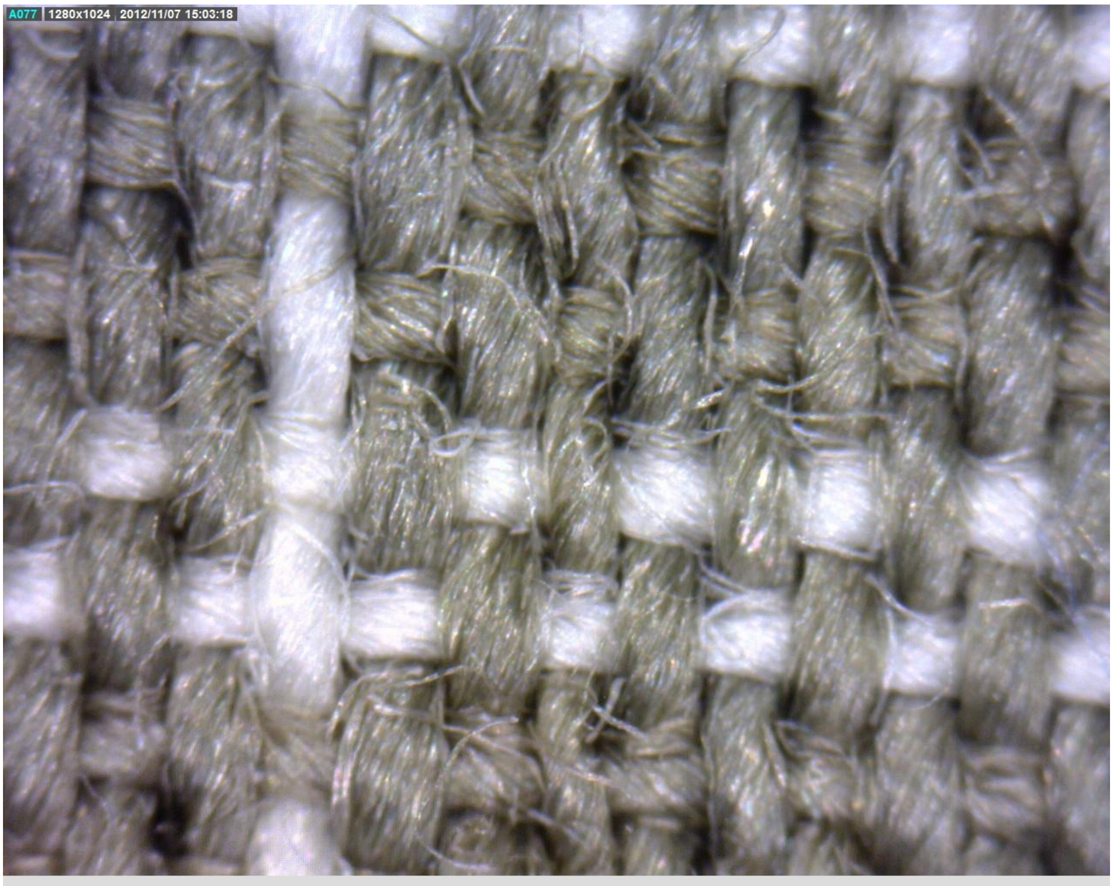

Figure 7.40: Fabric 14 with a cover factor of 17.35

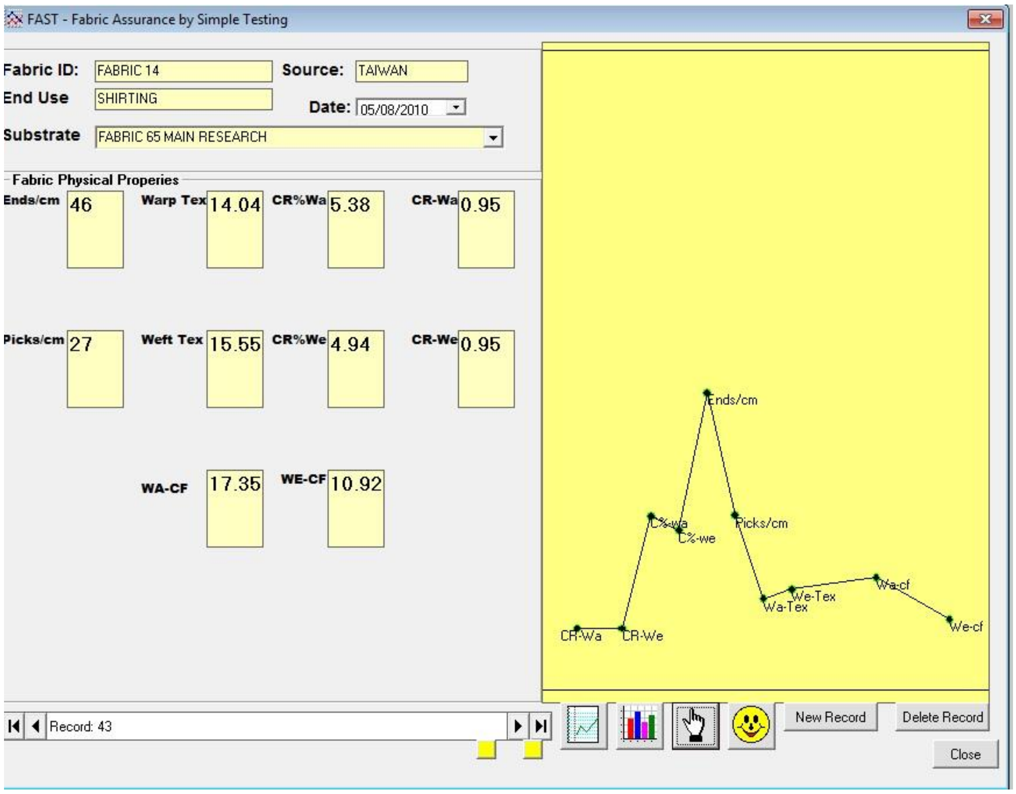

Figure 7.41: Fabric parameter map for fabric 14

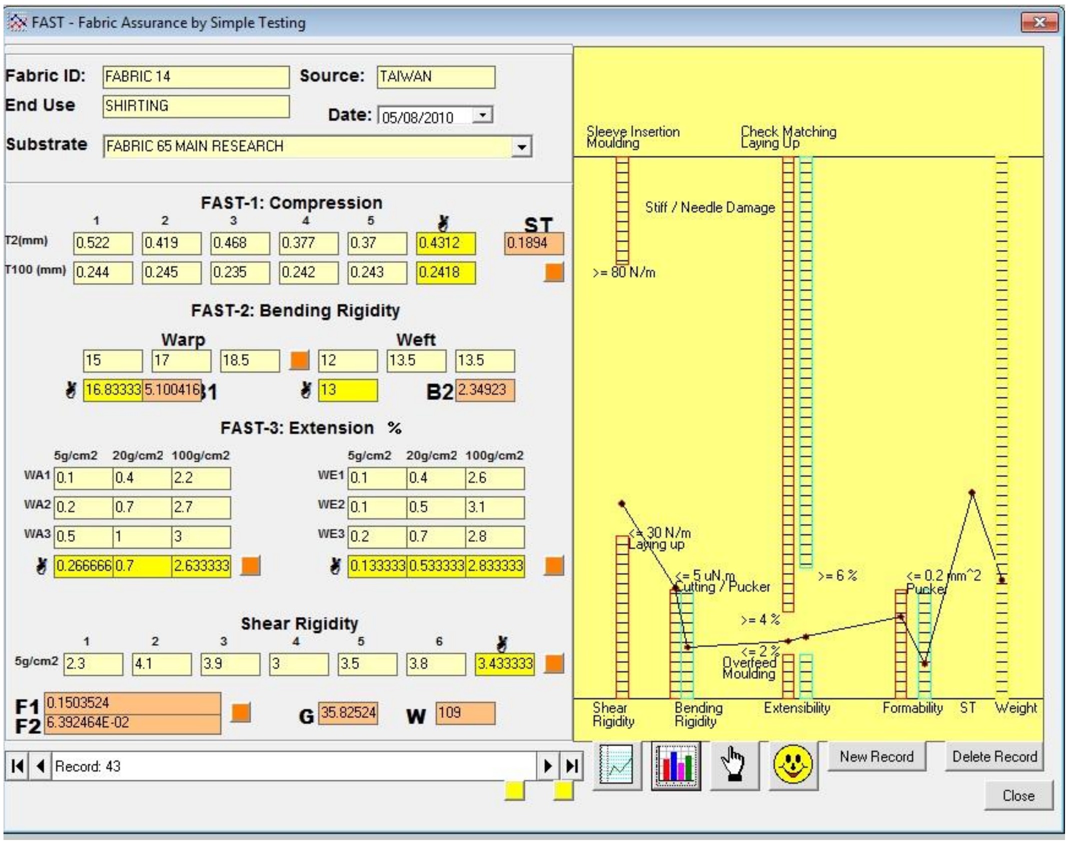

Figure 7.42: Fabric fingerprint for fabric 14

Fabric 15: This is another fabric that ranks very highly for stitching and is one of the highest reported here. It is also the only material with a different structure to plain woven; this fabric has a twill configuration. 7 judges give this ranking, high scores for sew-ability. This fabric has a cover factor of 14.87.

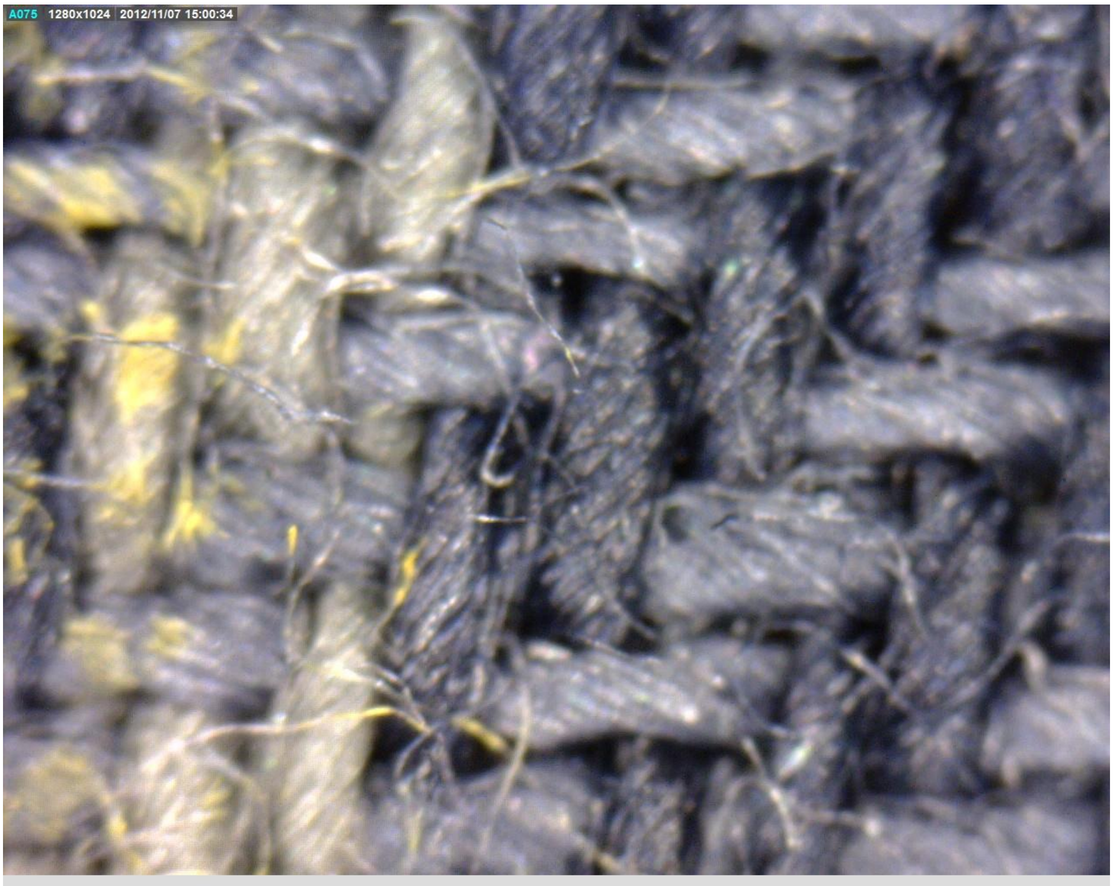

Figure 7.43: Fabric 15 with a cover factor of 14.87

The material does exhibit some good results from the FAST testing with the extensibility inside the comfort zones of the chart. The bending rigidity in the warp direction is low and the shear rigidity is also low which indicates that the fabric may perform poorly when laying up and being cut into garments.

Although the judges could not see the construction of the fabric, some did comment upon the fact that it had a slightly different handle to the other materials, feeling softer with a springier feel. This fabric can be observed in figures 7.44 and 7.45.

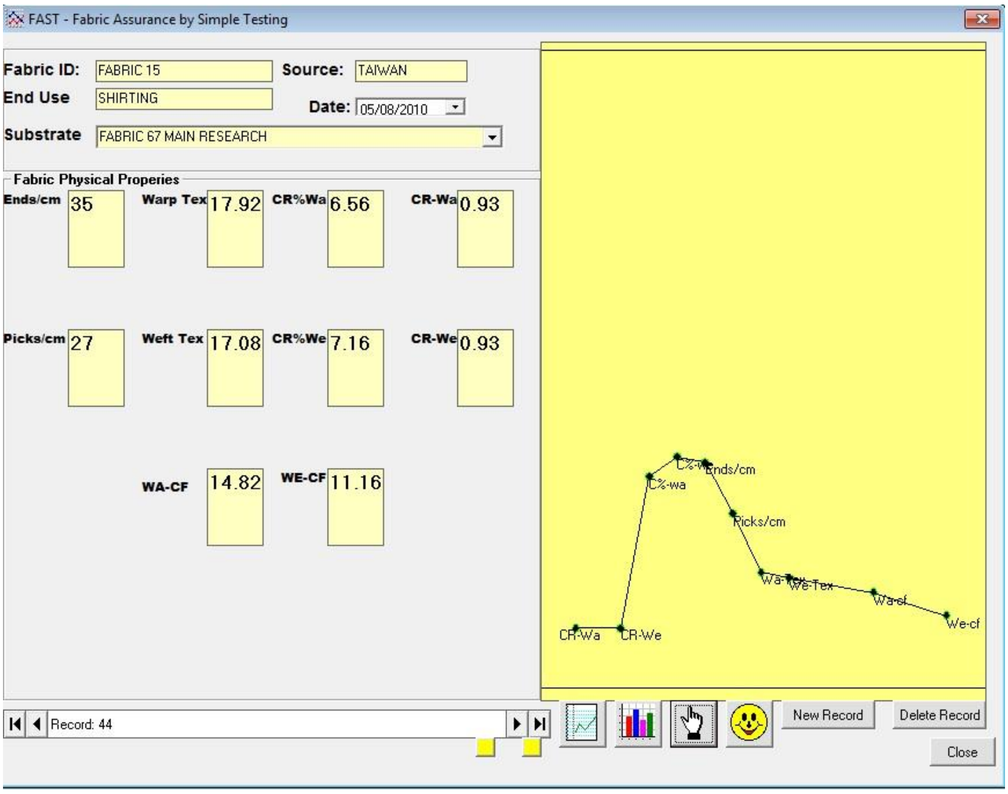

Figure 7.44: Fabric parameter map for fabric 15

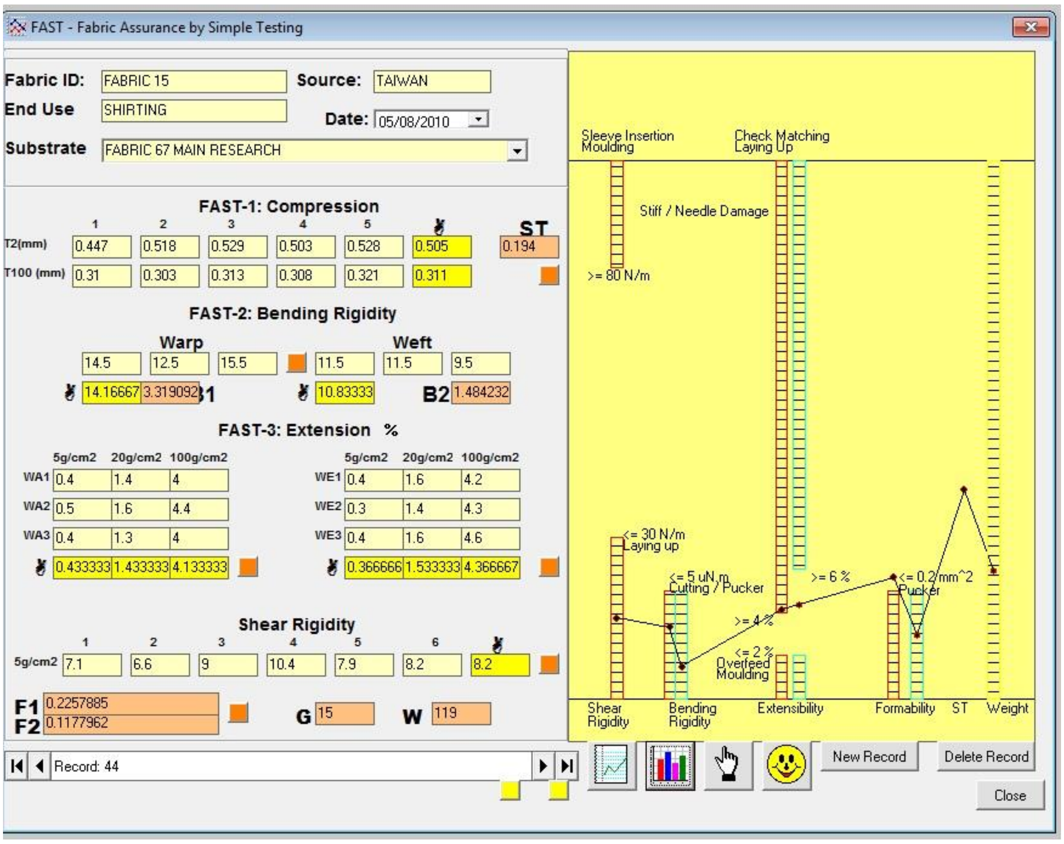

Figure 7.45: Fabric fingerprint for fabric 15

Fabric 16: Fabric 16 is one of the strongest fabrics here with all judges ranking the fabric highly. All scores where above 10 and comments from the judges included crisp handle, good feel and smooth finish. The cover factor of 13.1 is another relatively low value and the gaps between the yarns can plainly be seen.

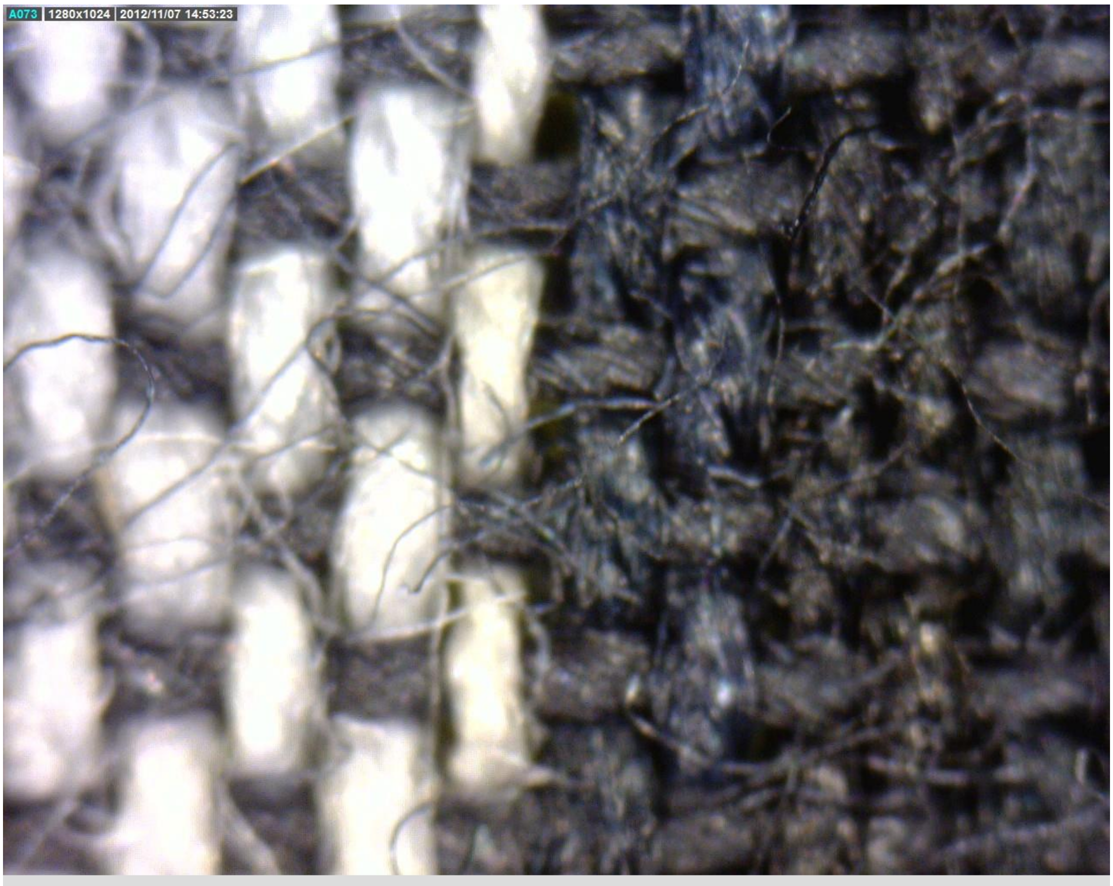

Figure 7.46: Fabric 16 with a cover factor of 13.42

The fabric weight is one of the lowest of all of the fabrics tested and the tests from the mechanical parameters show that most of the values lye within the danger zones of the FIT system. These results give a strong indication that there will problems in processing and stitching this fabric. This material can be observed in figures 7.47 and 7.48.

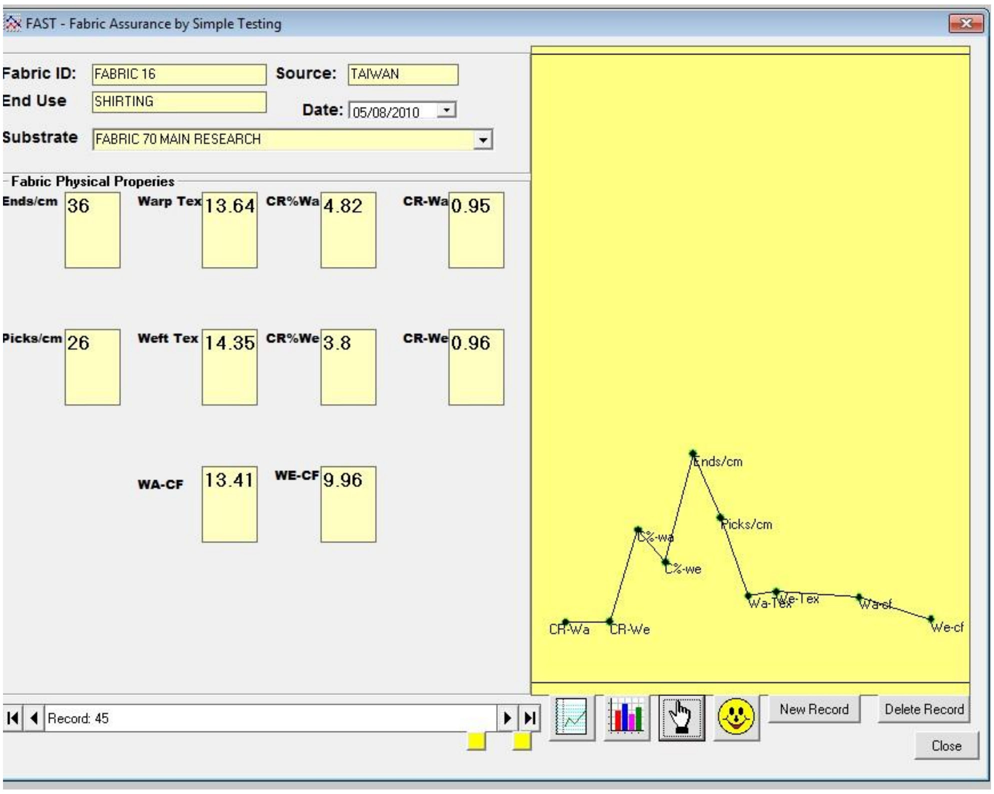

Figure 7.47: Fabric parameter map for fabric 16

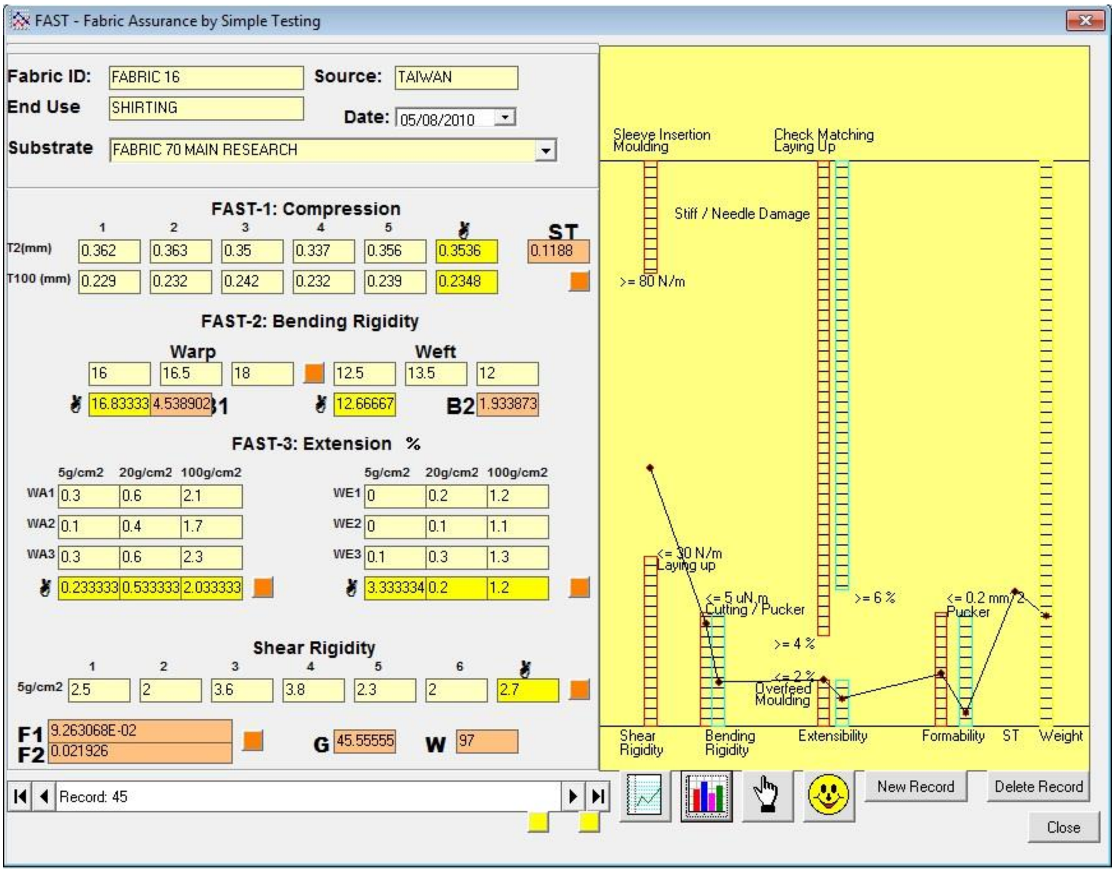

Figure 7.48: Fabric fingerprint for fabric 16

Fabric 17: This material ranks very poorly with 7 of the judges giving it a very low score of between 1 and 3. It can be seen that this material has similar properties to that of fabric 12 with a very similar cover factor of 14.7 as opposed to 14.31.

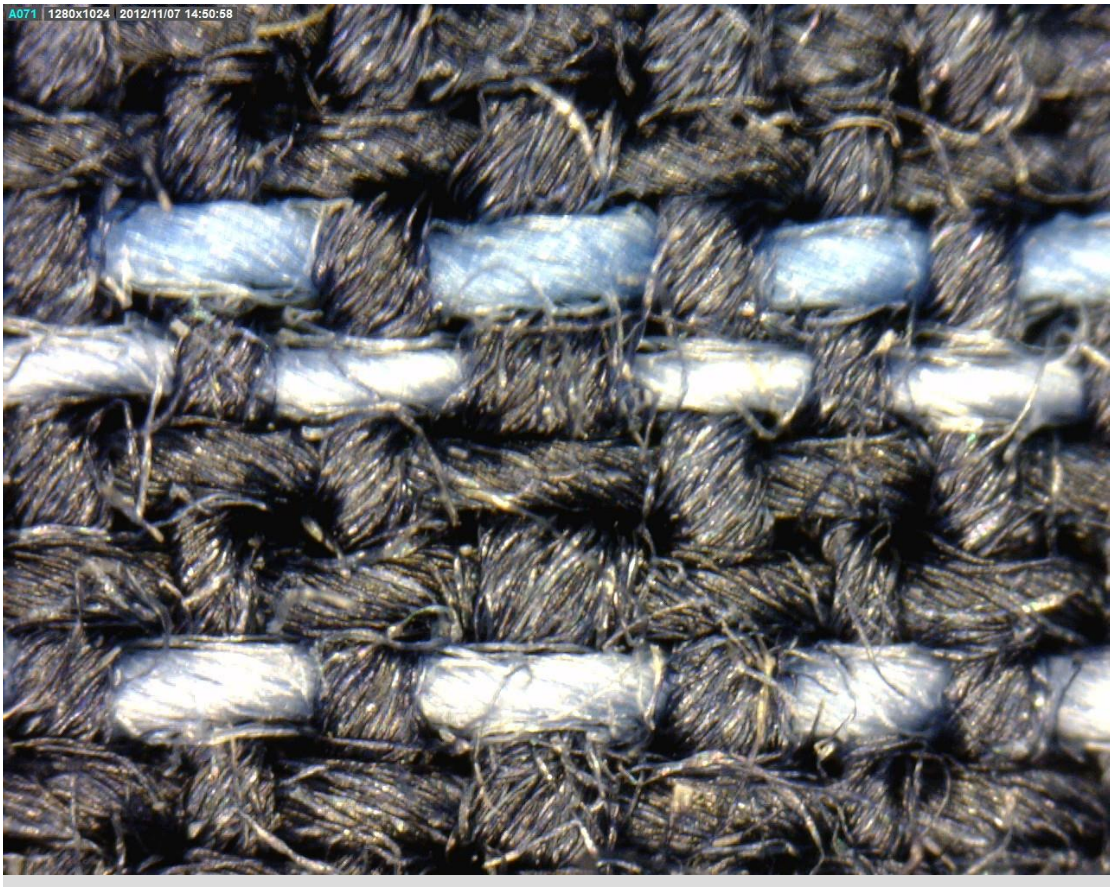

Figure 7.49: Fabric 17 with a cover factor of 14.7

The warp crimp percentage is also very high in this fabric as it is in fabric 12 and the fabric content is the same being 97% cotton and 3% spandex. The mechanical parameters show a similar picture to fabric 12 with very high extensibility in the weft direction and low bending rigidity and formability in the warp. These images are given in figures 7.50 – 7.51.

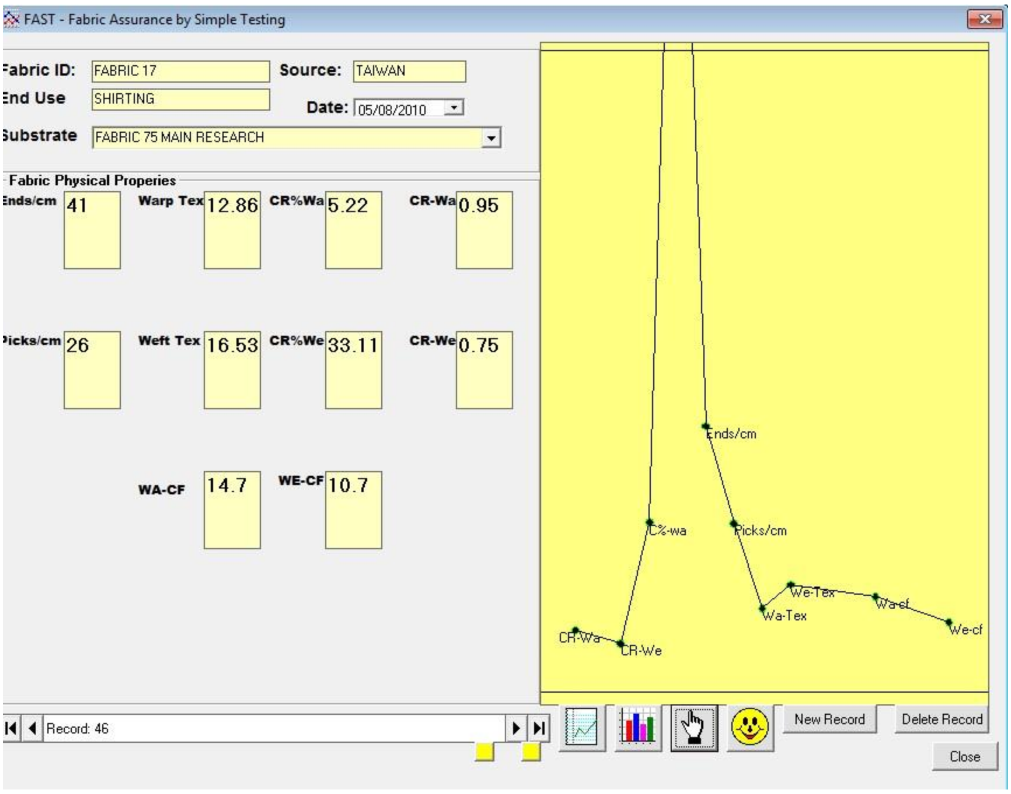

Figure 7.50: Fabric parameter map for fabric 17

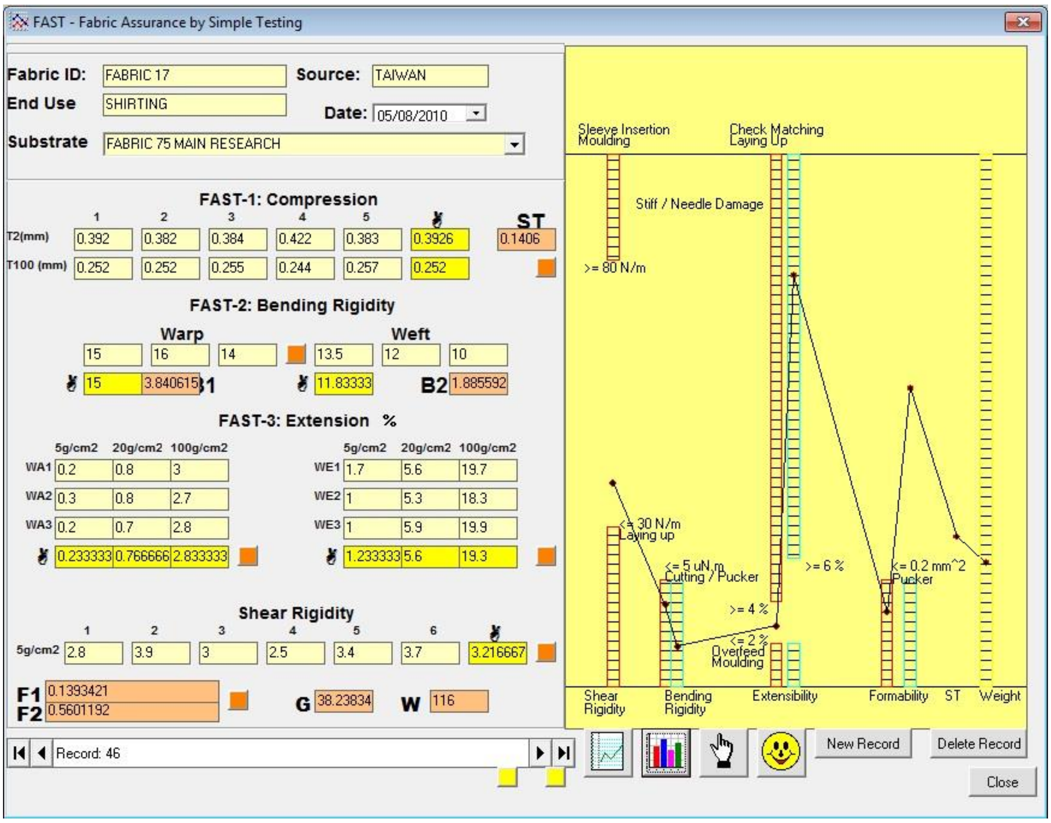

Figure 7.51: Fabric fingerprint for fabric 17

Fabrics 18, 19 and 20: All these fabrics have very similar properties and are strikingly similar so all 3 are discussed here.

The cover factors are all very similar:

Fabric 18: 21.66
Fabric 19: 21.84
Fabric 20: 20.98

It can also be seen from table 9.2 that all of the materials have the same ends per cm and that their weights are within 2 points of each other. These materials are given in figures 7.52 – 7.60.

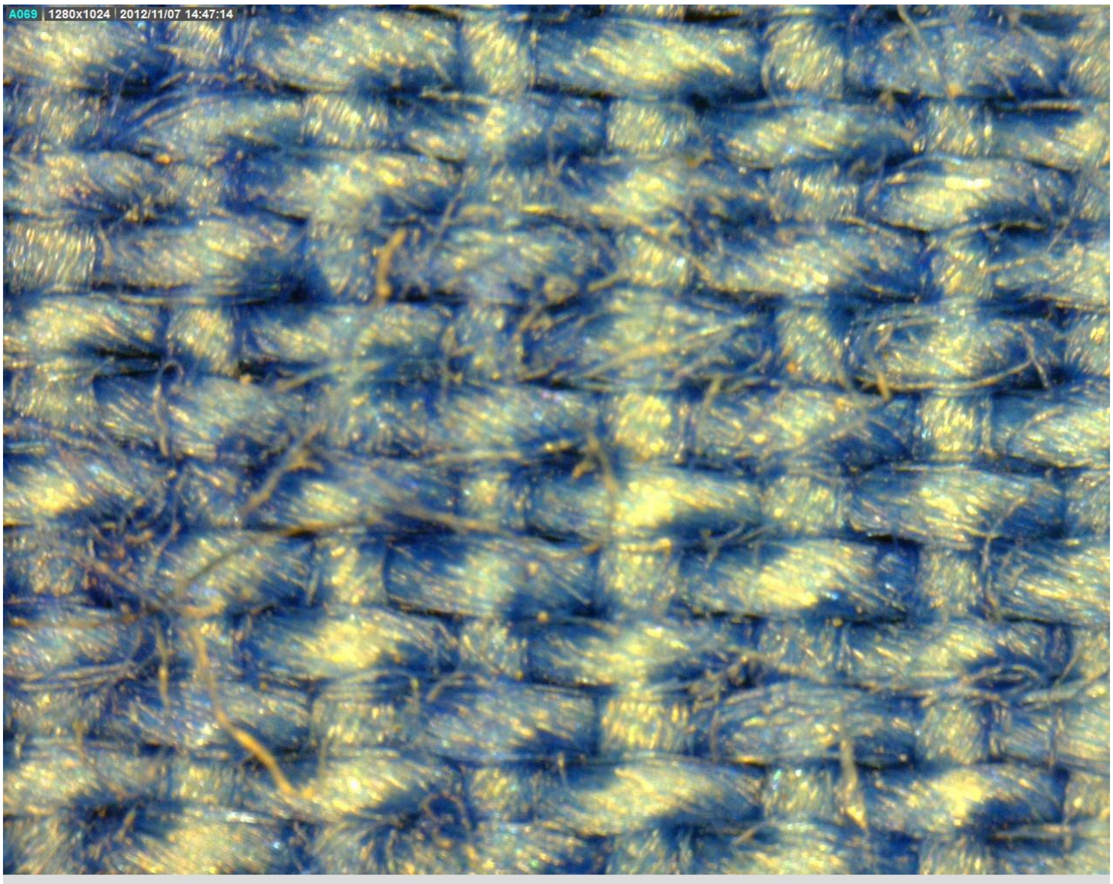

Figure 7.52: Fabric 18 with a cover factor of 21.66

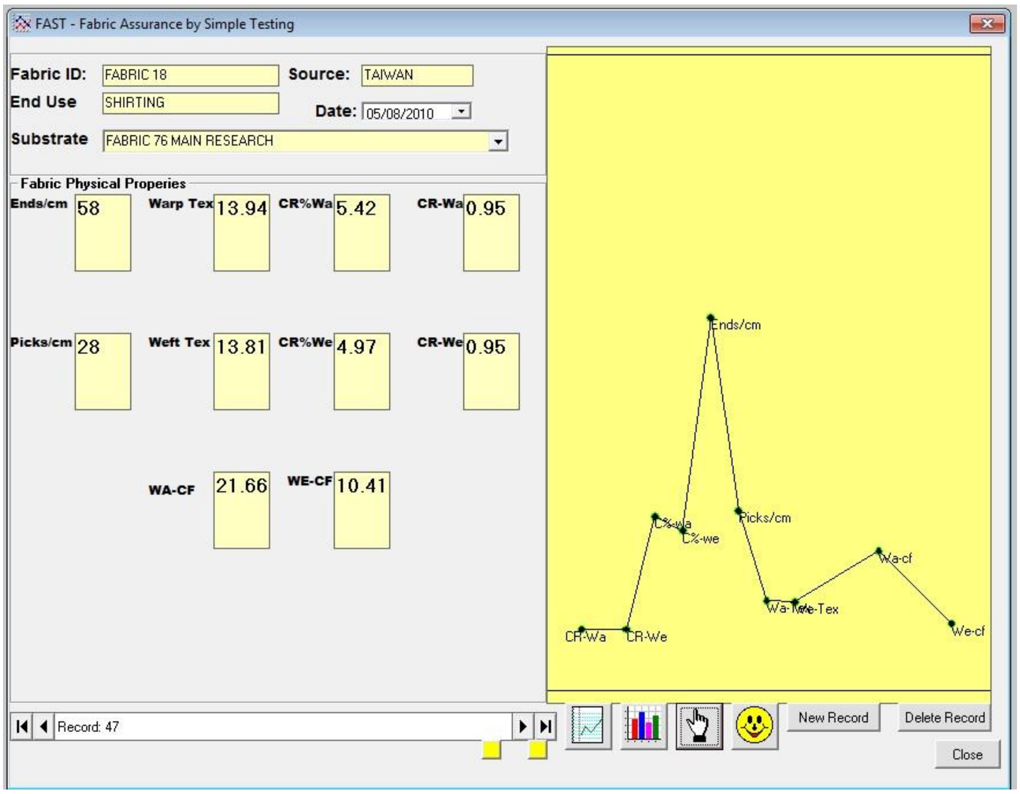

Figure 7.53: Fabric parameter map for fabric 18

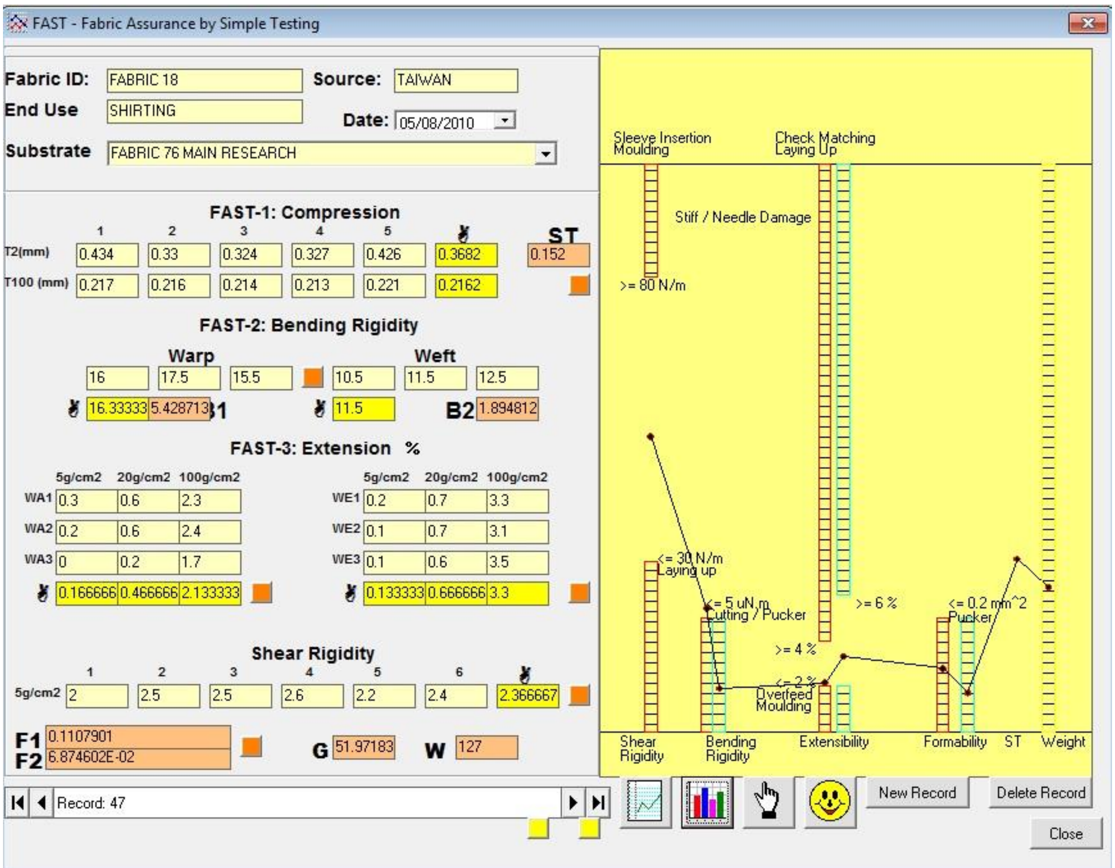

Figure 7.54: Fabric fingerprint for fabric 18

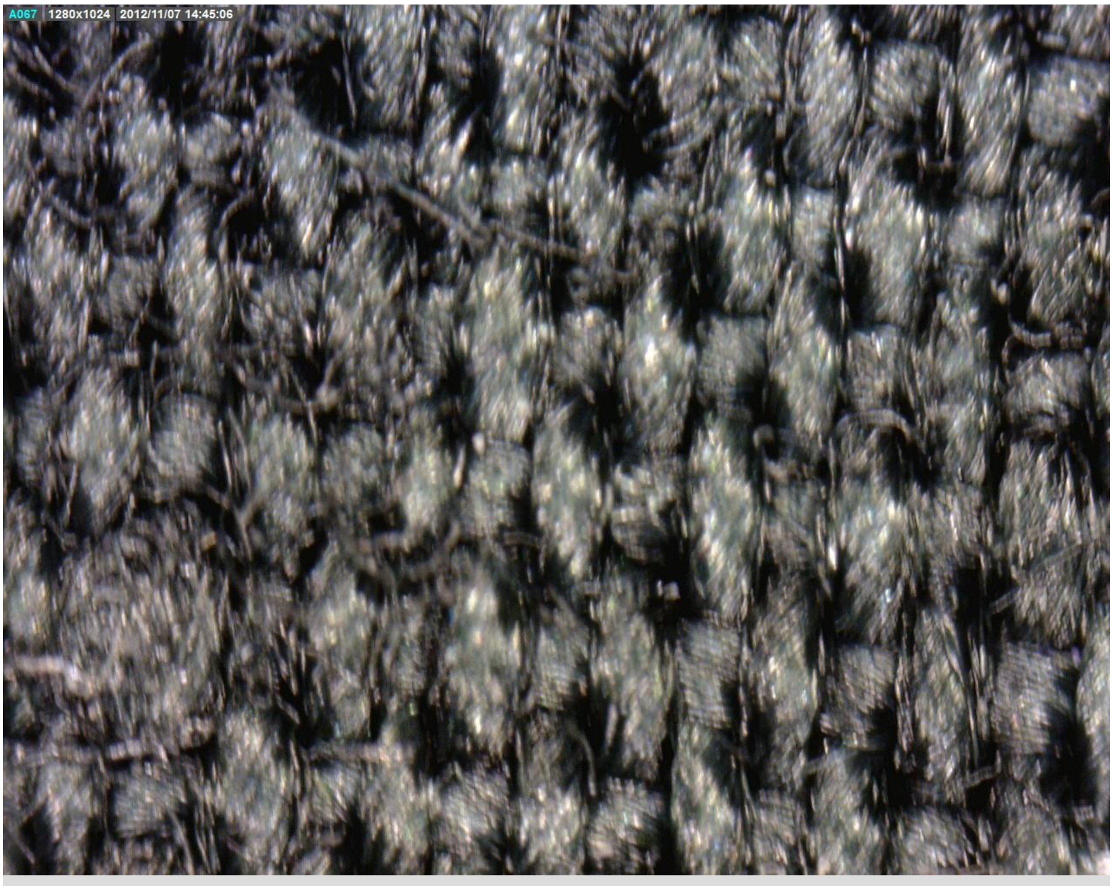

Figure 7.55: Fabric 19 with a cover factor of 21.84

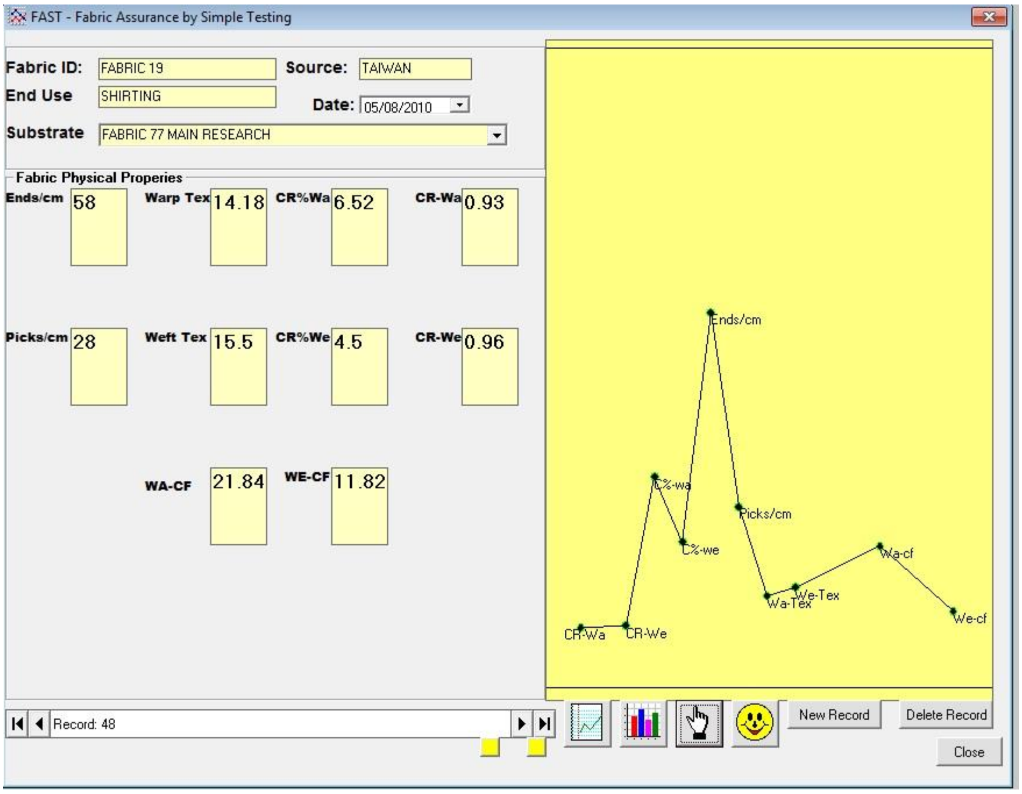

Figure 7.56: Fabric parameter map for fabric 19

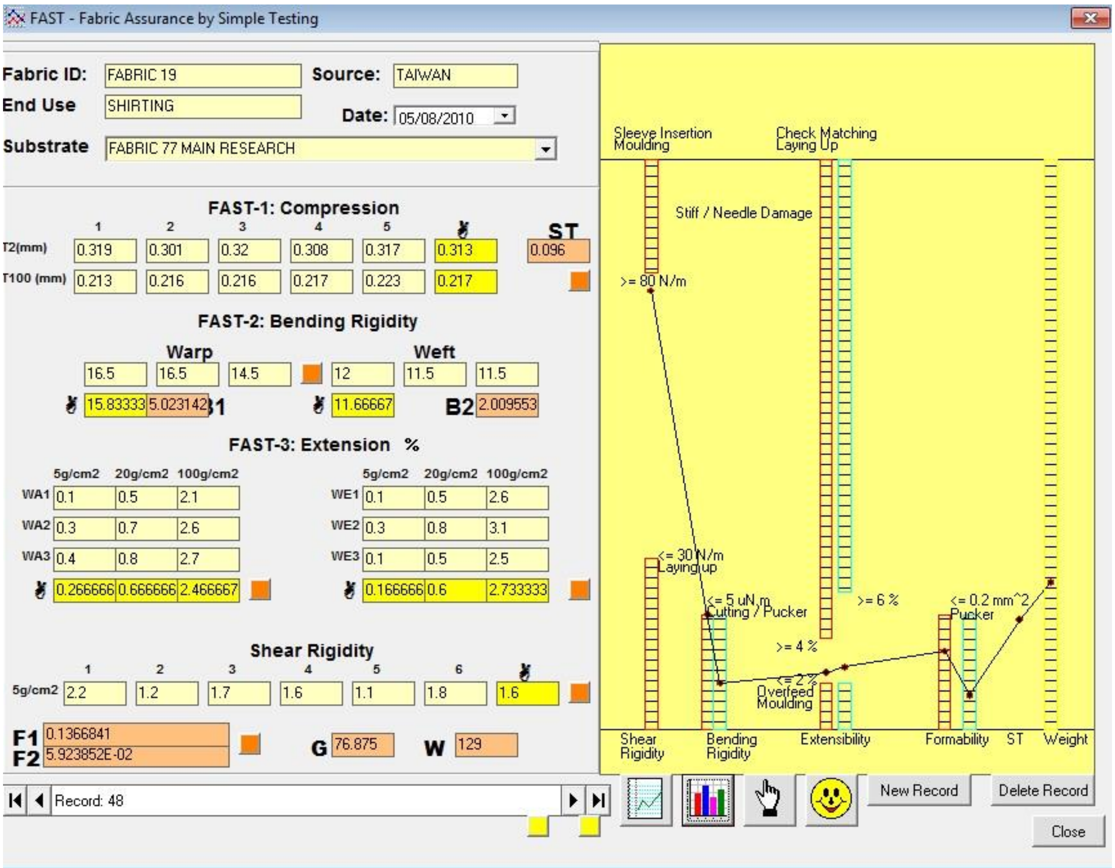

Figure 7.57: Fabric fingerprint for fabric 19

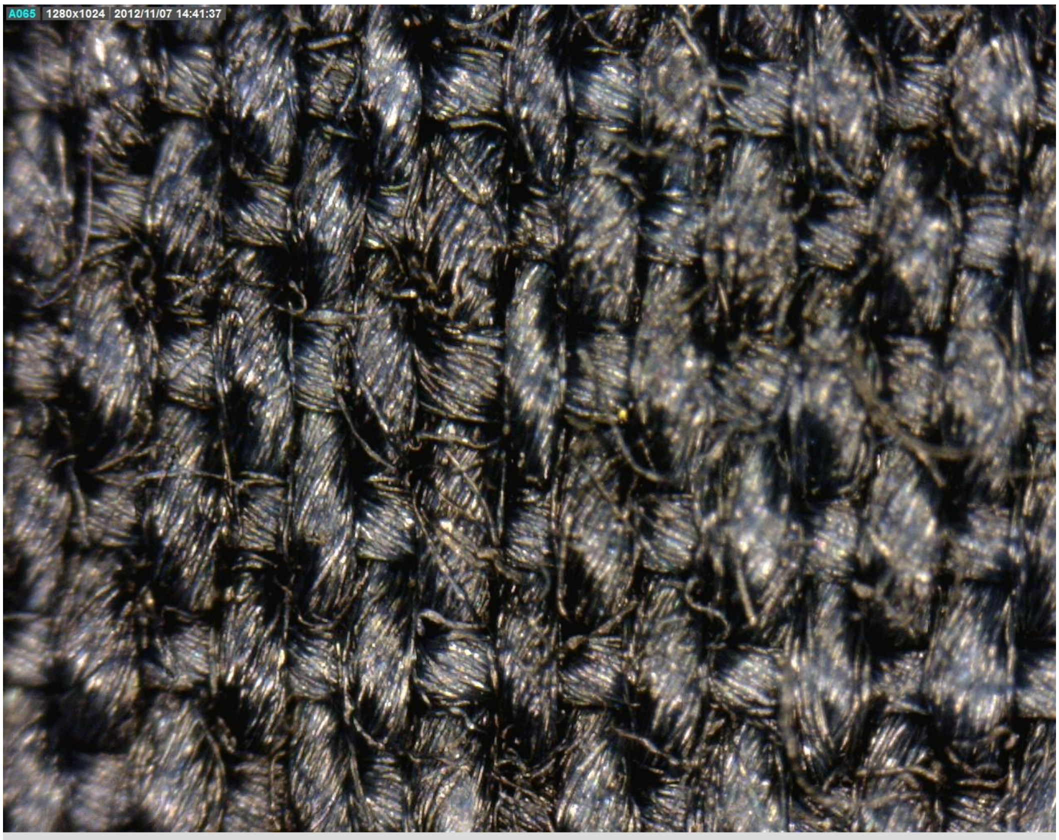

Figure 7.58: Fabric 20 with a cover factor of 20.98

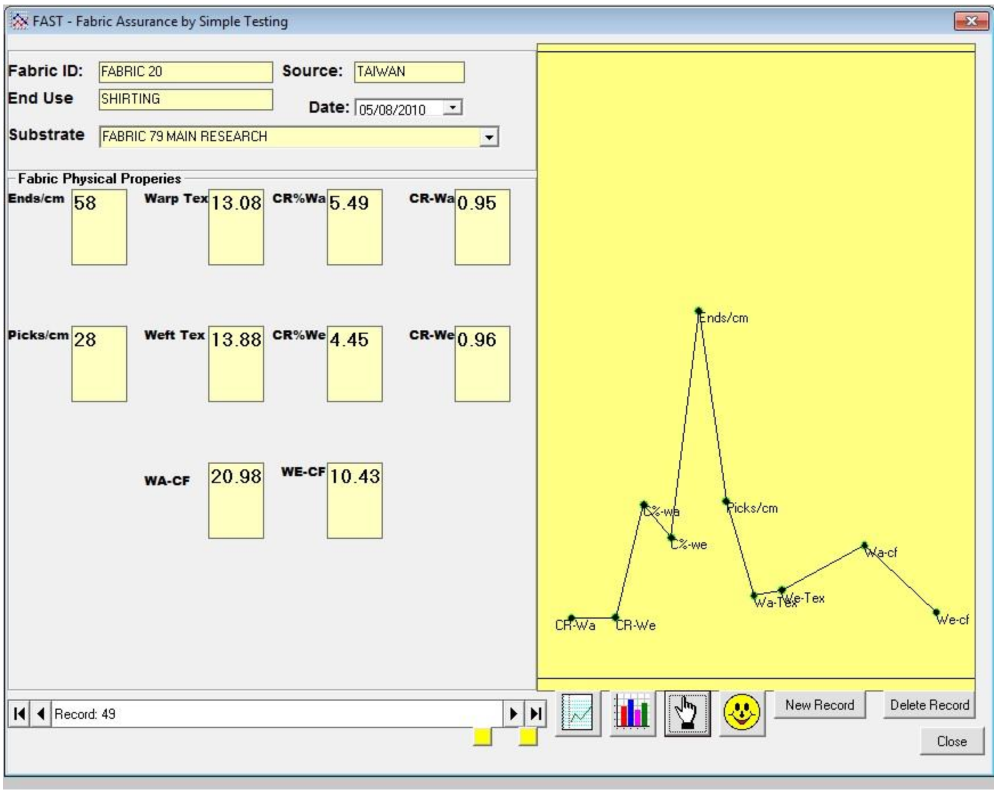

Figure 7.59: Fabric parameter map for fabric 20

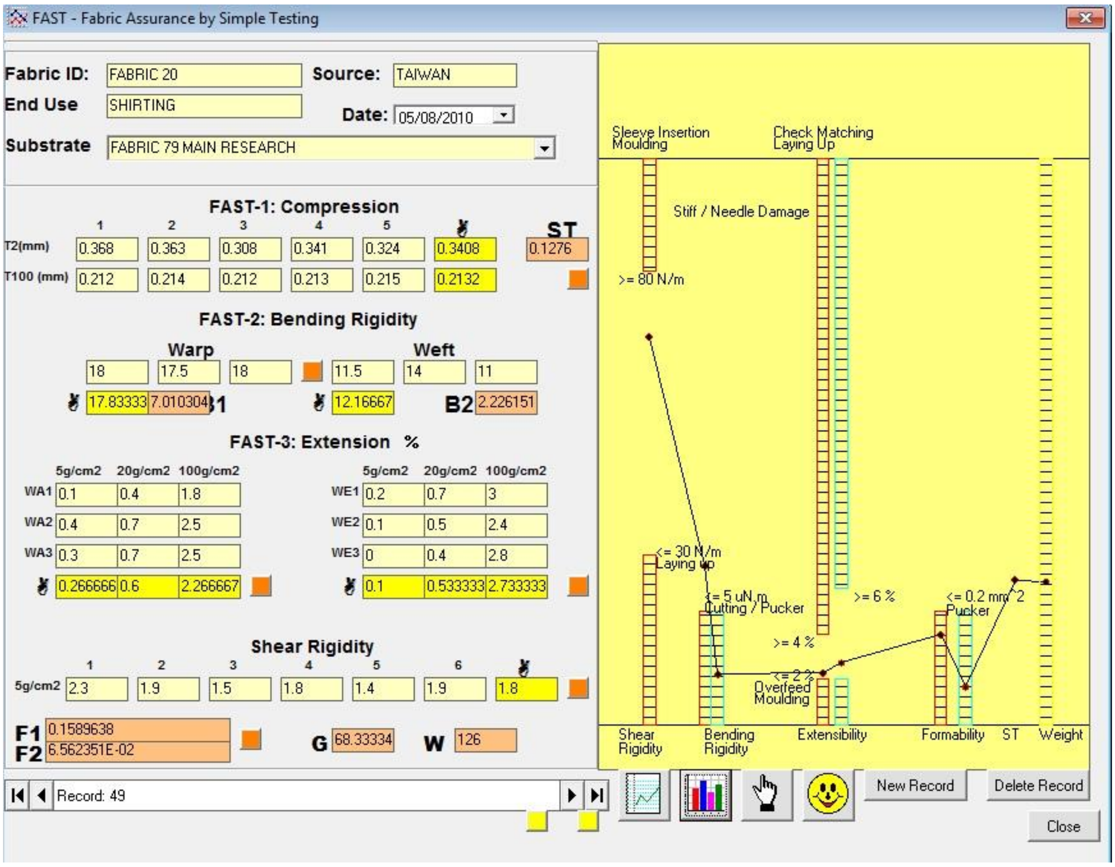

Figure 7.60: Fabric fingerprint for fabric 20

The mechanical properties of all the materials are also very similar with higher shear properties, acceptable extensibility and reasonable bending rigidity and formability. Fabrics and their magnification values are given in appendix 8.

7.4. Results from the sewing experiments

The originality of this work comes from the development of a suitable testing regime for the stitching of textile materials. The principles applied here were to acquire as much data as possible, both subjective and objective in order to create a holistic representation of the challenges encountered when this project was initiated.

The collection of the subjective data was very important as most stitching and fabric assessment in clothing manufacturing is still done by fabric handlers on the production floor.

The objective measurement from FAST was considered to be useful as it provided assessment that was independent from subjective handling.

The information gained from the experts was essential in gaining a collective representation of knowledge that is becoming scarcer in the United Kingdom. This knowledge was collated, summarised and used as a road map as the basis for generating is given in table. Several machine parameters and a adjustments were highlighted by the experts as essential to good seam appearance and quality. These were:

- Use the finest needle possible to reduce fabric buckling
- Use a polyester core-spun sewing thread reducing the diameter of the thread whilst maintaining seam strength
- Thread tensions and foot pressure to be as light as possible
- Feed setting one full tooth above the throat plate

Using these settings as a first basis the fabrics were stitched and adjusted individually to achieve the flattest seam possible. These are given in table 7.4.

	Seam App	P / F / F mm	FEED	M / SPEED	S/D	N / T / T g/f	B / T / T g/f	SEWING THREAD	NEEDLE SIZE	POINT TYPE	CHECK SPRING
Fabric 1	Flat	42	1 Full tooth	4000	5 /cm	151	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 2	Flat	42	1 Full tooth	4000	5 / cm	151	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 3	Flat	23	1 Full tooth	4000	4 / cm	154	14	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 4	Flat	42	H/TOOTH	4000	5 / cm	151	13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 5	Flat	43	H/TOOTH	4000	5 / cm	151	13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 6	Flat	43	H/TOOTH	4000	5 / cm	151	13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 7	Flat	42	H/TOOTH	4000	5 / cm	151	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 8	Flat	44	H/TOOTH	4000	5 / cm	151	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 9	Flat	42	1 Full tooth	4000	5 / cm	155	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 10	Flat	42	1 Full tooth	4000	4 / cm	160	14	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 11	Flat	44	H/TOOTH	4000	5 / cm	149	13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 12	Flat	45	1 Full tooth	4000	4 / cm	150	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 13	Flat	40	H/TOOTH	4000	4 / cm	155	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 14	Flat	39	1 Full tooth	4000	5 / cm	155	13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 15	Flat	40	H/TOOTH	4000	5 / cm	155	13	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 16	Flat	43	H/TOOTH	4000	5 / cm	150	14	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 17	Flat	41	1 Full tooth	4000	5 / cm	150	14	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 18	Flat	42	H/TOOTH	4000	5 / cm	150	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 19	Flat	42	H/TOOTH	4000	5 / cm	150	12	150ss poly/poly	70	Acute RP	SET TO WINK
Fabric 20	Flat	42	H/TOOTH	4000	5 / cm	150	12	150ss poly/poly	70	Acute RP	SET TO WINK
MEAN		41.15		4000			12.7		70		
σ		4.38		0			0.8		0		

Table 7.4: Machine adjustments for the twenty fabrics

- Seam App = Seam Appearance
- P / F / F = Presser foot force in ‘Newtons’
- M / SPEED = Machine Speed – Revolutions per Minute

- S / D = Stitch Density per Centimetre
- N / T / T = Needle Thread Tension – grams force / Newtons
- B / T / T = Bottom Thread Tension – grams force / Newtons

The fabrics were assessed for seam pucker using the American Society for Textiles, Chemists and Colourists (AATCC) chart. The fabrics were observed by 10 individual people who had substantial experience of stitching fabrics but were not related to the previous experts who recommended the machine settings. Also they were not sewing machine engineers but fabric and garment technologists from many areas of the sewn product industry. This was considered desirable in order to maintain impartiality of the research. The samples were presented to these new judges under a standard light box in an un-pressed condition. The observations for the 20 materials can be seen in table 7.5.

Fabric Number	O1	O2	3	O4	O5	O6	O7	O8	O9	O10
1	5	5	5	5	5	5	5	5	5	5
2	5	5	5	5	5	5	4	5	5	5
3	5	4	5	5	5	4	4	4	4	4
4	5	5	5	5	5	5	5	5	5	5
5	5	4	5	5	4	4	4	5	4	4
6	5	4	4	5	5	3	4	4	3	4
7	5	5	5	5	4	4	5	5	5	4
8	5	5	5	5	4	5	5	4	4	5
9	5	5	5	5	5	5	5	5	5	5
10	5	5	4	5	4	4	4	5	4	4
11	5	5	4	5	5	5	4	5	4	5
12	5	5	5	5	5	5	5	5	4	5
13	5	5	5	5	4	5	4	5	5	5
14	5	4	5	5	4	4	4	5	4	4
15	5	4	5	5	4	4	4	5	5	5
16	5	5	5	4	4	5	5	5	5	5
17	5	5	5	5	3	5	4	5	5	5
18	5	4	4	5	3	4	4	5	5	5
19	5	4	5	4	4	4	5	5	5	5
20	5	4	4	5	5	5	4	5	5	5
σ	0	0.5	0.444	0.307	0.67	0.606	0.502	0.366	0.604	0.47

Table 7.5: Verdicts given from the the independent experts

It can be seen from table 7.5 that fabric 1 has been given the best quality endorsement from all 10 judges. All the judges ranked this fabric at number 5 which is the best quality of seam. Using the standard deviation as a measure of the dispersion of the data, it can also be seen that the values of all the other 20 materials are between the values of 0.3 to 0.6 which can be considered to have a modest variation between the values. The stitched fabrics can be observed in figure 7.62.

An Ishikawa diagram for the sewing machine settings databank and the factors involved has been developed and is given in figure 7.61.

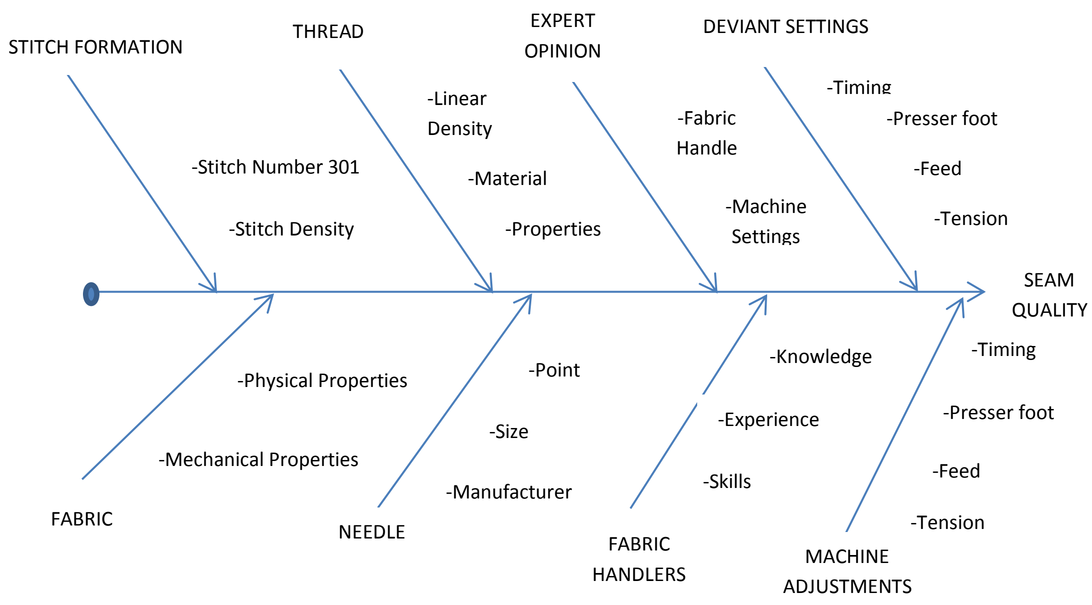

Figure 7.61: Diagram for analysing the databank for the quality of the seam

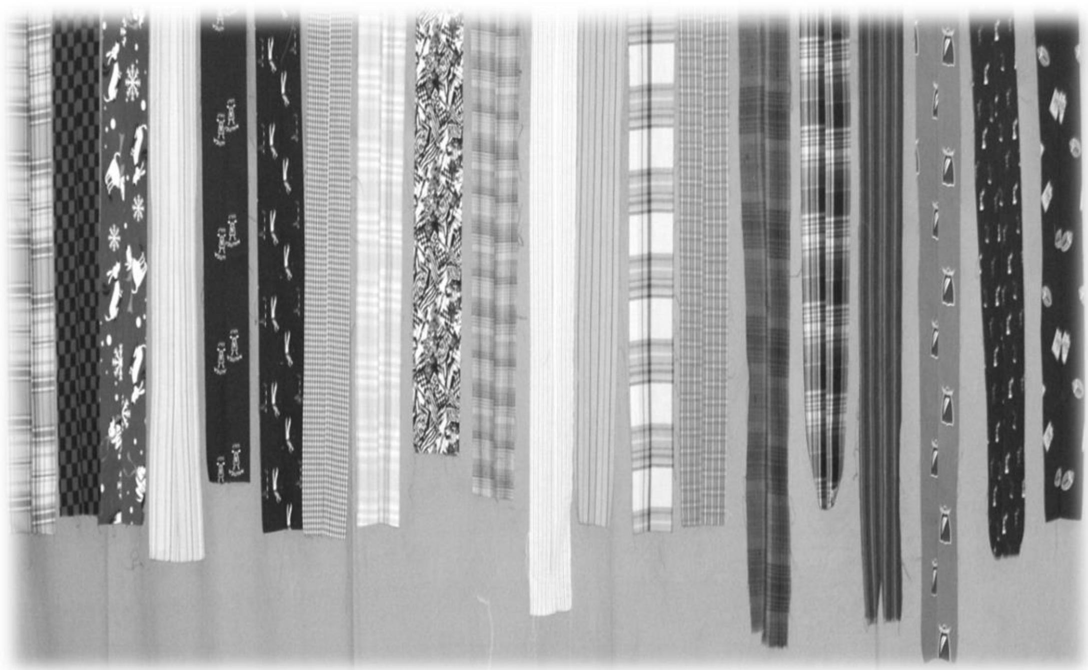

Figure 7.62: Seam results from stitching the twenty fabrics

So far, this work has described a concept of a framework for creating a sewing machine settings databank for stitching many types of material. This has included the physical deconstruction of materials, expert assessment and using FAST to determine their mechanical properties.

However, a new concept is proposed for measuring fabric physical parameters which can be much more cost effective than using FAST (an expensive system) by producing credible results quicker and more efficiently.

From the data gained from the experts, stitching experimentation and the information acquired from the physical and mechanical properties of the fabrics.

This can lead to a better understanding of how fabric parameters can affect the sewing parameters and their impact upon seam quality. It can be achieved by using a simpler method of assessment using a high performance digital camera.

The concept and a full explanation of the techniques for the exploitation for these methods are described below.

7.5. Introducing a new concept for stitching materials

Some of the concept for stitching shirting materials was derived from the pilot study in chapter 7.

In figure 5.33 (chapter 5), the illustration shows a picture of the sewing thread comparing the diameter of the thread to the yarns in the fabric. It was possible to observe this due to the high performance camera (with measurement software) used for this purpose. By using the same device, it was conceivable to count the ends and picks in the fabric making it much easier to make an accurate observation without the need to count threads manually using an eye piece and a picking needle. Figure 7.63 gives an example of this process.

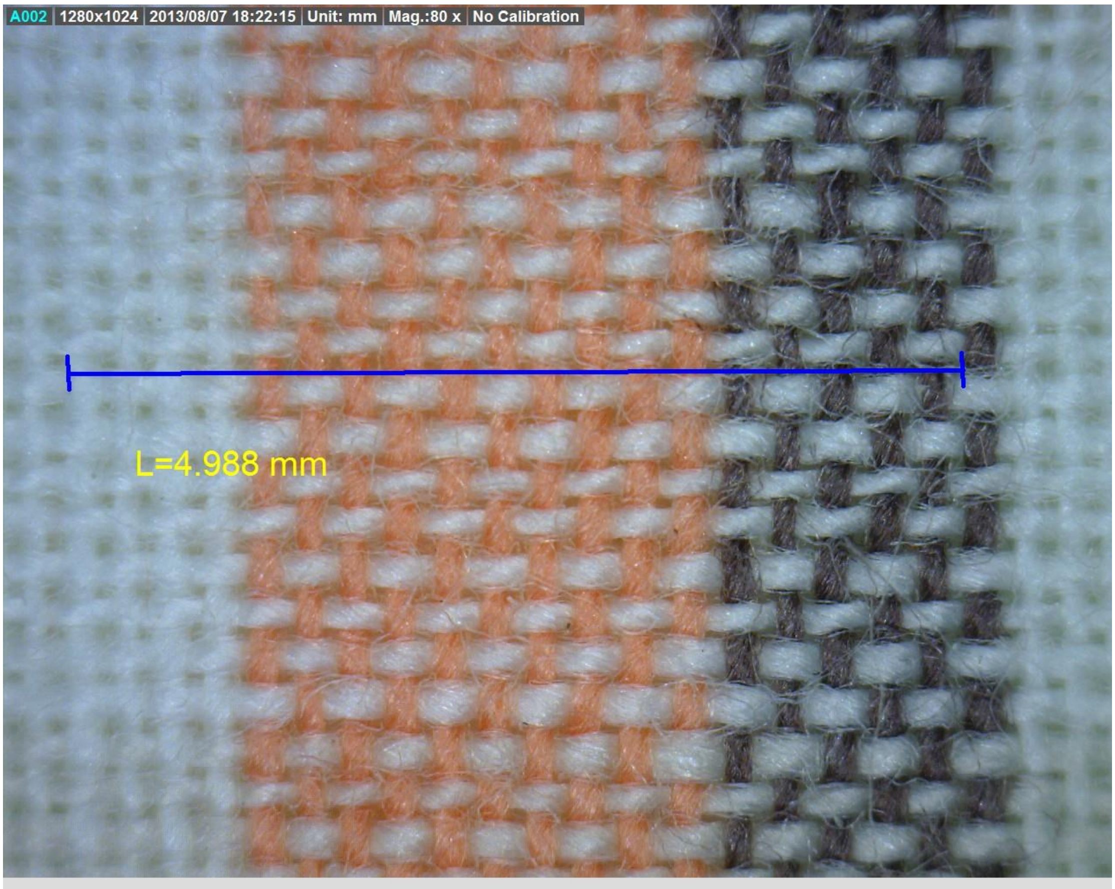

Figure 7.63: Fabric yarns measured in the warp direction

The yarns measured with the camera count up to 1 centimetre, and the Tex is calculated in the normal way by removing 10 yarns either warp or weft and weighing them.

From determining this simple data, all the other physical properties of the fabric can be calculated.

The scenario presented here is for Companies to have a simple method of establishing fabric parameters and by inputting them into software program, a databank for sewing machine settings can be created.

From all the work undertaken within the sew-ability project, models and algorithms have been created that have completely encompassed this mission. The model from the pilot study was an uncomplicated attempt to explain from the initial research, the relationships between the elements that make up the material. Further work has enabled more sophisticated prototypical avatars to be developed for creating the ultimate sewing machine settings databank. These models are described below:

Figure 7.64 illustrates the main factors that have influenced the outcomes of this work. Fabric finishing treatments can affect the frictional properties of the fabric therefore the presser foot needs to be at minimum pressure to feed the fabric without slippage. Much of the expert testimony mentioned frictional properties as a factor for potential stitching problems on fabrics and recommended presser foot adjustments as described previously.

The fabric composition contains all of the physical properties of the material. The ends and picks which can be calculated using the high performance camera and the crimp percentage which both influence the cover factor of the material.

The expert assessment feeds into all the fabric dynamics and sums up this thesis in that the stitching of the fabrics are still very much reliant upon the material handlers on the production floor.

The results from the mechanical analysis have proved to be a useful addition to this work but are considered to be expensive and beyond the scope of most clothing manufacturing companies. The resultant data combined from the physical properties can be collated and utilised for the sewing machine settings databank.

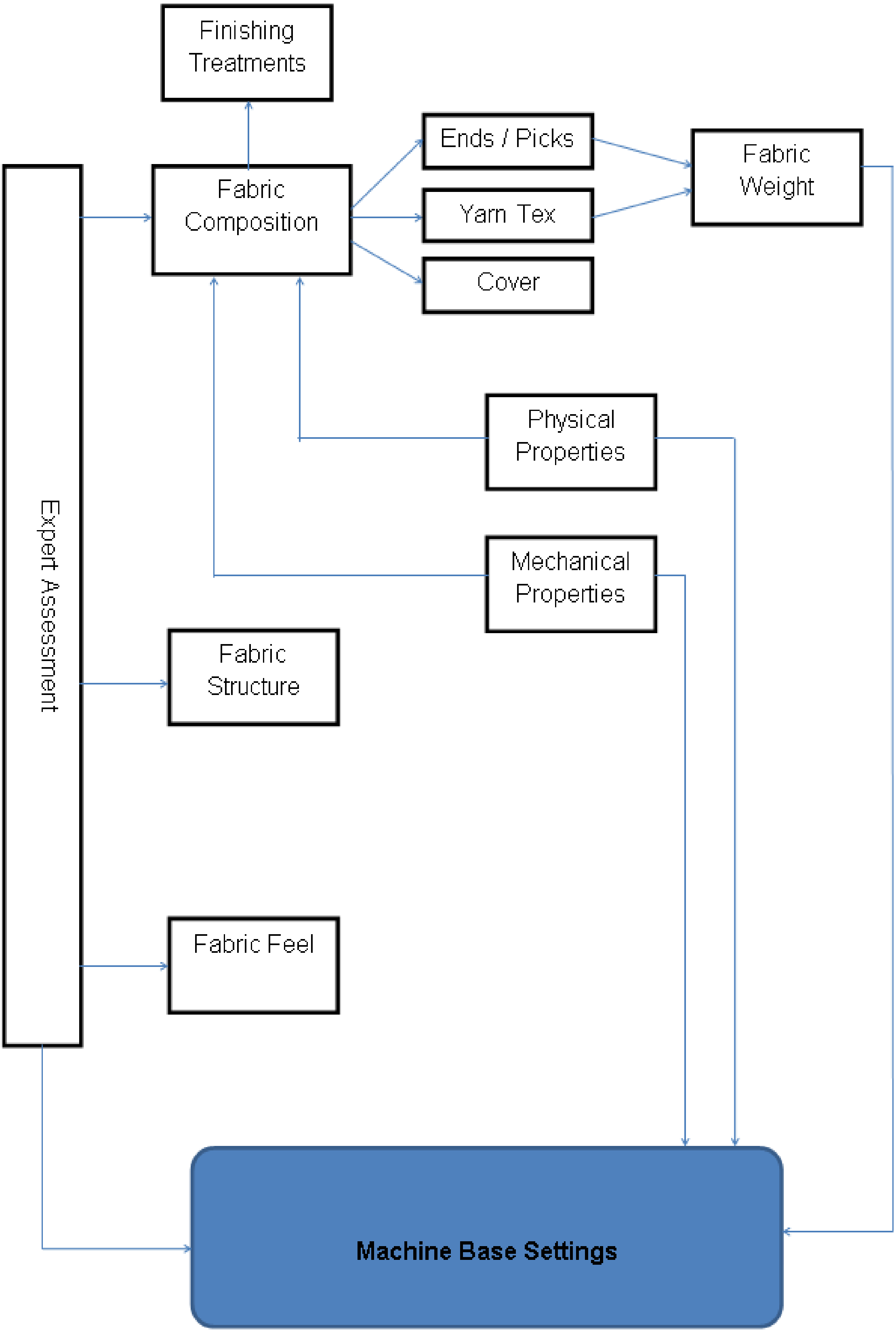

Figure 7.64: Machine base settings algorithm

Using the information from the model described above, algorithms were created for the sewing machine settings databank to be used by the FIT system. The algorithms were developed for the shirting materials. Examples of these algorithms are given in figures 7.65 and 7.66.

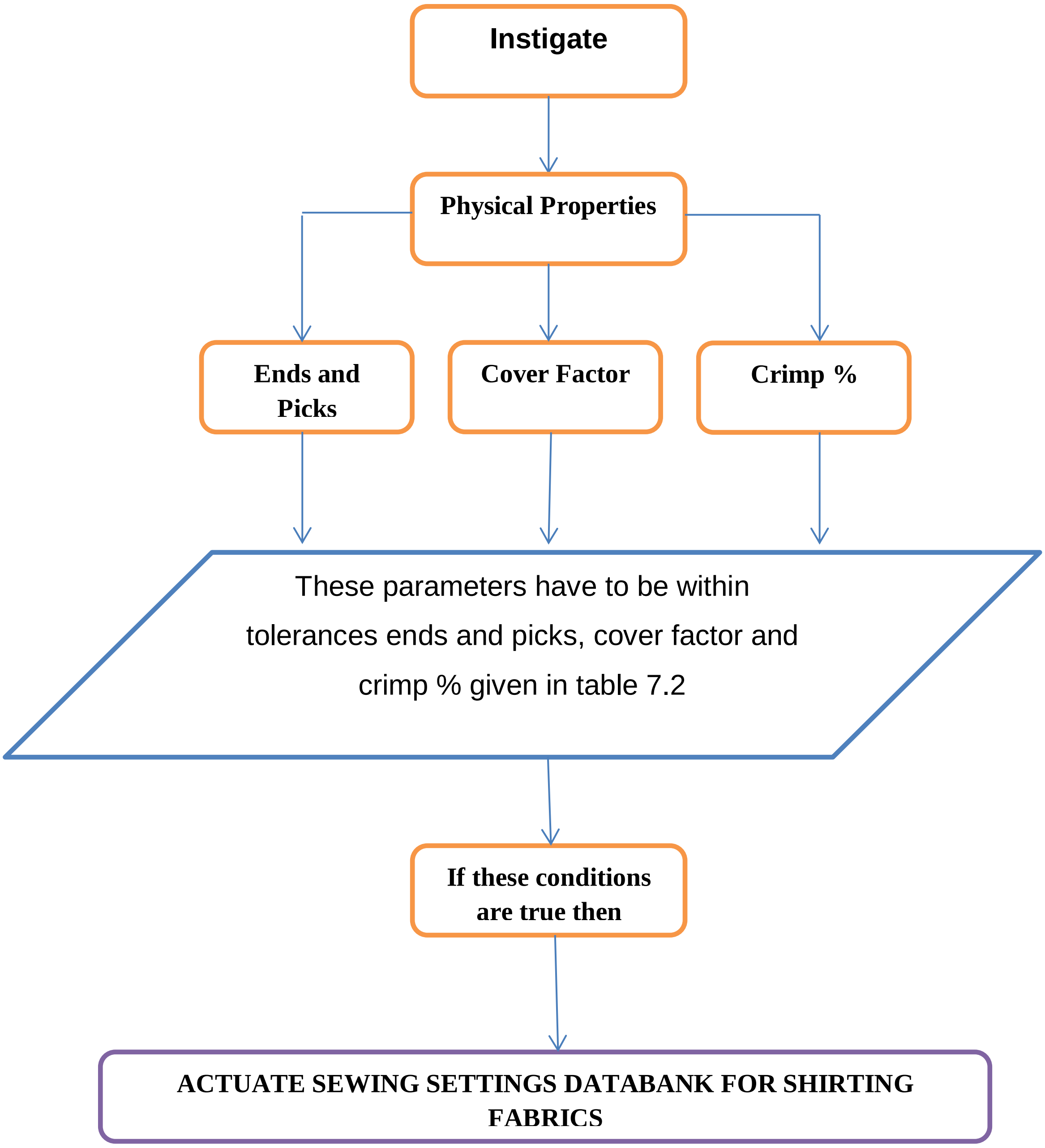

Figure 7.65: Control algorithm for the sewing machine settings databank

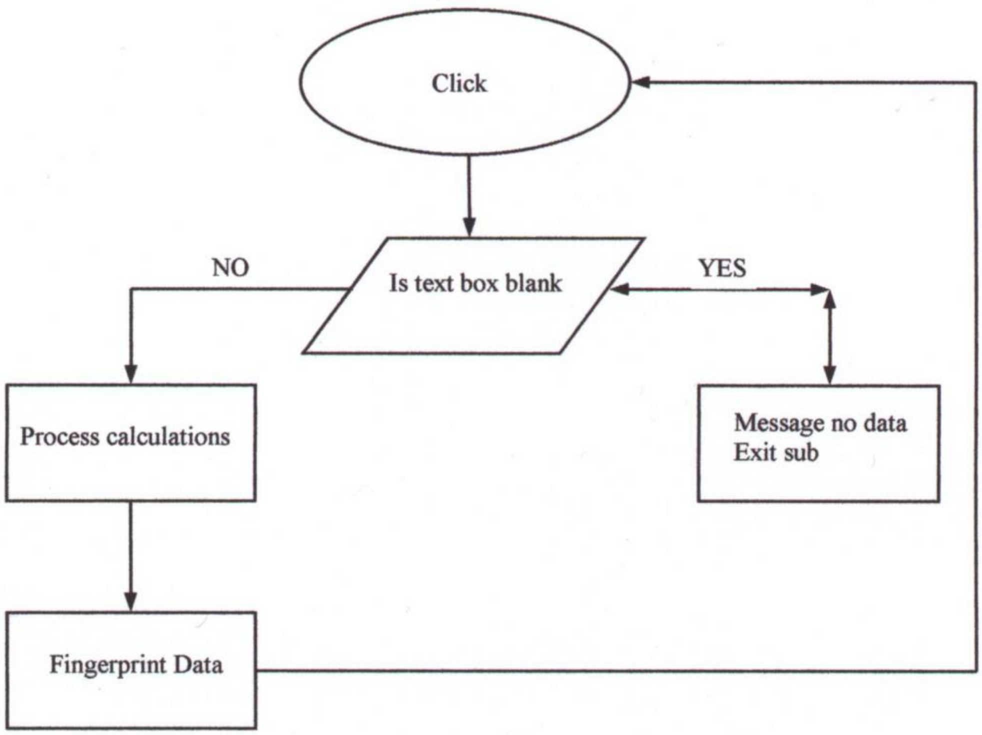

Figure 7.66: Process for the generation of fingerprint and parameter map

7.6. Validation procedures, results and analysis

In order to validate the database and guide the conceptual design of the investigation, general background research was done to gather information to build an understanding of validating projects (Owens, et al., 2015; Verleye et al., 2008).

The pilot study proved to be an essential process in order to test the hypothesis for the main investigation where six fabrics were stitched and the machine settings recorded and entered into the database.

In order to substantiate the database and validate the research model it was decided to include an independent authentication of the databank as follows:

- Choosing one company with a high degree of specialisation in stitching textile materials
- Six shirting fabrics chosen from the main study
- Gaining information on the stitching of materials from the company's expert engineer
- Setting the machine to a similar specification from the main study

- The company's senior engineer to stitch the materials and adjust if necessary
- Comparing the machine settings to those given from the main study
- Evaluate the quality of seam

The company that was chosen are called 'Advanced Enterprises' and are based in Wrexham in North Wales. They are leading suppliers of industrial textile equipment. This company is considered to be one of the best in the United Kingdom for stitching textile materials with clothing machine engineers with many years' experience in machine ergonomics, repairing and maintaining equipment and setting machines for seam quality.

The materials were stitched on a brand new, factory set Siruba single needle lockstitch (301) machine; model number DC 7000 – M1 – 13. The initial objective was to set the machine to the settings as given from the main study and to alter the settings as required to achieve a flat seam. But as an afterthought, it was decided to use the initial factory machine settings as presented and use these as a base setting in order to observe the seams quality before any adjustment might be made. The results obtained delivered some surprising insights as highlighted in table 7.6 and discussed below.

	Seam App	P / F / F (N)	FEED	M / SPEED	S/D	N / T / T – (N)	B / T / T – (N)	SEWING THREAD	NEEDLE SIZE	POINT TYPE	CHECK SPRING
Fab 1	Flat	20	1 Full tooth	4000	5 /cm	1.96	0.2	150s poly/poly	70	Acute point	SET TO WINK
Fab 15	Flat	20	1 Full tooth	4000	5 / cm	1.96	0.2	150s poly/poly	70	Acute point	SET TO WINK
Fab 3	Flat	20	1 Full tooth	4000	5 / cm	1.96	0.2	150s poly/poly	70	Acute point	SET TO WINK
Fab 9	Flat	18	1 Full tooth	4000	5 / cm	1.18	0.2	150ss poly/poly	70	Acute point	SET TO WINK
Fab 18	Flat	16	Feed tilted to rear 0.2mm	4000	5 / cm	0.7	0.15	150ss poly/poly	70	Acute point	SET TO WINK
Fab 5	Flat	16	Feed tilted to rear 0.2mm	4000	5 / cm	1.51	13	150ss poly/poly	70	Acute point	SET TO WINK
σ		16		0		1.16	0.80		0		

Table 7.6 Validation results from the 6 fabrics

There are small differences in some of the adjustments namely the needle thread and bobbin thread tension adjustments. The engineer recommended using acute round point needles as highlighted in the main study and emphasised in figure 3.28 (Chapter 3, page 68). This needle makes a smaller hole in the fabric thus creating less displacement to the yarns. However on some materials the sharpness of this point can cut the fibres thus resulting in a weaker seam. These needles are not recommended for knitwear materials where the acute sharpness of the point can cut the fibres creating more damage to the seam. They are recommended for fabrics with a high yarn density and this can include shirting materials.

The machine speed, sewing thread and check spring all remained constant as from the pilot study and methodology in chapters 5 and 6.

7.6.1 Comparison between experimental results for the fabrics

From the initial base setting on the machine, fabrics one, fifteen and three gave surprising results. The seams evaluated by the company were judged by the engineer to be flat where no seam distortion was apparent on both sides of the seam. It was noted that the presser foot forces and the thread tension settings are of a higher force than those given from the main study (table 7.6). The machine that stitched the fabrics is a different model and make from the machine that was used in the main study. The engineering of the mechanisms may differ due to the metals used in the manufacture of components which includes the presser foot force and tension mechanisms. Therefore the forces applied have slight tolerances and differences among them. The question that was answered here was that if the forces of the machine are higher for stitching these materials and still produce a flat seam then lower force settings like those used in the main study can be applied to achieve the same result.

Fabric nine did exhibit slight seam pucker down the length of the seam. Therefore the engineer made some slight adjustment by altering the presser foot force from the base setting of 20 Newton to 18 Newton's and the static thread tension was reduced from 1.96 Newton to 1.18 Newton. The spool thread tension remained the same.

Fabric eighteen did exhibit visible signs of seam distortion and it is noted from the main study that the feed was adjusted to a 'half tooth' setting in order to reduce the amount of contact with the feed to the material. In the case of the validation, the engineer tilted the feeder to a value of 0.2 millimetre in order to slightly stretch the fabric in accordance with the machine settings as described in chapter 3 (figure 3.7). Fabric five performed exactly the same as fabric eighteen.

7.7 Discussion summary

The process developed for assessing fabric characteristics and behaviour along with initial sewing machine settings and alteration ranges has been validated. However, the analyses of the results have indicated the difficulties associated with trying to predict the stitching of materials when they are assembled on machines from various manufacturers built from different materials and manufactured to slightly different designs.

Measuring and stitching textiles has sometimes been described as a process of measuring the unmeasurable (Hearle, 1994). The work described here concurs with this view to some extent. A robust attempt has been made to try to explain the relationships between subjective assessment and judgement from objective measurement apparatus.

The following pages conclude how this work can be utilised to enable people on the production floor make subjective assessments easier by using objective logic and how these two are inextricably linked together allowing production processes to be better controlled.

Chapter 8 CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

The research used a variety of shirting fabrics both from the pilot and the main study that were considered according to their lightweight nature and properties. The fabrics were stitched with different sewing parameters which included types of thread, needle size and point type and stitch density. Needle size and point type were selected in accordance with the advice given by the SPEC committee. The committee also provided information on engineering adjustments to the machine. An equation was developed to measure the level of agreement between the experts. The physical properties of the fabrics were determined by deconstruction and their mechanical properties were tested on the FAST system. Seam appearance was evaluated by a separate team of experts according to the AATCC seam pucker chart and a smart stitching database was created to contain the data and generate suggested engineering adjustments to the machine based on the properties of the materials and how they interact with the sewing machine.

Flow models were created, driven by the information given by the SPEC from their subjective evaluation of the fabrics helping to explain the relationships between the fabric properties, the machine interaction and the resulting seam quality of the material. Validation work was carried out to test the stitching database using selected fabrics from the main study and an independent company to stitch the materials, comparing the results with those obtained from the main study and evaluating the seam qualities produced under in both environments. Based on the experimental and modelling work that has been done for this research, the following conclusions can be drawn:

1. **Stitching adjustments have a significant effect on seam performance and quality (aim 2)**

   a. **Stitch density**

   Stitch density is an important setting that can affect the performance and quality of the seam. A low stitch density can significantly affect the quality with regards to seam pucker particularly inherent pucker due to having more thread on the fabric and a greater distance between stitch formations. This causes greater tension within fabric due to the interlacing pulling the stitches tighter together particularly with an excessive static tension. A high stitch density risks more damage to the yarns in the fabric due to excessive needle penetration which can reduce the strength of the seam. From this research, the stitch density used for the shirting fabrics was 5 per centimetre and deemed appropriate as it was revealed the properties of the materials were of a relatively low cover factor thus giving good results to the quality of the seam.

b. Thread size and properties

The selection of the thread size was based upon the lightweight nature of the fabrics and the size of the needle required. The thread used for this research was a fine polyester core spun thread with a polyester inner core and a spinning wrapped outer count. This thread was overwhelmingly recommended for its fine nature whilst at the same time maintaining a high degree of strength. It was also found that the sewing thread has an impact on seam quality. A sewing thread with a higher density than the yarns in the fabric causes greater displacement between the yarns and the sewing thread thus resulting in what is called inherent pucker. Also the sewing thread was chosen for its lack of extensibility. A sewing thread with a high extensibility can relax when the seam is stitched therefore shortening the seam. Both of these phenomenon's are discussed and described in the pilot study. Thread with high extensibility should be avoided for normal apparel applications. It should only be used for specialist apparel that requires elasticity.

2. Machine settings (aim 2 and aim 3)

In order to gain the best possible stitching parameters for the machine settings, valuable information was gained from experts in the field of sewing machine engineering. All of these people are experts in the repair and maintenance of sewing machines that stitch textile materials. Valuable data was obtained and recorded.

- Question the experts for their knowledge of setting machines for stitching fabrics.
- Provide them with a scientific appraisal of how fabrics can behave at the machine interface and to enhance their knowledge of materials technology.

The experts might know how to set the machine for stitching problems, but have little knowledge of why these phenomena occur, which can be due to the unpredictable behaviour of textile materials.

This helped to synthesise the understanding of the experts of why these problems can and do develop.

a. Presser foot force

The presser foot force measured in Newton's (N) controls the amount of force needed to feed the fabric through the machine without the fabric ply's slipping which also results in uneven stitch density and poor control of the fabric. It was set at its optimal setting which was as minimal as possible to avoid the ply's slipping whilst feeding the material uniformly through the machine. This was adjusted for each fabric stitched but for most fabrics only one setting was needed. It needs also to be mentioned that the presser foot on the single needle lockstitch machine has only contact on the top ply of the fabric so is to some extent a degree of handling to control the material is reliant on the operator keeping both plies together while being stitched.

b. Feeding adjustment

As with the presser foot, the feeder controls only one ply of fabric but in this instance it is the underneath ply of the material. In the case of the main study some small adjustments were required on the fabrics that have high extensibility where the feed was tilted slightly to feed more fabric into the machine to compensate for the extension. In the case of the validation, the adjustment remained constant at one full tooth above the throat plate for all of the fabrics stitched. One of the other factors that were highlighted was that the feed should be in good condition because if the teeth of the feed are worn or smooth then seam slippage can also result.

c. Machine speed

The machine speed was set to 4000 revolutions per minute and remained constant through the whole of this research. It was set at this speed due to the fact that this is the industrial standard for stitching garments in factory production.

d. Static (Needle) thread tension

The static thread tension, measured in Newton's (N) was also set to an optimal condition for each fabric stitched. The impact of this setting upon the quality of the seam was to reduce the tension to a minimum level in order to produce a good quality stitch which helped to create a flat seam.

e. Bottom thread tension

When setting the static thread tension, the bottom thread tension was also adjusted to the same optimum setting as described above. The two tension adjustments needed to be set simultaneously as there is a direct relationship between these adjustments.

f. Needle size and point type

Factors to consider when choosing a needle for the fabrics were:

- Fabric Type
- Fabric Density
- Fabric Composition
- The Type of Machine
- The Type of Sewing Thread
- Fabric Thickness

It was found that the most important aspect of needle design is the needlepoint because it has to penetrate the fabric without causing any damage to the material. It is also most diverse part of the needle due to the many different type of points used. These needle points are designed for sewing on many different fabric types and Seams. When fabrics are stitched together, the impact from the needle as it penetrates the fabric can cause buckling and distortion on the yarns and the fibres. The mechanical strain on the yarns increases if the needle is damaged thereby causing the fibres to rupture thus reducing the seam strength significantly. The following factors were taken into account in order to help avoid this problem:

- using a needle with a smaller diameter for the fabric and seam being sewn;
- making sure that the opening of the sewing plate fits the needle size;
- using a sewing thread with the correct diameter for the eye of the needle;
- using the correct needle point for the type of fabric that was stitched;

This data was contributory in helping to build up an image of how to set the machine for each fabric. This made a significant contribution to understanding how fabrics interact at the needle point. Furthermore, it was found that:

- Adjusting machine settings by eye still gives the best results for stitching fabrics on a production situation.
- The assessment of agreement between the experts can be measured statistically.
- This gave the argument in favour of objective measurement analysis, reducing disagreement in favour of a more scientific inquiry.
- The research illustrates the difference of opinion in subjective measurement therefore enhancing the need for an objective method of determination by using the fit system with its smart database.
- By synthesising the emerging understanding of how fabrics behave when stitched it was possible to produce a historical database of sewing machine settings utilised to solve production difficulties.

3. Objective measurement systems (aims 1, 2 and 4)

The most notable of these are the Fabric Assurance by Simple Testing (FAST) and the Kawabata Evaluation System (KES). The main findings were that:

- These systems have been broadly used by institutions such as textile Universities and testing facilities but have had little impact upon the sewing industry due to their cost and complexity.

- Fabric objective measurement systems do enable fabrics to be quantified scientifically and one major advantage of these instruments has been that a company is armed with the knowledge about a fabrics characteristic prior to manufacture. But the real impact on seam quality was unknown and it was this factor that initiated the development of the FIT system with the smart database to interpret the data with the objective to produce a list of sewing machine settings for stitching the fabric.
- Most of the industrial literature is not in the public or academic domain and remains specialist in nature within the apparel manufacturing industry.
- Most of the academic literature supports the advanced experimentation of fabric analysis that is difficult to understand by normal production management and working teams in industry.

4. Key fabric parameters that affect seam performance and quality (aim 2)

This was accomplished by analysing both the physical and mechanical properties of the material. Both of these properties were found to be closely interrelated, but with scrutiny, it was discovered that the physical properties seem to have a greater impact on the stitching of the seam than the mechanical parameters. It is true that the FAST system measures the mechanical properties of the fabrics for seam pucker, namely, bending rigidity and extensibility. Formability and shear properties are also determined. But it was found (by experience) that these can be controlled by the handling skills of the machine operator by handling and using the correct fittings and settings on the sewing machine. Therefore it is questionable how useful these systems are in actually being able to predict the performance of a fabric being stitched on the machine.

The physical limits of the fabric were found to be more interesting, difficult to manipulate and change and relied very much on physical interactions between the needle and the sewing thread. Also where inherent pucker is concerned, a high degree of skill was required in setting up the machine. This was found to be the case during this research and is one of the primary reasons for using the knowledge given by the engineering experts. These professionals made a major contribution in making this work original and credible. It was important to have a number of inputs into this work. Sewing machine engineers can and do disagree as to the setting of apparel machinery for a particular fabric. This is a healthy method of practise as it enables a number of opinions taken into account. Several engineers disagreed as to the type of needlepoint for example. Some recommended round point, while others recommended using an acute round point.

8.2 Recommendations for future work (aims 4 and 5)

The gap between work practice methods and research methods could be seen to be large. Many companies do not have the resources to finance the purchase of an objective measurement system. In fact many do not know of the existence of such systems at all. It is apparent that there are major difficulties involved in joining fabrics together at the machine interface by the sewing process. There are, however, a number of measures that may be taken in order to help alleviate this problem if not eliminate it completely. These methods are as follows:

- Further Develop the smart database for each style and fabric stitched;
- Establish more methods for dealing with seam pucker, understanding its causes and steps which may be taken to counter it;
- Giving technicians and production staff greater understanding of the properties associated with a fabric. This includes knowledge of fibres, yarns, yarn twist, frictional properties, shear , extensibility and bending rigidity;
- Using the Fabric intelligent system to correlate the results from the FAST system with the experimental measurement of fabric variables so that a low cost method can be applied to fabric testing;
- Extending the use of Fabric Objective Measurement systems in fabric manufacturing companies in order to enable warnings of material instability to be given prior to despatch at fabric apparel manufacturing companies;
- The performance of the seam can be widened to include weft and bias for both seam performance and strength analysis. For the current study, only the warp direction of the fabrics was stitched as this is the most common practice used in industry;

- The study can be significantly widened to include other stitch formations. For this research only single needle lock stitching was used;
- Further analysis could be done to include frictional and surface properties of the material when being stitched;

The use of low cost instrumentation for machine optimisation should be promoted; such equipment for measuring thread tensions and strain gauges currently exists and is inexpensive to purchase.

A larger population of stitching experiments needs to be performed in order to determine the most desirable machine settings for the material to be sewn. Fabrics may be ranked in a similar way according to their sewability properties. The instrumentation would be used to measure optimum thread tensions and presser foot pressures.

One of major areas in which the FIT system could be used would be in the fabric manufacturing companies in order to give advanced warnings on fabric sewability. A batch of fabric could be woven and then tested on a FOM system linked to the Fabric Sewability System. The resultant testing and report from the batch of fabric tested could then enable fabric companies to modify processes or correct potential problems before they reach the clothing manufacturer.

The outcomes from this work create a deeper understanding in stitching textile materials and add new knowledge to the body of literature on fabric sewability and stitching shirting fabrics. The study also contributes innovative and original information on the behaviour of textile materials when being stitched and the prediction of sewing machine settings using the framework of a smart database and its application. The framework underlines the significance of a system that can have a substantial impact in a clothing production company that can reduce seam distortion and improve seam quality. The application of an effective quality management system is vital to companies producing products for a global economy and to the overall well-being of the work force. This novel and innovative system should make a significant contribution to any QMS in the production of apparel products.

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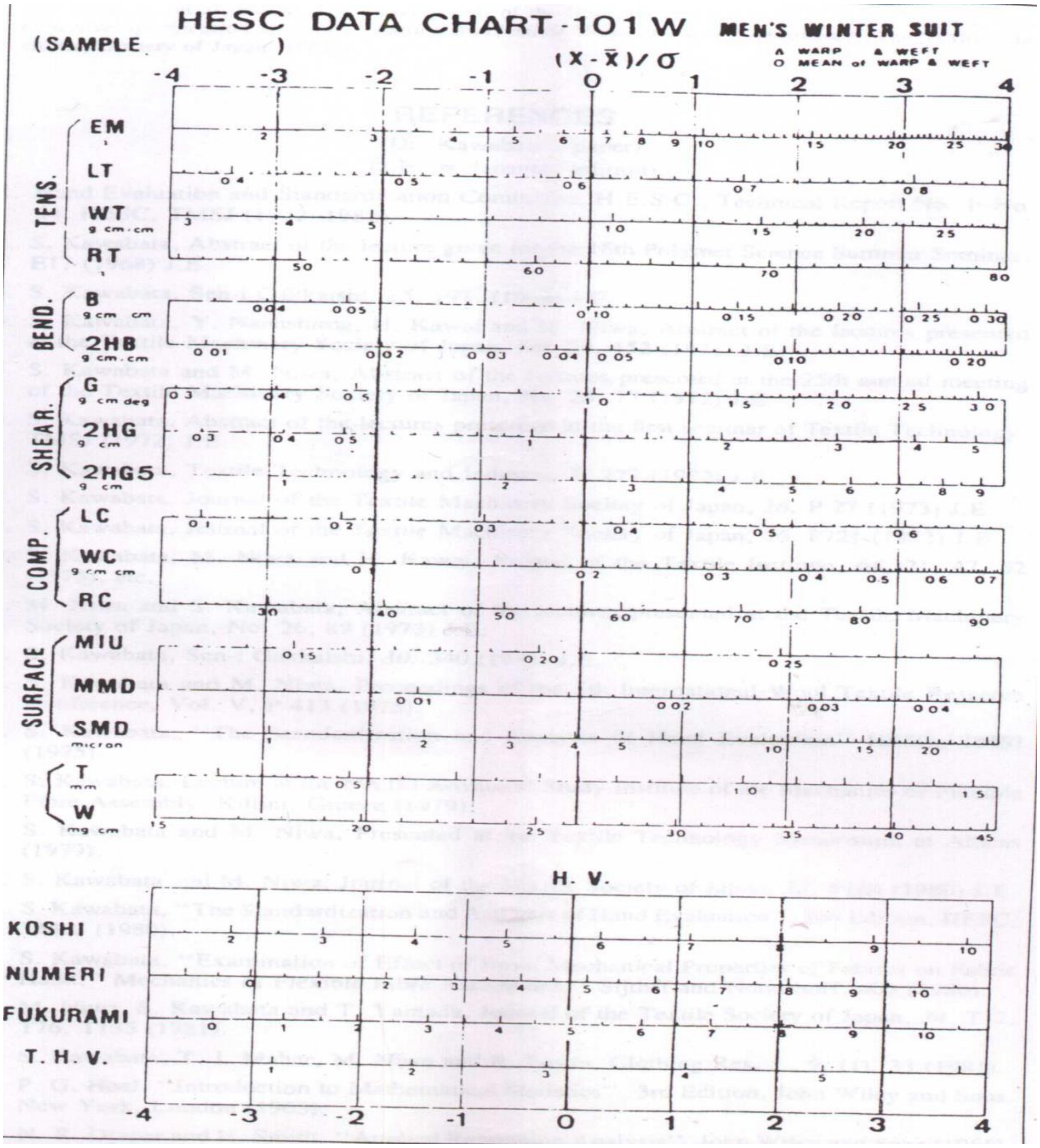
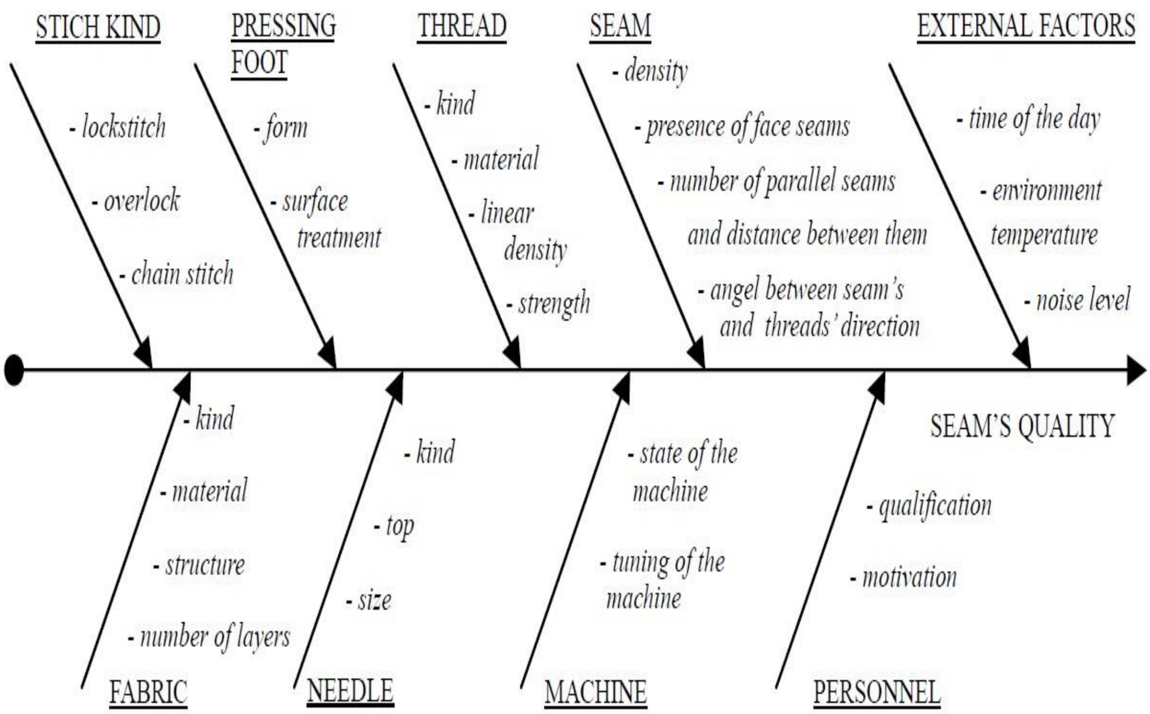
APPENDICES

Appendix 1- Example of the HESC Data chart

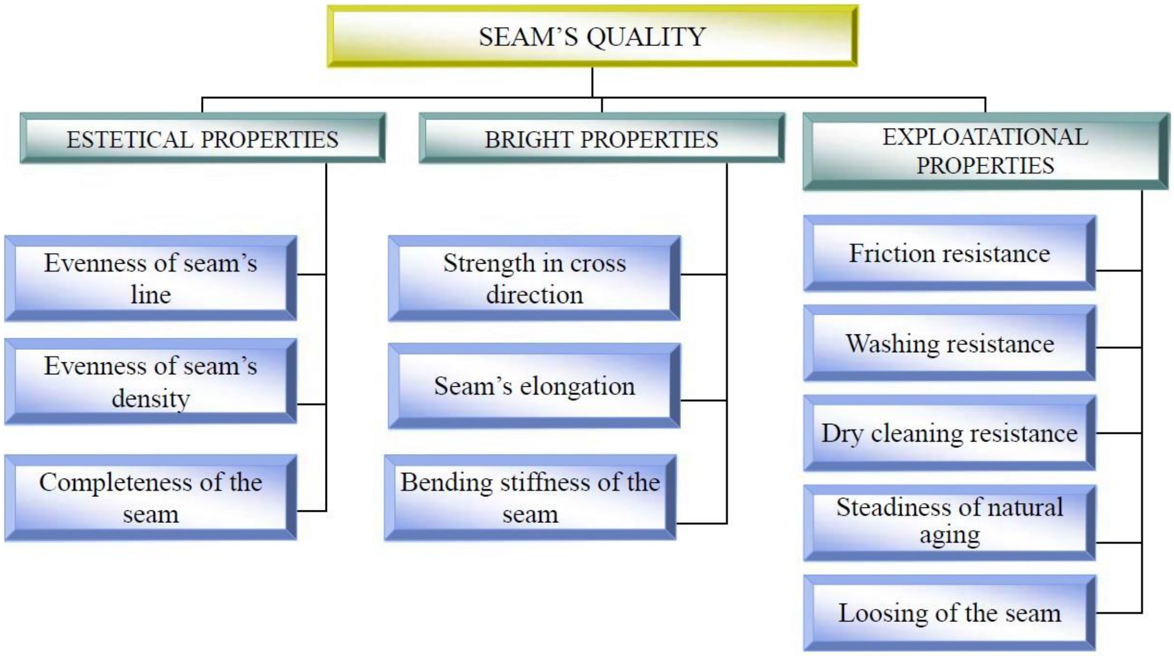


APPENDIX 2



Ishikawa diagram of cause and effect for a seams quality: (Germanova-Krasteva and Petrov, 2007)

APPENDIX 3



Factors for a seams quality: (Germanova-Krasteva and Petrov, 2007)

APPENDIX 4

SPEC 1

This person has worked in the sewn product industry for nearly 40 years and during that time has had a wide and ranging career in the sewn product industry. This expert has extensive experience in machine engineering, product quality and objective measurement testing and was responsible for generating the reports to industry on the measurement and testing of the fabrics on the Kawabata system

Appendix 5

Sewing parameter evaluation committee

Expert 1:

Forty years' experience in the sewn product manufacturing industry as a sewing machine engineer eventually working as senior technical manager for Brother UK Ltd;

Expert 2:

Fifty years of knowledge in clothing machine engineering, as a sewing machine engineer, production manager and factory manager;

Expert 3:

Twenty five years' experience as a sewing machine engineer eventually becoming chief engineer of a major clothing company, manufacturing for Marks & Spencers;

Expert 4:

Thirty years' experience as Senior engineer, technical manager and is currently corporate purchasing and technical director.

Expert 5:

Sewing machine engineer for 15 years' eventually becoming technical director of a major machine supplier and manufacturer with extensive experience in garment product development and factory production improvement;

Expert 6:

Senior engineer with 18 years' experience in machine engineering and maintenance;

Expert 7:

Technical manager for the UK's leading sewing machine supplier with 23 years' experience in garment make up;

Expert 8;

Technical manager for the world's largest producer of sewing threads for 7 years' Fifteen years' experience as a senior engineer in sewing technologies and currently technical manager for one of the largest retailing companies in the UK;

Expert 9

Twenty two years of experience as a clothing machine engineer working for major garment manufacturers in the UK;

Appendix 6

Example of the assessment form for the Sewing Parameter Evaluation Committee (SPEC) for fabrics 1 to 20

Ten judges will be asked to render their judgment on the following in reference to quality of each individual garment:

Which fabric has the best handle in terms of Fabric Handle and Sewability?
What machine settings will you recommend to maximise and improve quality?

Fabric	*1*	*5*	*8*	*15*	*22*	*24*	*34*	*39*	*43*	*50*	*51*	*53*	*64*	*65*	*67*	*70*	*75*	*76*	*77*	*79*
S^{I}																				

What machine settings would you recommend in order to maximise / improve the sewability of the fabric?

Fabric 1

Repeated for fabrics 1 to 20

Appendix 7

Expert evaluation given for seam pucker using AATCC chart

Assessor 1:

Technical manager for the world’s largest sewing machine needle manufacturing company with 30 years’ experience in sewn products manufacture;

Assessor 2:

Engineering manager for a leading M & S producer of ladies apparel with twenty years’ experience on machine technical and product development;

Assessor 3:

Garment technologist for a major M&S producer with ten years’ experience in garment technology and product costing;

Assessor 4:

Senior lecturer in clothing technology with 10 years’ experience of working in industry;

Assessor 5:

Senior garment technologist with 10 years’ experience of garment technology and retail experience;

Assessor 6:

Technical manager with 30 years’ experience in garment technology;

Assessor 7:

Garment technician with 30 years' experience in the industry, now working as a technician at a leading University in the UK;

Assessor 8:

Garment technician with 30 years' experience in the industry, now working as a technician at a leading University in the UK;

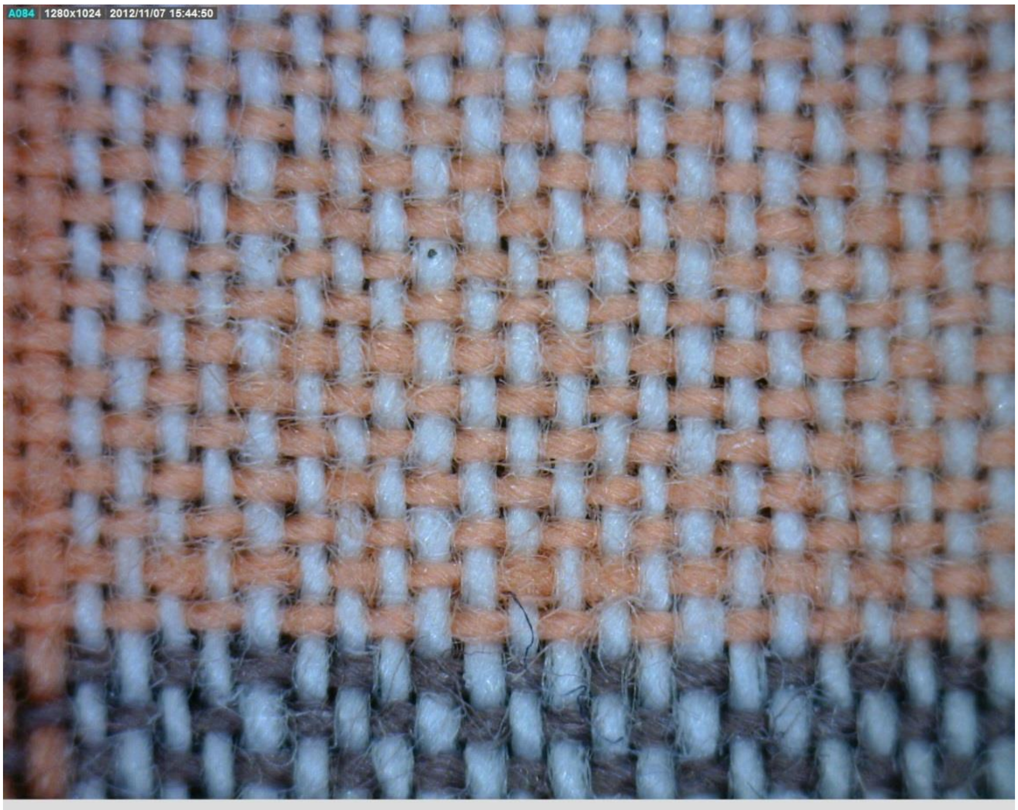
Assessor 9:

Garment technician with 30 years' experience in the industry, now working as a technician at a leading University in the UK;

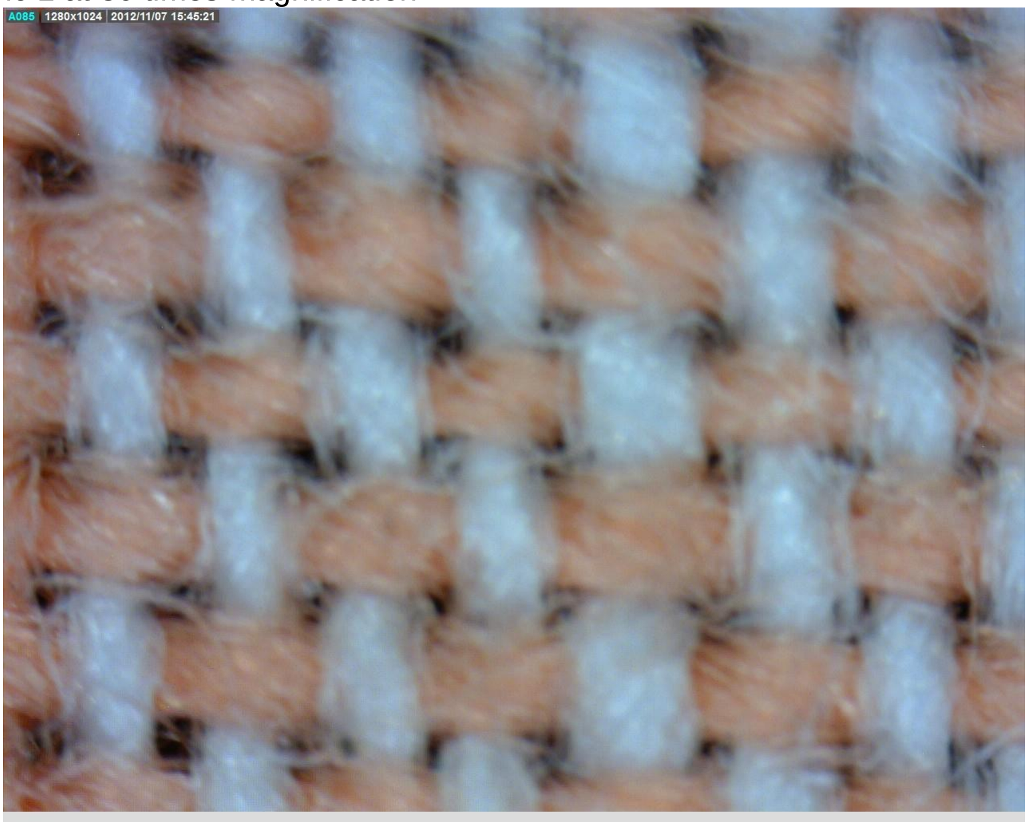
Assessor 10:

Garment technician with 30 years' experience in the industry, now working as a technician at a leading University in the UK;

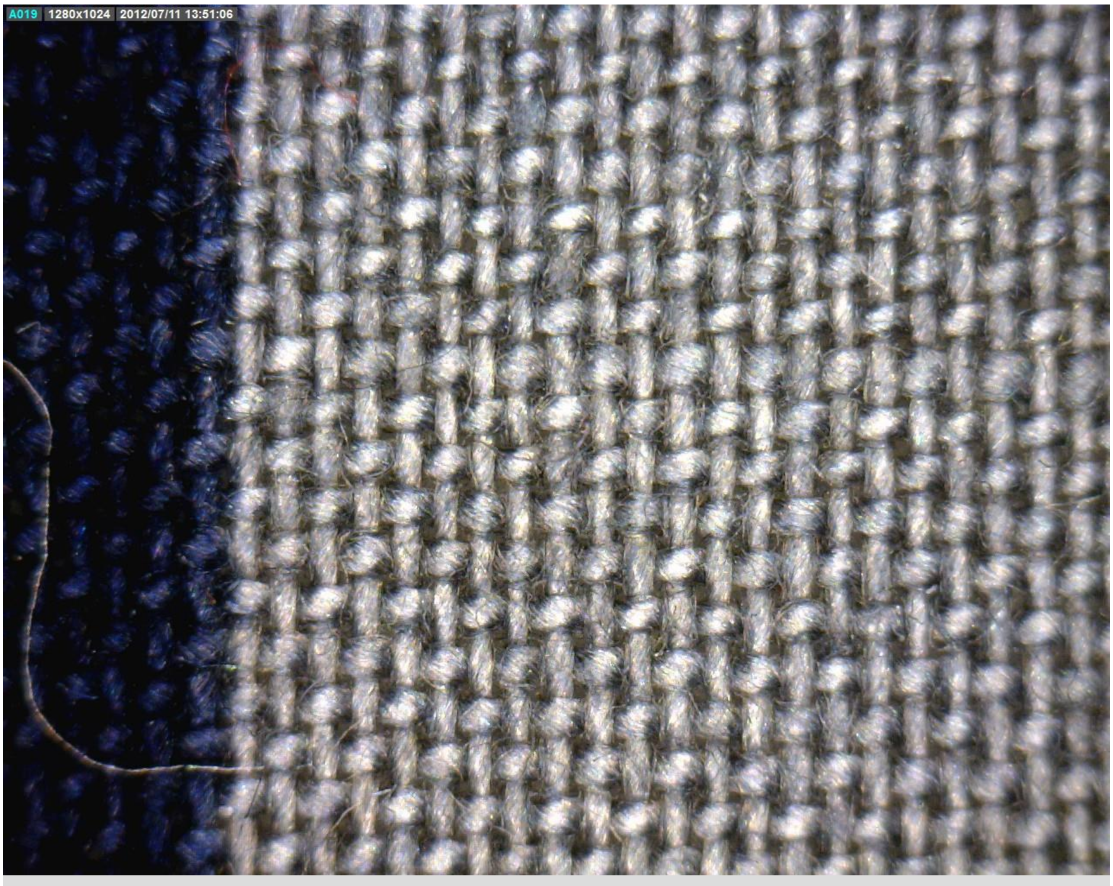
Appendix 8 FABRICS AT 80 TIMES AND 200 TIMES MAGNIFICATION



Fabric 1 at 80 times magnification



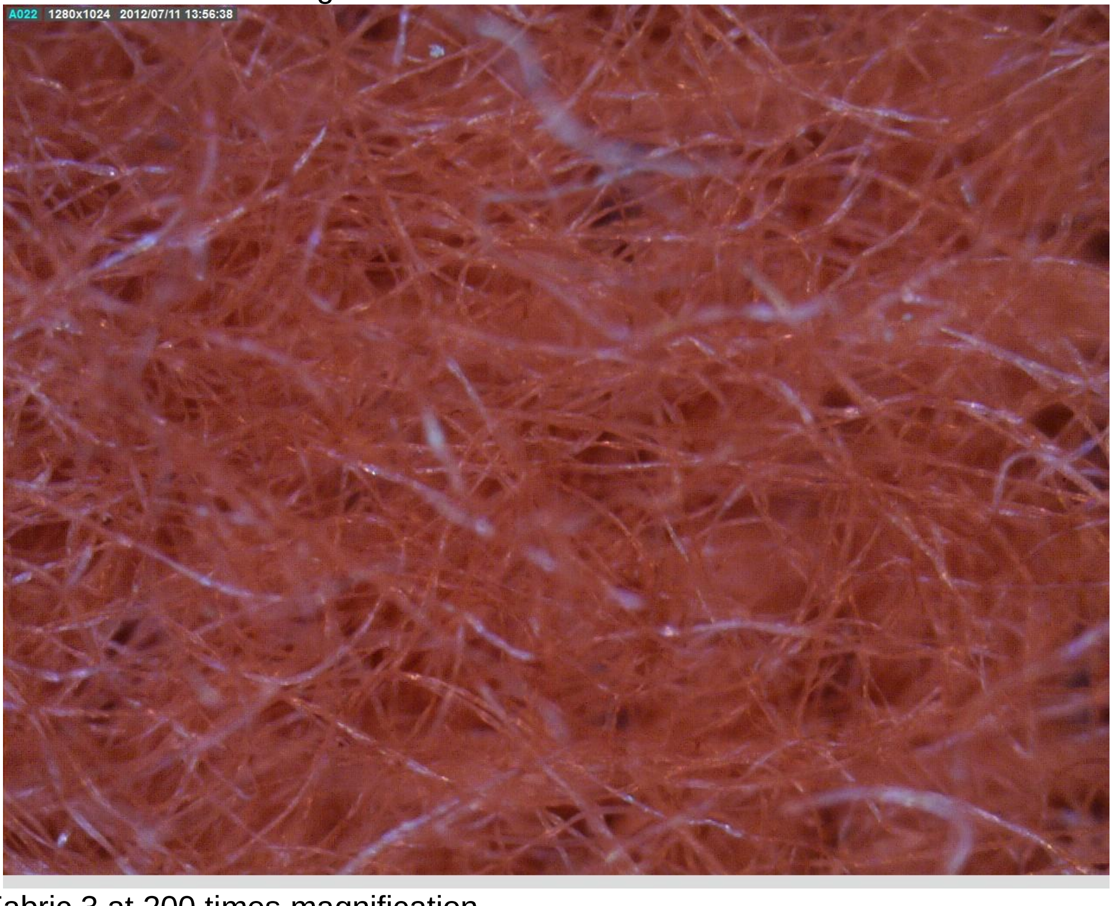
Fabric 1 at 200 times magnification



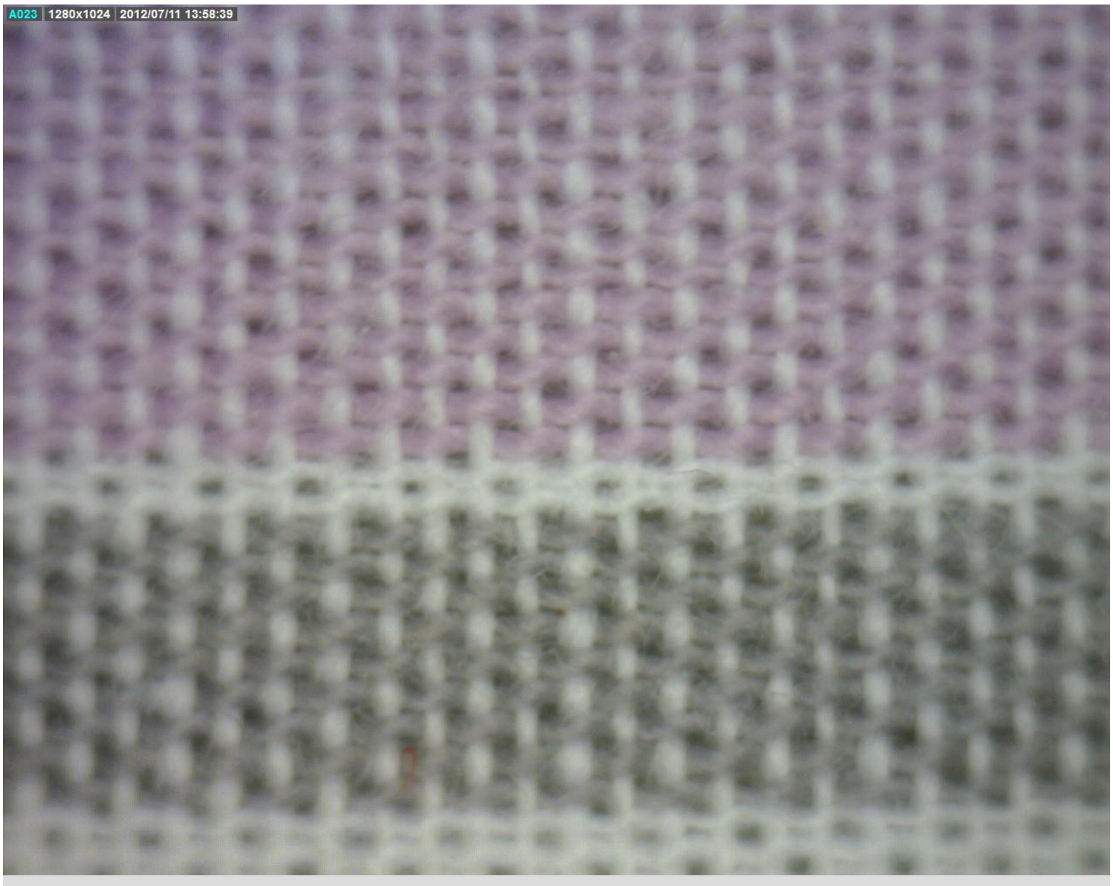
Fabric 2 at 80 times magnification

Fabric 2 at 200 times magnification

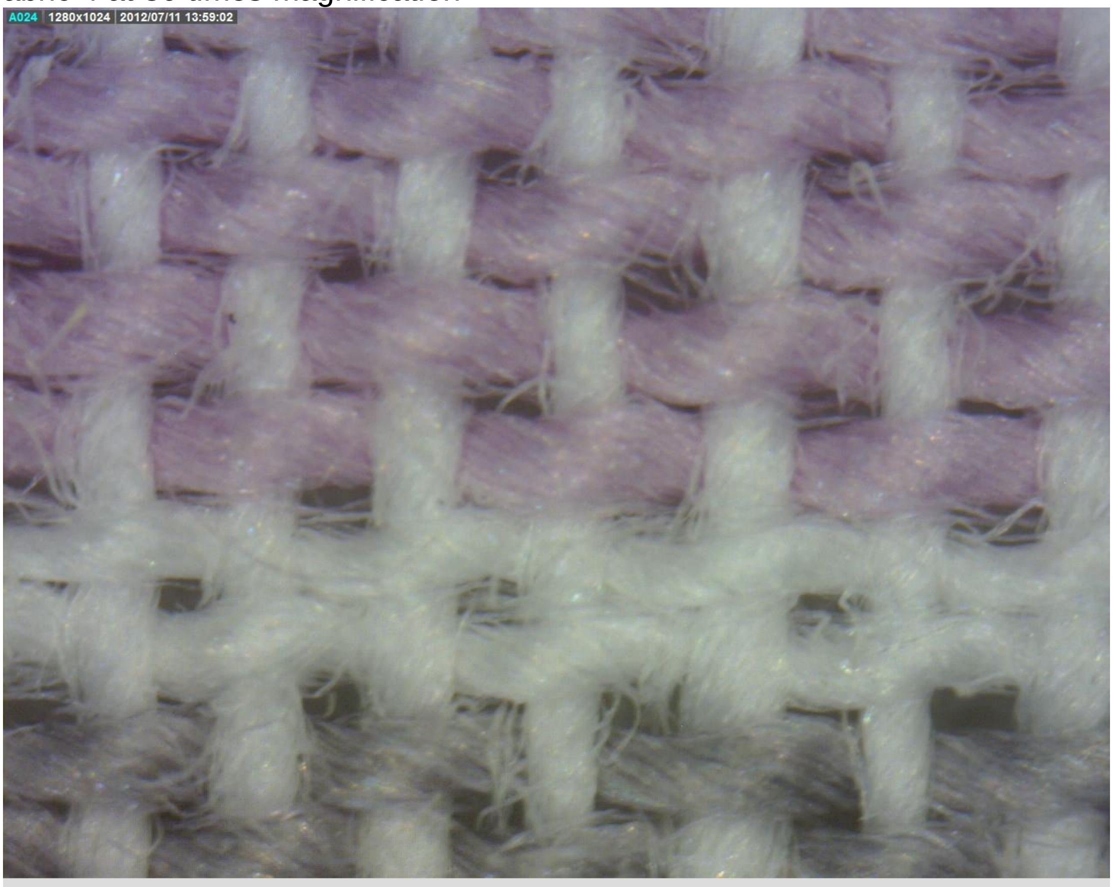
Fabric 3 at 80 times magnification



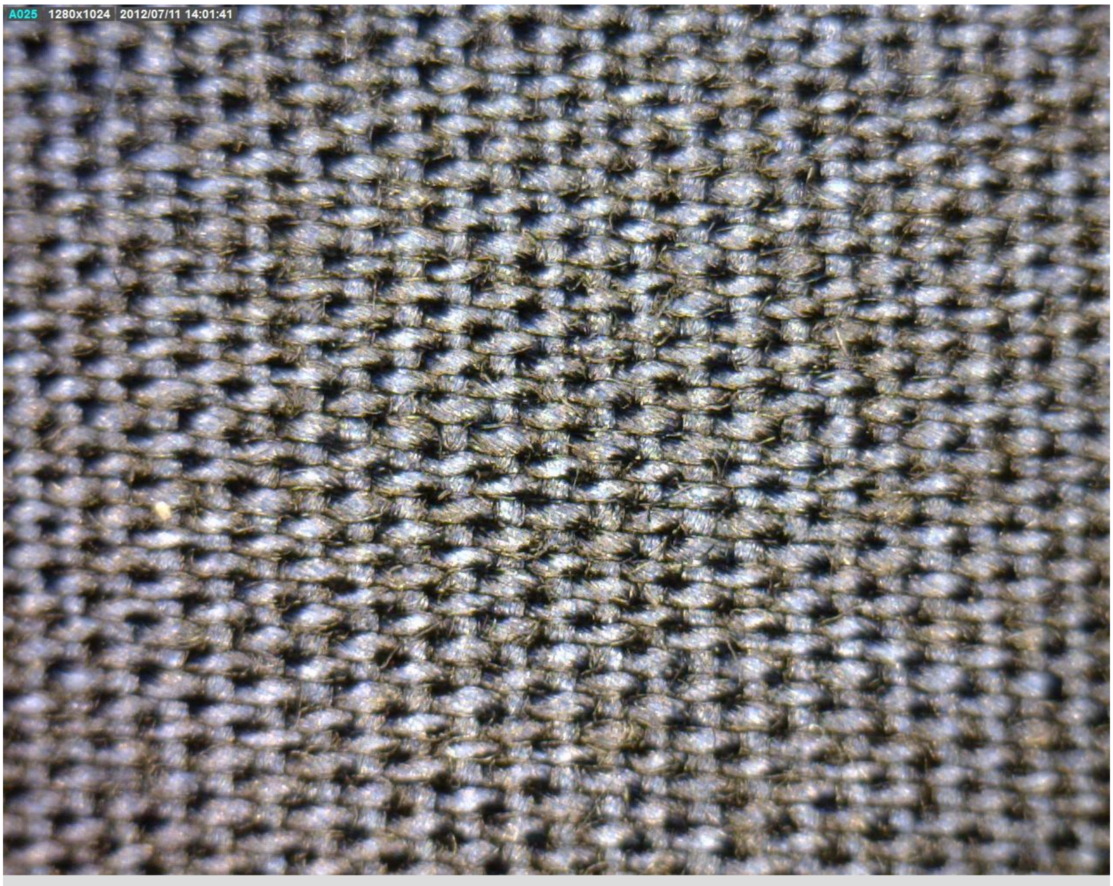
Fabric 3 at 200 times magnification



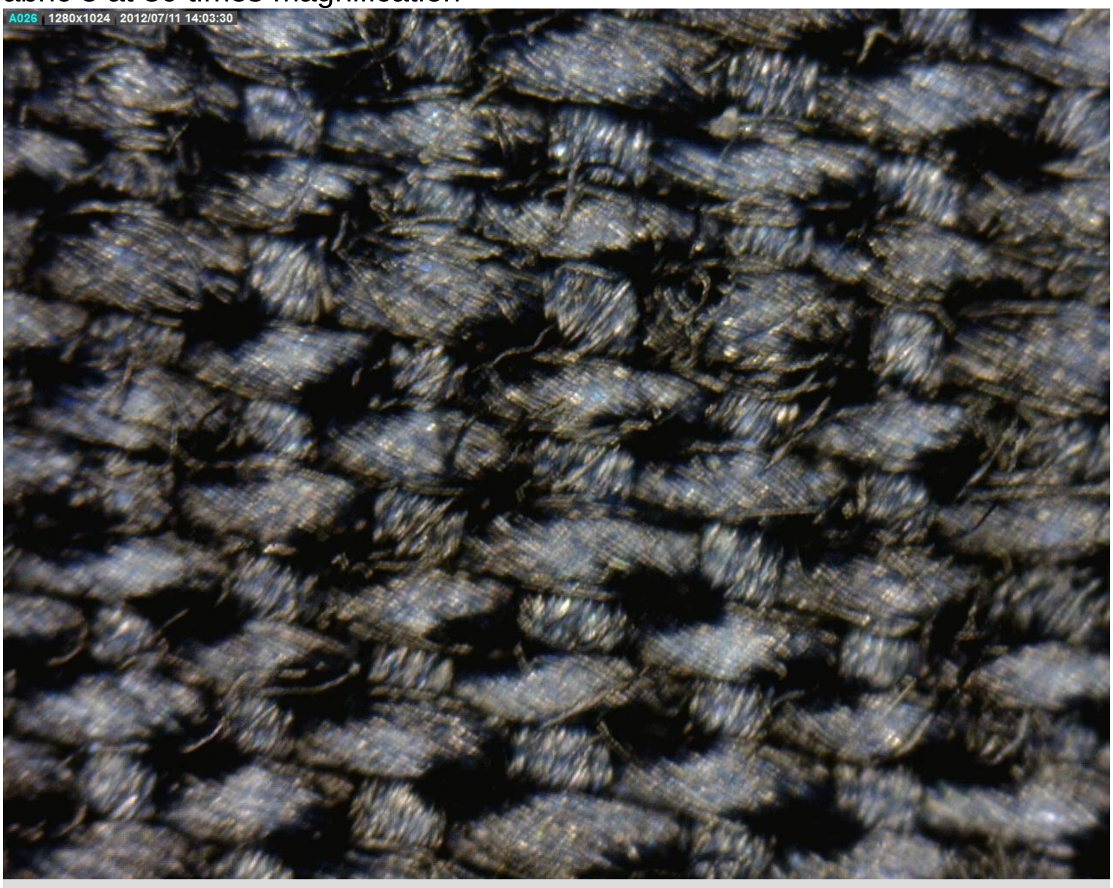
Fabric 4 at 80 times magnification



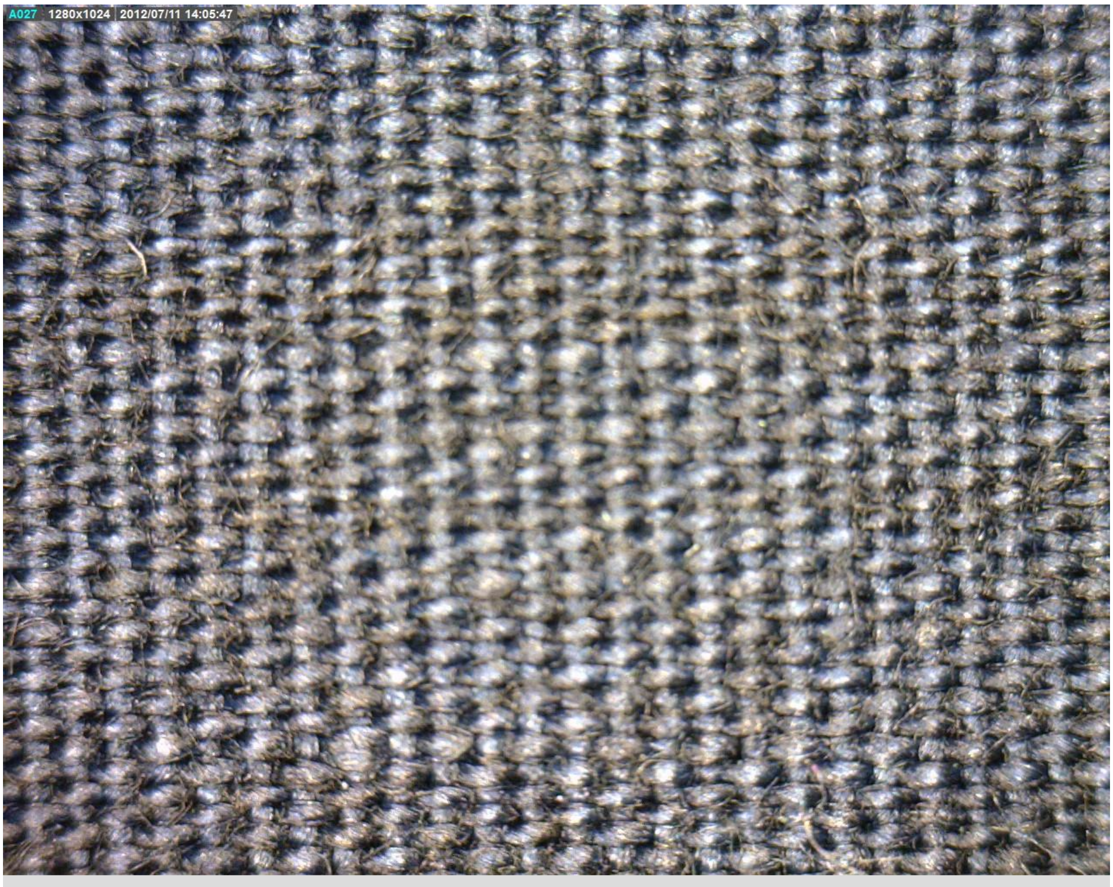
Fabric 4 at 200 times magnification



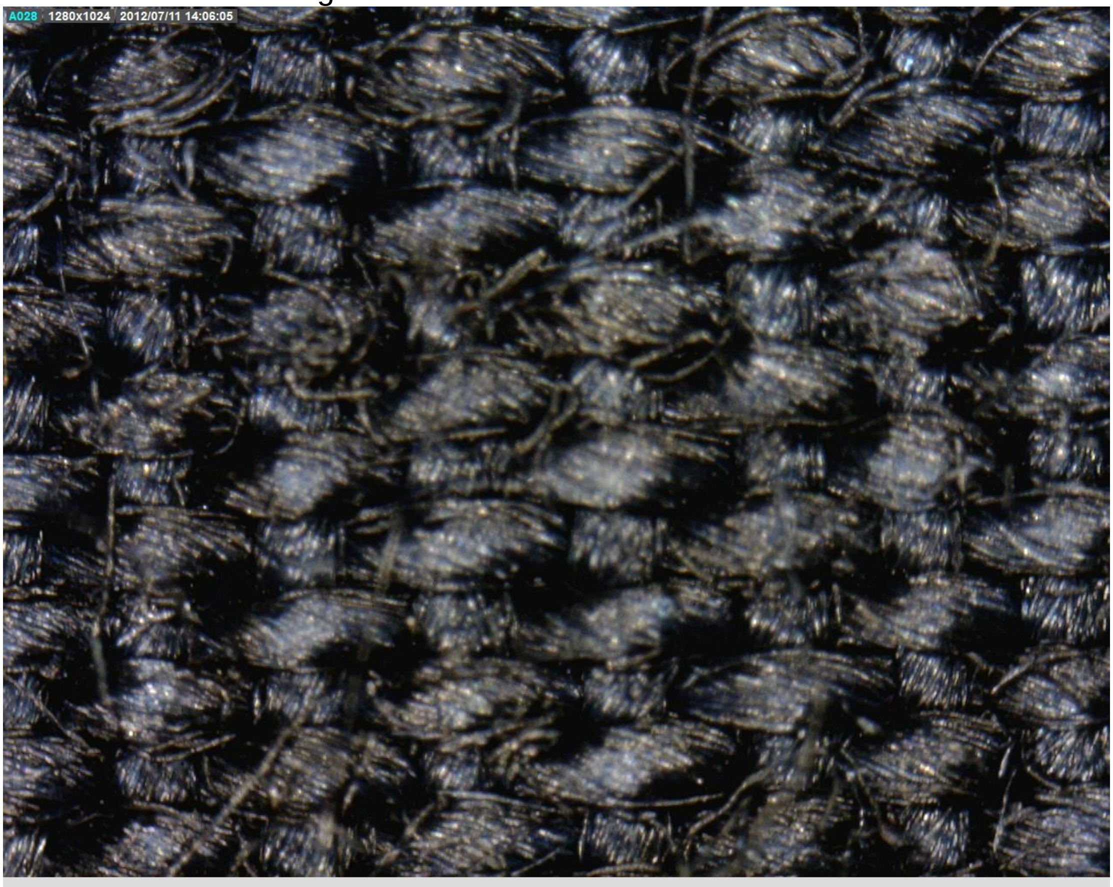
Fabric 5 at 80 times magnification



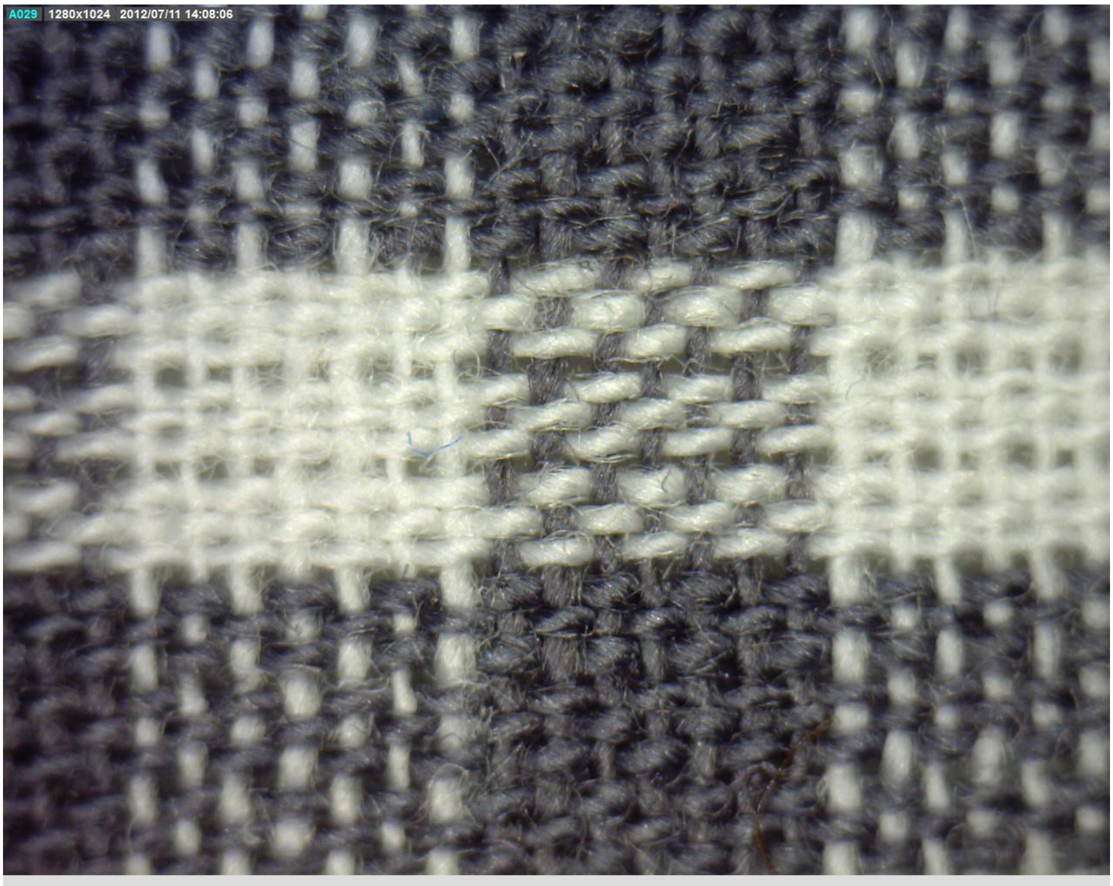
Fabric 5 at 200 times magnification



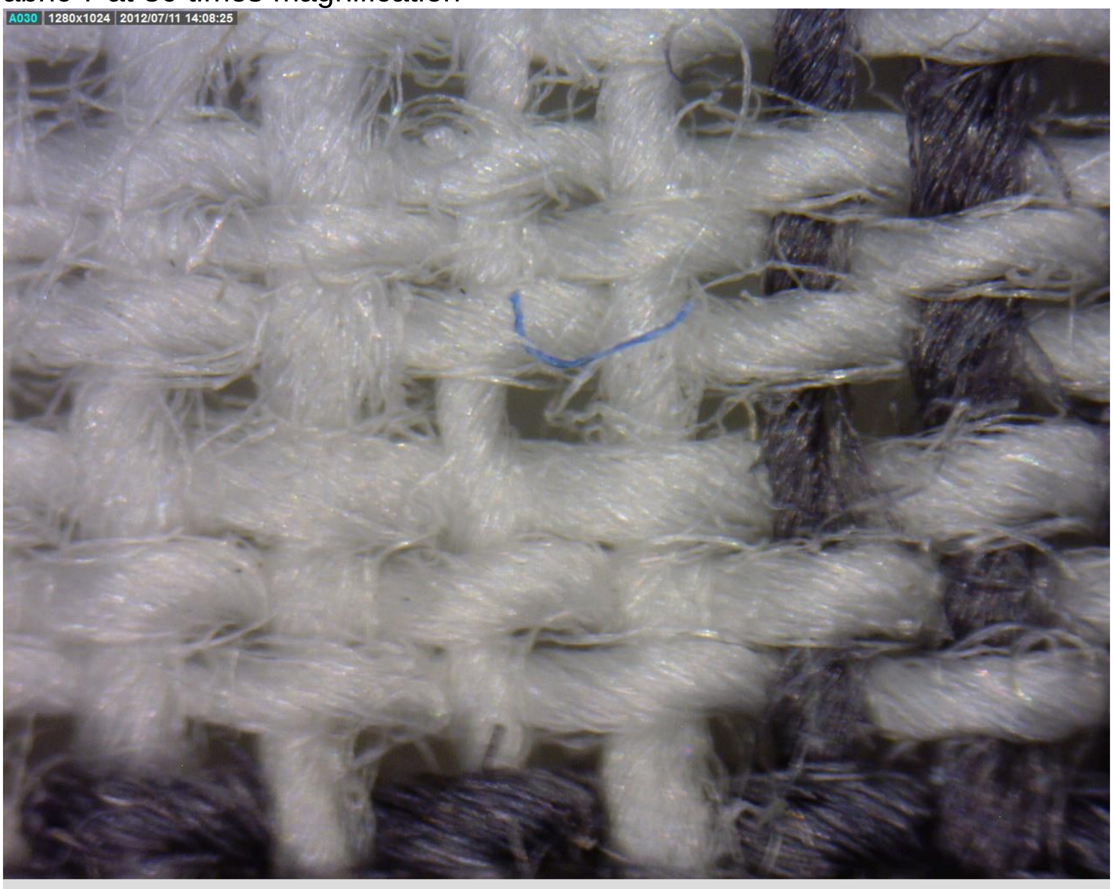
Fabric 6 at 80 times magnification



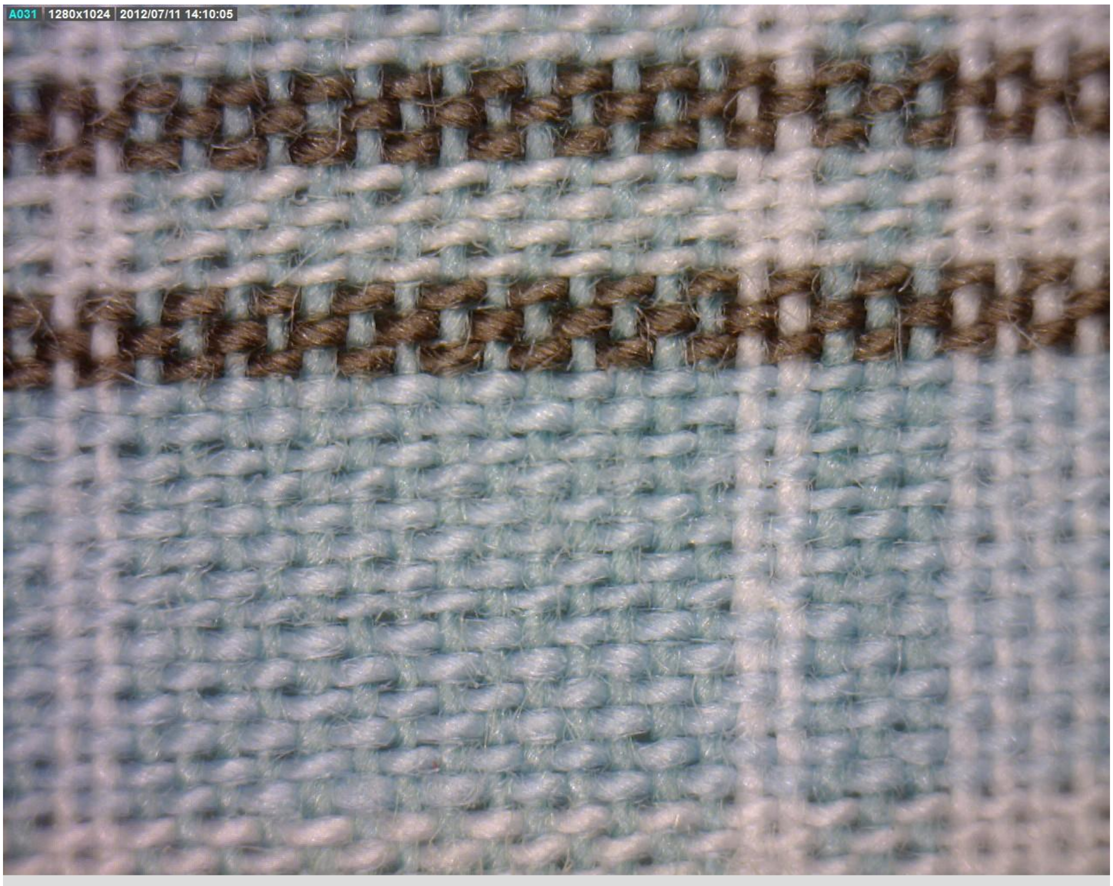
Fabric 6 at 200 times magnification



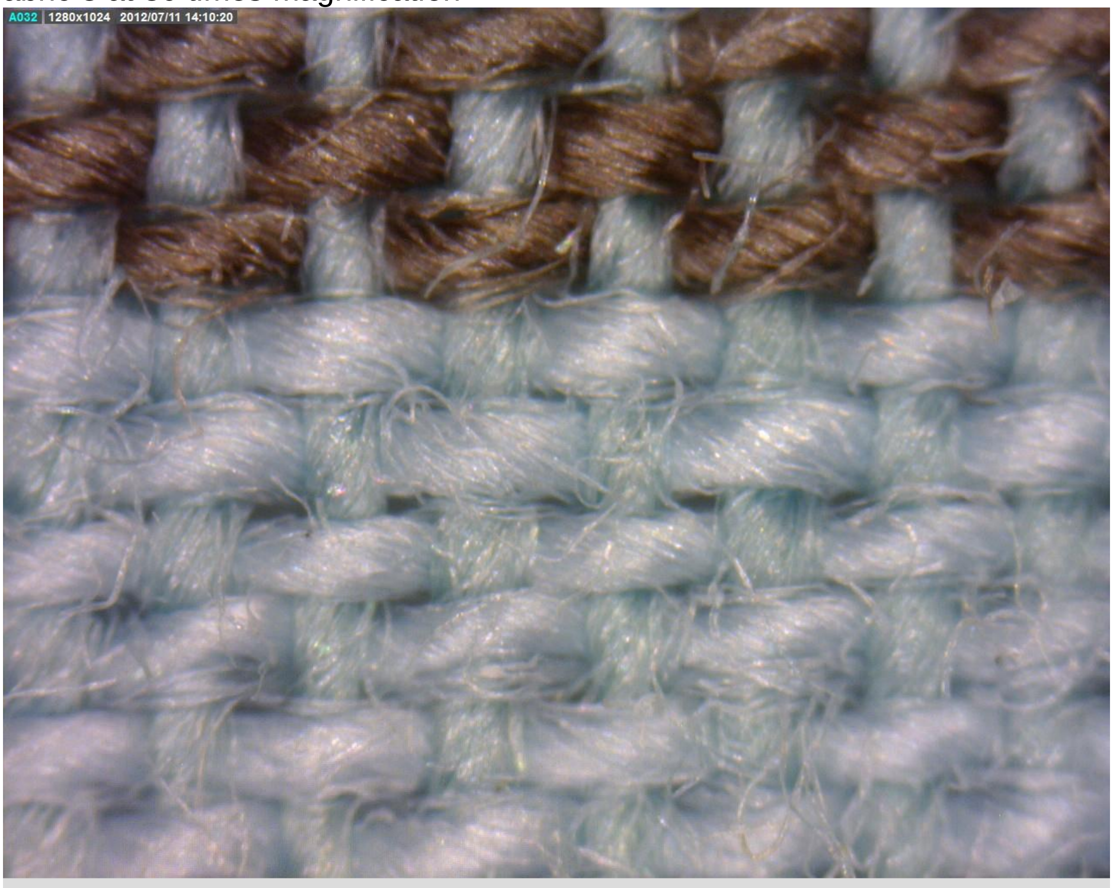
Fabric 7 at 80 times magnification



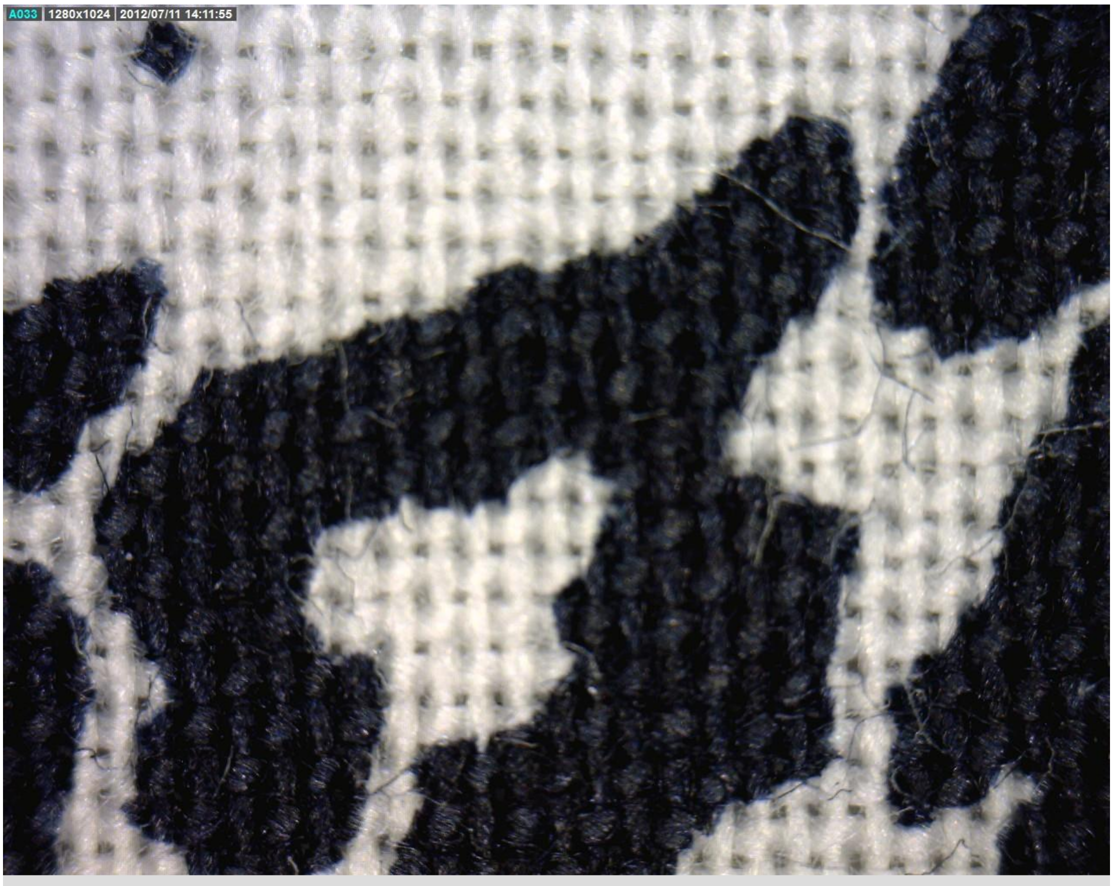
Fabric 7 at 200 times magnification



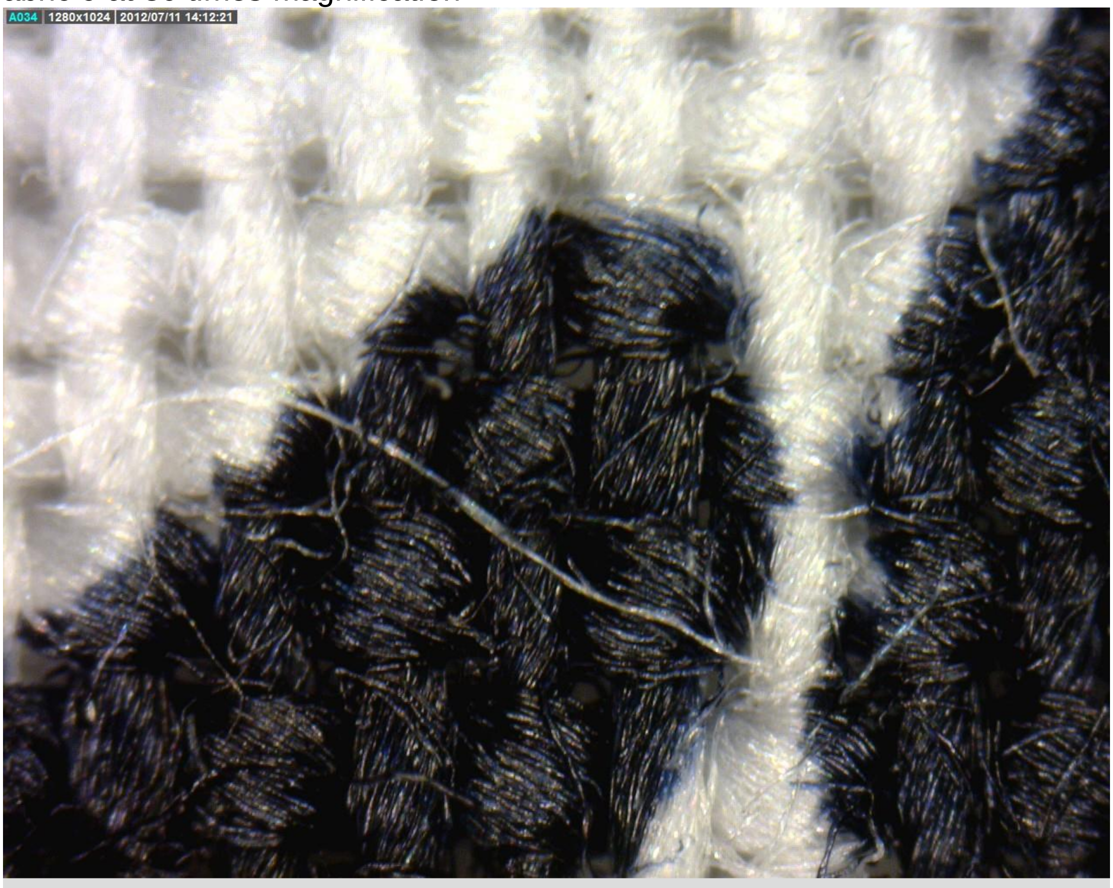
Fabric 8 at 80 times magnification



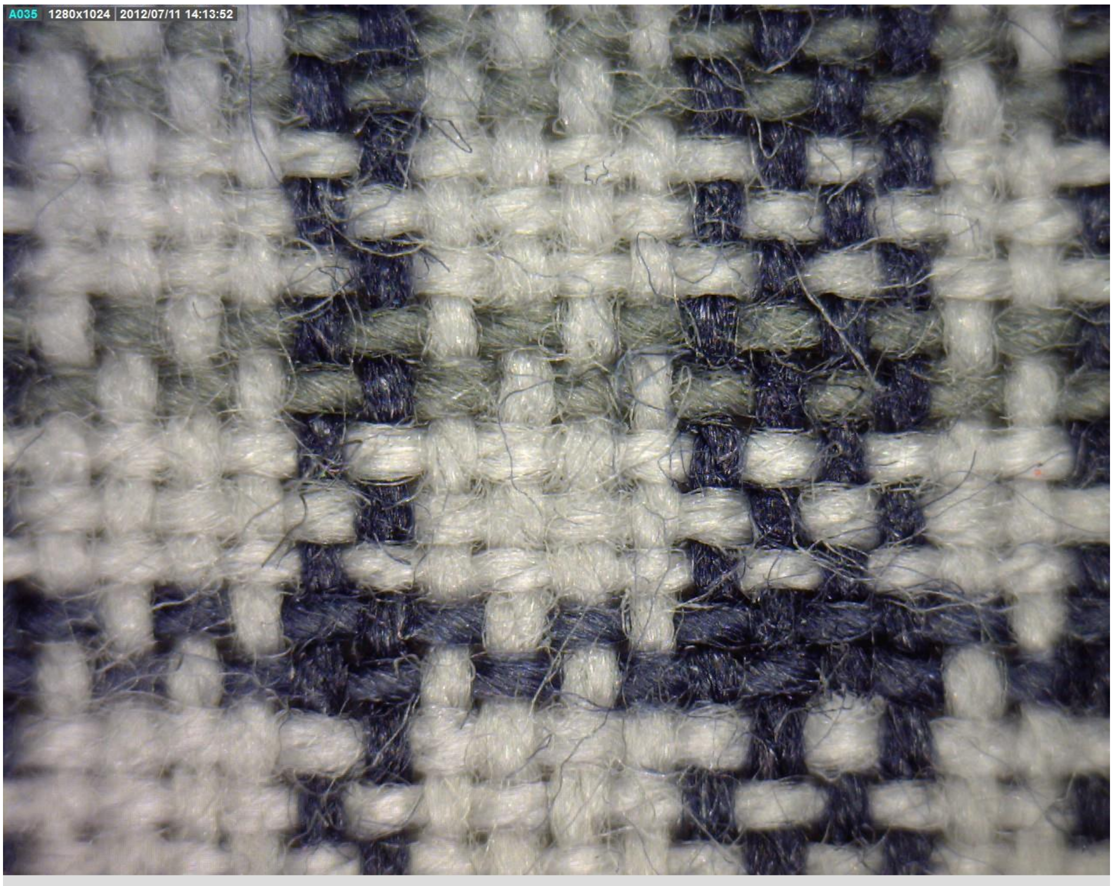
Fabric 8 at 200 times magnification



Fabric 9 at 80 times magnification

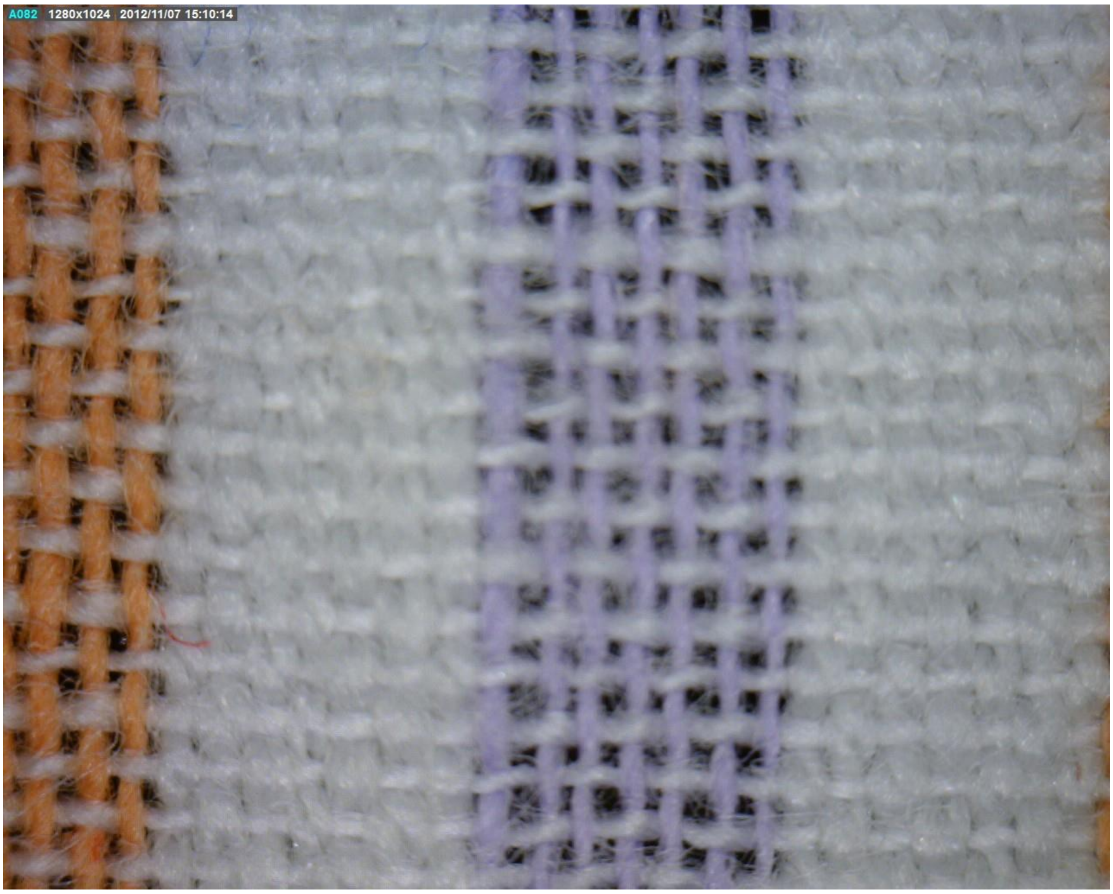


Fabric 9 at 200 times magnification

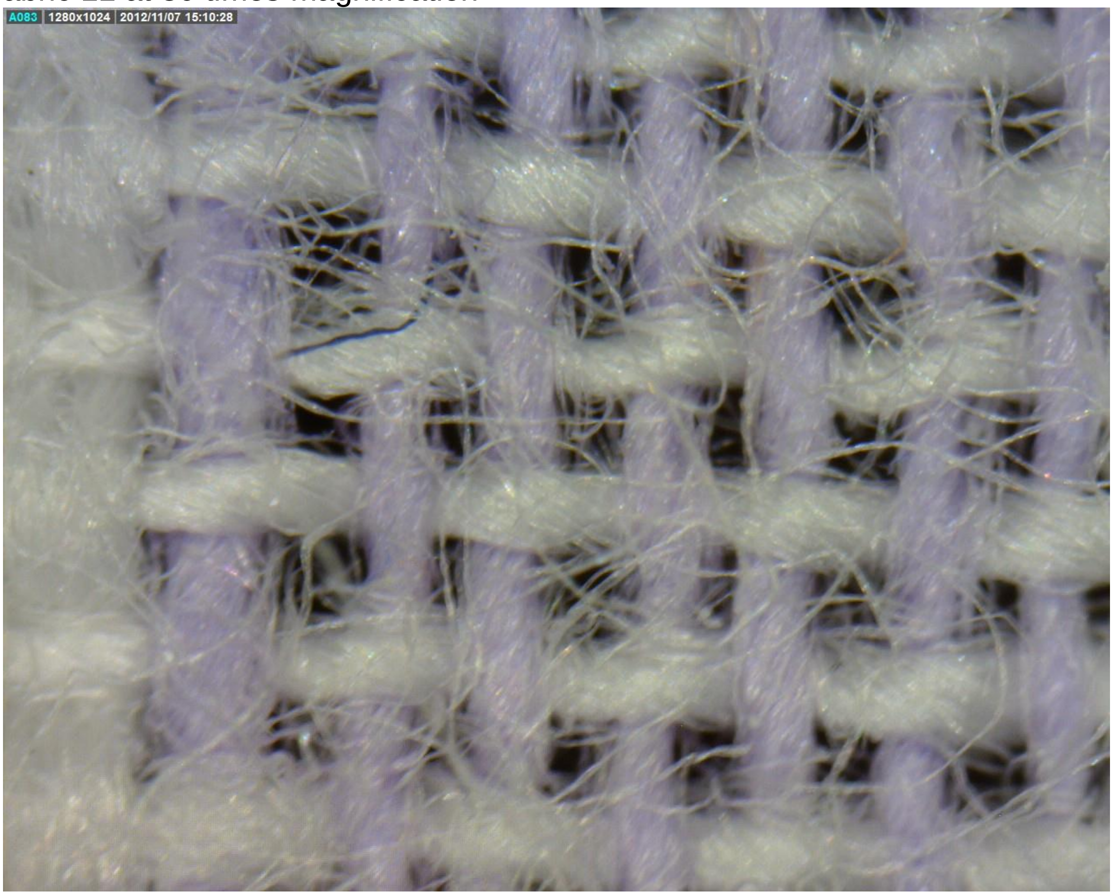


Fabric 10 at 80 times magnification

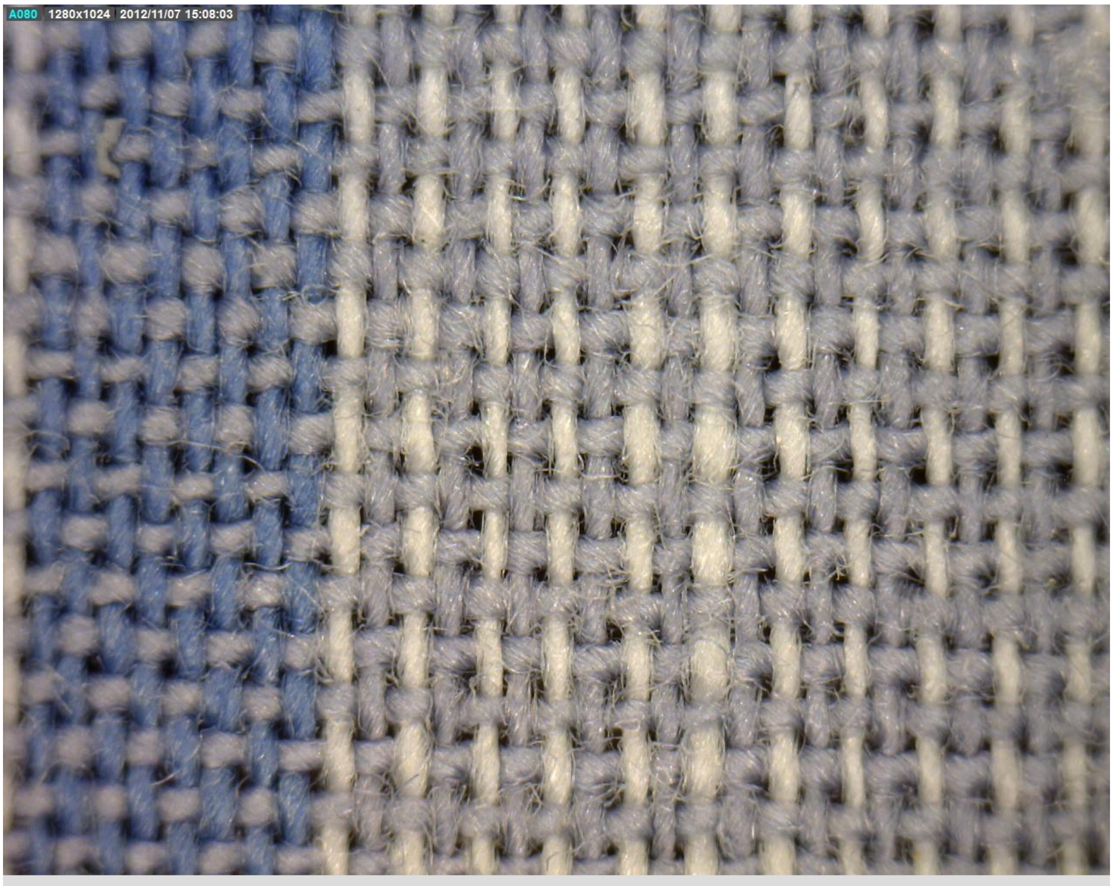
Fabric 10 at 200 times magnification



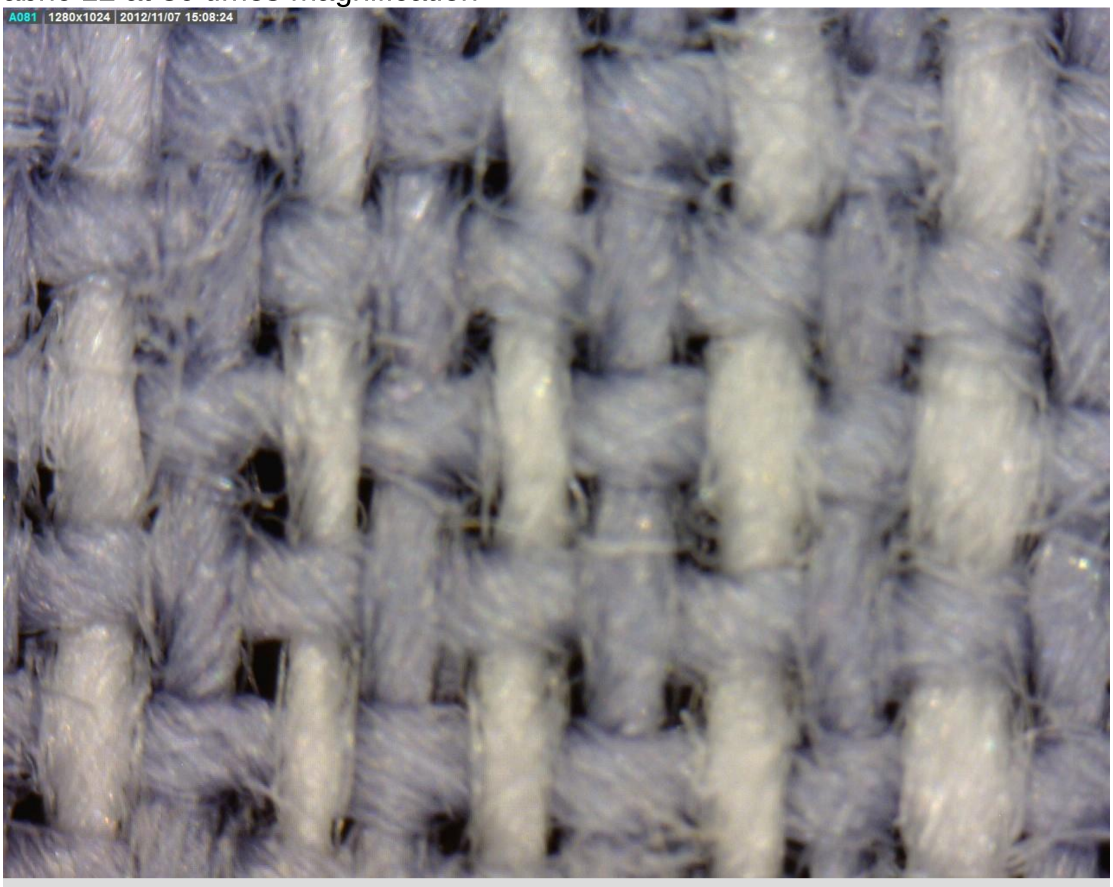
Fabric 11 at 80 times magnification



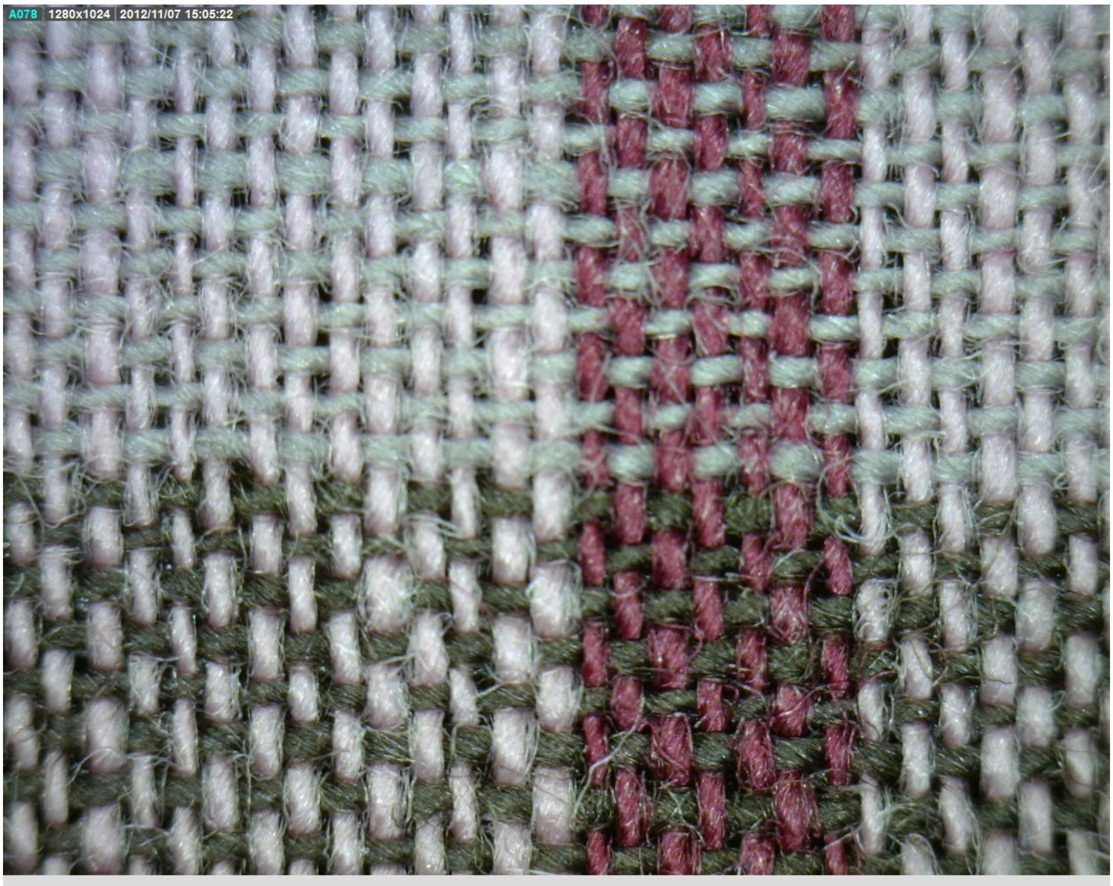
Fabric 11 at 200 times magnification



Fabric 12 at 80 times magnification

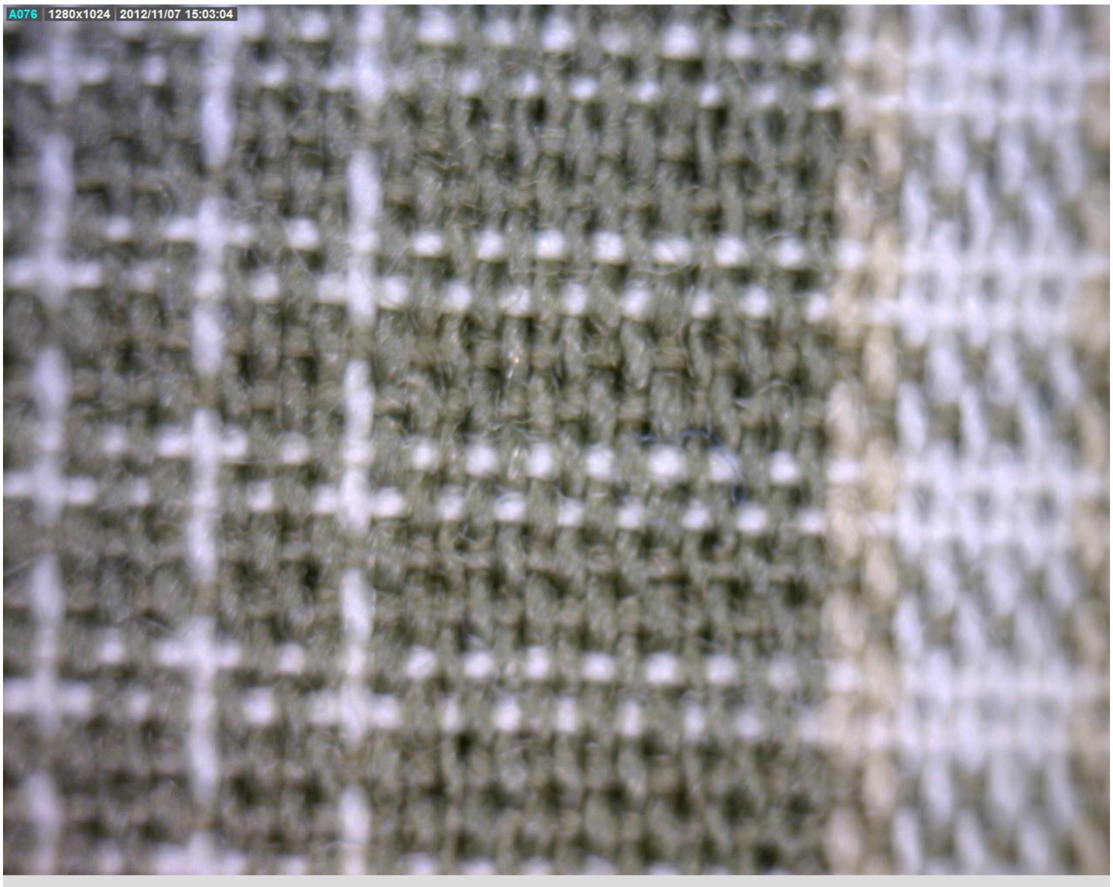


Fabric 12 at 200 times magnification

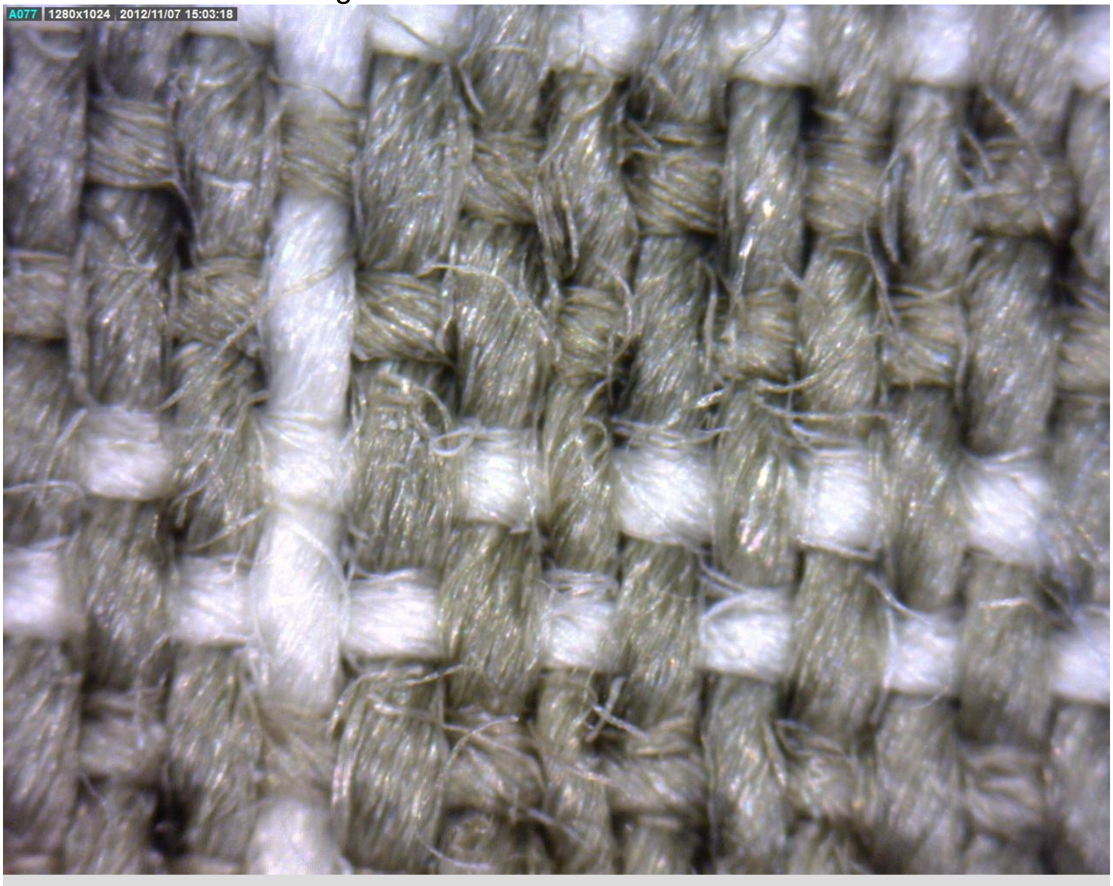


Fabric 13 at 80 times magnification

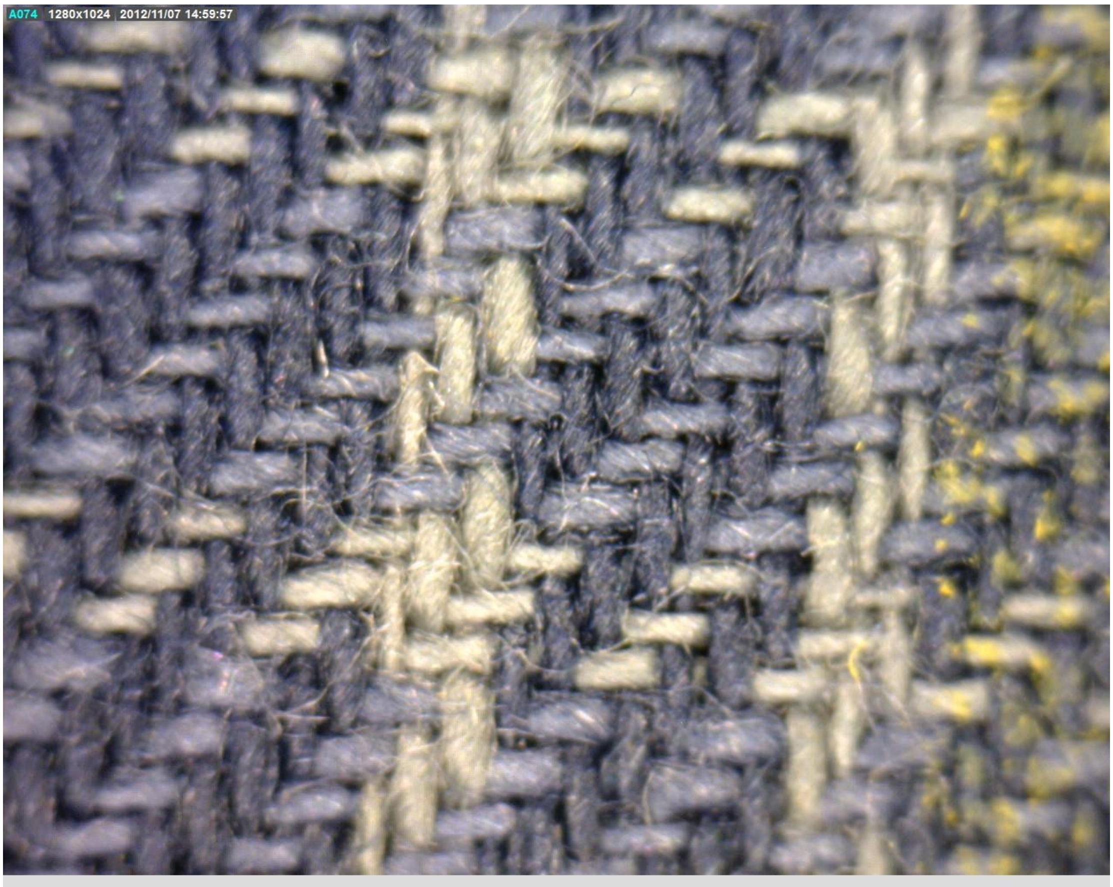
Fabric 13 at 200 times magnification



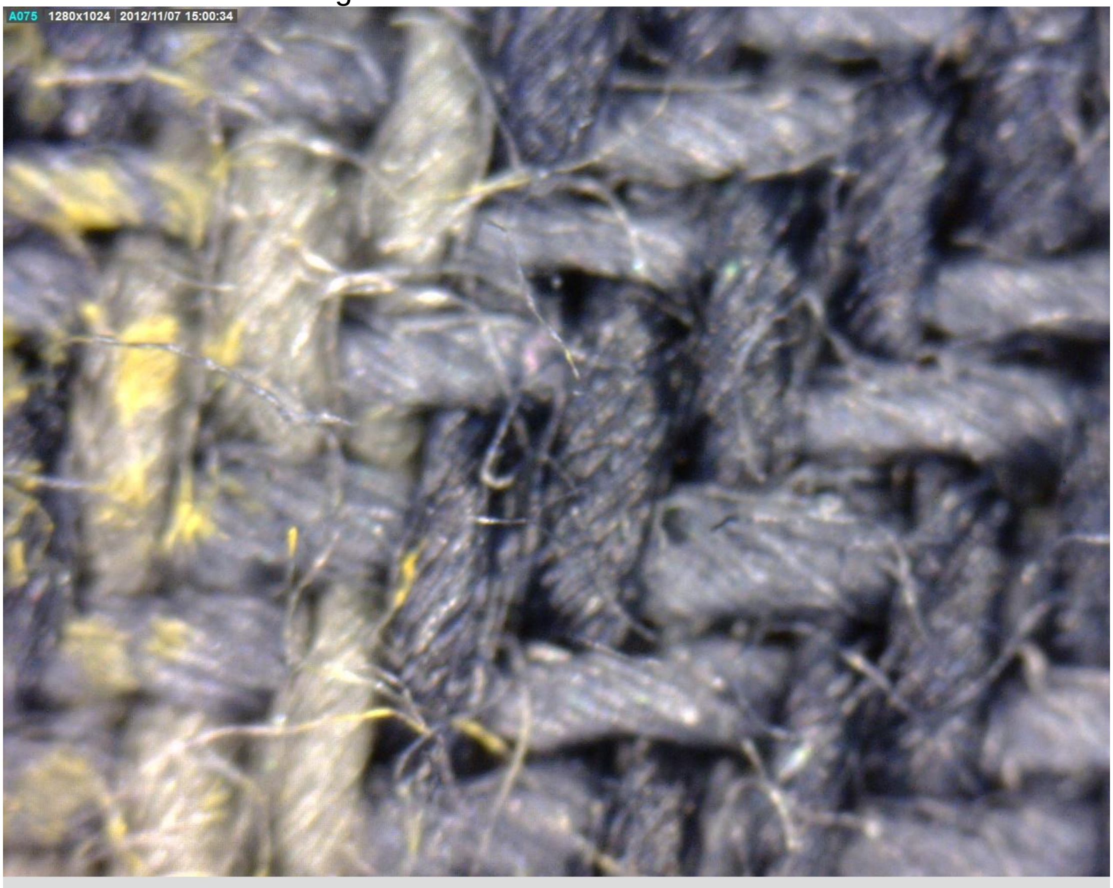
Fabric 14 at 80 times magnification



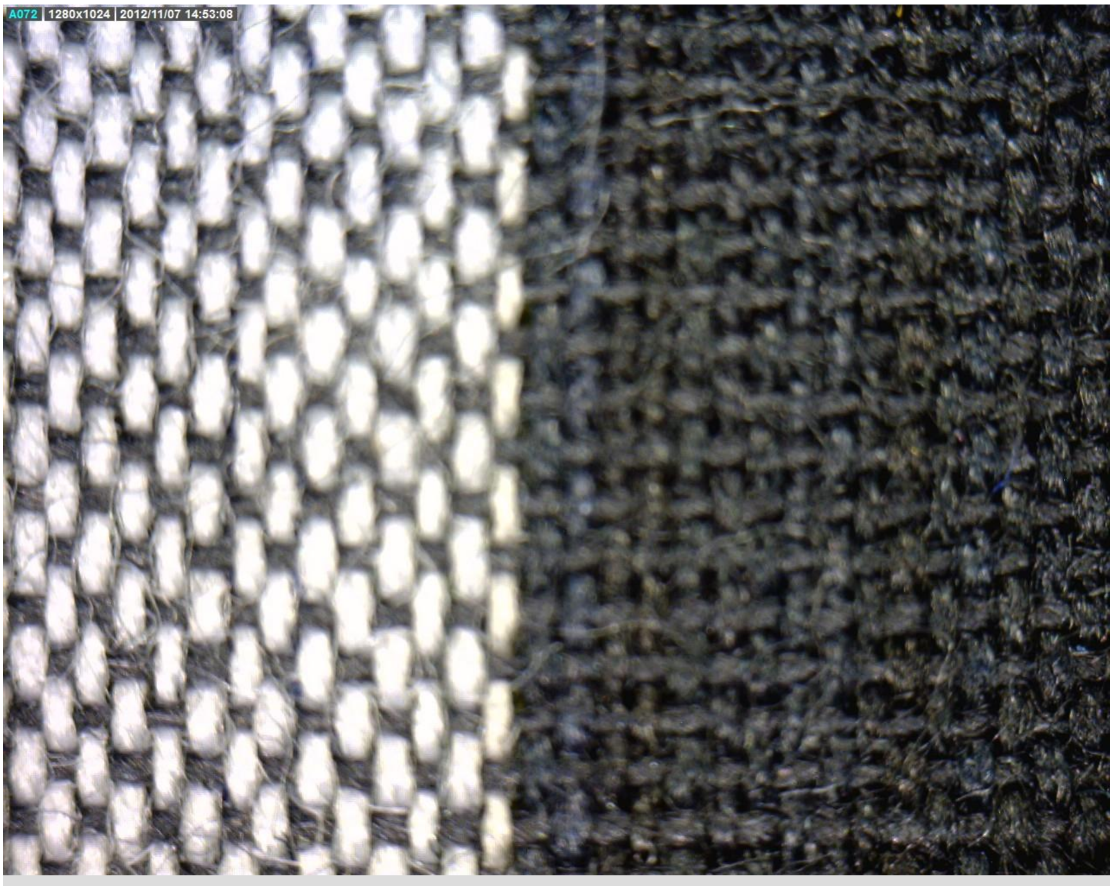
Fabric 14 at 200 times magnification



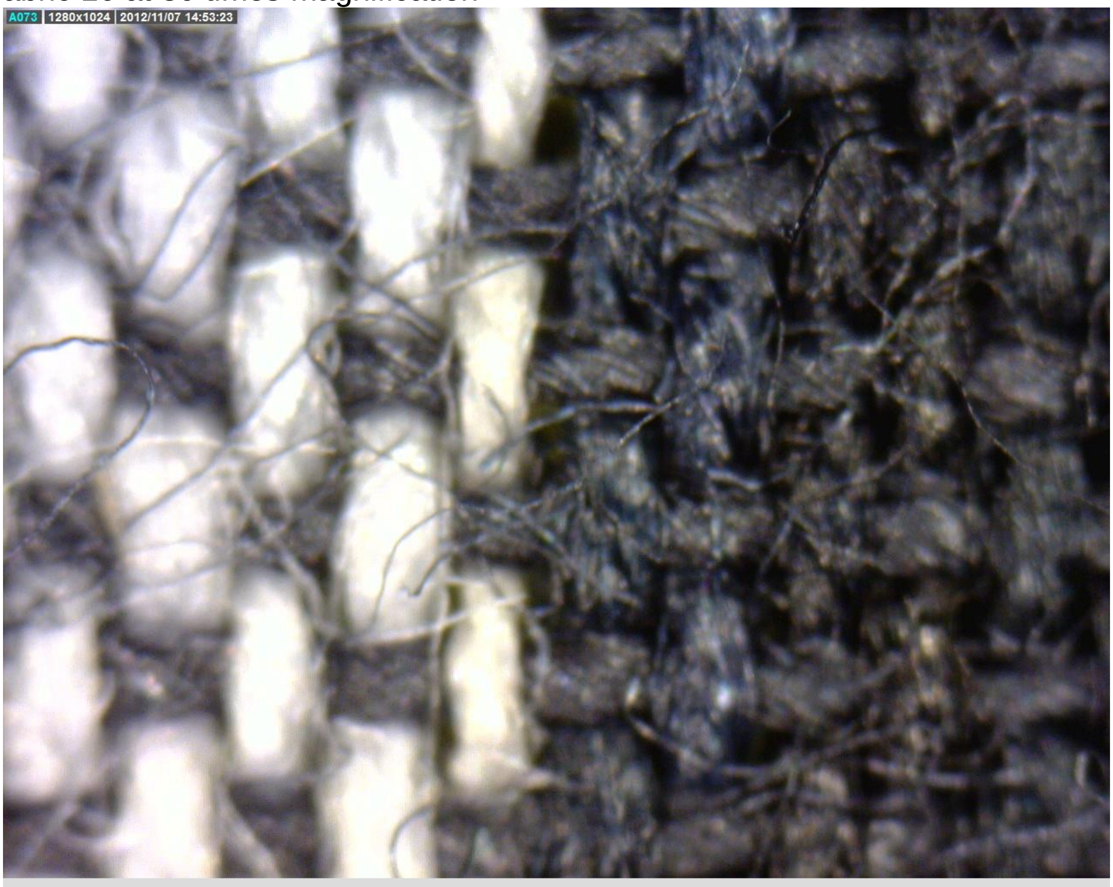
Fabric 15 at 80 times magnification



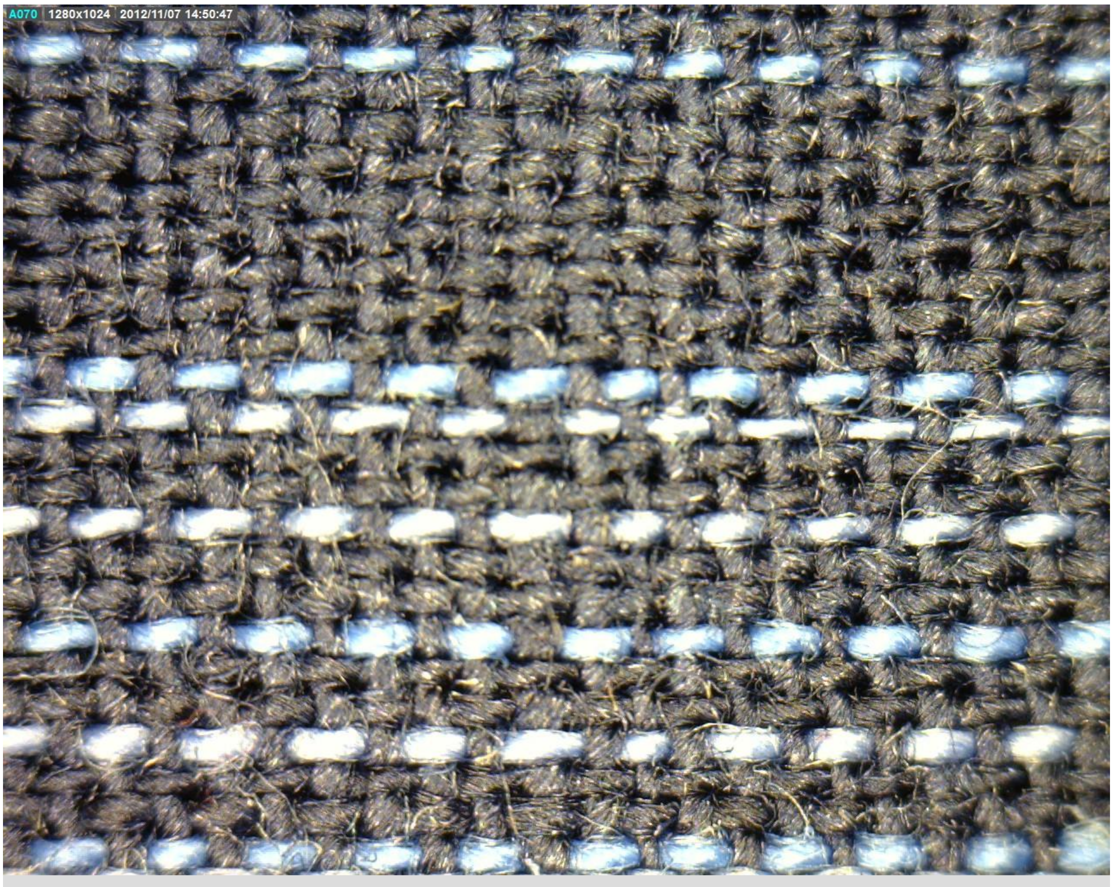
Fabric 15 at 200 times magnification



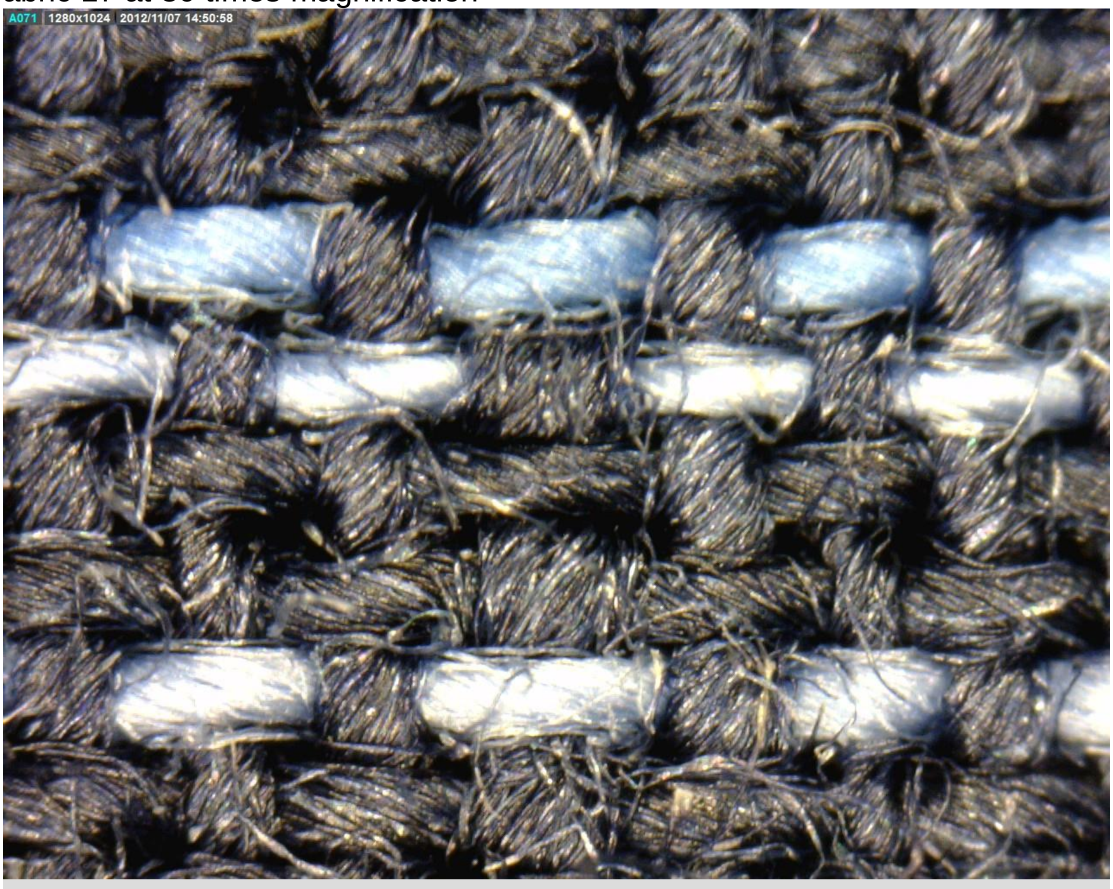
Fabric 16 at 80 times magnification



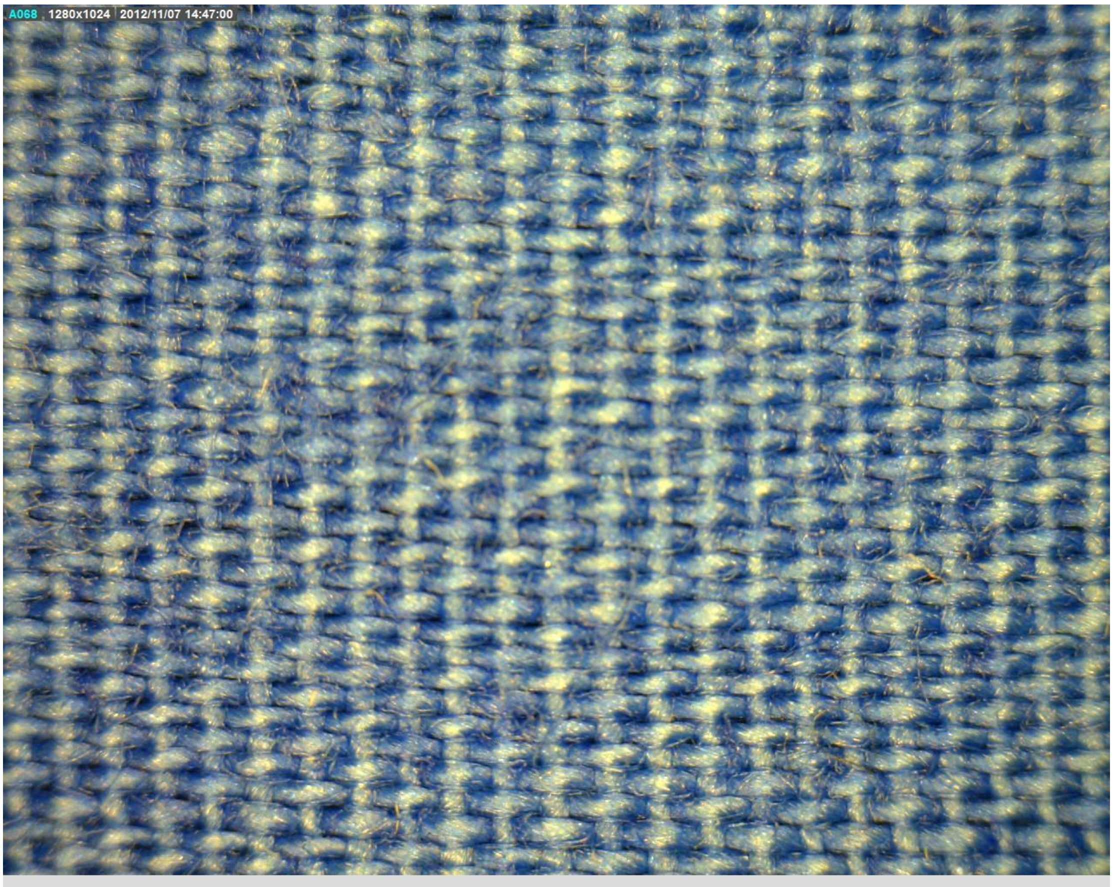
Fabric 16 at 200 times magnification



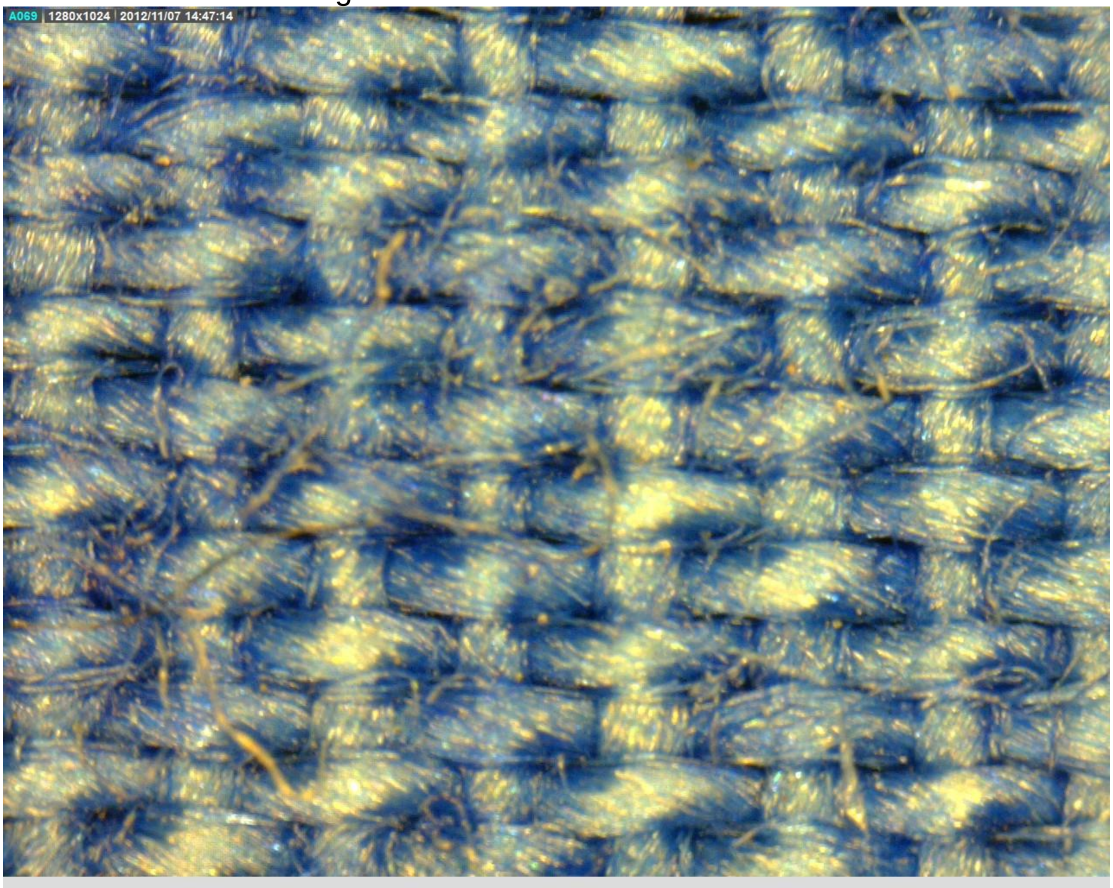
Fabric 17 at 80 times magnification



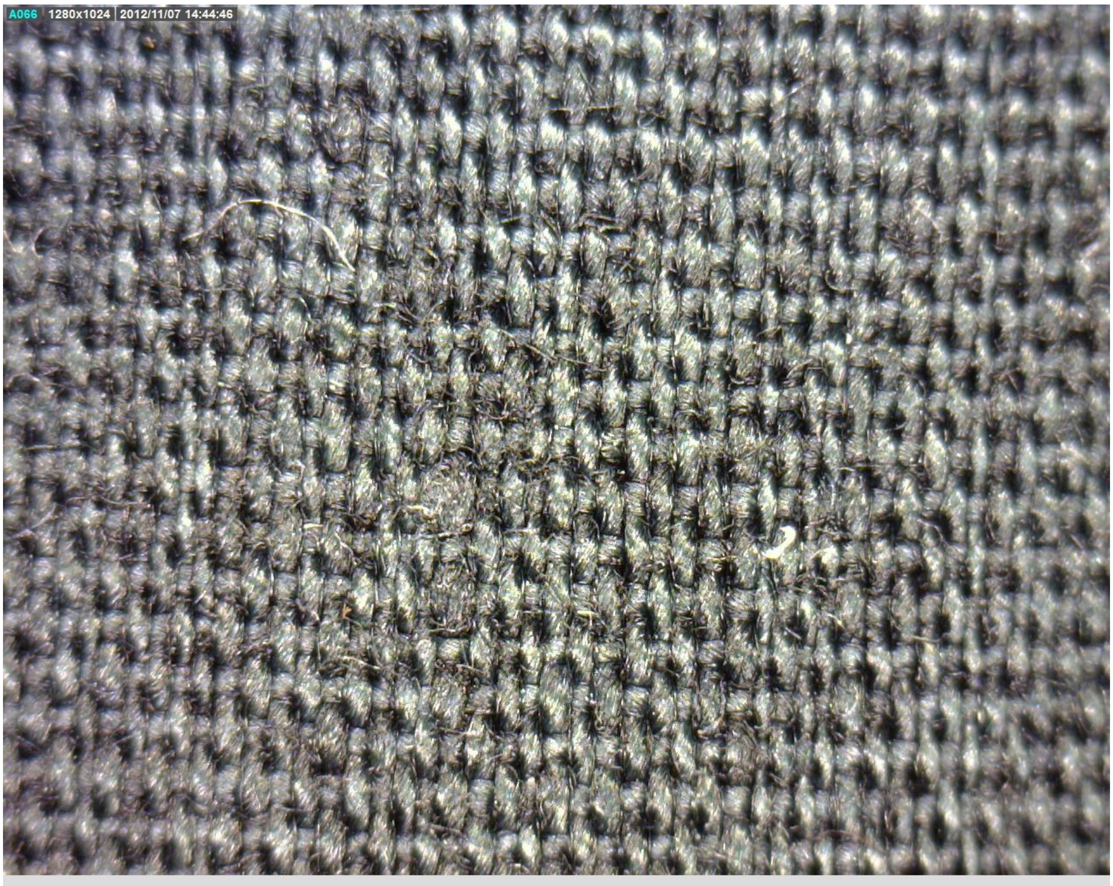
Fabric 17 at 200 times magnification



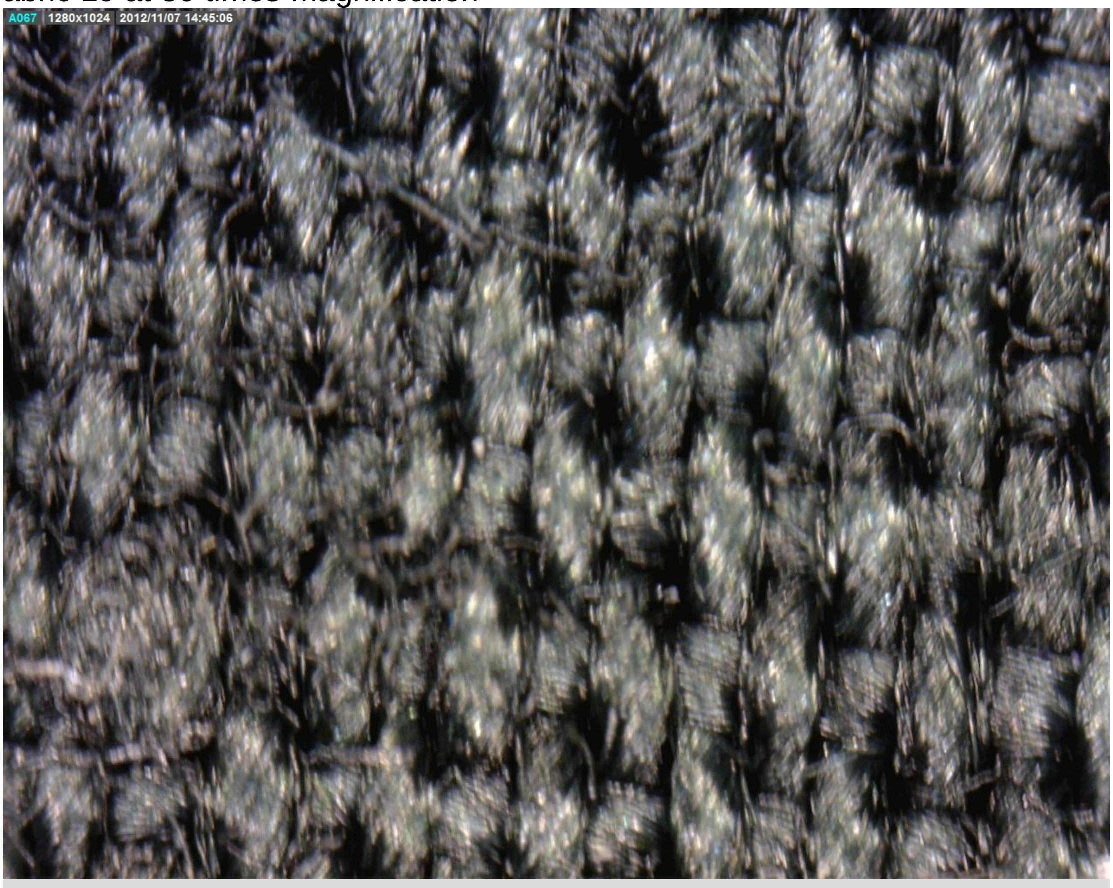
Fabric 18 at 80 times magnification



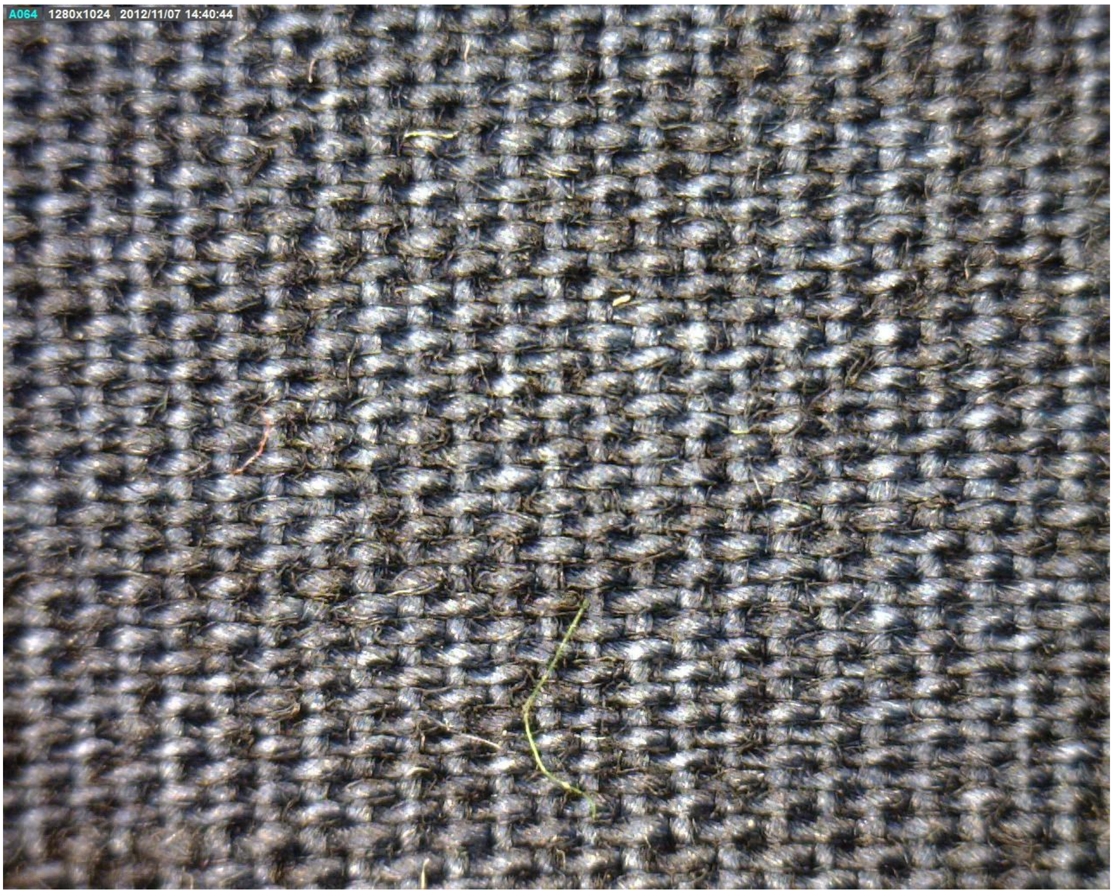
Fabric 18 at 200 times magnification



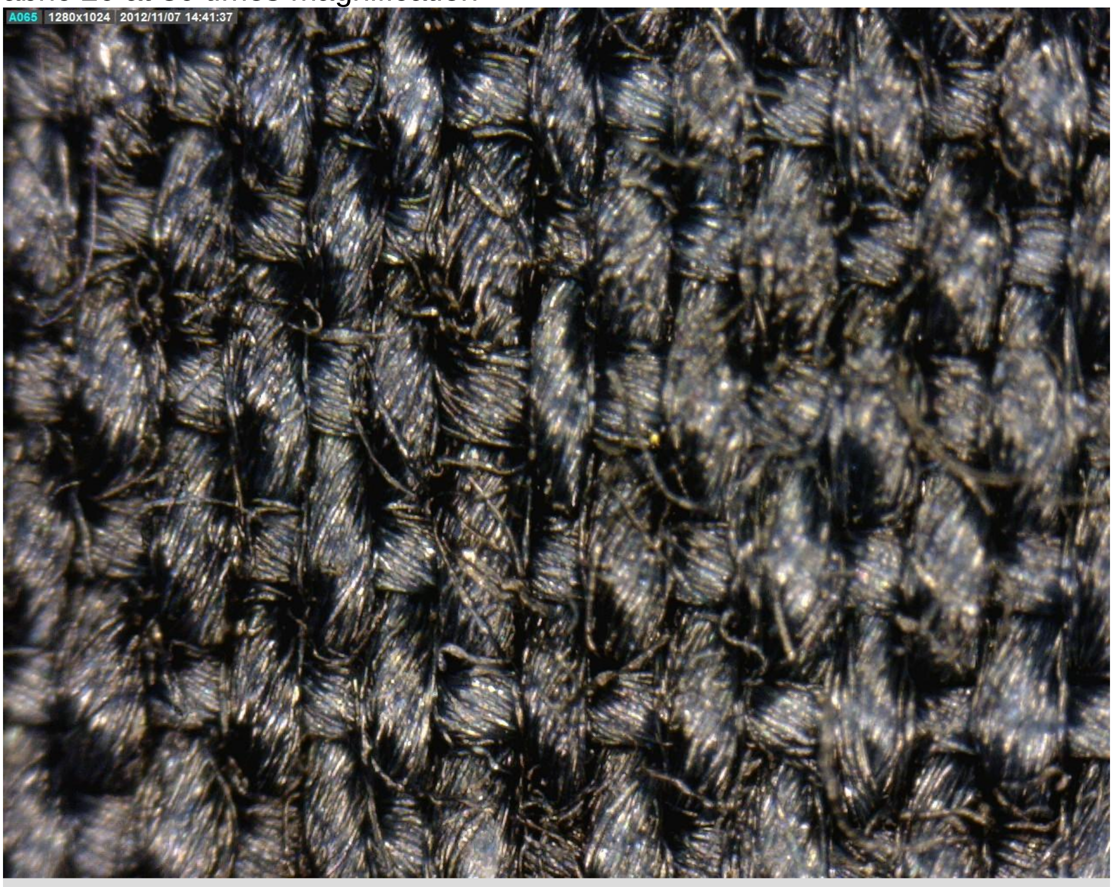
Fabric 19 at 80 times magnification



Fabric 19 at 200 times magnification



Fabric 20 at 80 times magnification



Fabric 20 at 200 times magnification

PUBLICATIONS AS RESULTING FROM THIS RESEARCH

1. McLoughlin, J. and Hayes, S.G., (2007). Automating objective fabric reporting. In: Ariadurai, S.A., & Wimalaweera, W.A., ed. The Textile Institute 85th World Conference, 1st - 3rd May 2007. Colombo, p568-582.

2. McLoughlin, J. and Hayes, S.G., (2008). An analysis on the relationship between sewing parameters and fabric parameters and of their impact on seam quality (part 1). In: ISBN 978-962-367-628-1. The Textile Institute 86th World Conference, 18th – 21st November 2008. Hong Kong

3. McLoughlin, J. and Cashman, P., (2010). An analysis on the perception of fabric and garment quality for a selection of men's suiting jackets. In: ISBN 978-0-9566419-0-8. The Textile Institute Regional Conference (North West Section) 10th – 11th June 2010. Manchester, England

4. McLoughlin, J., Sabir, T. and Hayes, S. (2010), 'Fabric parameter mapping for seam sewability', International Journal of Fashion Design, Technology and Education, First published on: 13th May 2010.

5. McLoughlin. J and Hayes, S. (2010). Computerised reporting for fabric sewability. Journal of the Textile Institute., First published on: 15th September 2010.

6. McLoughlin, J., Hayes, S., Rowe, H., (2010). Towards a smart database to optimise the sewing performance of fabrics (Part 2) In: ISBN 978-0-9566419-1-5. The Textile Institute 87th World Conference, 4th – 5th November 2010. United Kingdom.

7. McLoughlin, J., Hayes, S., Rowe, H., (2011). Fabric parameter modelling for fashion design, from empirical craft to designing for manufacture (Part 3) In: ISBN: 978-0-9566419-2-2. The Textile Institute regional conference 30th November 2011. United Kingdom.

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APPENDIX 9

Examples of Publications