POTENTIAL OF PRINTABLE INTERLINING IN PLACE OF FUSIBLE INTERLINING IN GARMENT MANUFACTURE

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Potential of Printable Interlining in Place of Fusible Interlining in Garment Manufacture

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ABSTRACT

Woollen fabric is main fabric in suit manufacture. Among the complicated suit manufacture process, interlinings play an important role to improve the formability and silhouette performance which enhance the suit performance. However, traditional fusible interlinings are costly with tedious production process and have some drawbacks such as strike through and bubbles. Printing technique has widely used in the garment manufacture, printing technique directly print on the woollen fabrics which could enhance quality and develop production and cost efficient as well.

The purpose of this thesis is to give a critical and comprehensive measurement of the existing woollen fabrics fused with interlinings for suit making, and explore the suitable printable interlinings which could in place of the fusible interlinings with production and cost efficient. Kawabata Evaluation System of Fabric (KES-F) objectively measured low-stress mechanical properties and hand value of both traditional fusible interlinings and printable interlinings on woollen fabrics.

It was confirmed that fusible interlinings changed woollen fabrics which dramatically increased bending and shearing properties, compression and tensile properties changed obviously, and surface properties were slightly affected. The most influenced primary hand value was stiffness of woollen fabrics with fusible interlinings. Fusible interlinings thickness, weight and adhesive density properties were highly related with stiffness, softness, smoothness and THV

of woollen fabrics with interlinings. Subjective evaluation showed that gender and education background of judges affected on softness and THV respectively in terms of woollen fabrics with fusible interlinings. In addition, it was found that printable interlinings obviously developed the total hand value of woollen fabrics which achieve the fusible interlinings' function. Printing technique was optimized based on orthogonal analysis, which resin viscosity, screen mesh, and squeeze frequency were analysed the optimized proportion for achieved the required hand value and low-stress mechanical properties using for garment manufacture.

LIST OF PUBLICATIONS

Refereed Journal

(1) Qian Zhang, Chee-Kooi Chan and Chi-Wai Kan, Low-stress Mechanical Properties and Hand Values Analysis of Different Combination of Woollen Fabrics and Fusible Interlinings, Journal of Fashion Technology & Textile Engineering, 2015, 3:4.

(2) Qian Zhang, Chi-wai Kan, and Chee-Kooi Chan, Relationship between Physical and Low-stress Mechanical Properties to Fabric Hand of Woollen Fabric with Fusible Interlinings, Fibers and Polymers, 2018, 19:1, 230-237.

(3) Qian Zhang, Chi-wai Kan, Hand Value and Low-stress Mechanical Properties: Comparison of Woollen Fabric with Fusible and Printable Interlinings, Fibers and Polymers (Accepted).

(4) Qian Zhang, Chi-wai Kan, A Study of Hand Value Evaluation by Judge Gender and Education Background Influence on Woollen Fabric Fused with Interlinings, AATCC Journal of Research (Accepted).

Conference Papers

(1) Qian Zhang, Chee-Kooi Chan and Chi-Wai Kan, The Coefficient Analysis between Interlining Physical Properties and Low-stress Mechanical Properties in terms of Fusible Interlinings and Woollen Fabric Bonded Interlinings, ISERD International Conference,Helsinki, Finland, Sep. 5-7, 2016, pp. 12-16.

(2) Qian Zhang, Chi-Wai Kan, Chee-Kooi Chan, Textile Summit and Research Student Conference, Hand Value Evaluation on Woollen Fabric Fused with Interlinings. Raleigh, NC, USA, American. Mar. 21-22, 2017.

(3) Qian Zhang, Chi-Wai Kan, Hand Value of Woollen Fabric Bonded Fusible Interlinings: Objective Testing and Subjective Evaluation Comparison. The 14th Asian Textile Conference, Hong Kong. Jun. 27-30, 2017.

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CONTENTS

LIST OF ABBERVIATIONS

KES-F	Kawabata Evaluation System of Fabric
SPES	sulfonated polyether sulfones
RH	relative humidity
WT	tensile energy
RT	tensile resilience
EMT	tensile extensibility
LT	tensile linearity
G	shear stiffness / shear rigidity
2HG	shear stress at 0.5°
2HG5	shear stress at 5°
B	bending rigidity
2HB	bending moment
LC	compressional linearity
WC	compressional energy
RC	compressional resilience
T_O	fabric thickness at 0.5gf/cm^2 pressure
T_M	fabric thickness at 50gf/cm^2 pressure
MIU	coefficient of friction
SMD	geometrical roughness

HV	primary hand value
THV	total hand value
KOSHI	stiffness
NUMERI	smoothness
SHARI	crispness
FUKURAMI	fullness and softness
HARI	anti-drape
PA	nylon
PES	polyether sulfone

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CHAPTER 1 INTRODUCTION

1.1 Background of study

Natural wool, especially woollen, is still considered as one of the most important kind of fibers for suit manufacture because of their numerous advantages such as good drape, smooth, durable and so on (Albrecht et al., 2006, Kawabata et al., 1990, Angel et al., 1990). However, woollen fabric has poor stiffness, elasticity and resiliency. As woollen fabrics are used for suiting and fine dress fabrics, this is the reason why the traditional suit needs fusing the interlinings to improve the silhouette and formability performance. Traditional fusible interlinings can have many drawbacks such as; strike-through, strike-back, and bubbles can often occur (Kim, 2006). In addition, the fusible interlinings are costly for the complicated technical processes (Kim et al., 1998). Therefore, the aim of this research study is to give a critical and comprehensive examination of the existing woollen fabrics fused with interlinings for suit manufacture for their mechanical properties and hand value evaluation. In addition, this study is to create a new technique with easy processing and less cost which would increase suit manufacture efficiency and reduce cost. The novel developments of technique would use directly printing on woollen fabric with resin in place of the traditional fusing interlining technique. Fabric mechanical properties and hand value were then evaluated to compare the woollen fabric with fusible interlinings and printable interlinings. The detailed process is discussed in later chapters.

1.2 Research scope

The scope of this study covers the different weight of suiting woollen fabric along with different weight of fusible interlining are used to show the current situation of fusing interlining for suiting manufacture. At the same time, the method of printable interlining using the fabric printing and a carefully planned method of resin preparation and mesh application was performed to obtain performance like those of fusible interlining or better. In understanding the performance, fabric handle is an important criteria and KES-F was used to measure their relative performance between the two different methods of fusible interlining and printable interlining in the same states of woollen fabrics.

1.3 Research aim and objectives

This project aims to investigate the printing technique in place of fusing technique in garment manufacture. It is perceived that screen-printing technology can be applied to substitute the fusing technology in manufacture. In order to study the possibility of applying printable interlining technology in the fusing process, this project will have the following objectives:

(i) To study the situation of conventional functional effect of fusible interlinings on woollen fabrics for suit manufacture,

(ii) To develop a process of using printing in place of a fusible interlining to obtain the effect similar to fusing in terms of method and technique,

(iii) To develop a recipe of the resin for the printable interlining,

(iv) To study the low-stress mechanical properties and handle properties of both printable and fusible interlining by using Kawabata Evaluation System of Fabric (KES-F) testing, and

(v) To study and analyze printing resins and technology in order to examine their substitutability.

1.4 Research methodology

1.4.1 Introduction

A comprehensive literature review was conducted to understand and strengthen the background knowledge of suit manufacture on woollen fabrics for mass-production. This study surveyed the recent technique of woollen fabric with interlinings as well as the reaction low-stress mechanical properties and hand value. Woollen fabrics with different fusible interlinings and printable interlinings were evaluated by KES-F and compare the performances. In order to well enhance the functional printable interlinings performance, screen printing technique and different resins or chemical's treatment were explored.

1.4.2 Understand the technique process

1.4.2.1 Fusible interlining technology

To visit the CO. KG Vileseline and Kufner Hong Kong Ltd. companies in HK (research and develop department as well as quality measurement department) and investigate the variety of the fusible interlining. These two brands are famous accessory companies especially for fusible interlinings, which were used in major apparel companies. The fusing parameters (pressure, time and temperature) used are according to the recommendation of the product. The fusing machine used PPS-L600, Maschinenfabrik Herbert Meyer GmbH, Germany, which supported by the faculty of Institute of Textile and Clothing (ITC) in The Hong Kong Polytechnic University (PolyU). This rotary drum continuous system affect fusing by holding the assembly to be fused with a conveyor belt whilst passing through a heat source and simultaneously applying pressure.

1.4.2.2 Low-stress mechanical properties and hand value testing

(i)To study the Kawabata Evaluation System of Fabrics (KES-F) machine and test the low-stress mechanical properties as well as hand value.

(ii)To learn the testing principles: compression; tensile; bending; shearing; surface; smoothness; stiffness; fullness and softness and applying to the subject of research.

(iii)To investigate the performance of woollen fabrics with interlinings and the new method in terms of different weight levels.

1.4.2.3 Exploration of the possibility of using resins or chemicals for printable interlining

To explore the functional cross field of the fusing and printing technology and find the potential of printable interlinings in place of fusible interlinings. In order to understand and study the details of the main techniques, visit to companies and factories were carried out and their processes were studied. Based on the literature review, several printing techniques have been learned in a printing factory in Guang Dong Province, China. Preliminary trials on various functional printing resins were conducted. The effects of printing resins and chemicals on the performance of woollen fabric was studied. Different operational factors and parameters such as: stroke frequency, screen mesh type, and resin viscosity affected the low-stress mechanical properties and hand values was studied. Experimental design to establish the optimum conditions for printable interlinings to obtain hand value similar to the fusible interlining was performed.

1.4.3 Investigation and development of printable interlining

Printable interlining is the main objective of this project. It is an easy process to print directly onto the fabric surface because there is no additional material and processes comparing with fusible interlinings (Miles and Leslie, 2010). The printable interlinings can reduce the manufacturing cost and quality problems comparing with using the fusible interlinings. The processes of printable interlining are shown below:

1.4.3.1 Raw materials (resin and chemical)

Resin and chemical development is the main consideration for the application and quality requirment of printable interlining. The resin was scraped through a screen mesh using a squeegee (Iwata and Koike, 1987). A suitable amount of resin passed through the screen mesh and deposit onto the wrong side surface of the fabric. The amount of resin is determined by the number of thickness and layers of resin applied. Pattern design and mesh size of screen are determined by final handle desired of the garment part (Koike and Iwata, 1988). Resins of printable interlining can be consider some soluble substances such as acrylic copolymer, polyurethane resin, rubber ink and their copolymers and any of their combination, where its application can be in a continuous form covering the entire surface of the fabric or intermittently in the form of various patterns.

1.4.3.2 Technique process-screen printing

The printable interlining is the result of resin deposited onto the surface of the fabric via screen printing. Resin from a soluble paste form to cured into a solid form and stick to the fabric surface permanently (Locher and Tröster, 2007). By using screen printing technology and the appropriate adhesive paste, it could be “printed” directly onto garment parts to a suitable density, it may be possible to achieve the support and control that a interlining provide and to do it more economically (Walter et al., 2009a).

1.4.4 Evaluation of the performance of printable interlining and finding product properties arriving

The feasibility of applying printing resin to improve the performance of functional printing process was conducted on woollen fabrics. Based on the literature review and experiments of woollen fabric with fusible interlinings as benchmark, low-stress mechanical properties and hand value of printable interlinings test by (KES-F). The results of printable interlining would obtain a similar or better performance comparing with fusible interlining. The study concept and process flow chart is shown in Figure 1.1. Fusible interlinings and printable interlining was conducted to the same woollen fabric. Mechanical properties and hand values were evaluated by KES-F. The result of woollen fabric with fusible interlining shown value A and value B reflected woollen fabric with printable interlining. If value A is the same as value B, it was proved that printable interlining could in place of fusible interlining. Figure 1.2 shown the printable interlining process flow chart. Printing condition designed according to the fabric type and performance request. Screen printing was conducted to print on woollen fabric by scrapping resin and dry curing. After that, KES-F test the hand value of the fabric. If the hand value of woollen fabric with printable interlining could achive the performance of fusible interlining that mean the experiment result is good. However, if the printable interlining performance is not as good as fusible interlining, the printing condition should be improved and controlled until to achieve the request performance.

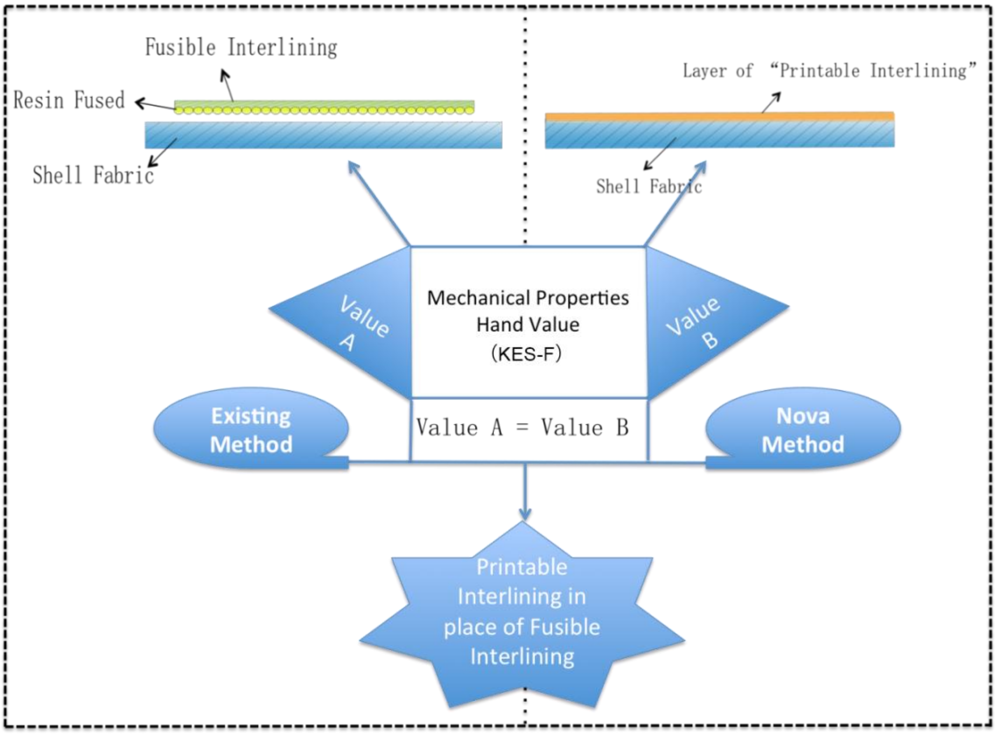


Figure1. 1 Study conception

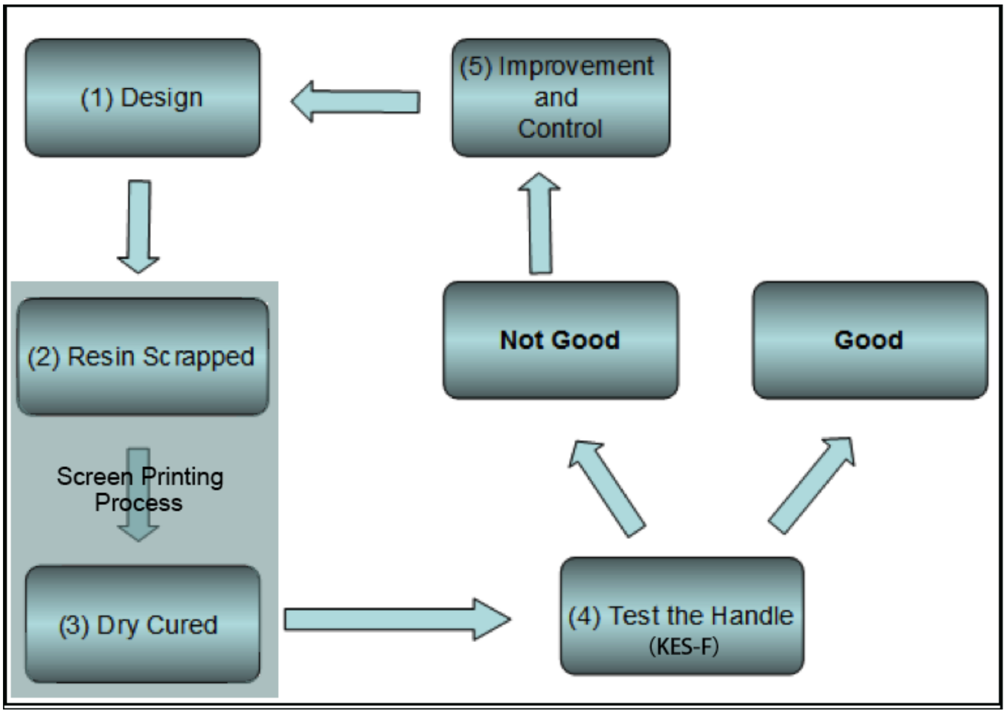


Figure1. 2 Process flow chart of the printable interlining

1.5 Research significance and value

Printing technique is a popular method in the apparel manufacturing industry for it high efficiency. Using the printing technique and technology to in place of fusible interlining can reduce cost, improved efficiency in production and enhance quality. With the development of the technology, the printing system could obtain different resultant fabric handle depending on the textiles and garments application. This study relates the printing of resin directly onto the fabric surface in particularly the wrong side to achieve the effects of a traditional fusible interlining.

Mentioned printable interlining is a cost-effective, and efficient technique, which is free from problems associated with fusible interlinings, hence, the printable interlining on textile will provide several advantages;

1. Garments can be produced with a consistent quality just like using a good fusible interlining.
2. Time and labor cost can be saved by reducing the machine operations required to fuse the interlining to the top-cloth.
3. Differential shrinkage between the top-cloth and fusible interlining would avoid.
4. The consequent distortion of fusing interlining parts is eliminated.

The garment will has less bulk and cleaner appearance upon its initial presentation. In addition, by systematic investigation of the relationship between print processes and final surface properties of printable interlined fabric, novel printing process developed to meet the technical and theoretical criteria. Thus, the technique offers a possible attribution to increase the competitiveness of local manufacturers in the rapidly expanding global apparel marketing.

1.6 Chapter summary

Based on the objectives, the thesis consists of seven chapters.

In Chapter 1, the background, scopes, objectives, methodology and significance of this research are introduced.

Chapter 2 is the literature review that gives an introduction of the woollen fabrics, and the conventional fusible interlinings used as well as the printing technique conducted on woollen fabrics. The evaluation of fabric low-stress mechanical properties and hand value instruments mainly include KES-F was studied.

In chapters 3 and 4, a series of experiments would be carried out to study efficiency of fusible interlining on woollen fabric. The study explores the low-stress mechanical properties and hand value performance of fusible interlinings objectively and subjectively. The relationships among fabric physical properties, mechanical properties, and hand value would be analyzed.

Chapters 5 and 6 explore the printing technique procedure on the woollen fabric and the optimization of the appropriate factors and parameters. The detailed analysis of printable interlining was carried out in terms of the low-stress mechanical properties and hand value which achieve the fusible interlinings performance or more controllable for different property requirements.

Chapter 7 provides a general conclusion of the present thesis. Recommendations for further study are also proposed in this chapter.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

2.1.1 Evaluation of men's suits

Suit is a traditional and standard formal menswear in the world (Li et al., 2010). More than 90% adult men wear a suit as business wear or attend formal occasions (Hansen, 2000). Suits have several decades of history (Honeyman, 2002). Since 1789, French Revolution presented the pompous style with a simple and a practical one of men's clothing, which has been regarded as a milestone. Since then, tailcoats became popular among Europeans and Americans, and men wore them in both everyday life and formal situations. Types of three-piece men's suit, i.e. tuxedo, vest, and pants, are regarded as the origin of men's suits (Black & Garland, 1985). During the Romantic period (1815–1850), men's clothing was influenced by women's fashion. In daily life, a frock-cock, a single-breasted jacket with a slim cut waist and wave hem, and slack pants were very popular especially for middle class. After the mid-nineteenth century, with the rise of hygiene concept, a more comfort conscious of people. Moreover, new H style (rectangular) clothing became fashionable with loosening the outline of clothing. In this trend, the sack-coat, a light suit or jacket with a square pocket, and a pair of straight-leg pants became the forerunner of the lounge suit later. Since mid-nineteenth century, there was no signature change in men's clothing in Europe and America till the end of World War I. It was not changed in lifestyle until the 1940s and later, people began to demand for simplicity and a slim silhouette, ready-to-wear suits were appropriate for high efficiency at work. At present, suits have become an important item in modern clothing, people wear suits or jackets in daily life and formal occasions, such as social gatherings and working. (Hansen, 1999, Kim et al., 2002). At the same time, there was a complicated progress in clothing manufacture; as a result of this, there was a trend of leisure suits made with different kinds of fabrics for developing men’s clothes (Jones, 2005). In the 1990s, compared with formal occasions, designers’ suits had become the mainstream of men’s fashion, which could be worn on various occasions when matched with different clothing items (Bouwstra et al., 2009, Hollander, 2016). With the cutting down in process and mass production of suit manufacture, the price of suits became more reasonable. In this way, suits became common and a part of ready-made clothing (Chuang and Hung, 2011, Li et al., 2010).

2.1.2 Fibers and fabrics used in suits

In 1957, Pierre Cardin, a famous designer for women’s fashion, became the first designer of men’s suit who brought ready-made suits to a new horizon (Galbraith et al., 1962). He helped to shape the two major trends in the modern men’s suits market: first, he cut down the fabric cost using synthetic fabrics for massive suit market as medium or low price. (Galbraith et al., 1962); second, he employed high-class woollen fabrics to tailor suits in designer’s brands with a fashionable look and fabulous quality as the principal garment (Hartmanns et al., 1995). Not only Pierre Cardin, but also Steele (2003), he investigated the factors and changing conditions to the look of Italian men’s suits after 1945. The quality, texture, patterns and the sense of touch of fabrics has been paid attention by more and more customers. He proposed designers of men’s suits led the public to high-class suits. Furthermore, he underlined the trend of feminine style and fabric should be made of pure wool as giving a magnificent outline and a high quality of sensation touch (Chuang and Hung, 2011). Since a long time ago, wool fabric of high quality is mainly used in the making of a suit as the aesthetic affection and function, prestigious Italian designers such as Giorgio Armani and Gianni Versace have adopted it (Chuang and Hung, 2011). Chosen for comfort, appearance, and longevity, wool garments are suitable for many situations and individual styles. Because of this, wool is both prestigious and practical for a wardrobe (Cheramie, 2006).

No matter the fashion visual, function or comfort request consideration for suits, wool fabric is the major fabric for suit manufacture. The selection of fabric can determine the shape, comport, texture and aesthetic appearance of the garment (Li et al., 2010). In order to improve the performance of the fabric, some fibers such as polyurethane might be blended with wool to provide strength with a lighter weight. Interlinings in garment manufacture are used to endow the volume due to good formability, silhouette to improve the wool fabric performance.

2.1.3 Suit manufacture

People wear suits at official situations, such as at work and in formal social gatherings, ready-made suit users account for about 81% (Subba Rao, 2000). As suits have been an important fashion item, the quality of suits has also been paid much attention (Momota and Makabe, 1998). Manufacturers make garments to their own size specifications, basing these up their own or their customers' experiences (Iansiti et al., 1997). Production of a man's suit can require more than 100 steps. However, modern technology, such as automation which means traditionally handwork oriented, and hand tailoring can be found in only the most expensive suits. Compared with the normal apparel production, suits have the significant difference is fusing interlinings before sewing which fusing or hand–stitch interlinings on front pieces, sleeves, pockets, collar and lapel crease for support (Hefele, 1984). After fusing the interlinings on woollen fabrics (main fabrics), the basic suit manufacture process includes: press, line and stitch on pockets; join main pieces together; set in sleeves; set in linings by machine or, in the case of bind seam edges; sew buttons and buttonholes and final ironing and pressing the suit (Kawabata et al., 1992, Kamat, 1988).

The suit quality evaluation was an important part of suit evaluation (Zhang et al., 1999, Swartz and Brown, 1989). However, there are several factors affecting suit quality. Figure 2.1 shows the suit quality indicators of product. This figure shows the hand value, physical property and mechanical properties are key points, which affect suit quality. In this way, researchers pay much attention on these points to develop the suit quality. The main approach is to develop or create technology in place of conventional technology.

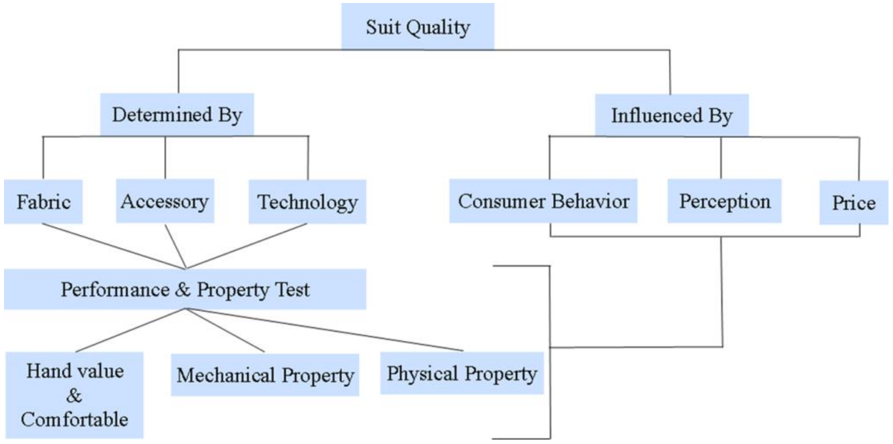


Figure 2. 1 Suit quality indicators of a product

Good appearance and fit of a worsted suit, which are affected by tailor ability of the fabric, make a considerable difference to the price which the customer is prepared to pay for it (Kawabata and Niwa, 1989, Kawabata and Niwa, 1991). Since such garments are usually relatively expensive, there are considerable economic benefits to be gained by maximizing the ratio of appearance and fit to the manufacture cost. It would be advantages if the fabric-manufacturing industry had objective specifications to which its products could be made in order to improve their tailor ability (Murtha, 1993, Belvís et al., 2014). More precise knowledge of the tailoring process would also assist garment designers in matching the requirements of their designs to fabrics with appropriate properties (Kawabata et al., 1982, Postle, 1983, Kawabata and Niwa, 1991, Kawabata et al., 1985).

2.1.4 The challenge of technique change

Garment manufacturing is an assembly oriented activity and there is several related process: merchandising, design, fabric and accessories resources, factory production, quality assurance and finishing packaging (Gong and Chen, 1999). Each of process is updating and innovating in terms of the technique for an efficiency production in recent years. Details to the apparel production, lots of conventional technologies have been replaced by advanced technologies (Lee and Chen, 1999, Bailey, 1993), such as 3D body scanning instead of tape measure for body sizing (Apeagyei, 2010), flatten 3D models instead of basic block for pattern design, complete garment knitting instead of knit to shape for knitting and so on. In order to achieve high efficiency of garment manufacturing, production technique should be the key points to be pay attention.

2.1.5 Importance of fusible interlinings of woollen fabrics

Interlinings here refer to fusible interlinings. Fusible interlinings are important to the intrinsic quality of garments and used to provide shape, stability, reinforce points and stress, increase retention of the original appearance during wear and care, and conceal garment interiors (Kim et al., 1998, Chapman and Holt, 1979). They are also available in a wide variety of physical characteristics, performance capabilities, and costs (Fukui et al., 1974, Fan et al., 1997b).

Interlinings serve two major functions: one is to produce and retain the desired aesthetic appearance and the other is to improve garment performance (Fan et al., 1997a). Interlinings that enhance the hand of the shell fabric and create the desired aesthetic characteristics for a garment component may be the preferred choice (Fan et al., 1997c, Jeong et al., 2000). In other instances, performance during sewing operations, wear, or care may be more critical. However, many considerations should be taken when selecting the reasonable interlining, such as the compatible with the shell fabrics for variable appeal styles and the adaptable to the equipment and process.

2.1.5.1 Aesthetics

Appropriately selected interlinings provide the foundation for the shape and hand of apparels and the stability to maintain the same performance through use, care, and storage. Aesthetic standards are usually subjective and vary by designers. One designer's interpretation of a soft silhouette may be interpreted as limp by another designer's standards. A firm with high quality standards may determine that shrinkage of either the interlining or shell fabric is unacceptable; other firms may allow tolerances for shrinkage if both the shell and interlining shrink the same amount. Interlinings help maintain or increase the hand, stability, durability, and resiliency of the shell fabric. Hand refers to the fabric stiffness, softness, fullness and drape of garment. Interlinings support a variable hand of fabric when determining the fusing combination. Chemical composition, structure, sizing, fusing time, pressure and temperature may affect the hand of a fabric. An interlining may be stiff but lightweight without a lot of bulk. Stiffness is important to suits that require a lot of support but little bulk. Different interlinings are often used for mass market merchandise than for more expensive garments produced for the better specialty markets. Mass market merchandise, which may be stored in warehouse for extended periods, often has a stiffer, more resilient type of interlining to provide hanger appeal and to prevent a limp appearance when displayed on the retail floor. More expensive garments may require a softer hand and different hanger appeal. Mass market merchandise and better upper end apparel often have different performance expectations in long term use and care.

2.1.5.2 Performance

Interlining performance may be evaluated from two perspectives: one is the performance during production that reduces raveling and improves the sew ability of fabrics and garment parts; another is the performance in the finished garment that facilitates the fabric handle (Kamat, 1983). In addition, there are frequently used under embroidery to stabilize fabrics for better executed stitching.

Performance of the garment may be enhanced by using interlining in small areas to reinforce points of stress and weakness and in larger area to provide stability and shape retention. Interlinings may be used for reinforcement and extended durability of yokes, necklines, welt pockets, buttons, buttonholes, and so on. Interlinings are used in larger areas to provide body, improve resiliency, and increase durability of many low-count and lightweight fabrics (Hua and Liu, 2003). Whole fronts of jackets or coats are frequently interlined to provide a smooth, clean look (Glock and Kunz, 2005).

Chuang and Hung carried out a market survey on Chinese men's suits selection. There were three criteria aspects for suits: (i) well-tailored, fit, and accurate in size for wearing performance; (ii) soft and delicate to touch in terms of fabric handle; (iii) stiff in shape and unwrinkled for fabric perspective. She suggested that a sustainable management of the appeal brands should be an important development direction. (Chuang and Hung, 2011). Lin's (1992) study provided an illustrated history of the development of men's suits which has been the reference for this study.

Interlining selection based on material specification, technical information, and product test results provided by suppliers. According to this information, suppliers of support materials may make recommendations for specific uses. However, some manufacturers need do their own testing of prototypes containing fusible interlinings and other specific support materials. Because of the constant change in styles, piece goods, and materials, it is sometimes difficult for the garment manufacturer to know the best options for every style. Therefore, they may work with vendors to make the most appropriate selection. However, the inappropriate fusible interlinings would occur after a period of display, wear or cleaning. In such cases, less expensive or less appropriate support materials may have been used to reduce costs. As a cost effective issue, support materials are sometimes neglected even though they may develop the performance of finished apparels. In this way, to improve or invent a new technique for fusible interlinings in the manufacture should be a big issue (Glock and Kunz, 2005).

2.1.6 Printable interlinings in place of fusible interlinings

In recent years some attempts have been made to eliminate the operations of fusing the interlining on to the garment part. If an appropriate adhesive paste, perhaps with some type of filler added, could be “printed” directly onto garment parts to a suitable density and thickness, it might be possible to achieve the support and control that interlining provide and to do it more economically (Walter et al., 2009b).

Printing technologies have been widely used in many aspects by the patterned application of functional inks containing soluble materials. Basically, screen printing is the process of using a stencil to apply ink onto another material in which a design is imposed on a screen. Many screens can be used to produce a multi colored image. As a result, screen printing technology is now widely used as it can satisfy people’s requirement in clothing and textile and clothing personalized production with advantages provided as follow (Riemer, 1988).

(i)Mass-production

Advantage of screen printing is that large quantities can be produced rapidly with new automatic presses.

(ii)High-speed

The current speed loading record is 2139 shirts in one hour by a single operator (Omar, 2013).

(iii)Versatility

Various inks can be used to work with different materials, such as textiles, ceramics, wood, paper, glass, metal, and plastic (Lin et al., 2008).

Printing is a cost-effective process in garment manufacture (Pardo et al., 2000); however, the technique currently has only been used in printing motifs and is designed for knitted and woven garments. It is perceived that this technology can be applied to substitute the fusing technology in certain garments. Printing technologies have been widely used in many aspects by the patterned application of functional inks containing soluble materials (Glock and Kunz, 2005).

2.2 Woollen fabrics

2.2.1 Introduction of wool

Today, wool is viewed as a luxury fabric due to the high cost in manufacturing and maintaining it. Wool crimps naturally, allowing the fibers to hold together and create a very strong yarn, but also creating air pockets that act as a natural layer of insulation and making it very desirable to wear in cooler weather. Woollen fabric has a lot of advantages such as warm, light weight, durable, absorbent, hydrophobic (absorbs water slowly, allowing the wearer to feel dry), flame retardant (self-extinguishes when burned), wrinkles easily fall out when exposed to humidity, wrinkle-resistant, extremely resilient when dry, good drape and good elasticity (ability of fabric to increase in length and return to original dimension). As these advantages, wool fabric is suitable for suit making and almost suits in the market use wool fabrics as main material (Black, 2000, Babu et al., 1995).

2.2.2 Wool fabrics classification

The fibers grown by sheep are known as wool. Wool is a natural fiber composed of proteins, as it comes from the fleece of sheep. Over 200 varieties of fleece exist that are used for wool fabric production (Cohen et al., 2010). The grades system is based on the quality and length of the fleece. There are two main ways of spinning yarns: woollen and worsted. Shorter fibers are made into woollen yarns providing a twisted look. Woollen yarns are thick and full and are used for such full-bodied items as tweed fabrics and blankets. The longer fibers are made into worsted yarns, which are smoother and more uniform in appearance due to the tightly twisted nature of the fibers (Black, 2000). Worsteds, usually made from longer fiber, are fine, smooth firm, and durable. Differences of woollen and worsted fabrics have shown in Table 2.1(Cheramie, 2006, Heaton, 1965). Almost all the woollen fabrics are used for suiting material but the worsted fabrics for dress materials (Postle et al., 1988, Rippon, 2003, Goldsworthy and Lang, 1954, Makinson, 1979).

Table 2. 1 Woollen and worsted differences

Woollens	Worsteds
Processing	
Spun from shorter wool fibers One to three inches in length Spun from fibers of a medium or coarse diameter Fibers are washed, scoured and carded	Spun from longer wool fibers Longer than three inches in length Spun from fibers of fine diameter Fibers are washed, scoured, carded, combed, and drawn
Yarn	
Bulky, uneven Low to medium slack twist Tensile strength lower-than worsted	Fine, smooth, even Tighter twist Higher tensile strength
Fabric Appearance	
Soft Fuzzy Thick, heavier weight	Crisp Smooth, clear-faced Lighter weight
Characteristics	
More insulator due to trapped air Not as durable as worsteds Nap reduces shine Does not crease well	Less insulator More durable than woollen May become shiny with use Where abraded during wear Holds crease and shape

2.2.3 Woollen fabrics application

Woollen fabrics have a widely application, the main part is garment fabric, such as suit, skirt, outerwear, sportswear, sweaters and socks. Another part is textile decoration such as carpets and wall hangings. The other part is industrial tools like felt pieces used in machines and clean up oil spills. Woollen fabrics are suitable for many situation and individual styles as it is comfort and durability appearance. To ensure that wool garments last for some time it is important to take proper care of them, such as dry-cleaning in a timely manner (Tang et al., 2011). There are three kinds of woollen fabrics used in suit manufacture which are serge, herring bone and flannel (Mishra, 2000).

Serge is used widely for the material of suits, school dresses and all kinds of uniforms. The plain colors like navy blue and black are used most commonly but other plain colors, marble colors and patterns (mainly, vertical stripes) are also used.

Herring bone, the texture of this woollen fabric is almost like serge fabric but for weaving, the herring bone pattern is used (twill of pointed feathers). This name is given because the weave looks like the shape of the bones of herring. It is mainly used for dress material.

Flannel widely used in suit manufacture. Flannel also is called as just Nell and in order to distinguish from cotton flannel, it is also called as main Nell or English Nell. Usually, single woollen or worsted yarns of 10-20 count are used for warps and wefts. The pattern is usually of flat weaving or 2/2 twill weave. This fabric has nap raised on the surface and the texture is soft and comparatively loose. The color is plain dye, stripes and grid stripes. The material of this study is flannel fabrics with different weights which are light, medium and heavy weight (Mishra, 2000, Manich et al., 2006, Tang et al., 2011).

2.3 Interlining

2.3.1 Introduction

Interlining is a layer of fabric placed between the garment fabrics and facing by bonding mechanically (sewn) and thermally (fused) to specific areas on garment components. The characteristic of interlinings includes knitted, woven or non-woven fabric. A interlining is one of the most important subsidiary materials in ready-to-wear, because of its role in the final appearance and function of the garment (Kim et al., 2013a). Hundreds of different interlinings are readily available from suppliers that specialize in support fabrics, it has several advantages, such as increase the handle and bulk, shape retention, shrinkage control, crease recovery, appearance in wear, appearance after dry-cleaning or washing and durability.

Selection of interlining with the suitable properties for the fabric and style requires knowledge of the available products, and an understanding of compatibility condition factors to be used. As styling needs change, producers of interlinings may create new fabrications, weights, and adhesives, the soft unstructured look that has been popular during the 1990s (Glock and Kunz, 2005).

2.3.2 Interlining types

The classification of interlinings is based on the base cloth (substrate). Substrate is an interlining material onto which the thermoplastic resin is coated, sprayed or printed. Substrate can be produced normally in a variety of woven, knitted and nonwoven forms and each type of interlining has a specific application. The classification by substrate construction as following:

2.3.2.1 Woven interlining

Woven Interlinings made from lightweight fabrics usually used for most demanding conditions like waistband, outerwear plackets, jackets etc. Woven substrates can be produced from animal hair, viscose, cotton, polyester fiber, acrylic fiber, wool, or in any number of combinations of these fibers. Because of their construction, woven fabrics are not easily distorted by wear or cleaning and, as a result, they exert maximum control on shrinkage and shape retention. However, these properties are not conducive to a soft and natural handle in the finished garment, special weaves, such as twills or fabrics with fine warps and coarse wefts, are recent developments that somewhat improving the handle and bulk. The possibility of using different types of yarns for the warp and weft enables substrates to be produced with special properties. An outstanding example of this application is an interlining with a soft handle in the warp and a firm handle in the weft. This interlining is specifically produced for the fronts of man's jacket and provides a firm basis for the length of the front and also prevents the lateral sections across the chest and shoulder from collapsing. Another development, utilizing the same principle, is the graduated interlining, which is woven with three different zones along the warp. Each zone possesses different properties in terms of handle, drape, and resilience.

(i)A front fusible cut from a graduated base cloth will possess all the necessary attributes for a jacket front:

(ii)A highly resilient shoulder area at the top

(iii)A resilient, but softer, chest area in the center

(iv)A super-soft, yet crease-resistant, lower forepart at the bottom

(v)This type of construction makes the garment lighter, improves its appearance, and significantly reduces labor cost in comparison with the traditional method of chest-area construction. Woven interlinings can be used for all types of fabrics, requiring the strength, stability, and good draping qualities. Their major disadvantage is the relatively high cost in comparison with other types available.

2.3.2.2 Knitted interlining

Fusible knitted interlinings are basically used in knit garments providing the perfect stretch basis for efficient production. Circular and jersey knit fusible interlines have stretch and recovery properties. The growing use of knitted fabrics for men's and women's wearing led to the introduction of knitted interlinings in the early 1960s. These interlinings, because of their construction, provided a considerable degree of elasticity to the fused components by yielding easily to body and limb movements. The first products were warp-knitted and it was used until the introduction of weft-inserted fibers into the warp-knitted construction that this type of interlining became widely accepted as a fusible for woven cloths.

The advantage of a weft-inserted interlining is that it has a nature handle while providing resilience in the weft direction, i.e. around the body. The newest weft-inserted types include a stretch property in the weft fiber that provides extensibility in this direction and thus makes it more compatible with the outer fabric. The warp-knitted interlinings are widely used for woman's light clothing, such as blouses and dresses made of crepe-de-chine, georgette, and polyester-fiber yams. These types of fusible are available in all weights and colors. The fibers used for knitted substrates are usually man-made and include polyester fiber, polyamide fiber, acrylic fiber, and viscose or any combination of these. Since the knitting process is generally faster than weaving, the cost of knitted substrates is somewhat lower than that of an equivalent woven product.

2.3.2.3 Nonwoven interlining

High quality non-woven interlinings are made from 100% polyamide products with ultra fine coating to heavier blends. These are thermally or chemically bonded and used depending on applications. Generally these are available in very lightweight fabrics of 100 grams around. The nonwoven interlinings used by clothing manufacturers originate from the paper industry and their development was brought about by shortages of traditional fabrics. A nonwoven substrate is a series or mixture of fibers, held together at bond sites, and its end-performance is determined by the following factors:

(i)Fibers: whether natural, synthetic, or a mixture of both

Owing to the cost of nature fibers, the great majority of nonwoven substrates are made from man-made fiber, as follows:

- Viscose - This fiber is made from a cellulose base and is sometimes referred to as regenerated-cellulose fiber.
- Nylon - It is a generic term and refers to a class of fiber that can be modified to meet particular requirements.

- Polyester Fiber - During the research that led to the discovery of the polyamides used for the manufacture of nylon, another related type of fiber-forming polymer emerged, which is known as polyester.
- Acrylic fiber - This fiber is far more amenable to ordinary dyeing processes than other synthetic of a similar type.

(ii)Web formation: how the fibers are orientated in the substrate

The basic methods of orientating the fibers that form the substrate or web include:

- Dry-laid web formation - The dry-laid web is the most generally used because it achieves a good balance between handle, strength and elasticity. Web-laid formations tend to be paper-like and beardy but have some applications where high strength is required. The spun bonded webs, although strong and elastic, are used mainly for sew-in interlinings.
- Wet-laid web formation - The wet-laid process is basically used in the manufacture of paper. The fibers are suspended in liquid and are fed onto a conveyor screen, thereby forming the web. Suction devices under the screen remove the liquid, which result in the fibers orientation in a three-dimensional formation.
- Air-laid method - An air-laid web is formed by blowing single fibers onto a screen so that the fibers are orientated in random positions. The resultant web has neither parallel nor transverse orientation.

(iii)Bonding: the process whereby the fibers are looked together

- Spun bonding - Spun bonded webs: A spun bonded web is formed by melting and extruding the polymer through a system of rotating spinnerets. The extruded filaments are drawn by air onto a conveyor to form the web.

(iv)Non-woven fibers:

There are some non-general interlinings includes:

- Water repellent interlinings - Water Repellent Interlinings are thermal bonded, the base fabric are usually non-woven and circular knits which can withstand the rigors of commercial wash processes. These are specifically designed for rainwear piece productions.
- Hair interlinings - Hair Interlinings are woven canvas made from horse hair mostly used in men's formal jackets and blazers etc (Dapkūnien, 2008). Basically there are two types of applications: fusible and non-fusible (sew-on). The former is attached to the backside of the shell fabric through thermal bonding or fusing while the latter is attached by stitching. Using strengthened interlinings can provide stability to the shell fabric, reduce creases, improve drape and firmness to the shell fabric (Fairhurst, 2008).

2.3.3 Interlining characteristics

There are three basic characteristics of interlinings that are material (fiber) content, weight, and fabrication. These factors contribute to the aesthetics and performance of interlinings.

2.3.3.1 Fiber content

Fiber content contributes to the strength, hand, weight, and resiliency of interlining. Fibers may be blended to incorporate the best properties of each. Woven and knits structure contribute strength, and resiliency without adding bulk and weight. Monofilament nylon fiber may be used for stiffness and resiliency, producing a lightweight material with little bulk. Identification of the fiber content of garment interlinings is not required by law, which makes it difficult for consumers to relate interlining performance to fiber content since the information is often unavailable.

2.3.3.2 Weight

Interlinings are available in a wide range of weight from 0.4 to 4.0 ounce per square yard. Heavier interlinings provide more support for heavier, more structured apparels such as coats and suits. Lighter-weight interlinings offer resiliency and some support, and they may provide a softer hand (Hwang, 1985). In recent years, fashion trend has been to softer materials and less structured look in men's and women's clothing, however, it may decrease the stability and resiliency of garments.

2.3.3.3 Fabrication

Interlinings are available in four basic fabrications: fiber webs, woven, knits, and foam laminates. Fiber webs are widely used fabrication for interlining due to low cost, versatility, and the ease of engineering specific characteristics into the interlining.

(i)Fiber webs may have less strength but not ravel in handling, which is a benefit during sewing operations. The performance of interlinings made of fiber webs is very closely linked to fiber content, fabric weight, and the fiber orientation in the web.

Fiber web interlinings are most often found in washable garments. Pilling is a problem often associated with fiber webs since fiber webs tend to have low abrasion resistance. Abrasion from the garment itself may cause pills to form and continue to enlarge with use. Pills tend to collect lint, and when used with light-colored fabric, they show through.

(ii)Woven interlinings may be produced from almost any type of fiber. This fabrication is usually the most expensive and subject to raveling and shrinkage. Woven interlinings usually cut on the same grain as the garment component for satisfactory performance. However, interlinings sometimes used as true bias for greater flexibility and as straight grain to stabilize a bias component. When like grains of the shell and interlining are not used together, stretching, distortion, and poor drape ability of garment pieces can result. Woven interlining used in collars and front shirt bands may be cut on the bias to provide good flexibility and shaping as the collar rolls and bends.

(iii)Knit fabrics used for interlining are primarily warp knit tricots, raschels, and weft insertion raschels. The tricots and raschels used for interlining purposes are produces in varied weights with high stability and little or no stretch. They are used for strength in relation to weight, low bulk, and smooth hand.

(iv)Foam substrates may be laminated to shell fabrics or linings to improve body and increase stiffness, durability and warmth. Foam, which also provides insulation, may be used as interlining on moderate-priced cloth coats.

2.3.3.4 Adhesive points

Interlinings are available in different adhesive points. By using the thermoplastic resin to bond, adhesive interlinings are the representative material to give clothing a suitable appearance and stability (Ohta, 1985). Therefore, quantifying the effect of adhesive point is desirable. Some researchers have investigated the efficiency of adhesive point, in particular, the prediction of mechanical properties for laminated fabric bonded with adhesive interlining is of great interest (Kim et al., 2012, Kim et al., 2013a). Adhesive method of fusible interlining affects the fabric physical property. Bubbles and strike through and back would be occurred when excessive adhesive or unreasonable adhesive conditions (Kim et al., 1998, Glock and Kunz, 2005).

2.3.4 Interlining function

Fusible interlinings in apparel manufacturing are used to support good formability, silhouette and shape retention, in another word, they are the ease of garment in order to stability of shell fabric (Kim et al., 1998). Interlinings are used for various purposes such as:

(i)Interlining is used in parts of clothing giving them thicker, firmer look, and extra strength that gives the garment a more formal and appealing looks.

(ii)Interlinings are soft, flexible, act as the insulators (Amar and Gamal, 2015), so it can be used in winter coats and pants, thus giving a thicker layer to the clothes.

(iii)Interlinings help to increase the garment sewing efficiency, being easier and faster (Phebe et al., 2014).

2.3.5 Cost of interlinings

When evaluating the cost of using interlinings in garments, the aesthetics, hanger appeal, quality, and consumer needs and expectations must be evaluated. Interlinings require special equipment and extra handling and processing. The increased costs of materials, inventory and production time, equipment, and quality control must be figured into the total cost of the garment. Fusible interlinings require special equipment, handling, and additional energy costs. The cost of maintaining consistent quality may also be a factor in total garment cost. Fusible interlinings are particularly susceptible to inconsistencies involving the materials, equipment, and fusing process. Extra quality control may be required to inspect the fused garment parts and test fusing equipment and performance of fused parts (Glock and Kunz, 2005).

2.4 Fusing technology

Fusible interlinings are materials applied to the base cloth, and when subjected to heat and pressure, they become the sole bonding resin between the top-cloth and the lining. Fusible interlinings are fabrications coated with some form of resin or adhesive that serves as a bonding resin to hold the interlining to the shell fabric. Substrates may be woven, knits, or fiber webs. Fusible interlinings must be fused to shell fabric prior to the construction of components. The fusing process usually requires that garment pieces be individually matched with interlining pieces and fused together. Fused garment parts have more body, do not ravel, and are easy to handle in sewing.

Fusing is the process of bonding fabric layers by application of heat and pressure for a specific amount of time. The time required for fusing is called dwell time. The precision of the fusing process depends on three elements: heat that softens the resins, pressure that spreads the resin and forces it onto the fabric surfaces, and time needed for application of heat and pressure. Cooling time is also necessary to allow the resin to set. Fusing may require more direct labor initially, but it may also reduce handing and irregularities as garment components are assembled. The development of fusing technique was a fairly rapid process and required the combination of three separate elements (Kim et al., 1998).

2.4.1 Textile

Textile of fusible interlining is the necessary production type of base cloths. Base cloths can be produced in a variety of woven, knitted, and nonwoven forms, each type having a specific application, according to the planned end-use. The classification of interlining will introduce in the next part.

2.4.2 Resin

Resin is a kind of thermoplastic adhesives for heat bonding. Thermal plasticity, which means the plasticity is changing with heat, is the basis of all fusible interlinings. The adhesive coating in its cold state is not adhesive but, when subjected to heat and pressure, melts and creates a bond between the substrate and top-cloth.

The word “resin” usually refers to a natural product formed by secretion in almost all trees and plants. Today, no naturally occurring resins are used for interlining, but an extensive and varied range of thermoplastic synthetic resins is employed. Resins are applied to substrates in three different densities; low, medium and high, where the degree of density refers to the actual mass per unit volume of the resin material itself. This physical density is related to the melting point of the resin and its resistance to dry-cleaning solvents. As a general rule, the higher the density, the greater is the resistance to dry-cleaning solvents, the main characteristics of the thermoplastic resins most widely used for fusible interlining are as follows (Kalbe et al., 2006):

(i)Polysulfones are a family of thermoplastic polymers. These polymers are known for their toughness and stability at high temperatures. These polymers are rigid, high-strength, and compaction resistance.

(ii)Polyamides: polyamide resins, which were developed in the mid-1970s, are generally thermo polymers made by reacting the basic ingredients of nylon 6, 6.6, and 11 or 12. By varying the constituents, a wide range of such properties as melting range and flexibility can be achieved. All polyamide resins produce full, dry-cleanable bonds, but the lower the recommended fusing temperature, the lower is the resistance to hot washings. With the exception of some special resins, two classes of polyamides are generally used for fusible interlinings: (a) Higher-melting range- dry-cleanable and washable up to 60˚C; (b) Lower-melting range- dry-cleanable only. These melting ranges reflect the different temperatures achieved in the normal washing and dry-cleaning processes of base fabrics (Kamat, 1988).

2.4.3 Engineering

Fusing machines were used to fuse the interlining to the shell fabrics. The fusing equipments including the hand iron or steam press; flat-bed fusing press and continuous fusing press. Interlinings fused on fabric panel, which can give reinforcement, durability and also stabilize or prevent stretching.

2.4.4 Interlining properties required

Interlining is one of the most important subsidiary materials to develop the material properties of finished garment. In order to achieve a satisfied quality of garment, the properties of interlinings are required and details of interlinings as following:

(i)It must take up the dye from the bath to a similar level as that of the outer fabric.

(ii)The adhesive bonding the outer fabric to the interlining base must remain intact during and after the dyeing operation.

(iii)The handle after the dye treatment should be that required by the customer.

(iv)There should be no adverse coloration caused by dye absorption in the fusible resin used in the fusible.

(v)The main components of any fusible are: Basic fabrics, basic-fabric finish and the fusible resin coating (Judd, 1989).

Each resin type has its own specific characteristics, and these have to be considered in relation to:

(i)Upper-limit fusing temperature: this must be below the temperature that would damage the top-cloth or cause changes in color. Theoretically, this temperature would vary according to the composition of the top-cloth. However, in practice, it is rare for this temperature to exceed 174˚C (345˚F).

(ii)Lower-limit fusing temperature: this temperature is limited because of the necessity to ensure the adequacy of the bonding required in order to withstand the handling to which fused components are subjected during production. For most cloths, this lower limit is about 110˚C (230˚F). Although leather and suede garments would require much lower temperatures.

(iii)Clean ability: The adhesive qualities of the resin have to withstand washing and /or dry-cleaning throughout the life of the garment.

(iv)Thermo-plasticity: This particular property of the resin must be such that the change of heat combined with the correct pressure is sufficient for the resin to penetrate the top-cloth and form an efficient bond.

(v)Color for the majority of end-uses, the resin must be white or transparent unless there are specific color requirements.

(vi)Handle: The resin must contribute to the desired handle of the final laminate between the top-cloth and interlining.

- Safety: For obvious reasons, the resin must be harmless in processing and end-use.
- The style of garment being produced
- The top-cloth and the handle required
- The fusing equipment available in the factory

The development and improvement of resins are an on-going process, with new products being continually added to the existing wide range of options. Thus the garment producer has a growing choice from which to “fine-tune” the fusible used for specific cloths and effects.

To sum up, all fusible interlinings require temperature, pressure, and time to ensure their correct application to the top-cloth. There must be a source of heat that will change the morphology of thermoplastic resins which from a dry, non-tacky solid, tacky, to viscous adhesive. This heat source must pass through the substrate layer to the resin itself and then on to the top cloth. With the application of pressure for a predetermined period of time, bonding will occur. On cooling, the bond is retained, and the resin reverts to its original solid state. Every fusible coating has an optimum fusing temperature at which it will give the best results. Too high temperatures or too long fusing time can also cause problems. In addition, if the resin becomes too fluid, then under pressure it will strike-back or strike-though the top-cloth or substrate or both.

2.4.5 Bonding

As a result of the web-forming process, the fiber is orientated but not locked together. Bonding is the process that locks the fibers together, the characteristics of bonding as following:

(i)Mechanical bonding - The most widely used method of mechanical bonding is the needle-pinching or felting technique. The substrates produced by this technique are referred to as needle-punched. The process consists in piercing the web with barded needles to lock the fibers together and thus form a strong fabric. Another mechanical-bonding process locks the fiber together by spraying the web with high-pressure water jets while it is moving on a perforated conveyor.

(ii)Chemical bonding - The chemical adhesives are widely used for fiber-bonding as follows:

- Nitrite rubber: This base gives a substrate with good draping qualities; however, the interlining tends to “yellow” with time.
- Acrylic: Although this produces a pure white substrate, the resultant interlining tends to be somewhat stiff.
- Styrene butadiene: Styrene-based products are generally used as binders for low-cost nonwoven fabrics, and the result fusible are mainly limited to wash-and-wear products.

It is important that the chemical-bonding resin not only preserves the formation of the fibers for the life of the garment but also imparts softness and drape to the fabric. The methods of chemical bonding are as follows:

- Impregnation: The web is saturated by being passed through the bath of the binder, squeezed between two rollers, and then dried at the temperature appropriate for bonding the fibers.
- Spraying: The web is transported on a conveyor and sprayed with the binder. Correct penetration is achieved by use of a powerful vacuum positioned under the conveyor.

- Foaming: The web is saturated with a foamed binder that allows the fiber to interlock in a consistent form. This gives the substrate superior elasticity and crease-recovery characteristics.
- Print bonding: An engraved roller applies the binder as the web passes under the saturated roller. The fibers are interlocked by the pattern of the roller; this method is used mainly for parallel-type webs.
- Thermal bonding: This is achieved by blending a low-melting-point adhesive powder with the web fibers. When the web is heated, the thermoplastic adhesive bonds the fiber structure together.
- Heat welding: This method utilized the thermoplastic properties of the fibers themselves. The fibers are Hetero-filaments of the core-sheath type to which the core has a high melting point and the sheath has a low melting point. When a web of these fibers is heated to the melting point of the sheath, bonding is affected at the site where the fibers are in contact. This kind of bonding gives a soft handle than that achieved by chemical binding resin s owing to the ratio between the Heterofil and monofil fibers. A typical monofil fiber construction that has been chemically bonded contains a larger proportion of binder material, which tends to “harden” the handle of the interlining.
- Ultrasonic: The web is transported under an ultrasonic transducer, and a pattern of ultrasonic beams melts the fibers and bonds the structure. This newly developed method creates fabric patterns similar to those obtained by weaving.

Nonwoven structures are finished in much the same way as woven fabrics. These processes include calendaring, dyeing and printing. Nonwoven substrates, because of their method of fabrication, are generally less expensive than woven or knitted fabrics.

The component of fusing irrespective of the fusing method and type of machinery employed, fusing is controlled by four processing components that is temperature, time, pressure and cooling (1972, Yoon et al., 2010), and they must be accurately combined in order to achieve an optimum result. Details of the fusible interlinings produce technology shown in follow sections.

2.4.6 Processing temperature

There is a limited range of temperatures that are effective for each fusible resin. With too low a temperature, there is an inadequate development of the adhesive properties. Too high a temperature causes the resin to become too fluid, which could produce a possible strike-back or strike –through of the resin (Lyall, 1987, Yoon et al., 2010).

In general, resin-melt temperatures can range from 130 to 160˚C, and their optimum performance will normally occur within ±7˚C of the specified temperature. This situation requires a heating source and system that they can ensure the maintenance of the selected resin-melt temperature of fusing cycles of varying times. Practically, this means that the heating source must have a very high capacity coupled with excellent conductivity in order to ensure an even distribution of the temperature over the entire heating area. All modern fusing machines are fitted with temperature-control thermostats, and, in practice, they should control the applied temperature within a maximum range of ± 5 ˚C. The thermostat should be precise and react immediately to any slight variations in the fusing-area temperature. We should notice that the reaction time of the slower model was not short enough to achieve an applied temperature within the allotted fusing-time cycle.

Most thermostats fitted to fusing machines show the indicated temperature of the heat source and not the actual applied temperature in the resin-heating zone, the difference between these two temperatures is due to:

(i)Covers over the heat source, such as conveyor belts, protective frames;

(ii)The pressure support system;

(iii)The residual moisture content of the fabric being fused;

(iv)The insulating properties of the cloth and fusible;

(v)Machine environment, i.e., air agitation, ambient temperature

It is therefore essential to measure the applied temperature, and this is usually done by using thermal papers or electro-mechanical calorimeters. The readings thus obtained are used, when necessary, to calibrate the indicated temperature settings.

For a particular purpose, thermostat dials must be easily seen and read and located where they can be easily operated. The control itself should be capable of being locked at a particular calibration so that any accidental movement of the setting is avoided. The calibration and control of the applied temperature are central to the quality of the fusing process.

2.4.7 Processing time

The processing time starts from assemblies are actually being heated, this time temperature relates to:

(i)The time when the two plates of the press actually meet with the correct specific pressure, or

(ii)The time for which the assemblies are actually in the heating zone of a continuous machine is employed.

The actual fusing time can be controlled by the use of electro-mechanical timing devices or programmed card units. Generally, a flatbed press has a mechanical timer that runs to the zero point and then signals an impulse, which activates the mechanism for opening the press (Hol et al., 2007). With continuous fusing, it is possible to relate conveyor speeds to the actual time in the heating zone. The accuracy of the timing controls can be verified by comparison with a stopwatch or by measuring the conveyor-belt speed with a tachometer (Yoon et al., 2010).

The particular time cycle to be used for any particular fusible is based on:

(i)Whether the interlining has a high-or low-melt resin system

(ii)If a light or heavy substrate is being used

(iii)The nature of the top-cloth, the amount of moisture present, and whether the cloth has been siliconized

(iv)Whether large or small areas have to be fused

(v)The type of fusing equipment, i.e. continuous, flatbed, steam-press, or hand-iron

2.4.8 Processing pressure

With the resins in current use, it is necessary to apply pressure to fuse in order to ensure:

(i)There is an intimate contact is affected between the top-cloth and fusible interlinings.

(ii)The heat transfer is adequate.

(iii)There is a controlled and even penetration of the resin into the fibers of the top-cloth.

Pressure is usually applied via platens, bucks, or nip rollers, depending on the type of machine being used. The energy used to create pressure can emanate from pneumatic. Hydraulic or manual sources and is transferred to the pressure surfaces by means of flinders or mechanical linkages or both. Suppliers of fusible interlinings will generally indicate the specific or applied pressure at which the optimum bond strength is obtained for a particular fusible. Too much or too little pressure can result in inadequate bond strength and other problems. The pressure component of fusing is no less important than the temperature component (Hol et al., 2007).

2.4.9 Process cooling

The effect of enforced cooling on fused assemblies is to achieve a consolidated bond, which enables the assembly to be handled immediately after cooling is completed. Enforced cooling can be carry out by water-cooled plates and forced-air circulation vacuum (Mills III, 1993).

2.4.10 Fusible interlining problems

(i)Strike back - Strike back is the penetration of resin to stick to the fusing press, conveyor, or shuttle tray. It can affect both cost and quality of fusing. It may be the result of too much resin for the type of interlining fabrication or too much pressure during the fusing process.

(ii)Strike through - Strike though is the penetration of resin though to the face of the shell fabric. It may be caused by too much pressure, too high a fusing temperature, or too long a fusing time. This is a greater problem with sheer, lightweight, nonabsorbent fabrics than with heavier, bulkier, more absorbent ones. Strike through is the cause of many other problems such as color change, differential shrinkage, bubbling, poor strength, and broadness. This is a common problem with microfiber fabrics because of the construction and weight.

(iii)Shrinkage - Shrinkage may cause performance problems if one garment part shrinks because of application of fusible interlining and adjoining pieces do not shrink. It is possible that high fusing temperature causes the fabric to shrink. This may make accurate seaming impossible, create puckered seams, or cause puckered surfaces of shell fabric. With proper testing the amount of potential shrinkage of the shell fabric and interlining can be determined and adjustment made in patterns.

(iv)Delamination - Delamination is the loss of bond between the interlining and shell fabric. Resin, because it migrates toward heat, becomes embedded in the interlining substrate instead of the shell fabric, which prevents an effective bond between the two materials. The shell fabric may appear to be bubbled. Delamination may be the result of under fusing, over fusing, not enough cooling time, or incompatibility of resin and the shell fabric.

(v)Color change - Color change may be a temporary or permanent discoloration caused by the high temperatures and resins used in the fusing process. Fusible interlinings with dying process may change color when the application of high temperature.

(vi) Bubbling - Bubbling occurs when the face fabric or interlining becomes puckered from delamination, poor bonding, differential shrinkage, uneven temperatures or pressure, and inconsistent use of resin.

(vii) Boardness - Boardness is another problem related to the inappropriate selection of adhesives used on fusible interlining. Resins liquefy and run together to form a resin coating instead of being retained in a sintered or dotted manner, a stiff hand is produced. This can be the result of over fusing, too much adhesive, and the application of excessive heat and/or pressure. This is a problem when the interlining distorts the shape of microfiber fabrics (Glock and Kunz, 2005, Kamat, 1984).

2.5 Printing technology

2.5.1 Introduction

Textile printing has often been described as a localized dyeing process to produce single or multi-colored patterns on fabrics. It utilized the same dyes or pigments of similar principles of application and color fastness properties as that of textile dyeing. In spite of the various methods and styles of printing, the typical textile printing procedures include the following steps (Adams, 1996):

(i)Preparation of ground color of the fabric;

(ii)Preparation of print paste;

(iii)Printing;

(iv)Drying;

(v)Fixation;

(vi)Washing-off

The method of printing can mainly be classified as roller printing, rotary screen printing and flatbed screen printing. Among each method of production, various techniques or types of prints can be applied. The common examples are direct print, resist print, discharge print and burn-out print (Handbook, 2000).

2.5.2 Methods of printing

Roller printing, flat screen printing and rotary screen printing, are widely used in commercial production. However, transfer printing and digital printing are entering the market. Each of them has their own characteristics and Table 2.2 shows the comparison of all printing methods. Details of each method will be discussed in the following paragraphs.

Table 2. 2 Comparison of printing methods

Printing Methods	Advantages	Disadvantages
Roller	- best for long production runs	- limited size of repeat, normally 16 inches

	- best for fine lines and small patterns e.g. paisley - half-tone and fall-on effects possible	maximum - not economical for short yardage due to long machine set up time and high engraving costs - limited number of colors according to machine type - dull colour due to very high pressure exerted during printing - wet-on-dry printing impossible (not suitable to knitted fabric) - requires skilled workers
Hand screen (flat)	- Best method for low yardage, small items (e.g. towel) and garment parts (front panel) - large repeat size possible - Wet-on-dry effect possible - No limitation on number of colors - Good colour brightness with good definition - Rapid preparation of screen and thus rapid style change possible - Can be applied on all fabric types	- Half- tone effect impossible - Not recommended for lengthwise stripes, fine lines and small patterns - Very low productivity
Fully automatic flat screen	- Better productivity than hand screen method - Large repeat size possible - Good color brightness with good definition - Rapid preparation of screen and thus rapid style change possible - Can be applied on all fabric types	- Larger machine investment than hand screen - Half-tone effect impossible not recommended for lengthwise stripes fine lines and small patterns - Wet-on-dry printing impossible - Higher cost in screen preparation that flat screen

		method and thus
Rotary screen	- The highest production capacity among all printing methods - Larger repeat size possible compared with roller printing, but smaller than flat screen printing methods - Good colour brightness with good definition - Rapid changeover of designs possible - Can be applied on all fabric types	- Higher cost in screen than flat screen method and thus not economical for short yardage - Not recommended for fine lines and small patterns - Half-tone effect not as good as roller printing - Wet-on-dry printing impossible
Transfer printing	- Not further after treatment required - Simple process - Print defects are low because print paper can be inspected prior to printing - No environmentally pollution - Excellent sharpness and clarity of design	- Special transfer paper and dyestuff to be used - Special dye fixation treatment required for natural fibres - Safety margin for ordering transfer paper to avoid short shipment - Minimum order for transfer paper, otherwise additional charge required
Digital printing	- Print pattern can be produced directly from design - Design requirement can be transfer electronically - Order-to-delivery lead time much shorten - High resolution approaching photographic quality	- High capital investment In CAD system and ink jet printer - Production rate is lower than other methods - Use special dyes for the ink

2.5.2.1 Roller printing

Roller printing is a continuous automatic production in which the process is carried out with the aid of engraved copper rollers. A separate engraving roller is used for each color. The photographic engraving method, together with the chemical (mainly strong acids) etching technique, is the widely used approach. The size of the print repeat is governed by the printing machine and the size of the roller. The numbers of colors within a print repeat are limited by the numbers of rollers that the machine can accommodate.

2.5.2.2 Rotary screen printing

This printing method, which utilized seamless cylindrical screens made of nickel foil, combines the advantages of the high production roller printing and flexible flat screen printing. It has proved very successful, especially in terms of large production at relative lower cost than roller printing.

The basic operation of rotary screen printing is very similar to that of the fully automatic flat screen machine. The fabric is gummed onto an endless conveyor belt blanket which moves continuously in contrast to the intermittent action of the automatic flat screen machine. The rotary screen, which are equipped with special types of print paste feeding device and squeegee inside the screen, are continuously rotating at a relatively high speed to force the print paste through the screens to the fabric. The printed fabric successively undergoes drying, fixation and washing-off.

2.5.2.3 Transfer printing

By a simple heat process, a design printed on a piece of paper is transferred to the fabric. The dyes used are capable of vaporizing under the heat conditions of the process and therefore have a high affinity for the fibers of the fabric. Thansfer printing has long been used on polyester and ployamide. Starting from the late 80’s, attempts have been made in developing a method for indirect reactive printing on natural fibers.

2.5.2.4 Digital printing

This is process of creating prints generated and designed on a computer and then printing the design on textile substrates using ink jet technology. The use of digital technology means that a digital file can be communicated worldwide, and fabrics of identical color patterns, and quality produced anywhere in the world.

2.5.2.5 Flat screen printing

Flat screen printing is so called because the process makes use of meshed screen for transferring the print paste to the fabric. Printing squeegees simultaneously operated among all screens while the fabric is stationary. After one operation step, the screen is lifted up and the blanket moves to carry the fabric to a next stop for printing (Babu et al., 1995, Calamari and Harper, 2000). A number of screens can be used to produce a multi colored image.

(i)Screen printing types

- In fully automatic production, the fabric to be printed is gummed onto an endless conveyor belt type blanket which moves and stops at intermittent fashion, one screen repeat distance at a time.
- In semi-automated production, some manual works, such as raising and lowering of the screen, filling of print paste and activating of the squeegee, are replaced by automatic means. It requires less labor than hand screen printing, but the productivity is still not high when compared with fully automatic production.

- In hand screen printing, which was originally done by hand. All operations, such as precise positioning of the screen frame, operating the squeegee and handling of the fabric, etc. are manipulated by workers. Although the method is of less commercial interest in the sense of long production runs, it is used for small sized production of garment parts or very large design which cannot be achieve by other means.

(ii)Aspects affecting screen printing quality

The screen printing process is simple in concept. Yet looking at the basic elements of the process in greater depth there are a total of 53 variables that control those basic elements. The variables are classified into eight categories: the film image; stencil; screen fabric; squeegee/flood bar; ink; substrate; press/dryer; and environmental factors (Hoff, 1997). The detail shows in Table 2.3.

Table 2. 3 Fifty-three screen printing variables

Fifty-three screen printing variables	
Film - Image density - Film base density - Image resolution	**Environmental factors** - Airborne contamination - Ambient temperature - Ambient humidity
Screen - Mesh fiber composition - Thread structure - Mesh count - Thread diameter - Mesh opening - Weave structure - Mesh color - Screen tension - Frame stability	**Stencil** - Mesh preparation - Stencil thickness - Stencil characteristics - Stencil durability - Moisture content - Exposure intensity - Exposure distance - Exposure duration - Stencil processing
Squeegee/Flood bar	**Press/Dryer**

- Blade hardness - Blade shape - Blade angle - Stroke speed - Squeegee pressure - Flood bar edge shape - Flood bar angle - Flood bar stroke speed - Flood bar pressure	- Off-contact distance - Peel-off adjustment - Press bed evenness - Press bed to screen parallelism - Color sequence - Curing temperature - U.V. lamp intensity - Curing duration
Ink - Particle size/distribution - Pigment dispersal - Viscosity - Tack - Flow characteristics - Adhesive properties - Dry/cure rate	**Substrate** - Surface texture - Surface porosity - Color - Thickness consistency - Static effect

(iii)Screen printing for experiment

Comparing to all these printing methods, flat hand screen method is the best choice to do the experimental test. Screen printing can be applied on woollen fabrics. The required sample size and quantity are variable, especially for small size which is suitable for experiment. In addition, screen printing method is easy to control experiment technique condition as all the operations are straightforward.

2.5.3 Screen printing process

Screen-printing is a versatile applicable printing process. Generally speaking, it consists of a structured stencil mounted in a frame for stabilization. The frame lies on top of the printing medium or fabric and the ink is pressed through the stencil by a scraper onto the fiber (Locher and Tröster, 2007). The screen printing process is based in six basic components: stencil, screen fabric, screen frame, squeegee, ink, and substrate. Each plays a distinctive role in the process. Other secondary factors, such as the press, also play a role in the process (Hoff, 1997).

2.5.3.1 Screen printing technique

Screen printing was originally done by hand. All operations, such as precise positioning of the screen frame, operating the squeegee and handling of the fabric, etc., are manipulated by workers. It is used for small sized production of garment parts or very large design which cannot be achieved by other means.

Screen printing is a printing technique. A mesh, stencil form, ink or other printable materials, and squeegee are mayor materials for printable interlinings. A mesh is to support an ink-blocking stencil which is used to transfer ink. A fill blade or squeegee is moved across the screen stencil, forcing or pumping ink into the mesh openings for transfer by capillary action during the squeegee stroke (Li-dong and Lugscheider, 2002). During printing, the fabric to be printed is spread smoothly onto a table whose surface has been coated with a light semi-permanent adhesive, such that fabric is guaranteed not to move during printing. The mounted screen is positioned accurately and the print paste is then poured onto the screen. The print paste is forced through the open areas of the screen with a flexible, synthetic rubber blade (known as the squeegee). The squeegee is drawn steadily across the screen at a constant angle and pressure to ensure a sharp and uniform printing quality. The steps are repeated when multi-color is required in the design. The printed fabric is then taken away from the table for successively drying, fixation and washing-off (Handbook, 2000).

2.5.3.2 Screen printing apparatus

(i)The usage of hand screen printing, the screens are wooden frames over which is stretched a fine polyester mesh. Synthetic screen meshes are classified in two ways, one is screen mesh count, the other is mesh grading. The number is printed at intervals along the selvedge of the screen fabric denotes the number of single threads in the weave per linear centimeter. In addition, the number denoting mesh count is followed by the letters "T" which signify the thickness of the fibers using to weave the mesh, here T refers medium light quality. In this study, there were three kinds of mesh were used in this experiment which are 100T, 160T and 200T.

(ii)Images on transparent acetate sheets were transferred on the screen through a photographic process. Current experiment used square with 20×20 cm.

(iii)Screens were placed on the fabric, held in position by metal rails. resin s were poured in at one side and pressed through the mesh of the screen using a stiff rubber blade (squeegee). As the experiment did not use the pigment, all the printing lamination process would repeat using the required resin by different screens.

2.5.4 Textile screen print ink/resin

Screen printing inks are formulated using resins whether traditional solvent-based, water-based or UV curing. A resin is a solid or semi-solid material that can be dissolved into a liquid, and suspended in a vehicle to make an ink, which when dry becomes the solid part of the dry ink film. The types of resins used are acrylic, alkyd, epoxy, polyester, urethane and vinyl. The vehicle and binder are formulated by dissolving resin in a dry powdered state with a solvent. These resins are selected based on the substrate and ink characteristics desired. Resins are formulated into a liquid state with proper viscosity and flow characteristics suitable for the screen printing process. These formulations vary considerably for each ink type to change from its liquid state into a dry ink film. There are a number of different resins and solvents that determine the ink characteristics. By selecting the proper resin and solvent, the properties of the ink can be modified, to produce properties such as gloss, hardness, adhesion, flexibility, flow and viscosity.

Inks contain solvents and thinners to give the desired characteristics of flow, viscosity and ink density. Water-based inks are widely used which are made up of a large proportion of water but also proportion of water but also have a small amount of volatile solvents to assist in achieving the desired characteristics.

2.5.5 Textile screen print bases

There are several different types of base that may be added to modify inks. Bases do not have any colorant. Since they are in the gelled state and not a liquid state, they do not decrease viscosity of ink as a thinner or solvent. Different types of bases are extender base, transparent base, halftone base and a clear base. These types of bases are not available in all kinds of ink. In some cases there is only one base that is used for more than one purpose.

2.5.5.1 Extender base

Extender base is a paste-like compound, whitish yellow in color. It is used to increase ink volume without affecting viscosity. Extender base is less expensive than ink and can be added to ink that is heavily pigmented to make a lower cost ink. This should be done when printing on white or light colored substrates since extender will have some effect on ink opacity and color intensity based on the amount added, yet less than a transparent base. In addition to lowering ink cost, it also improves the printability of the ink, extender base is also useful in color matching.

2.5.5.2 Transparent base

A transparent base is used to make the ink more transparent and to significantly reduce the color intensity of the ink. It makes the ink softer or less intense in appearance. Attempting to add excessive amounts of thinner or solvent to an ink will affect it to the point where it becomes difficult to print due to the change in viscosity. A significant amount of transparent base may be added without affecting its printability. A transparent base is also useful in color matching of inks.

2.5.5.3 Halftone base

Halftone base is clear in color although over time it may darken and lead to problems with color matching. The inks are more intense in color than desired and must be reduced by adding halftone base. A second purpose of halftone base is to increase its viscosity or thixotropic nature. Addition of the proper amount of halftone base will prevent this from occurring.

2.5.5.4 Clear base

Clear base has several uses. It may be used mixing varnish for metallic inks. For the best results, mixing should be done by adding a small amount of the base to the metallic powder to form a heavy paste. It should be completely mixed until it is smooth and free of lumps. It is important that the clear base selected is compatible with the substrate to be printed. Adhesion will be affected if too much metallic powder is added to the base. Another important usage for clear base is as a varnish. By overprinting a varnish it improves durability, rub resistance and maximizes the print for exterior use. It can also be made to an area appear glossy in appearance by applying the clear base in desired areas.

According to the literature review step of the study, some drawbacks and gaps of the traditional fusible interlining technology can be found. However, some advantages of printing technology can be found and it might be possible to solve the existent problems of fusible interlining.

The available formulation would be explored in the experiment. As resins are monomers, they tend to cross-link to the cellulosic when subject to a high temperature treatment, called curing, at 160°C to 210°C. However, woollen fabric could not suffer such high temperature and the resin would be selected self-crosslink type. In addition, in order to achieve the target stiffness handle and the fabric strength, base would be pay much attention. Due to the above characteristics of screen print bases, it could be main component of printable interlining. Last but not the least, the resin selection would avoid release of free formaldehyde during the resin finish (Orikasa et al., 2000).

2.6 Fabric mechanical properties

2.6.1 Mechanical properties of fusible interlining

The mechanical and physical properties of fused composites were first investigated by Morris and Chamberlain (1971), who examined the effects of outer and fusing interlining fabrics and fusing conditions on crease retention, abrasion resistance, drape, air permeability, and extensibility of fused composites. The relationship between the mechanical properties (extension stiffness, residual extension, bending stiffness, shear ability, shear stiffness, wrinkle and crease recovery) of the fused composites and those of the outer and fusible interlining fabrics were previously studied by Shishoo (Shishoo et al., 1971). They concluded that certain mechanical properties of fused composites could be predicted from the corresponding properties of the constituent components. Shiloh (Shiloh, 1972) showed the effect of fusing on the wrinkling and bending performance of the fused composites by comparing the performance of fused composites and outer fabrics. Later, Kanayama and Niwa (Kanayama and Niwa, 1982, Kanayama and Niwa, 1983) also studied the bending and shear rigidities of fused composites both theoretically and experimentally, and as a result, they proposed empirical equations to predict the bending and shear rigidities of the fused composites from the properties of outer and fusible interlining fabrics (Fan et al., 1997b).

Later, Nagano proposed an acceptable range of mechanical properties of fused composites for the front parts and facings of tailored jackets based on KES-F measurements (Nagano, 1986). Nitta studied the optimum combination of face and interlining fabrics, suggesting optimum ranges for mechanical properties of fusible interlinings based on past experience (Nitta, 1983). KES-F has been an important test method for fabric low-stress mechanical properties and hand value evaluation, which is widely used in research area.

2.6.2 KES-F evaluation

The low-stress mechanical properties of fabrics are objectively measured to assess the tactile characteristics of fabrics. Kawabata Evaluation Systems for fabrics (KES-F) is a kind of fabric objective measurement technology that has been gradually developing since the 1930s. Radhakrishnaiah (Radhakrishnaiah et al., 1993) first identified the fabric physical and mechanical properties related to hand. In the early 1960s, Lindberg (Lindberg et al., 1961) and his team in Sweden conducted many surveys of fabric tailor ability or performance and how that is affected by fabric low-stress mechanical properties. Lindberg defined an important parameter called “formability,” which is the product of bending rigidity and longitudinal compressibility. In 1970, Kawabata in Japan developed the KES-F system to make it more accurate. Kawabata and his research team developed transformation equations to objectively evaluate the hand of woven fabrics based KES-F low-stress mechanical properties measurements (Kawabata and Gakki, 1980). Since the KES-F system was not easily affordable or completed for control testing options in the industry, many attempts (Kim and Slaten, 1999, Pan et al., 1988) were made to develop cost-effective and smarter instruments for broad applications (De Boos and Roczniok, 1996).

KES-F is fabric objective measurement systems which have been adopted for the prediction of fabric performance in apparel manufacturing. KES-F concludes four tester measuring which are tensile, shear, bending, compression, and surface properties. Objective specification of fabric handle has been evaluated from the correlation of low-stress mechanical properties and related equations (Hui et al., 2007, Bisset and Morris, 1996).

The low-stress mechanical properties including tensile, bending, shearing, surface friction and compression were evaluated by the KES-F. The fabrics were conditioned at 21±1°C and 65±2% Relative Humidity for 24 hours prior to any testing. The KES-F manufactured by the Kato Tech Co., Ltd comprises four specialized instruments, including KES-F1 for measurement of tensile and shearing characteristics, KES-F2 for measurement of bending characteristics, KES-F3 for measurement of compressional characteristics as well as KES-F4 for measurement of surface friction and roughness. Total 16 low-stress mechanical properties can be tested which is shown in Table 2.4 (Lam, 2012). Figure 2.2 shows the interrelationships between fabric characteristics and pairs of polar adjectives of tactile sensations.

Table 2. 4 Low-stress mechanical properties in KES-F system

Properties	Symbol	Definition	Characteristics	Unit
Tensile energy /tensile work	WT	Energy used for extending fabric to 500gf/cm width.	WT refers to the ability of a fabric to withstand external stress during extension. Fabric with good tensile strength and toughness will have a large value of WT.	gf.cm/ cm^2
Tensile resilience	RT	Percentage energy recovery from tensile deformation.	The reduced fabric RT value implies that the fabric becomes difficult to restore to its original shape after releasing the applied	%

			tensile stress.	
Tensile extensibility	EMT	Percentage extension at the maximum applied a load of 500gf/cm specimen width.	EMT has a good correlation with fabric handle. The greater the value of EMT, the larger the elongation of the fabric under a known applied stress will be.	%
Tensile linearity	LT	Linearity of load extension curve	LT is a measure of the deviation of the load extension curve straight line.	-
Shear stiffness / shear rigidity	G	The average slope of the linear regions of the shear hysteresis curve to ±2.5° shear angle.	G refers to the ability of a fabric to resist shear stress which is the ease with which the fibers slide against each other. Lower values indicate less resistance to shearing corresponding to a softer material having better drape.	gf/cm degree
Shear stress at 0.5°	2HG	The average width of the shear hysteresis loop at the ±0.5° shear angle.	2HG is the ability of a fabric to recover after applying the shear stress value of 0.5°shear angle. The greater the value of shear stress, the worse the recovery ability of the fabric and stiffer the fabric will be.	gf/cm
Shear stress at 5°	2HG5	The average width of the shear hysteresis loop at the ±5° shear angle.	2HG5 is the ability of a fabric to recover after applying shear stress value of 5° shear angle. The greater the value of shear stress, the worse the recovery ability and stiffness of the fabric will be.	gf/cm
Bending rigidity	B	Average slope	B is the ability of a fabric	$gf.cm^2/$

		of the linear regions of the Bending hysteresis curve to 1.5cm-1.	to resist the bending moment, which is related to the quality of stiffness when a fabric is handled. Higher B value indicates greater resistance to be bent.	cm
Bending moment	2HB	The average width of the bending hysteresis loop at 0.5cm-1 curvature.	2HB refers to the recovery ability of a fabric after being bent. It is measured as a specimen is bent through a range of curvatures from 2.5cm-1 to -2.5cm-1. The smaller the value of 2HB, the better the bending recovery of the fabric will be.	gf.cm/ cm
Compressional linearity	LC	The linearity of a compression-thickness curve.	LC determines the compressibility along with the change in fabric thickness after treatment. The high value of LC indicates a fluffy fabric with high compressibility.	-
Compressional energy	WC	Energy used for compressing fabric under 50gf/cm^2.	The WC value represents a fluffy feeling of the fabric. The higher the value of WC, the higher the compressibility of the fabric will be.	gf.cm/ cm^2
Compressional resilience	RC	Percentage energy recovery from lateral compression deformation.	RC indicates the recoverability of the fabric after the compression force is removed. A higher value indicates better recovery ability from compression.	%
Fabric thickness at 0.5gf/cm^2 pressure	To	Fabric thickness at 0.5gf/cm^2 pressure.	TO measures the surface thickness at a pressure of 0.5gf/cm^2.	mm

Fabric thickness at 50gf/cm^2 pressure	T_M	Fabric thickness at 50gf/cm^2 pressure.	TO measures the intrinsic thickness at a pressure of 50gf/cm^2.	mm
Coefficient of friction	MIU	The coefficient of friction between the fabric surface and a standard contactor.	MIU represents the fabric smoothness, roughness, and crispness. The value demonstrates the ratio of the force required to slide the surfaces to the force perpendicular to the surfaces. The higher the value of MIU, the greater the friction of the fabric will be.	-
Geometrical roughness	SMD	Variation in surface geometry of the fabric.	SMD refers to the fabric surface evenness. The lower the SMD value, the more even the fabric surface will be.	micron
Mean deviation of MIU	MMD	Mean deviation of coefficient of friction	MMD is the frictional measurement.	-

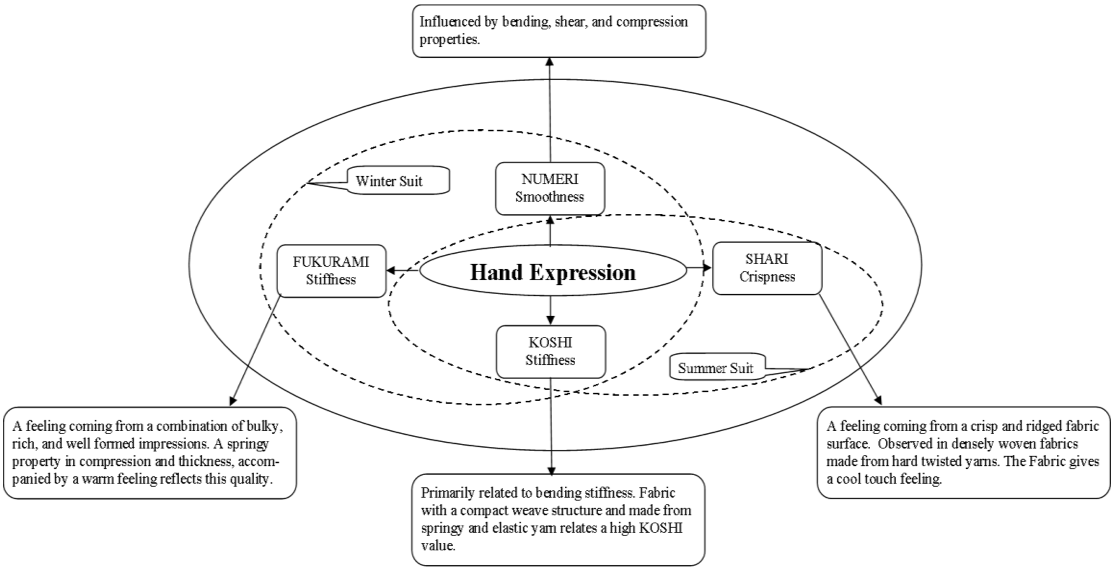


Figure 2. 2 Primary hand expressions and related fabric properties

(Kawabata, 1980)

2.6.2.1 Tensile and shearing tester

The mechanical properties of fabric under tensile and shearing stress are very important characteristics. The uniaxial tensile test is popular by its simplicity for measurement, however, biaxial extension property is sometimes more useful on practical view points for cloth. The tensile properties of specimens were evaluated by the Tensile and Shearing Tester, KES-F1. In this instrument, a sample having wide width was clamped with the small span between two clamps was stretched. This deformation is a kind of biaxial tensile deformation. For shearing testing, the sample was given a constant tensile force and then applied a shear deformation. The sample of which width in 20 cm was clamped by two chunks having a special groove by a very simple operation. The sample was not slipped until the large tensile stress of which maximum capacity is 50 kgf by the clamping system. In usual operation, shear deformation properties of the sample were measured at first and then the tensile properties without replacement of the sample. The obtained data under the standard conditions of testing could be used for objective evaluation of fabric handle.

In this testing, the fabric having the dimension shown in Figure 2.3 is stretched unidirectional up to the upper limit load, F_m then recovered. The rectangular shape was 5 cm long and 20 cm in width. The tensile property included the tensile energy, tensile resilience, and tensile extensibility. Textile resilience and textile strain which was related to the ability to maintain fabric shape and the extensibility or stretch ability of the fabrics as well as the tensile energy. The samples were mounted on the machine which automatically measured the tensile property. The system of the tensile test in this instrument was that the tensile strain of the sample is given by the backward movement of the back chuck B in Figure 2.4 the front chuck A was fixed on a drum having a 4cm diameter and connected with a torque meter using a strain gauge installing on the axis of the drum. The tensile strain was detected by the potentiometer which detects the movement of the back chunk. The output voltage of this potentiometer is proportional to the strain. Two of tensile rates can be selected using change gears. When the output voltage of tensile force arrives at a preset value, the motor turns automatically to the recovery process. The one cycle or repeating measurement can be done. The rate of the extension and the recovering is constant (two selections). The strain along width direction was restricted because of this long width shape of the specimen, therefore, the deformation was one of the biaxial extension called “strip biaxial”. The force-strain curve shown in Figure 2.5 was usually obtained for both warp and weft directions. The upper-limit load can be chosen by a preset potentiometer but is set at 500 gf/cm for the standard test.

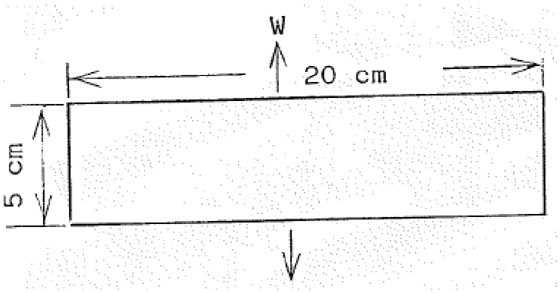


Figure 2. 3 Sample
(Kawabata, 1980)

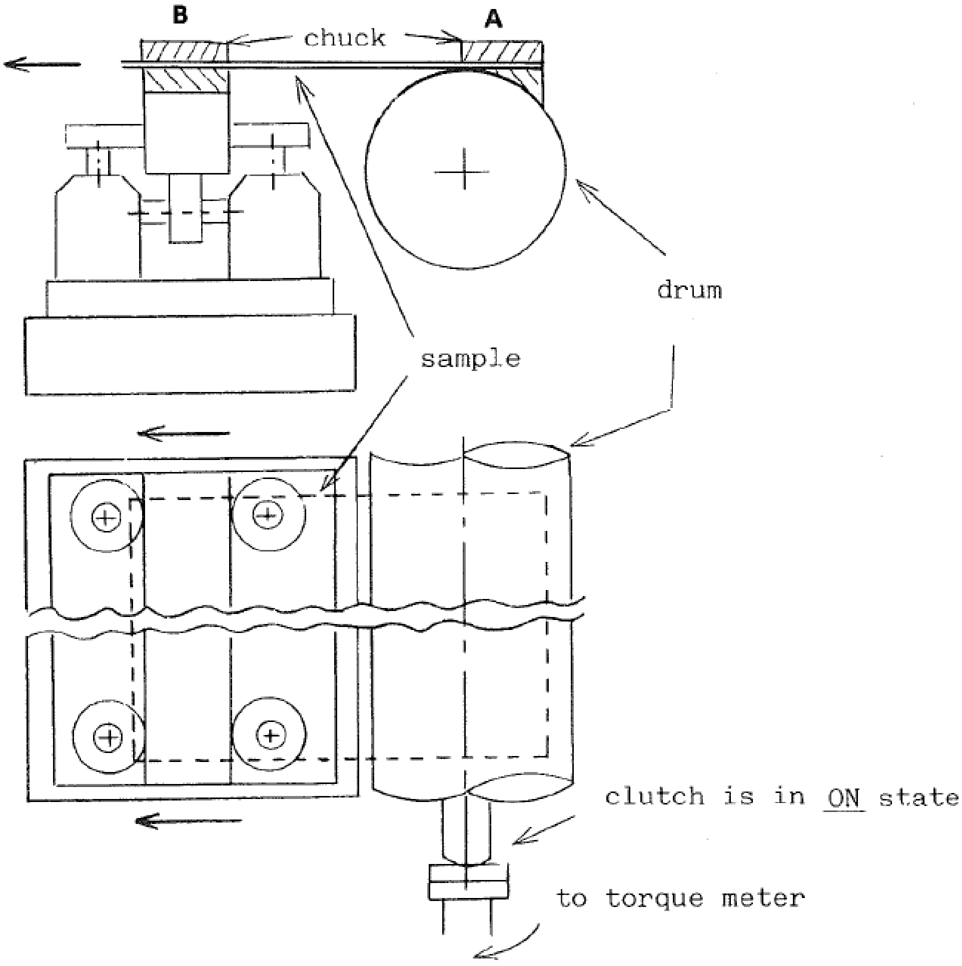


Figure 2. 4 Principle of the tensile property testing
(Kawabata, 1980)

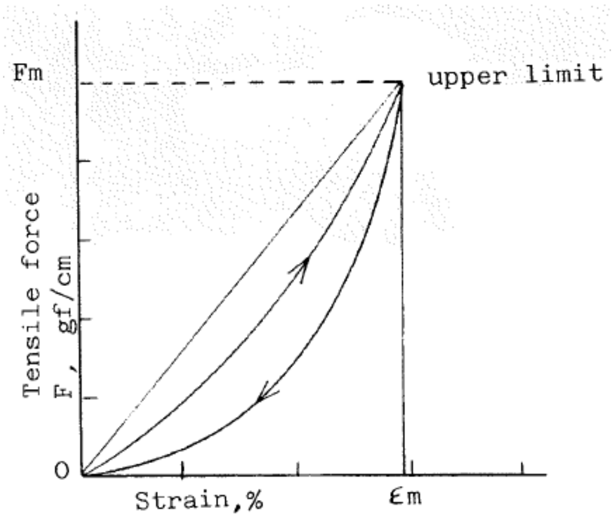


Figure 2. 5 A typical force-extension curve of woven fabric

(Kawabata, 1980)

Shearing property is composed of shearing stiffness, a hysteresis of shear force at 0.5° of shear angle and hysteresis of shear force at 5° of shear angle. Shear stiffness is related to the softness handle of the fabric. The samples were mounted on the machine which automatically measured the shearing property in both warp and weft direction. Both tensile and shearing properties were recorded with the average result of six measurements taken along the warp and weft directions. The shearing measurement a constant tensile is applied to the fabric by a weight mounted on the drum which rotates freely by removing clutch as shown in Figure 2.6. The shear force is detected by a transducer connected to the back chunk along the shear direction. The sample is given a constant tensile force by an attached weight on the drum and then the back chuck moves perpendicular to the direction of the tensile stress by a synchronous motor at a constant rate. The shear strain is detected by a potentiometer mounted near the synchronous motor. When the back chuck slides to the position at 8° (Standard condition) of shear-angle, then motor turns back. The turn back shear-angle can be selected by a preset potentiometer. The upper limit of shear strain can be changed in the range of 0° to 8°. The output voltage of tensile force is processed by an integrator. As mentioned before, the tensile and shear testing can be done without replacement of sample. The tensile deformation is more severe deformation than the shear deformation, therefore it is recommended that the shear test should be done first and then the tensile test. As shown in Figure 2.7, the testing is the type "shear deformation under a constant extension load”. A typical result obtained in this testing is shown in Figure 2.8. For the objective evaluation of hand, following characteristics are used.

G; slope measured between θ=0.5 and 2.5 degree (gf/(cm.degree))

2HG; Hysteresis of F_s at θ=0.5 degree (gf/cm)

2HG5; Hysteresis of F_s at θ=5 degree (gf/cm)

Usually, the mean value obtained at the positive and the negative shear angle regions for each of these characteristic values are used.

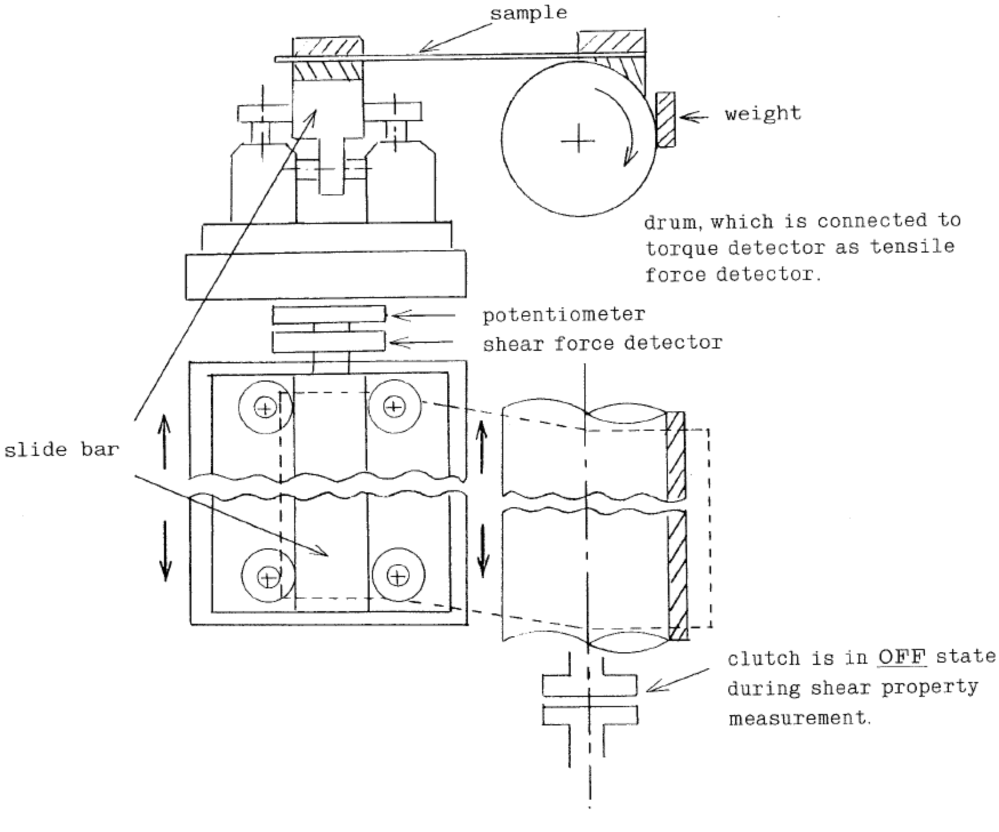


Figure 2. 6 Principle of the tensile and shear tester (shear tester) (Kawabata, 1980)

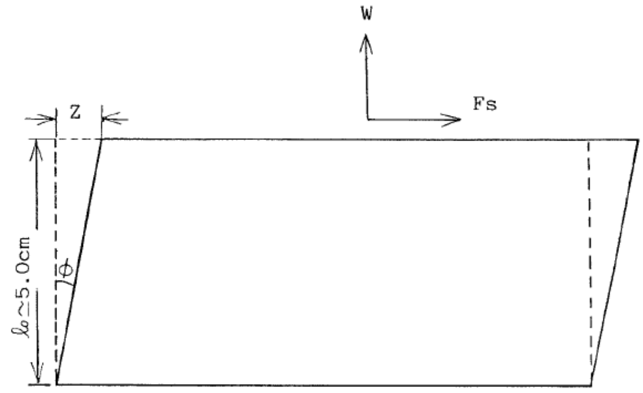


Figure 2. 7 Shear deformation under a constant extension load W (Kawabata, 1980)

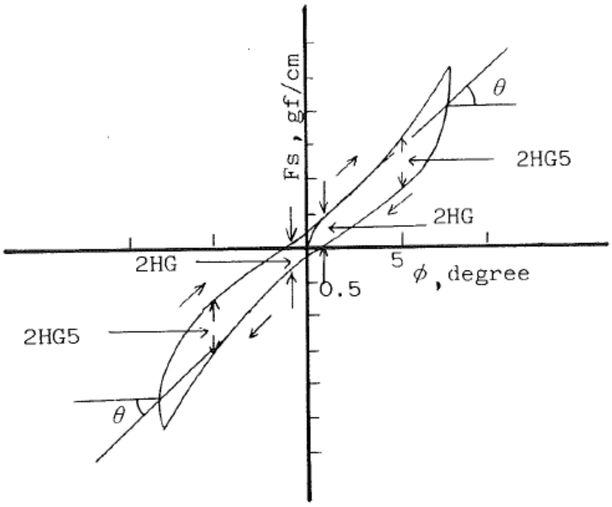


Figure 2. 8 typical shear force-shear angle curve of woven fabric (Kawabata, 1980)

2.6.2.2 Bending tester

KES-F2 bending tester measures the bending properties of a woollen specimen. The bending properties include bending rigidity and hysteresis of bending moment which indicates the softness of a fabric and the resilience to bending or wrinkle resistance respectively. Effective dimension of a specimen is 2.5cm long and 1cm in width. The longitudinal length of the specimen can be chosen at an appropriate size between 2cm and 20cm. These samples were mounted on the machine subsequently to measure the bending properties of the woollen specimens in both the warp and weft directions. The reading was recorded with the average result of six measurements. The bending characteristics are the general key elements to measure not only the fabric texture but also bending rigidity in a woollen fabric. Although these characteristics have been measured only by the cantilever method, this tester now can realize the ideal measurement of longitudinal bending. The tester allows the whole specimen to be exactly bent in an arc at a certain curvature which can vary at the constant speed, thereby detecting a very small bending moment subsequently generated and thus realizing an exact and swift measurement of the relationship between bending moment and curvature. This tester sets the bending moment at 20 gf·cm but can change it to 50 gf·cm at a full scale. Bending moment relative to curvature can be easily measured and automatically stored by an X-Y recorder only by holding a specimen of the woollen fabric with two clamps and then switching on. The reproducibility of data is extremely excellent, and one measurement is completed within one minute and additionally with high precision and ease. Data downloading is stored by using an X-Y recorder and personal computers. This tester can also be used for the production management in production facilities, e.g. in the fields of research on the property of film or fabric, or control of texture in the fabric, other than the measurement of bending rigidity which has previously been determined by touching from the experience. As shown in Figure 2.9, bending property is measured by fixing one end of the specimen and moving the other end of the dotted line. Movable chuck in Figure 2.9 travels along the specified track, shaking its head at the specified angle. At any moment uniform curvature is maintained in the measuring mechanism by precisely seeking the relationship between bending moment M and curvature K.

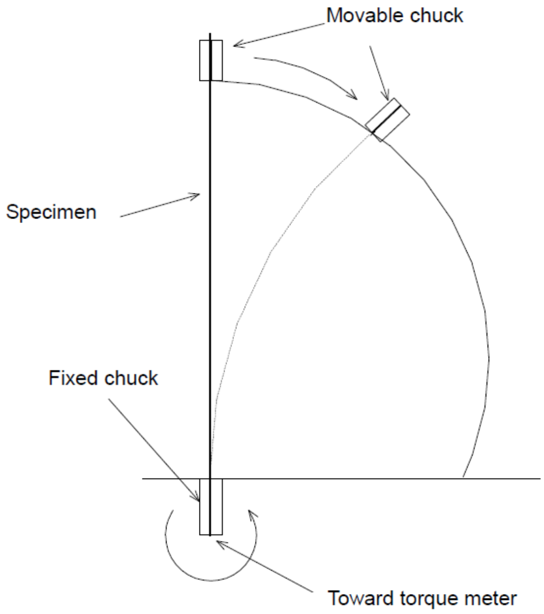


Figure 2. 9 Genuine bending deformation (Kawabata, 1980)

2.6.2.3 Compression tester

KES-F3 compression tester measures the bending properties of a woollen specimen. In the compression tester, the compression properties such as compressional linearity, compressional energy, and compressional resilience were measured. After the sample was mounted on the machine and the procedure started when the sensor was scanning a certain part of the fabric surface at a constant speed. Three district points were measured automatically by the machine. All measurements were repeated at three distinct points on the fabrics and then averaged with the analytical tolerance limited to 5%. This instrument can be used for wide variety of samples (Maximum stroke is 20 mm). Effective dimension of specimen compressed area is 2cm^2 of a circle. A specimen of 2.5cm long and 2.0cm in width is used and the longitudinal direction is taken along either warp or weft direction. Also velocity is changeable from 0.001cm/sec to 1cm/sec according to objects. This instrument consists of two parts connected with cables. One is a measurement unit and the other is an amplifier that has circuits such as force detecting, data processing, motor control and displacement detection.

2.6.2.4 Surface tester

KES-F4 bending tester measures the bending properties of woollen specimen. The data obtained from this machine have a good correlation with human fingers. Feeling or handle of materials when you touch it is evaluated objectively by the mean frictional coefficient (MIU), its mean deviation (MMD), and mean deviation of thickness (that is, roughness=SMD) by the machine. The data was plotted on an X-Y recorder and/or taken into the computer and are shown by Figure 2.10. Samples were measured in both weft and warp directions respectively. After the samples were mounted on the machine, the procedure started when the sensor was scanning a certain part of the fabric surface at a constant speed. The surface of 2cm long and 0.5cm in width must be measured effectively. The contactor for measurement of surface roughness is made by a steel piano wire of which diameter is 0.5mm. The wire used under the contact force of 10g (allowance, ±0.5 g) given by a spring of which spring constant is 25±1 gf/mm. The natural frequency of the system should be more than 30 Hz when the contactor is out of the contact. At the both roughness and the friction measurement, the specimen is moved between 2cm interval by a constant velocity of 0.1 cm/sec on a smooth steel placed horizontally where the tensile of the specimen is kept 20 gf/cm (force per unit length) and the contactor is kept its position. All the measurements were repeated at three distinct points on the fabrics on both warp and weft directions and the average with the analytical tolerance limited to 5%.

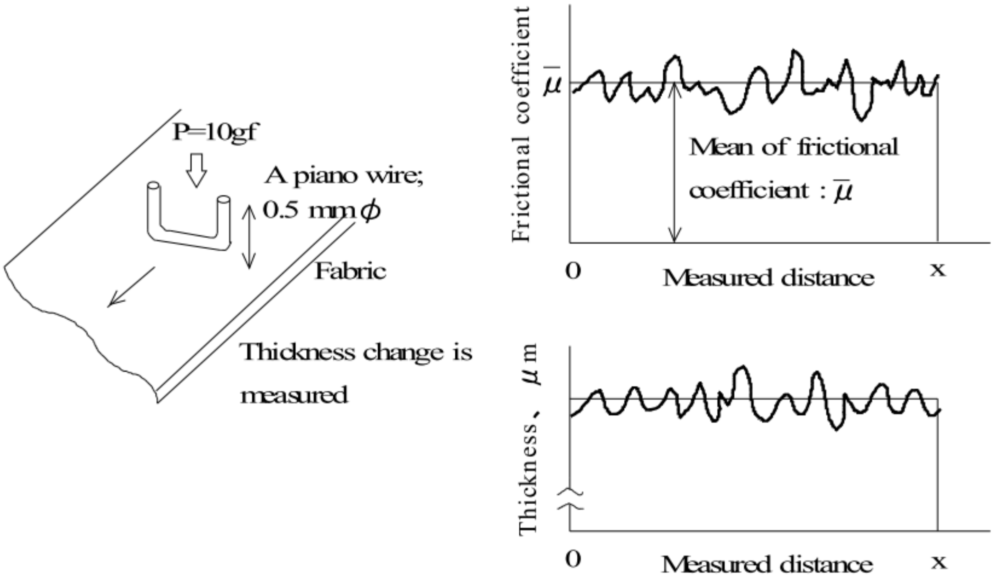


Figure 2. 10 Principle of surface property measurement

(Kawabata, 1980)

2.7 Hand value

2.7.1 Introduction

Fabric handle may define as the human tactile sensory response towards fabric, which involves not only physical but also physiological, psychological and social factors (Pan, 2007, Anand et al., 2010).

Fabric quality is generally perceived through tactile sensations. In a commercial environment, the “control” may lie within the memory of the customer. Consumers touch the product before buying them and majority of rejections are due to poor hand. Fabric handles influence consumers' perception of the usefulness of the product, which could guide their action and consequently retailer's salability of the apparel. The fabric handles are critical to garment designers, manufacturers and merchandisers in developing and selecting textile materials (Pan, 1993) and it has been recognized as one of the most important performance attributes of textile intended for use in apparel (Behery, 2005).

The ASTM Committee on Sensory Evaluation developed terms that are used to describe hand (ASTM D 123). The AATCC has also developed a standard protocol for hand evaluation (AATCC Evaluation Procedure 5).

Traditionally the fabric handle characteristics are evaluated subjectively by sensing the roughness, smoothness, softness, harshness, flexibility, thickness, scratchiness, prickle ect. Fabric tactile is the sense of touch, which is directly related to the fabric handle characteristics. On the other hand, fabric handle has been defined by the subjective assessment of a textile obtained from sense of touch (Radhakrishnaiah et al., 1993). Howorth and Oliver for the first time identified the three quality attributes, which directly affect the handle of suiting fabrics. These quality attributes, namely fullness, springiness, and stiffness (Howorth, 1958). Hand is influenced by flexibility, compressibility, fold ability, stretch ability, pliability, and surface friction (Alley Jr, 1978, Pan, 1993).

Since the 1970s, objective evaluation of fabric hand been attempted by textile researchers used two instrumental approaches. i.e. the Kawabata Evaluation System (KES-F) (Tester, 1990). Fabric hand determines the tactile comfort perceived by humans and it incorporate with low-stress mechanical property (tensile, bending, shear, compression and surface) measurements by the KES-F (Kawabata and Gakki, 1980, Shin et al., 2005a, Shin et al., 2005b). KES-F also distinguished range of hand value by different seasons. Figure 2.11 shows the interrelationships between fabric characteristics and pairs of polar adjectives of tactile sensations. Details of hand value evaluation by KES-F has introduced in next section.

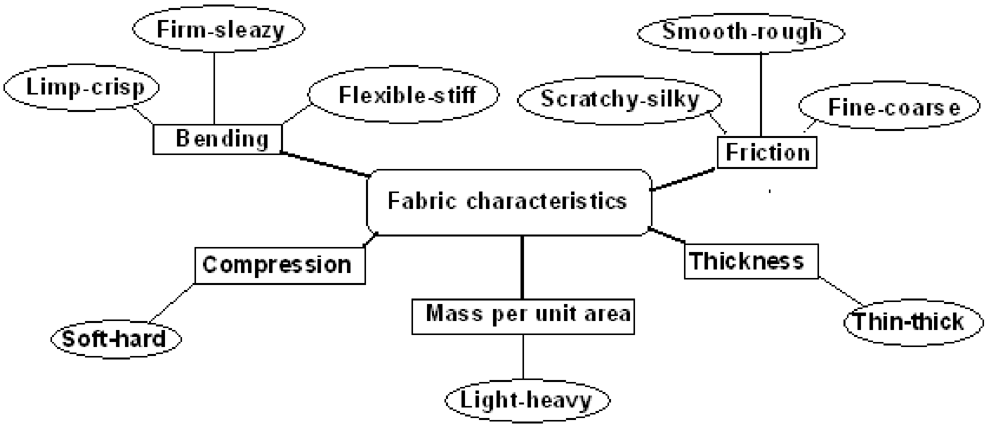


Figure 2. 11 Fabric characteristics and tactile attributes (Kawabata, 1980)

Application of science over the years has related that the wearing performance and qualities of appeal fabric comfort, fabric handle, drape, crease, and wrinkle recovery, tailor ability and garment appearance are related to the low stress mechanical properties of fabrics such as tensile, shear, bending, compression, and fabric surface properties. These properties of fabrics are decided by the raw material used, manufacture techniques employed, constructional parameters selected and finishing sequence adopted. However, subjective evaluations of hand do not produce results that can be used to guide manufacturing and design of textiles to give consistent quality (B.K. Behera, 2006, Kim and Slaten, 1999). Many industries or researchers improved fabric handle by developing finishing or create new fibers and so on. They have used these methods to measure the effect of fabric construction of finishes on changes in hand (Grover et al., 1993a, Kim et al., 1993) and correlations were generally good between these mechanical properties and sensory hand responses (Kim and Slaten, 1996).

2.7.2 Hand value evaluation

Objective evaluation of fabric hand value is developed by Kawabata and Niwa. The primary hands selected here are essentially the experts' hand. Each of these experts in the textile factories especially in the finishing process has studied and judgment is based on the information which has been gathered from many people, including customers, concerned with the clothing materials during a long time. For details， fabric softness is a complex tactile sensation, which determines the initial tactile perception of a wearer towards the clothing even before the wearing of the clothing. People perceived fabric softness or fullness sensation by pressing or squeezing by finger.

The objective KES-F tests the softness or fullness sensation of fabrics is expressed by compressibility and resilience characteristics. Fabric roughness and scratchiness are the important characteristics, which directly affect the tactile sensation of clothing. It has been reported (Li, 2001) that the sensation of roughness correlated with fabric surface roughness characteristics (frictional force, mean surface roughness coefficient and deviation of surface roughness coefficient), compressional characteristics of fabrics (compressibility and compressional energy), fiber diameter, tensile characteristics of fiber (breaking load and breaking elongation), and tensile characteristics of fabric (breaking elongation, elastic recovery). The sensation of scratchiness, on the other hand, is related to fabric tensile characteristics (breaking elongation, work of rupture and the modulus), fabric surface roughness (frictional force, mean surface roughness coefficient, and deviation of surface roughness coefficient), and compressional characteristics of fabrics (compressibility, linearity of the compression curve, compressional energy and slope of the compression-thickness curve).

For details, there are several equations for different kinds of garments and wearing seasons in KES-F system based on fabric low-stress mechanical properties. Objective evaluation process for fabric handle such as Primary Hand Value (HV) and Total Hand Value (THV) is shown in Figure 2.12. This is a simulation process of subjective evaluation of fabric handle by expert members of HESC. Professional experts touch the fabric at first, then stretch, bend and rub the fabric, feeling the mechanical and surface properties of the fabric. They judge the degree of strength of primary hands such as “KOSHI”, “NUMERI”, etc. Then, they decide total hand value (THV), that is, total fabric quality from the optimum combination of HVs. In objective evaluation method, the conversion equation (I) is used to calculate HVs from 16 mechanical parameters. Then, THV is calculated from the combination of several HVs by the equation (II). Coefficients of the conversion equations (I), (II) are decided for men's autumn/winter suit fabrics, men's spring/summer suit fabrics.

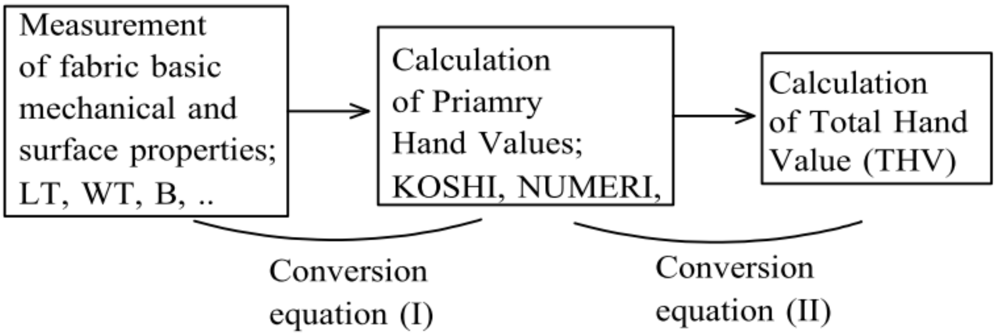


Figure 2. 12 Objective evaluation process of fabric handle (Kawabata, 1980)

$$Y = C_0 + \sum C_i \frac{(X_i - M_i)}{\sigma_i}$$ ……………………………**Equation（I）**

Where：Y; Primary hand value evaluated objectively (KOSHI, NUMERI, etc.),
C_o, C_i; Constants (i=1~16), Parameters see table 2.5 (a) for men's men's winter suit fabric, Table 2.5(b) for men's summer suit fabric
X_i; i-th mechanical parameter (refer table 2.6(a) for men's winter suit fabric, and table 2.6 (b) for men's summer suit fabric)
M_i; Mean value of the population of X_i
σ_i; Standard deviation of the population of X_i
C_i is called a standard partial regression coefficient

Table 2.5 (a) Parameters of constant coefficient for men's winter suit fabric

KOSHI			NUMERI			FUKURAMI		
i	**Ci**	**R**	**i**	**Ci**	**R**	**i**	**Ci**	**R**
0	5.7093		0	4.7533		0	4.9799	
4	0.8459	0.740	13	-0.9270	0.595	10	0.8845	0.600
5	-0.2104	0.780	14	-0.3031	0.633	9	-0.2042	0.616
6	0.4268	0.849	12	-0.1539	0.645	11	0.1879	0.630
7	-0.0793	0.854	10	0.5278	0.734	13	-0.5964	0.754
8	0.0625	0.854	9	-0.1703	0.742	14	-0.1702	0.768
15	-0.1714	0.868	11	0.0972	0.749	12	-0.0569	0.770
16	0.2232	0.889	8	-0.3702	0.794	1	-0.1558	0.782
2	-0.1345	0.896	6	-0.0263	0.794	2	0.2241	0.793
3	0.0676	0.898	7	0.0667	0.792	3	-0.0897	0.795
1	-0.0317	0.899	4	-0.1658	0.807	8	-0.0657	0.799
10	-0.646	0.900	5	0.1083	0.803	6	0.0960	0.800
9	0.0073	0.901	1	-0.0686	0.808	7	-0.0538	0.802
11	-0.0041	0.901	3	-0.1619	0.812	15	-0.0837	0.807
13	0.0307	0.901	2	0.0735	0.813	16	-0.1810	0.805
12	0.0254	0.901	16	-0.0122	0.813	5	0.0848	0.805
14	0.0009	0.901	15	-0.1358	0.812	4	-0.0337	0.806

Table 2.5 (b) Parameters of constant coefficient for men's summer suit fabric

KOSHI			SHARI			FUKURAMI			HARI		
i	Ci	R	i	Ci	R	i	Ci	R	i	Ci	R
0	4.6089		0	4.7480		0	4.917		0	5.3929	
4	0.7727	0.712	14	0.9162	0.605	1	-0.4652	0.455	4	0.8702	0.672
5	0.0610	0.714	12	-0.2712	0.631	2	-0.1793	0.489	5	0.1494	0.681
6	0.2802	0.760	13	0.1304	0.637	3	0.0852	0.495	12	-0.3662	0.738
7	-0.1172	0.767	4	0.4260	0.702	16	0.2770	0.564	13	0.1592	0.747
8	0.1110	0.774	5	-0.1917	0.711	15	-0.0591	0.567	14	0.1347	0.755
12	-0.2272	0.804	1	0.2012	0.723	6	0.0567	0.570	8	0.2345	0.776
14	0.1208	0.817	2	0.1632	0.731	8	-0.0944	0.577	7	-0.0938	0.779
13	0.0472	0.816	3	0.1385	0.739	7	0.0361	0.578	6	0.0643	0.781
10	-0.1139	0.823	11	-0.2252	0.751	12	-0.1157	0.589	9	-0.1153	0.786
11	-0.1164	0.828	9	0.0828	0.753	14	-0.0560	0.592	10	-0.0846	0.789
9	-0.0193	0.828	10	-0.0486	0.754	13	-0.0635	0.595	11	-0.0506	0.790
2	0.1154	0.833	8	0.1237	0.757	10	0.1411	0.611	16	0.0918	0.796
3	0.0955	0.839	7	-0.0573	0.759	11	0.0440	0.612	15	0.0067	0.796
1	-0.0031	0.839	6	0.0400	0.759	9	-0.0388	0.613	2	-0.1115	0.802
16	0.0549	0.844	16	0.0824	0.764	4	-0.0209	0.614	1	0.0156	0.803
15	0.0245	0.845	15	0.0001	0.764	5	0.0201	0.614	3	0.0194	0.803

Note: log means Log 10

Each of these characteristic values which belongs to blocks 1, 2, 3 and 5 is the mean value of those of warp and weft directions. After mean value is calculated from the characteristic values of both directions then the mean value is transformed into its logarithm to obtain Xi, for each sample.

Table 2.6 (a) Parameters of equations for translating mechanical values into hand value of men's winter suit fabric X_i, M_i, σ_i table

Block	**i**	**X_i**	**WINTER SUIT (N=214)**	
			M_i	**σ_i**
	0			
1	1	LT	0.6082	0.0611
	2	log WT	0.9621	0.1270
	3	RT	62.1894	4.4380
2	4	log B	-1.0084	0.1267
	5	log 2HG	-1.3476	0.1081
3	6	log G	-0.0143	0.1287
	7	log 2HG	0.0807	0.1642
	8	log 2HG5	0.4094	0.1441
4	9	LC	0.3703	0.0745
	10	log WC	-0.7080	0.1427
	11	RC	56.2709	8.7927
5	12	MIU	0.2085	0.0215
	13	log MMD	-1.8105	0.1233
	14	log SMD	0.6037	0.2063
6	15	log T	-0.1272	0.0797
	16	log W	1.4208	0.0591

Table 2.6 (b) Parameters of equations for translating mechanical values into hand value of men’s summer suit fabric X_i, M_i, σ_i table

Block	i	X_i	Summer SUIT (N=156)	
			M_i	σ_i
	0			
1	1	LT	0.6286	0.0496
	2	log WT	0.8713	0.0977
	3	RT	66.4557	5.4242
2	4	log B	-1.1052	0.1081
	5	log 2HG	-1.5561	0.1635
3	6	log G	-0.0662	0.1079
	7	log 2HG	-0.0533	0.1769
	8	log 2HG5	0.3536	0.1678
4	9	LC	0.3271	0.0660
	10	log WC	-0.9552	0.1163
	11	RC	51.5427	8.8275
5	12	MIU	0.2033	0.0181
	13	log MMD	-1.3923	0.1707
	14	log SMD	0.9155	0.1208
6	15	log T	-0.3042	0.0791
	16	log W	1.2757	0.0615

$$THV = C_{00} + \sum C_{i1} \frac{(Y_i - M_{i1})}{\sigma_{i1}} + \sum C_{i2} \frac{(Y_i^2 - M_{i2})}{\sigma_{i2}}$$ ……………….. **Equation（II）**

Where：C_{oo}, C_{i1}, C_{i2}; Constants (i=1~3,4)
Y_i; i-th primary hand value
M_{i1}; Mean value of the population of Y_i,
Y_i^2; Square value of Y_i,
M_{i2}; Mean value of the population of Y_i^2
σ_{i1}; Standard deviation of the population of Y_i
σ_{i2}; Standard deviation of the population of Y_i^2

This study focuses on the men’s suit hand value evaluation. The evaluation system includes men’s summer suit fabric and men’s winter suit fabric. In addition, different evaluation target has different key points. Corresponding to the experts’ conception about the hand expressions, the mainly related properties with its hand expressions are analyzed in both summer suit fabric and winter suit fabric. In terms of the summer suit fabric, there are KOSHI (stiffness), SHARI (crispness), FUKURAMI (fullness & softness) and HARI (spread & anti-drape) handles. For summer winter suit fabric, there are KOSHI (stiffness), NUMERI (smoothness) and FUKURAMI (fullness & softness) handle. Each of the handles has the mainly related mechanical properties. NUMERI refers to smoothness which comes from a smaller variation of frictional force and smooth surface. Each of bending, shearing and compressional properties has small rigidity and is springy. KOSHI refers to stiffness which relates to stiff in the bending, shearing and compressional properties. Thin fabric in terms of its weight increase KOSHI. FUKURAMI refers to fullness and softness. The softness in the compressional property and smooth surface and soft extensibility are calculated. SHARI for summer refers to rough surface and high shearing resistance, rough surface and high shearing rigidity, especially high 2HG5 also increases HARI. FUKURAMI for summer refers to extensible, especially in the relatively small tensile strain. As shown in Figure 2.13, these three hands, KOSHI, NUMERI, and FUKURAMI cover the blocks of the properties as shown in this figure.

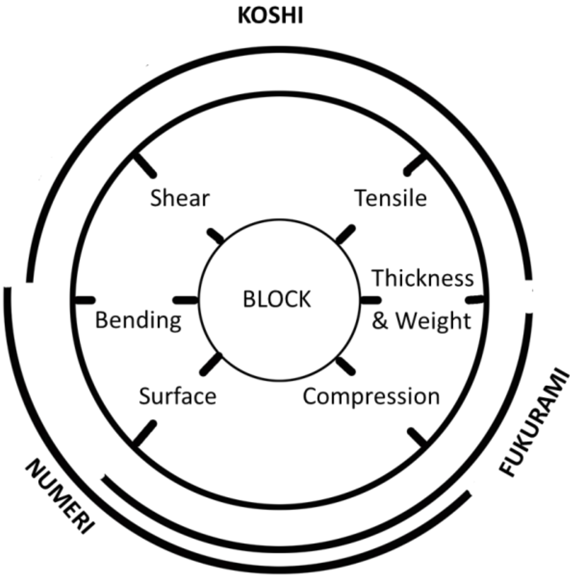


Figure 2. 13 Relation between the three primary hands and mechanical properties (Kawabata, 1980)

2.8 Conclusion

Suit has been one of the most popular formal wear. The quality and fashion performance have been pay much attention. As the manufacture process is complicated, many textile researchers attended to explore new production technique to improve the garment quality, develop production process and decrease the manufacture cost. Woollen fabric is the major material of suit due to its functional advantages. Furthermore, woollen fabric is economical compared with other fabrics. Therefore, woollen fabric is the ideal choice for this project. However, the most important difference between suit and other normal garment is that suit should have some accessories to support in order to have the required performance. Interlinings play an important role to enhance formability and appearance and improve the manufacture sewing efficiency. However, there are some drawbacks for current widely used fusible interlinings. Fusible interlining is (i) costly for its multiple program processing; (ii) quality problems such as strike-back, strike-through or bubbling; (iii) difficult to select fusible interlining; (iv) difficult to control process; and (v) time consuming. Hence, existing developments and creation of the interlining could be a mainly target at reducing these problems. Printing technique could achieve a desire fabric property. Screen printing has some advantages compared with other technique for this project. First of all, screen printing can be used for woollen fabrics and the experimental sample size and quantity is variable. Secondly, screen printing is operable, as it can control process condition directly, such as the screen mesh density, squeegee stroke frequency and resin density. Thirdly, screen printing is a cost-effective process in garment manufacture, it is perceived that this technology can be applied to substitute the fusing technology in certain garments. In order to study and evaluate the possibility of applying printable interlining technology in the interlining process, the mechanical properties and hand value of fabric should be studied and compared.

CHAPTER 3 LOW-STRESS MECHANICAL PROPERTIES AND HAND VALUES OF DIFFERENT COMBINATION OF WOOLLEN FABRICS AND FUSIBLE INTERLININGS

3.1 Introduction

Fusible interlinings are widely used in woollen fabrics for men's suits. In order to study the function of fusible interlinings, the experiment explored the difference in the low-stress mechanical properties and hand values of woollen fabrics under the effect of fusible interlinings (Qian et al., 2016). In addition, this study analyzes the correlation ship between thickness and the mechanical properties of woollen fabric with and without interlinings. The low-stress mechanical properties are investigated using the Kawabata Evaluation System for Fabrics (KES-F). The results show that different fusible interlinings affect the properties of woollen fabric in terms of low-stress mechanical properties and hand values. It has implications for apparel manufacturing and could be adjusted by control the characteristics of interlining (Qian et al., 2016).

One major indicator of fabric quality specification is fabric handle. A common way of showing fabric handle is the use of hand value. Kawabata Evaluation System for Fabrics (KES-F) is a popular method based on low-stress physical and mechanical properties to evaluate fabric handle, which includes tensile, bending, compression, shearing, surface properties, and weight, thickness. The system has evaluated that the most important fabric handle characteristics contain the fullness, smoothness, firmness, crispness and anti-drape.

Different fabrics and their finishing methods can produce different fabric low-stress mechanical properties and hand values, both of which affect the aesthetic quality, garment manufacturing efficiency and end use (Taylor, 1990). Several studies have used KES-F to measure the effect of finishing treatments on changes in hand. They reported correlations between low-stress mechanical properties and hand value (Naebe et al., 2015, Grover et al., 1993b, Morino et al., 2005). Currently, fusing of interlining to the shell fabric is widely used in apparel production. Adhesive interlinings are used on the inside of the shell fabric and it can improve garment formability for a beautiful silhouette during wearing, and can also enhance the appearance and wearing properties of the garment. Many researchers have studied the interlining field in different aspects (Amar and Al-Gamal, 2015, Fan and Ng, 2001, Kim et al., 2013b, Jeong et al., 2000) such as the development and selection of the fusible interlining. However, much uncertainty still exists about the degree of changes in woollen fabric fused with interlining and without interlining in terms of the low-stress mechanical properties, hand value and the relationship between the two.

This chapter attempts to evaluate the impact of the fusible interlinings on the mechanical properties of woollen fabrics and to analyze the difference in the hand value of woollen fabrics with and without fusible interlinings.

3.2 Experimental details

3.2.1 Experiment design and material

Woollen fabrics purchased from Tai Tung Textiles Company, Hong Kong was used for experiments. Fusible interlinings specimen supported from two renowned brands-KUFNER(KUFNER HONG KONG LTD.) and Vilene (Freudenberg & Vilene International Ltd., Hng Kong) companies were used for experiments in order to confirm the recognized good quality of fusible interlining (Qian et al., 2016). According to the suitability, interlinings selection was based on the respective brand’s recommendation.

The experiment consists of three fabrics groups of varying thickness, which are thin fabric (I), medium fabric (II) and thick fabric (III). Each group has two comparison groups: first, woollen fabric without interlining as the control group, second, fabrics with two kinds of interlinings as the experimental groups. In other words, the three thicknesses of woollen fabric groups were applied for without interlining, with interlining A, and with interlining B respectively. It means that there are nine kinds of testing fabrics and each kind fabric is tested for a total of six times repeatedly. So a total of 54 samples are used for discussion and analysis. Specifications of the samples are shown in Table 3.1. The fabric thickness of three testing groups increases from 0.552 to 2.527 mm, likewise, weight value rise from 15.305 to 35.85 mg/cm^2. The shell fabrics are 100% woollen and interlining basic fabric is PES (polyether sulfone) and component of glue dot is PA (nylon). All the fabric structures are woven and the adhesive density ranged from 42 to 110 dots/cm^2.

Table 3. 1 Samples specification

Fabric Code	**Samples**	**Thickness (mm)**	**Weight (mg/cm^2)**	**Component**	**Structure**	**Adhesive Density (dots/cm^2)**
I	Thin Fabric	0.552	15.305	100% wool	Cross Twill 2/1	
IA	Thin Fabric with Interlining A (KUFNER) FW 2048	0.774	20.105	100%PES	Cross Twill 2/2	110
IB	Thin Fabric with Interlining B (Vilene) MBB60	0.900	21.105	100%PES	Cross Twill 3/1	66
II	Medium Fabric	0.979	22.625	100% wool	Cross Twill 2/1	
IIA	Medium Thickness Fabric with Interlining A (KUFNER) FW2065	1.220	28.925	100%PES	Cross Twill 2/2	42
IIB	Medium Thickness Fabric with Interlining B (Vilene) MBB80	1.593	31.025	100%PES	Cross Twill 3/1	52
III	Thick Fabric	2.132	26.35	100% wool	Cross Twill 2/2	
IIIA	Thick Fabric with Interlining A (KUFNER) FW2080	2.360	34.55	100%PES	Cross Twill 2/2	52
IIIB	Thick Fabric with Interlining B (Vilene) MBB95	2.527	35.85	100%PES	Cross Twill 3/1	52

3.2.2 Fusing interlining treatment

All the fusible interlinings fully fused on woollen fabrics. A continuous fusing machine was used (straight conveyor belt-Maschinenfabrik Herbert Meyer GmbH PPS-L 600).Fused parameters of the woollen fabric were adopted: temperature: 120ºC; speed: 3m/min; pressure: 5N/cm^2 based on interlining specification recommended.

3.2.3 Fabric objective and hand value

Mechanical properties were measured by the Kawabata Evaluation for Fabric System (KATO TECH CO., LTD.). All the experiment testing was in a standard conditioned lab (65±2% RH; 21±2° C). The KES-F includes five properties: tensile, bending, shearing, surface, and compression. All samples were tested following standard procedure.

3.3 Evaluation of woollen fabric with fusible interlinings

3.3.1 Interlining effect on tensile properties

The tensile properties of the woollen fabrics with and without interlinings are shown in Table 3.2, which includes the tensile resilience (RT), tensile extension at 500gf/cm load (EMT), tensile energy (WT) and tensile linearity of extension cure (LT) (Kawabata and Gakki, 1980). In Table 3.2, no significant relationships between thickness and each term of tensile property of woollen fabrics is found. However, thickness and LT, RT value have significant coefficient of woollen fabrics with interlinings, in another word, fusible interlinings effect the LT and RT properties.

Table 3. 2 Pearson's correlation between the mechanical properties and thickness of woollen fabrics and woollen fabrics with interlinings

Thickness of (mm) / Low-stress Mechanical Properties		Woollen Fabrics	Woollen Fabrics with Interlinings
Tensile	**EM**	0.817	0.457
	LT	0.175	0.033 ★
	WT	0.927	0.856
	RT	0.381	0.048 ★
Bending	**B**	0.528	0.001 ★
	2HB	0.197	0.003 ★
Shear	**G**	0.735	0.173
	2HG	0.137	0.618
	2HG5	0.392	0.396
Compression	**LC**	0.97	0.359
	WC	0.017 ★	0.010 ★
	RC	0.793	0.174
Surface	**MIU**	0.184	0.006 ★
	MMD	0.186	0.054
	SMD	0.855	0.642

★a<0.05

Tensile resilience RT (%) reflects the recovery of the fabric when the applied force is removed under the maximum force 500gf/cm (Kawabata and Gakki, 1980). A higher value indicates greater recovery from stretching. Table 3.3 shows obvious increment in terms of woollen fabrics with interlining. The medium thickness and thick fabric show a higher increased value ranging from 11.5% to 25.8%, while thin fabric RT value increases only slightly compared with the fabric without interlining. This shows that fusible interlining can improve the fabric recovery from stretching.

Tensile extension percentage value of fabric at 500gf/cm load (EMT) presents the stretch of material. From Table 3.3, it can be seen that the fabric extension value decreases from 16.5% to 3.2% of woollen fabric with interlining. It means the fusible interlining reduces the elongation of the woollen fabric after fusing interlining.

Tensile energy (WT) refers to the work required when extending the fabric. The higher WT value, the higher tensile strength of the fabric is (Sun and Stylios, 2005). Table 3.3 shows the WT value dropping moderately, from 12.6% to 0.4%. However, for the thin fabric, there is a slightly increase by 0.2% after fusing the interlining. These reflect that the fabric becomes more firm and resistant to deformation after fusing with interlining.

Linearity of extension curve (LT) reflects the elasticity of the fabric. The higher the value, the stiffer the material is. Table 3.3 reflects that the LT value of fabric goes up after fusing the interlining, which increases from 3.1% to 11.0%. This phenomenon shows that the fabric becomes stiffer and easier to model the silhouette after fusing the interlining. Tensile properties data indicates the fusible interlining develops the elastic resilience, stiffness and firmness of woollen fabric (Qian et al., 2016).

Table 3. 3 Results of tensile properties of woollen fabric with and without interlining

Tensile Properties	Woolen Fabric Without Interlining			Woolen Fabric With Interlining A			Woolen Fabric With Interlining B		
	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick
EM (Tensile Extension at 500gf/cm load)									
Average	6.253	10.530	8.480	5.770	8.790	7.430	6.053	9.530	7.700
Standard Deviation	0.126	0.136	0.258	0.063	0.140	0.135	0.083	0.321	0.224
Percentage changes comparing fabric without interlining				-7.6%	-15.6%	-12.4%	-3.2%	-9.5%	-9.2%
LT (Linearity of Extension Curve)									
Average	0.711	0.618	0.572	0.738	0.642	0.635	0.733	0.661	0.623
Standard Deviation	0.006	0.007	0.007	0.004	0.008	0.009	0.007	0.007	0.014
Percentage changes comparing fabric without interlining				+3.8%	+3.9%	+11.0%	+3.1%	+7.0%	+8.9%
WT (Tensile Energy)									
Average	11.262	16.220	12.030	10.760	14.170	11.820	11.238	15.760	11.980
Standard Deviation	0.186	0.262	0.301	0.123	0.357	0.157	0.153	0.642	0.288
Percentage changes comparing fabric without interlining				-4.5%	-12.6%	1.7%	+0.2%	-2.8%	0.4%
RT (Tensile Resilience)									
Average	69.428	53.260	49.340	69.483	63.050	62.070	69.452	59.380	58.730
Standard Deviation	0.276	0.610	0.571	0.384	0.867	0.794	0.472	0.457	0.784
Percentage changes comparing fabric without interlining				-0.1%	+18.4%	+25.8%	-0.003%	+11.5%	+19.0%

Remark: "+" refers to increase and "-" refers to decrease

Remark: "+" refers to increase and "-" refers to decrease

3.3.2 Interlining effect on bending properties

Bending test includes B - bending stiffness (g.cm^2/cm) and 2HB - Bending Hysteresis moment (g.cm/cm). Table 3.2 shows there are no significant correlation of thickness and each term of bending property of woollen fabrics. By contrast, both B and 2HB of bending property have significant coefficient with thickness of woollen fabrics with interlining. It means that fusible interlining effect the bending properties of woollen fabrics.

Bending stiffness indicates the fabric stiffness and bending hysteresis reflects the elasticity and recovery of fabric in both the warp and weft directions (Lam and Postle, 2006). According to Table 3.4, B value of woollen fabric with interlining increases from 216% to 625% and 2HB value improves from 217% to 526% respectively. It proves that woollen fabric with interlining increases their stiffness greatly and decreases the recover properties significantly. Figure 3.1 indicates a significant increase of woollen fabric with both interlining A and interlining B. This phenomenon might be due to the bending resistance properties of fibers and yarns as well as the fabric structure increase greatly when the fabric thickness increased (Sun and Stylios, 2005). The change of bending properties also affect the fabric draping, the higher B and 2HB value, the less draping of fabric (Qian et al., 2016).

Table 3. 4 Results of bending properties of woollen fabric with and without interlining

Bending Properties	Woolen Fabric Without Interlining			Woolen Fabric With Interlining A			Woolen Fabric With Interlining B		
	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick
B(Bending Stiffness)(g.cm2/cm)									
Average	0.079	0.057	0.098	0.250	0.332	0.748	0.284	0.399	0.711
Standard Deviation	0.004	0.003	0.002	0.011	0.007	0.025	0.011	0.004	0.005
Percentage changes comparing fabric without interlining				+216.5%	+482.5%	+663.3%	+259.5%	+600%	+625.5%
2HB (Bending Hysteresis moment)(g.cm/cm)									
Average	0.027	0.025	0.064	0.088	0.133	0.400	0.087	0.149	0.351
Standard Deviation	0.003	0.001	0.002	0.004	0.004	0.014	0.004	0.006	0.009
Percentage changes comparing fabric without interlining				+223.4%	+439.8%	+525.5%	+216.8%	+507.3%	+448.8%

Remark: “+” refers to increase and “-” refers to decrease

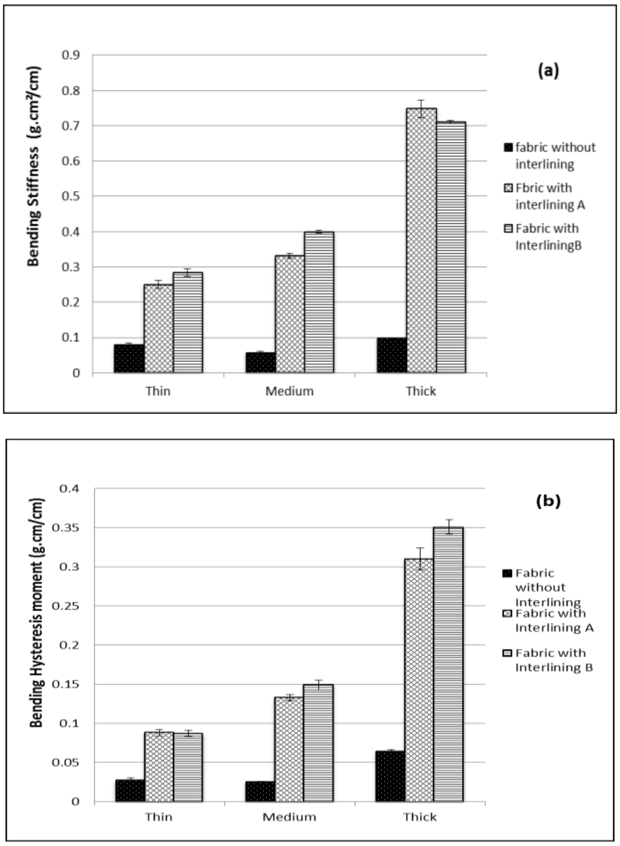


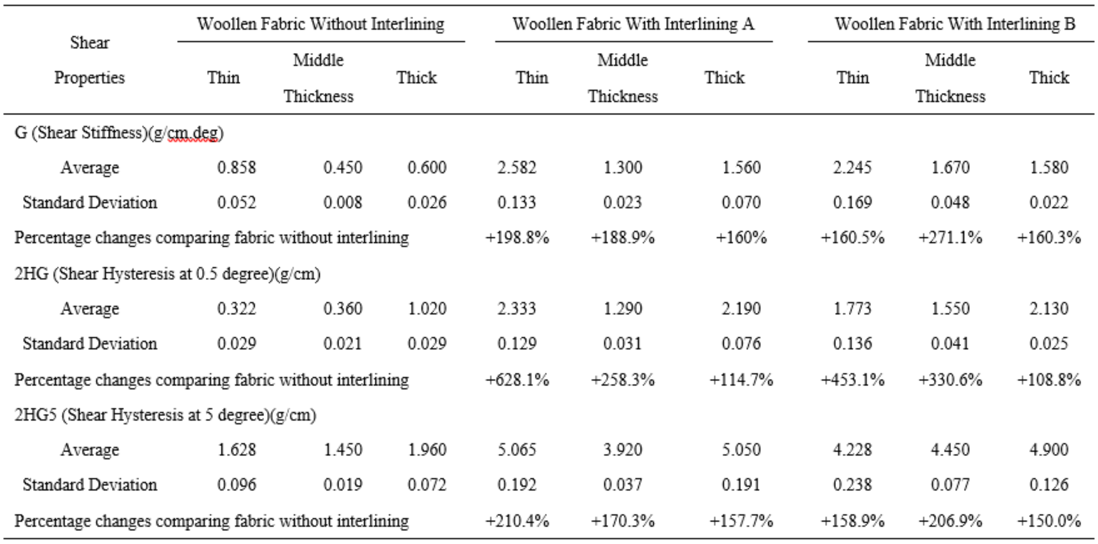
Figure 3. 1 Bending properties:
(a) Bending stiffness; (b) Bending hysteresis moment

3.3.3 Interlining effect on shear properties

Differences of shear properties for woollen fabrics after fusing interlining are shown in Table 3.5, which includes: Shear stiffness (G), (g/cm.deg); Shear Hysteresis at 0.5 degree (2HG), (g/cm); Shear Hysteresis at 5 degree (2HG5), (g/cm). Shear properties are measurement of inter-yarn friction force. They represent the stability of fabric to withstand in plane mechanical distortion. Table 3.2 indicates that there are no significant correlation of thickness and each term of shear property on both woollen fabrics with and without interlinings.

According to the Figure 3.2, woollen fabrics with fusible interlinings have increased noticeably in terms of G, 2HG, and 2HG5 value, respectively. Shear stiffness (G) increases from 160% to 198.8%. In other words, the woollen fabrics become stiffer after fusing interlinings. Furthermore, the shear hysteresis value at both 0.5°and 5° are significantly increased. Shear hysteresis at 0.5 degree (2HG) increases 108.8% to 628.1% when compared with the interlining fused before and after. In addition, the increasing value of shear hysteresis at 5 degree (2HG5) ranges from 150% to 210.4%. The rapid growth of 2HG and 2HG5 values indicate the woollen fabric with interlining has a low resilience property which is due to the greatly increased inter-yarn friction in fabrics and inter-yarn pressure after fusing interlining (Qian et al., 2016).

Table 3. 5 Results of shear properties of woollen fabric with and without interlining



Shear Properties	Woollen Fabric Without Interlining			Woollen Fabric With Interlining A			Woollen Fabric With Interlining B		
	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick
G (Shear Stiffness)(g/cm.deg)									
Average	0.858	0.450	0.600	2.582	1.300	1.560	2.245	1.670	1.580
Standard Deviation	0.052	0.008	0.026	0.133	0.023	0.070	0.169	0.048	0.022
Percentage changes comparing fabric without interlining				+198.8%	+188.9%	+160%	+160.5%	+271.1%	+160.3%
2HG (Shear Hysteresis at 0.5 degree)(g/cm)									
Average	0.322	0.360	1.020	2.333	1.290	2.190	1.773	1.550	2.130
Standard Deviation	0.029	0.021	0.029	0.129	0.031	0.076	0.136	0.041	0.025
Percentage changes comparing fabric without interlining				+628.1%	+258.3%	+114.7%	+453.1%	+330.6%	+108.8%
2HG5 (Shear Hysteresis at 5 degree)(g/cm)									
Average	1.628	1.450	1.960	5.065	3.920	5.050	4.228	4.450	4.900
Standard Deviation	0.096	0.019	0.072	0.192	0.037	0.191	0.238	0.077	0.126
Percentage changes comparing fabric without interlining				+210.4%	+170.3%	+157.7%	+158.9%	+206.9%	+150.0%

Remark: "+" refers to increase and "-" refers to decrease

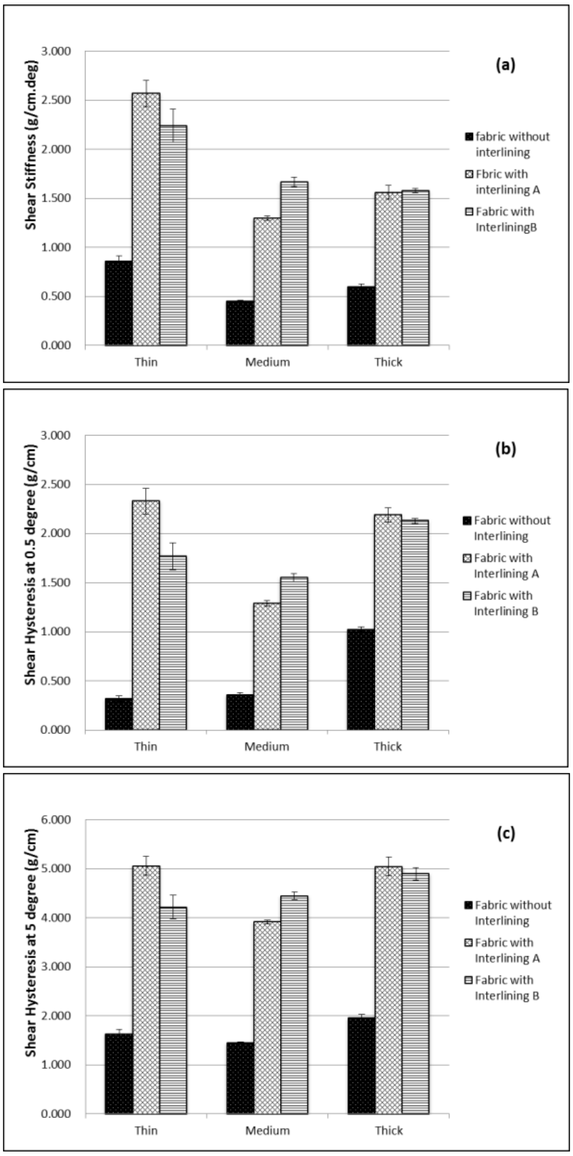


Figure 3. 2 Shear properties: (a) Shear stiffness; (b) Shear hysteresis at 0.5 degree; (c) Shear hysteresis at 5 degree.

3.3.4 Interlining effect on the compression properties

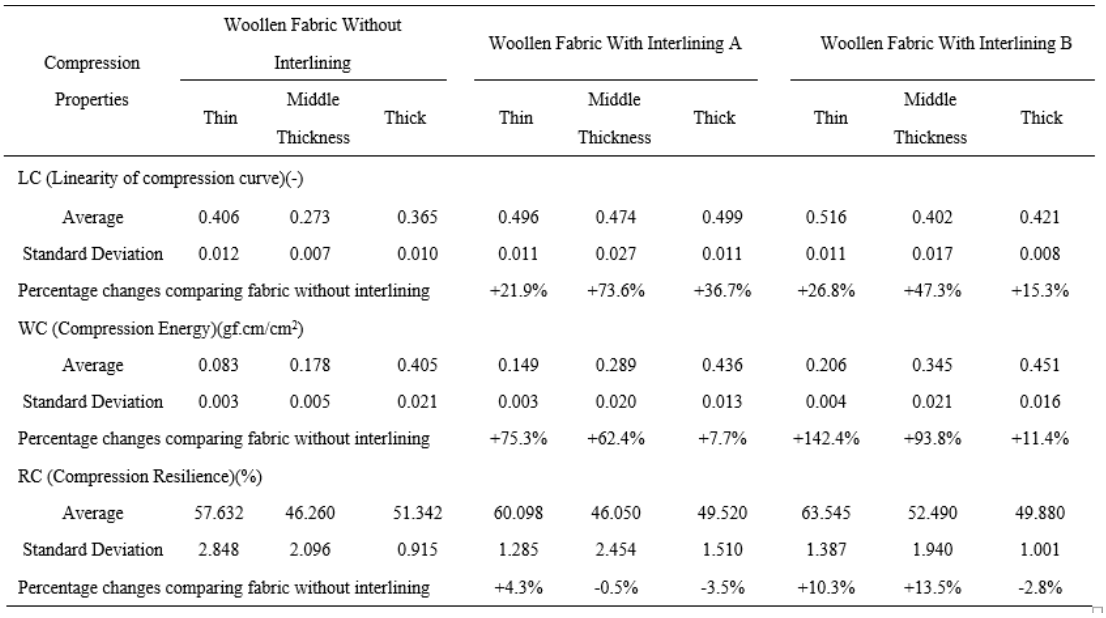
The compression properties of woollen fabric with interlining and without interlining are shown in Table 3.6, including linearity of compression curve (LC), compression energy (WC) (gf.cm/cm^2), and compression resilience (RC) (%). Table 3.2 reflects that there is only WC property has significant correlation of thickness on both woollen fabrics with and without interlinings.

Fusible interlining leads to change in WC value of woollen fabric with interlining from 7.7% to 142.4% increase when compared with fabrics without interlining. Thin fabrics with interlinings have a substantial increase as well as the medium thickness woollen fabrics with interlining, while the thick level fabrics have a slight upward trend. The WC express the energy required to compress the fabric to be prefixed maximum load level (Kawabata and Gakki, 1980), which reflects the softness of fabrics. Table 3.6 represents that the fusible interlining treatment develops the softness of woollen fabrics.

Compression resilience (RC) reflects the extent of recovery or regaining in the thickness diversion. Higher values of RC mean a better recovery and more fullness. Table 3.6 shows that thin fabrics with interlining has an increased value varying from 75.3% to 142.4% comparing the fabrics without interlining, while the medium thickness fabrics have no significant change. However, RC values of the thick fabrics with interlining decrease after fusing the interlining. This phenomenon causes by the interlocking between fibers, after fusing the interlining the thin fabric develop the fullness, nevertheless, the thick fabric turns to move roughness and decrease the compression resilience and elasticity as well.

Table 4.6 indicates linearity of compression curve (LC) value of woollen fabrics with fusible interlining showing various levels of increase ranging from 15.3% to 73.6%. LC presents the softness of fabrics, which also means that the interlining treatment improves the softness of woollen fabric (Qian et al., 2016).

Table 3. 6 Results of compression properties of woollen fabric with and without interlining



Compression Properties	Woollen Fabric Without Interlining			Woollen Fabric With Interlining A			Woollen Fabric With Interlining B		
	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick
LC (Linearity of compression curve)(-)									
Average	0.406	0.273	0.365	0.496	0.474	0.499	0.516	0.402	0.421
Standard Deviation	0.012	0.007	0.010	0.011	0.027	0.011	0.011	0.017	0.008
Percentage changes comparing fabric without interlining				+21.9%	+73.6%	+36.7%	+26.8%	+47.3%	+15.3%
WC (Compression Energy)(gf.cm/cm^2)									
Average	0.083	0.178	0.405	0.149	0.289	0.436	0.206	0.345	0.451
Standard Deviation	0.003	0.005	0.021	0.003	0.020	0.013	0.004	0.021	0.016
Percentage changes comparing fabric without interlining				+75.3%	+62.4%	+7.7%	+142.4%	+93.8%	+11.4%
RC (Compression Resilience)(%)									
Average	57.632	46.260	51.342	60.098	46.050	49.520	63.545	52.490	49.880
Standard Deviation	2.848	2.096	0.915	1.285	2.454	1.510	1.387	1.940	1.001
Percentage changes comparing fabric without interlining				+4.3%	-0.5%	-3.5%	+10.3%	+13.5%	-2.8%

Remark: "+" refers to increase and "-" refers to decrease

3.3.5 Interlining effect on surface properties

Surface properties of the woollen fabric with fused interlining are shown in Table 3.7, which includes coefficient of friction (MIU), mean deviation of MIU (MMD) and geometrical roughness (SMD). The surface measurement sensor is designs to simulate the human finger to test the fabric coefficient and roughness. The coefficient of friction (MIU) measures the resistance of the samples. Table 3.2 shows that there is no significant correlation of thickness and surface properties of woollen fabrics. However, there is significant coefficient of thickness and MIU property on woollen fabrics with interlinings. That is to say, fusible interlinings affect the woollen fabric surface property.

A higher value corresponds to greater friction or resistance and drag (Sun and Stylios, 2005). After fusing the interlining, woollen fabric with interlining's coefficient of friction decreases slightly by 1.4% to 3% in comparison with fabric without interlining. The appearance is changed by the increased intrinsic thickness and density of the fabric after fusing the interlining. The geometrical roughness (SMD) reflects the roughness features of the fabric surface. As seen in Table 3.7, the roughness value of the fabric decreases from 34.6% to 10.4% after fusing the interlining. On the other hand, interlining improves softness and fullness of the woollen fabric (Qian et al., 2016).

Table 3. 7 Results of surface properties of woollen fabric with and without interlining

Surface Properties	Woollen Fabric Without Interlining			Woollen Fabric With Interlining A			Woollen Fabric With Interlining B		
	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick
MIU (Coefficient of Friction)(-)									
Average	0.133	0.143	0.152	0.133	0.140	0.154	0.129	0.141	0.149
Standard Deviation	0.005	0.002	0.006	0.005	0.001	0.003	0.004	0.003	0.003
Percentage changes comparing fabric without interlining				0%	-2.1%	+1.3%	-3.0%	-1.4%	-2.0%
MMD (Mean Deviation of MIU)									
Average	0.012	0.012	0.009	0.010	0.009	0.009	0.011	0.009	0.008
Standard Deviation	0.002	0.001	0.000	0.002	0.001	0.000	0.001	0.001	0.001
Percentage changes comparing fabric without interlining				-22.8%	-23.3%	-6.6%	-13.8%	-21.6%	-12.1%
SMD (Geometrical Roughness)(-)									
Average	5.502	4.590	5.470	4.935	3.420	4.310	4.630	3.000	4.080
Standard Deviation	0.487	0.133	0.165	0.102	0.153	0.121	0.157	0.091	0.125
Percentage changes comparing fabric without interlining				-10.4%	-25.5%	-21.2%	-15.8%	-34.6%	-25.4%

Remark: "+" refers to increase and "-" refers to decrease

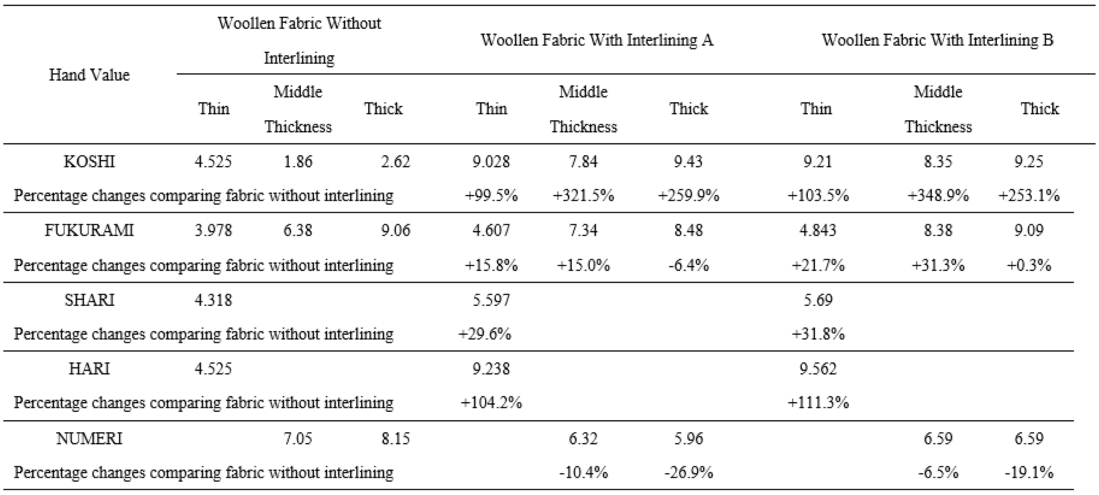
3.3.6 Fabric hand value

Hand value summarizes the low-stress mechanical properties of fabrics and Table 3.8 shows the hand value of all the specimens. As the basic fabrics in three thickness levels are all woollen used for men's suits, we evaluate the thin fabrics as men's summer suits while the medium thickness fabrics and thick fabrics for men's winter suit (Qian et al., 2016). The hand value of summer men's suits includes KOSHI (Stiffness), FUKURAMI (Fullness and Softness), SHARI (Crispness), HARI (Anti-drape). In addition, hand value of winter men's suit contains KOSHI (Stiffness), FUKURAMI (Fullness and Softness), NUMERI (Smoothness). The HV evaluation program "KSAN-S2" is used to carry out these conversions (Kawabata and Gakki, 1980). The formula shows in Equation (1), where Y is the hand value; C_0, C_i is the constant (parameters of constant coefficient); X_i denotes the mechanics after normalized by the standard deviation.

$$Y = C_0 + \sum_{i=1}^{16} C_i X_i \qquad X_i = \frac{x_i - \overline{x_i}}{\sigma_i}$$

Equation (1)

Table 3. 8 Hand value of woollen fabrics and woollen fabrics with interlinings



Hand Value	Woollen Fabric Without Interlining			Woollen Fabric With Interlining A			Woollen Fabric With Interlining B		
	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick	Thin	Middle Thickness	Thick
KOSHI	4.525	1.86	2.62	9.028	7.84	9.43	9.21	8.35	9.25
Percentage changes comparing fabric without interlining				+99.5%	+321.5%	+259.9%	+103.5%	+348.9%	+253.1%
FUKURAMI	3.978	6.38	9.06	4.607	7.34	8.48	4.843	8.38	9.09
Percentage changes comparing fabric without interlining				+15.8%	+15.0%	-6.4%	+21.7%	+31.3%	+0.3%
SHARI	4.318			5.597			5.69		
Percentage changes comparing fabric without interlining				+29.6%			+31.8%		
HARI	4.525			9.238			9.562		
Percentage changes comparing fabric without interlining				+104.2%			+111.3%		
NUMERI		7.05	8.15		6.32	5.96		6.59	6.59
Percentage changes comparing fabric without interlining					-10.4%	-26.9%		-6.5%	-19.1%

Remark: “+” refers to increase and “-” refers to decrease

KOSHI refers to stiffness. Equation (1) shows that the most important factors affect the KOSHI values are: Bending Stiffness (B), Coefficient of Surface Friction (MIU) and the Shear Stiffness (G). According to Table 3.8, KOSHI increasing value reaches to 348.9% after fusing the interlining. This result may be explained by the fact that the improving thickness and the high-density of fabrics after fusing interlining and the stiffness property relate to elasticity. Moreover, it gives proof that the woollen fabrics with interlinings become elastic. FUKURAMI means fullness and softness. Equation (1) reflects the depending factors are Tensile Linearity of Extension Curve (LT), Tensile Energy (WT) and Compression Energy (WC). FUKURAMI of hand value focus on the combination of the fabric bulky, rich and well-formed (Kawabata, 1980b). From Table 3.8, it can be seen that the value of thin fabric and medium thickness fabric score, ranging from 15.8% to 26.8%，this shows that the fusible interlining can improve the fabric fullness. However, thick fabric with interlining expresses the FUKURAMI value decreases or a tiny-increase when compared with the fabric without interlining. The phenomenon causes by the increasing thickness of woollen fabric, which enhances the stiffness, but influences the fullness and softness performance SHARI is fabric crispness, which comes from the crisp and ridged fabric surface According to the Equation (1), the main effect factors are Bending Stiffness (B), Coefficient of Surface Friction (MIU) and Tensile Linearity of Extension Curve (LT). Table 3.8 indicates that the SHARI value increases from 29.6% to 31.8% comparing with the fabric without interlining. It reflects fabrics become hard and strongly after fusing the interlining. Furthermore, as the MIU value decreases, it shows that the woollen fabric with interlining is softened (Qian et al., 2016).

HARI refers to anti-drape, it is the special evaluation condition for summer men's suits. Equation (1) indicates the effect factors are Bending Stiffness (B), Coefficient of Surface Friction (MIU) and Shear Hysteresis at 5 degree of angle (2HG5). As Table 3.8 shows that, the anti-drape value increases more than 100 per cent after fusing the interlining, which also means the woollen fabrics with interlinings were stiffer (Qian et al., 2016).

NUMERI means smoothness, which evaluates the condition used for the winter men's suits. Based on the Equation (1), it reflects the major impacts are: Coefficient of

Surface Friction (MMD), Compression Energy (WC) and Shear Hysteresis at 5 degree angle (2HG5). Table 3.8 reflects the values of the smoothness decrease after fusing the interlining in both the medium and thick fabric. The mixed feeling of the smoothness depends on several low-stress mechanical properties. The first one is surface property, it is known that the fabrics with interlinings have developed the roughness as the MMD value decreased. The second one is compression property, it represents the soft properties as the compression energy increase.

3.4 Conclusion

This chapter focused on the low-stress mechanical properties and hand values of the woollen fabric with interlining. The experiment covered three thickness levels of woollen fabrics and compared low-stress mechanical properties as well as the hand values of the woollen fabric with and without fusible interlinings by using fabric objective measurement of KES-F.

The coefficient analysis showed that low-stress mechanical properties and thickness had good relationships to the woollen fabrics fusing interlinings (i.e., LT, RT, B, 2HB, WC and MIU). Experiments results revealed that the most important low-stress mechanical properties were bending and shear, which contribute to more than 100 per cent sorting after fusing the interlining. Several basic low-stress mechanical properties had changed obviously after fusing interlining which were bending stiffness (B) value increased dramatically, shear stiffness (G) had a sharp increased performance, shear hysteresis at 5 degree (2HG5) had the similar changing with G value, compression energy (WC) also increased slightly and linearity of extension curve (LT) increase as well. However, mean deviation of MIU (MMD) value had a rapid decline, tensile energy (WT) also decreased steadily, the coefficient of friction (MIU) appearance a slight decreased.

Experimental results also indicated the degree of the changes in hand value of woollen fabric with interlining especially increase stiffness (KOSHI) significantly and at the same time decrease the anti-drape (HARI) handle. Fullness and crispness developed slightly while the smoothness value declined moderately compared with the fabric without interlining. As the experimental results above, it could be used to assess the quality of interlining and determine the interlining end use application (Qian et al., 2016).

This study had implications for woollen fabric with interlining, considering that woollen fabric and end use for making suits. The low-stress mechanical properties and hand value reflected the same woollen fabric had different readings by fusing different fusible interlinings. The information database can be used not only in the manufacturing process but also in marketing consumer’s hand value requirements.

CHAPTER 4 RELATIONSHIP BETWEEN PHYSICAL AND LOW-STRESS MECHANICAL PROPERTIS TO FABRIC HAND OF WOOLLEN FABRIC WITH FUSIBLE INTERLININGS

4.1 Introduction

Fabric is the basic material for clothing. Different types of fabrics are used for different types of garments. Woollen fabrics have been widely used for men's suits (Chuang and Hung, 2011) . Besides, fabrics accessories like interlinings are also necessary for apparel manufacture. Interlining is a layer of fabric inserted between the face and the lining of a garment (Shiloh, 1972); interlining here refers to the fusible interlining. Generally speaking, interlinings are soft, thick and flexible and play an important role in deciding the quality and purchase decisions of garments (Sneddon et al., 2012, Suelar and OKUR, 2007). The function of interlining is to make sewing easier and help retain shape for improving material appearance (Nayak and Padhye, 2015, Wang et al., 2015). Interlinings are used for several types of garments and clothing. One of popular applications is suit making which increases the suit performance with stable shape and improves the quality. Interlining fusing technique plays a very important role in the production of men's suits and is used in more than 60 per cent of the suit, such as the front piece, collar and sleeves, all of which have different requirements (Lai, 2001). This reflects the importance of matching suitability of interlinings and suit face fabrics. However, fabric quality is generally perceived through tactile sensations (Jevsnik et al., 2014). One of the most important evaluations of fabric quality and comfort is hand value (Ishtiaque et al., 2014). Based on the traditional way of suit manufacture, efficiency of fusible interlining on woollen fabric is measured by hand value. Low-stress mechanical properties and hand value are explored to evaluate woollen fabric with and without interlining.

Currently, there is no clear interlinings production guidance for consumers. In the past, most garment factories relied on experience when combining interlining and face fabrics, a very subjective and non-effective process (Lai, 2001, Wang et al., 2012). However, not all customers have rich experience for choosing available interlinings which cause many problems in garment manufacture. Many researchers have studied interlinings and find some automatic matching methods (Fan and Ng, 2001, Kim et al., 2011, Šaravanja et al., 2015, Kim et al., 2013c). Some researchers have explored mechanical properties of fabrics fused with interlinings by moduli (Kim et al., 2012, Wong et al., 2003, Wong et al., 2004, Majumdar et al., 2010, Behera and Muttagi, 2004). However, those methods are not easy to understand for normal consumers and it is difficult to control the required parameters (Shiloh, 1972). Therefore, finding an available interlining with convenient control method for consumers without rich experience is an important research issue. Many factors contribute to the differences in fabric hand behaviour, such as the fabric physical properties (Zhang et al., 2002). However, many researchers have explored different properties affecting the handle, but they do not give an overall evaluation on both the subjective assessment and objective test. In this study, the relationships of physical properties and hand value were explored on different types of fusible interlinings bonded with woollen fabric. In this way, people can choose the required interlinings according to their physical properties. Furthermore, for investigating detailed reasons of different hand value performances affected by interlinings, this chapter studied relationships between physical properties of interlinings and low-stress mechanical properties.

4.2 Experimental details

4.2.1 Material

The basic specifications of the specimen are shown in Table 4.1. A total of seven specimens composed of 100% woollen fabric, fusible interlinings and woollen fabric bonded with different fusible interlinings were used in this study. Fusible interlinings with different physical properties, such as thickness, weight and adhesive density were used. All fusible interlinings were from CO. KG Vileseline. A continuous fusing machine (PPS-L600, Maschinenfabrik Herbert Meyer GmbH, Germany) was used with a straight conveyor belt. According to the interlining recommended, fusing parameters of the woollen fabric were: 115°C; speed: 3 m/min; pressure: 5 N/cm^2.

Table 4. 1 Specimen specification

Fabric Code	Samples	Thickness (mm)	Weight (mg/cm^2)	Composition (warp* weft/cm)	Component	Structure	Adhesive Density (dots/cm^2)
I	Woollen Fabric without Interlining	0.243	15.352	66*60	100% wool	Cross Twill 2/1	
A	Interlining A-MBB40	0.280	4.662	50*43	100%PES	Cross Twill 2/2	66
B	Interlining B-MBB60	0.380	6.198	56*53	100%PES	Cross Twill 3/1	66
C	Interlining C-ME9003	0.174	2.664	100*66	100%PES	Plain	140
D	Interlining D-ME9201	0.185	2.943	100*76	100%PES	Plain	200
E	Interlining E-MBB95	0.492	9.265	60*45	100%PES	Cross Twill 3/1	52
F	Interlining F-MBB70	0.467	8.049	66*45	100%PES	Cross Twill 3/1	52
IA	Woollen Fabric with Interlining A-MBB40	0.570	21.246				
IB	Woollen Fabric with Interlining B-MBB60	0.553	21.150				
IC	Woollen Fabric with Interlining C-ME9003	0.424	19.368				
ID	Woollen Fabric with Interlining D-ME9201	0.445	19.740				
IE	Woollen Fabric with Interlining E-MBB95	0.735	25.540				
IF	Woollen Fabric with Interlining F-MBB70	0.710	24.978				

4.3 Test methods

This study analyzed the relationships and correlation coefficients between physical properties of interlinings and hand value by a subjective test (Daukantiene and Gutauskas, 2002, Hui et al., 2004, Kan and Wong, 2015, Kim and Ryu, 2008). Then, it explored the relationships between physical properties and low-stress mechanical properties by the Kawabata Evaluation for Fabric System (Kato Tech Co., Ltd.) – KES-F test objectively (Kawabata, 1980a, Chen et al., 2001, Alamdar-Yazdi and Amirbayat, 2000, Ji and Lee, 2016). In this study, hand value refers to stiffness, softness, smoothness and total hand value while physical properties include thickness, weight and adhesive density (Grinevičiūtė and Gutauskas, 2004, Jeguirim et al., 2010).

4.3.1 Subjective evaluation of fabric handle

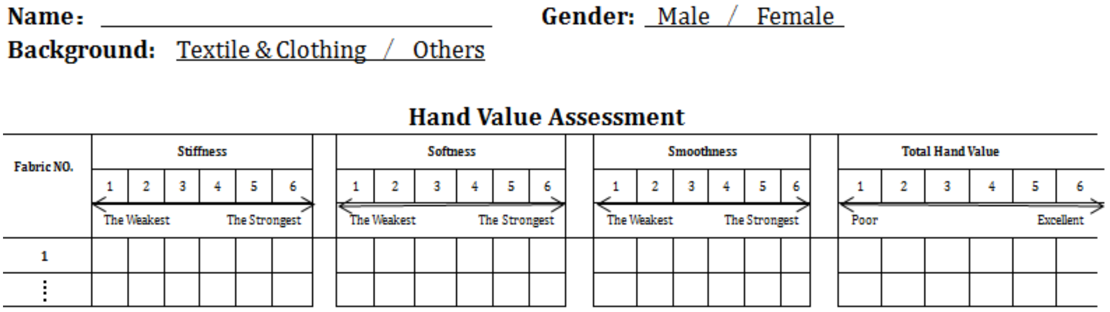
AATCC EP5 describes guidelines for presentation of fabrics for the evaluation of hand value. Following this standard, a specimen was presented to an evaluator. Evaluators were blindfolded, so they could not see the fabrics, but could feel and evaluate the handle freely (Barker and Scheininger, 1982). For this study, the panel size of judges was 40 and the judges conducted subjective assessment on seven specimens, and each specimen was retested three times (Pan, 2006, Alley, 1980, Cook, 1997). Specimens were evaluated by individuals who scored stiffness, softness, smoothness and total hand value of woollen fabric with and without interlining based on personal suit wearing experience in real life. Two groups of judges comprised males and females, composed of university students, with and without textile backgrounds. Judges communicated evaluation rankings through a recorded questionnaire, Figure 4.1 shows details (Choi and Lee, 2006). The evaluation scale ranged from 1 to 6 (1 was the weakest and 6 the strongest value of the handle properties) as shown in Table 4.2 which was used for the assessment. In order to acquire the measurement results with less diversity, judges were asked to follow designated handing gesture. The essential steps involved in the subjective handle evaluation include the following steps:

(i)Handing gesture for stiffness- pick up the sample, rub and press the sample with thumb and finger.

(ii)Handing gesture for softness- squeeze the sample with thump, finger and palm to make a fist.

(iii)Handing gesture for smoothness- use fingertip to touch the sample with little pressure; hold down the fabric with one hand, stroke with another.

(iv)Total hand value- the evaluation based on summer suit fabric experiences and request.



Name： ______________________ **Gender:** Male / Female
Background: Textile & Clothing / Others

Hand Value Assessment

Fabric NO.	Stiffness						Softness						Smoothness						Total Hand Value					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
	The Weakest					The Strongest	The Weakest					The Strongest	The Weakest					The Strongest	Poor					Excellent
1																								
⋮																								

Figure 4. 1 Questionnaire

Table 4. 2 Evaluation ratings and ranking information for judgement on

Stiffness, Smoothness, Softness and Total hand value					
1	2	3	4	5	6
The Weakest	←			→	The Strongest

4.3.2 Objective measurement of fabric handle

Low-stress mechanical properties were measured by KES-F after keeping specimens in standard conditions of 65±2% RH and 21±2°C for at least 24 hours before measurement and the whole testing period. The measurement detailed test specifications are shown in Table 4.3.

Table 4. 3 Low-stress mechanical properties

Properties	Symbols	Characteristics	Unit
Tensile	EMT	Extensibility, Strain	%
	LT	Linearity of Load	-
	WT	Tensile Energy	gf.cm/cm
	RT	Tensile Resilience	%
Bending	B	Bending Rigidity	gf.cm/cm
	2HB	Hysteresis per unit length	gf.cm/cm
Shearing	G	Shear Stiffness	gf.cm.degree
	2HG	Hysteresis at 0.5 degree	gf.cm
	2HG5	Hysteresis at 5 degree	gf.cm
Surface	MIU	Coefficient of Friction	-
	MMD	Mean Deviation of MIU	-
	SMD	Surface Roughness	micron
Compression	LC	Linearity of Compression	-
	WC	Compression Energy	gf.cm/cm
	RC	Compression Resilience	%

4.3.3 Statistical analysis

Pearson’s correlation was used for figuring out the relationship between physical properties on both hand value and low-stress mechanical properties of woollen fabric with and without interlinings. Specimens in Table 4.1 were tested to explore whether the physical properties are highlighted under hand value evaluation and which physical properties affect the low-stress mechanical properties that cause the different fabric hand values. IBM SPSS Statistics 22.0 (IBM Corp., Armonk, NY) was used for analyzing the statistical relationship with a 95% confidence level.

4.4 Reliability check

In order to make sure the subjective test results are effective, Cronbach's alpha test was conducted and all hand value reliability statistics are highly effective, ranging from 0.703 to 0.781 (values >0.7 for Cronbach's alpha are considered a good internal consistency) (Santos, 1999, Chung et al., 1998). Details Hand Value Cronbach's Alpha Test is shown in Table 4.4.

Table 4. 4 Hand value Cronbach's Alpha test of subjective test

	Stiffness	Softness	Smoothness	Total Hand Value
Cronbach's Alpha	0.724	0.703	0.781	0.771

4.5 Physical properties internal relationship

Twelve specimens come from interlinings and woollen fabric with interlinings (A to F and IA to IF). Figure 4.2 shows the scatter plot of thickness, weight and adhesive density. It reflects there are relationships between thickness, weight and adhesive density properties and the thickness and weight have dramatically increased after woollen fabrics fused with interlinings. Table 4.5 shows statistical analysis of the correlations among physical properties including thickness, weight and adhesive density of fabric. The correlation coefficient is a measure of the degree of linear correlation (dependence) between two variables. The given value is from +1 to -1 inclusively, where 1 represents total position correlation, 0 represents no correlation, and -1 represents total negative correlation. N refers to the number of data points measured. In this chapter, significance indicates 95% confidence level; all correlations are regarded as significant when the significance value is equal to or less than 0.05 (Kan and Wong, 2015). From Table 4.5, the significance level of the correlation between thickness and weight is 0.000 and between thickness and adhesive density is 0.044, both less than 0.05. Thus, the correlations between thickness, weight and adhesive density are significant. The coefficient of correlation between thickness and weight is 0.874, which shows a positive correlation. However, the coefficient of thickness and adhesive density is -0.588 which shows a negative correlation.

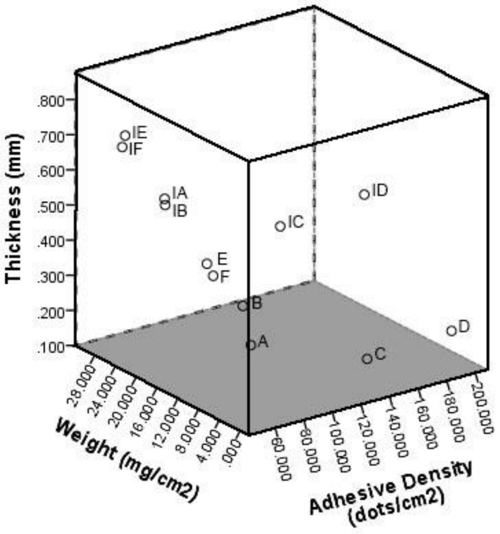


Figure 4. 2 Relationship among thickness, weight and adhesive density

Table 4. 5 Physical properties correlations (N=12)

		Weight	Adhesive Density	Thickness
Thickness	Pearson Correlation	0.874**	-0.588*	1
	Sig. (2-tailed)	0.000	0.044	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.6 Subjective test relationships

The most sensitive skin areas are the face, the torso and the hand (Tawil et al., 2012). This study uses questionnaire to evaluate the fabric hand value by real subjects and analyses the relationships between hand value and woollen fabric’s physical properties, with and without interlinings. This study explores whether the hand value is highlighted under quality evaluation (Yim and Kan, 2016). In order to determine the physical properties correlation level, statistical data are analysed by each physical property as a single variable in a group. I, IA, IB and I, IC, ID and I, IE, IF are classified as weight, adhesive density and thickness single variable groups respectively (Cross twill 2/2 and Cross Twill 3/1 have the same mixed fabric in the unit area, which can be seen as the same structure). The relationships between physical properties and hand value are shown in Figure 4.3 to Figure 4.5. Correlations statistics of physical properties and hand value are reflected in Table 4.6.

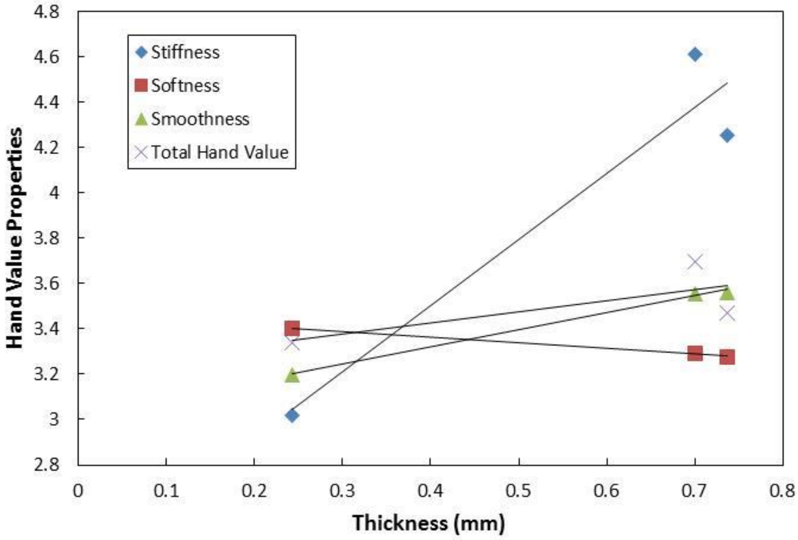


Figure 4. 3 Relationship between thickness and hand value properties (Stiffness, Softness, Smoothness, and Total Hand Value)

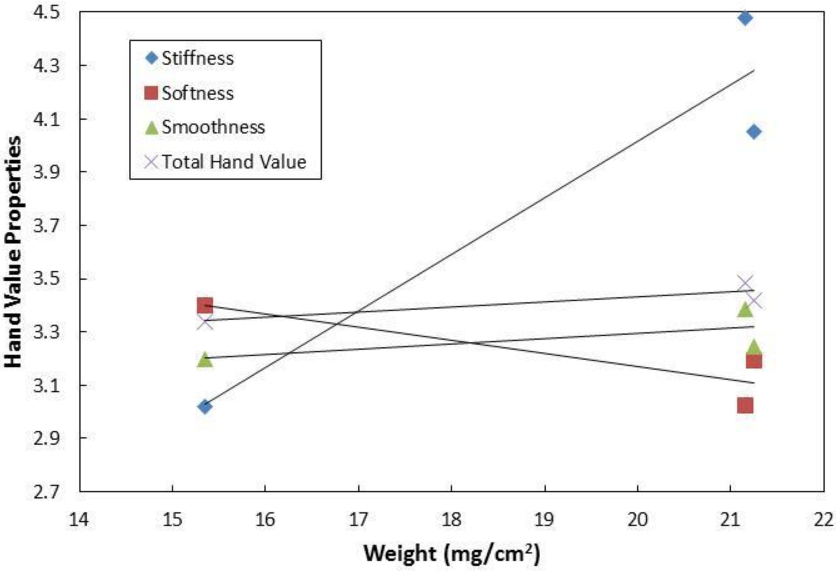


Figure 4. 4 Relationship between weight and hand value properties (Stiffness, Softness, Smoothness, and Total Hand Value)

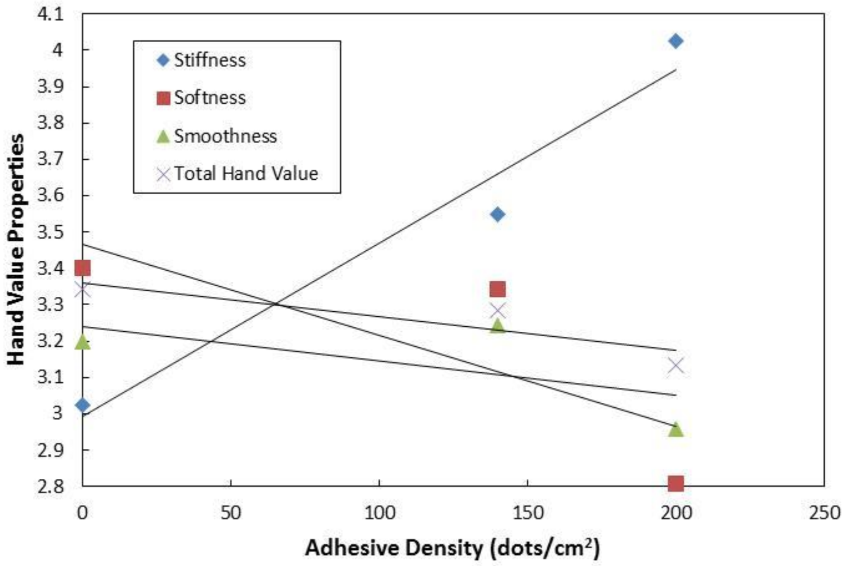


Figure 4. 5 Relationship between adhesive density and hand value properties (Stiffness, Softness, Smoothness, and Total Hand Value)

Table 4. 6 Correlation statistics of physical properties and hand value (N=360)

		Stiffness	Softness	Smoothness	THV
Thickness	Pearson Correlation	**0.447****	**-0.120***	**0.127***	**0.123***
	Significance (2-tailed)	**0.000**	**0.022**	**0.016**	**0.019**
Weight	Pearson Correlation	**0.458****	**-0.123***	**0.130***	**0.134***
	Significance (2-tailed)	**0.000**	**0.020**	**0.014**	**0.011**
Adhesive Density	Pearson Correlation	**0.223****	**-0.244****	-0.081	-0.065
	Significance (2-tailed)	**0.000**	**0.000**	0.127	0.221

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.6.1 Fabric thickness and hand value properties

Figure 4.3 shows that when fabric thickness increases, the fabric properties of stiffness, smoothness and total hand value have an increasing trend, but the tendency of softness property decreases. As the thickness increases, yarn density increases and the friction of inter-yarn develops. Woollen fabric becomes fuller and does not easily distort and maintains the fabric silhouette with more smooth and it becomes stiffer. However, the lamination structure of fusible interlining determines the fabric compression involved, which reflects a weaker softness performance (Ali and Begum, 1994). For the total hand value evaluation, evaluators tend to the thicker fabric which is stiffer and smoother. Statistical analysis of thickness correlations with hand value properties reflected in the second to the third rows of Table 4.6 shows that thickness property gives positive correlation value of 0.447, 0.127 and 0.123 in terms of stiffness, smoothness and THV respectively. While thickness has a negative correlation of -0.120 on softness. The correlation coefficient has a significance level of 0.000 between thickness and stiffness, which is less than 0.01. In addition, the correlation coefficients also have the significance level of 0.022, 0.016 and 0.019 on softness, smoothness and THV respectively. Thus, the correlation between stiffness and thickness is significant, while softness, smoothness and THV have less significant correlations. Therefore, thickness is a significant factor affecting hand value properties of woollen fabric with and without interlinings. The thicker is the fabric, the stiffer, smoother and better hand value the fabric has.

4.6.2 Fabric weight and hand value properties

Figure 4.4 reveals that stiffness, smoothness and total hand value increase with increase in weight, while softness decreases at the same time. This implies that the fabric weight affects the handle properties. It is because higher weight has higher yarn density. Bulkier fabric is a formed impression of stiffer feeling of fabric. Fabric with a compact weave structure has high smoothness. However, with the inter-yarn friction increases, fabric softness decreases. In terms of total hand value evaluation, evaluators prefer massy fabric which is stiffer and smoother. Correlations of weight and hand value properties are shown in the fourth to fifth rows of Table 4.6. It can be seen that the correlation values of weight and stiffness, softness, smoothness and THV are 0.458, -0.123, 0.130 and 0.134 respectively. Weight and stiffness has a significance level of 0.000, which is less than 0.01. In addition, the correlation values of weight and softness, smoothness and THV are 0.020, 0.014 and 0.011 respectively (less than 0.05). Thus, weight is a significant impact factor of hand value. Woollen fabric with interlinings has higher stiffness, smoothness and THV, however this decreases the softness.

4.6.3 Fabric adhesive density and hand value properties

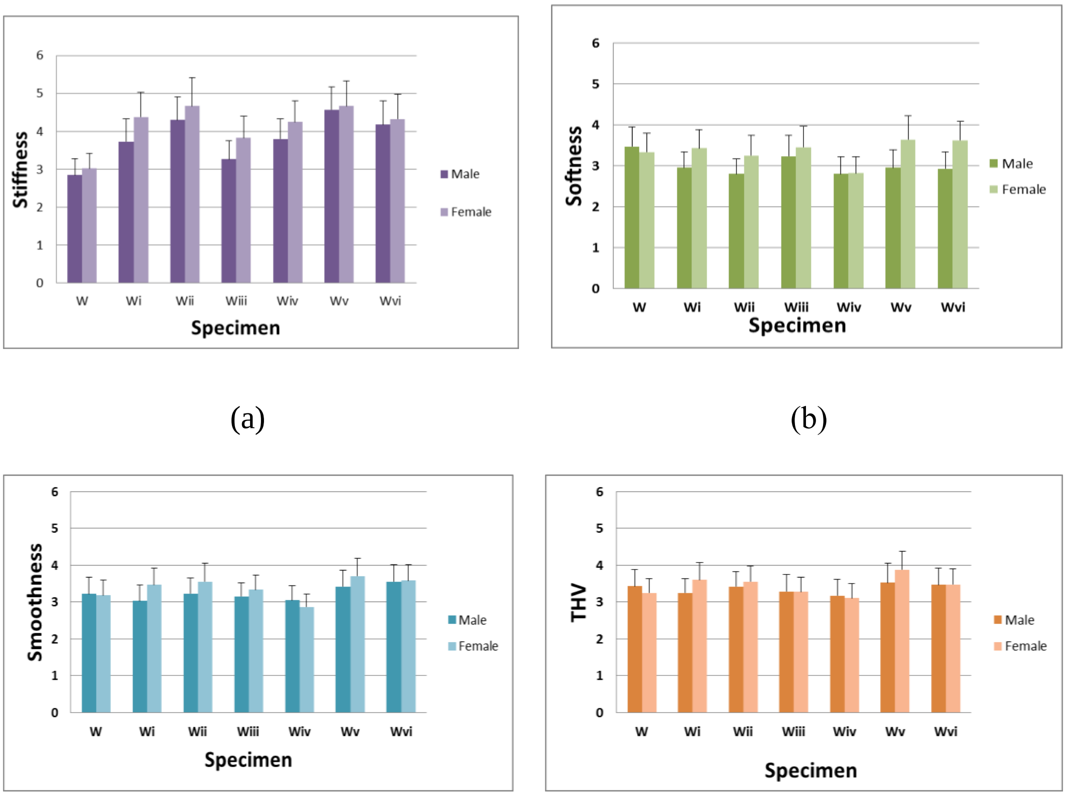
Figure 4.5 shows the efficiency of adhesive density on woollen fabric with interlinings which affect the hand value properties. Figure 4.5 reflects the stiffness value increases when the adhesive point density increases, however, the softness, smoothness and total hand value decrease meanwhile. The more adhesive contact points, the better is the fusing between fabric and interlining which makes the fabric more rigid and shows a stiffer performance. Adhesive points increase the inter-yarn force and yarn friction, which decreases the softness of fabric. However, adhesive density does not have significantly impact on fabric smoothness and THV. This may be due to adhesion points not having much effect on fabric surface property. Table 4.6 indicates there are correlations between adhesive density and stiffness and softness with values of 0.458 and -0.244 respectively. Both the stiffness and softness have significance coefficient level of 0.000 (less than 0.001). However, the significance levels of smoothness and THV are 0.127 and 0.221 which are more than 0.001. Thus, adhesive density affects the fabric stiffness and softness performance. However, it is not significant factor in terms of smoothness and THV properties.

4.6.4 Gender influence

For subjective hand evaluation, 20 males and 20 females were invited and their average ratings on the specimens are analyzed and shown in Table 4.7. Male and female ratings are similar. The differences in rating between each sample of male and female are less than 0.4 (mean value) and total hand value shown the minimum difference with 0.16. Figure 4.6 (a-d) shown the primary hand value and total hand value by gender influence, and the results are valid and consistency. Figure 4.7 shows radar chart of the hand value evaluation results by gender influence. It reflects stiffness has the highest score on both male and female judges. Females give a higher rate than males especially in the stiffness and softness. Male and female have the similar score in terms of THV and smoothness. Figure 4.8 shows that there are significant changes after fusing the interlinings in terms of the stiffness and softness on both male and female judges. The stiffness value has a remarkable increase for male and female judges and the softness value decrease especially for male judges. The relationship between gender and hand value is shown in Table 4.8. From the results of T-test, it reflects that only softness has the significant correlation with gender evaluation by 0.030 which is less than 0.05. This shown that fabric softness has significant correlation with gender influence on the hand value evaluation. In addition, all the T-test values are negative which reflects that females give higher sores than males. This may be due to the fact that female is more sensitive than male for fabric hand value evaluation.

Table 4. 7 Influence of gender on subjective hand rating

Attributes	**Stiffness**			**Softness**			**Smoothness**			**THV**		
Specimen	Male	Female	Difference	Male	Female	Difference	Male	Female	Difference	Male	Female	Difference
W	2.85	3.20	0.17	3.47	3.33	0.14	3.22	3.18	0.04	3.43	3.25	0.18
Wi	3.73	4.38	0.65	2.95	3.43	0.48	3.03	3.47	0.44	3.25	3.60	0.35
Wii	4.30	4.67	0.37	2.80	3.25	0.45	3.23	3.55	0.32	3.42	3.55	0.13
Wiii	3.27	3.83	0.56	3.23	3.45	0.22	3.15	3.33	0.18	3.29	3.28	0.01
Wiv	3.80	4.25	0.45	2.8	2.82	0.02	3.05	2.87	0.18	3.17	3.10	0.07
Wv	4.57	4.67	0.10	2.95	3.64	0.69	3.42	3.70	0.28	3.52	3.88	0.36
Wvi	4.18	4.33	0.15	2.93	3.62	0.69	3.55	3.58	0.03	3.47	3.48	0.01
Mean	3.81	4.16	0.35	3.02	3.36	0.38	3.23	3.38	0.21	3.36	3.45	0.16



(a) (b)

(c) (d)

Figure 4. 6 Fabric hand value results by gender influence (a-d)

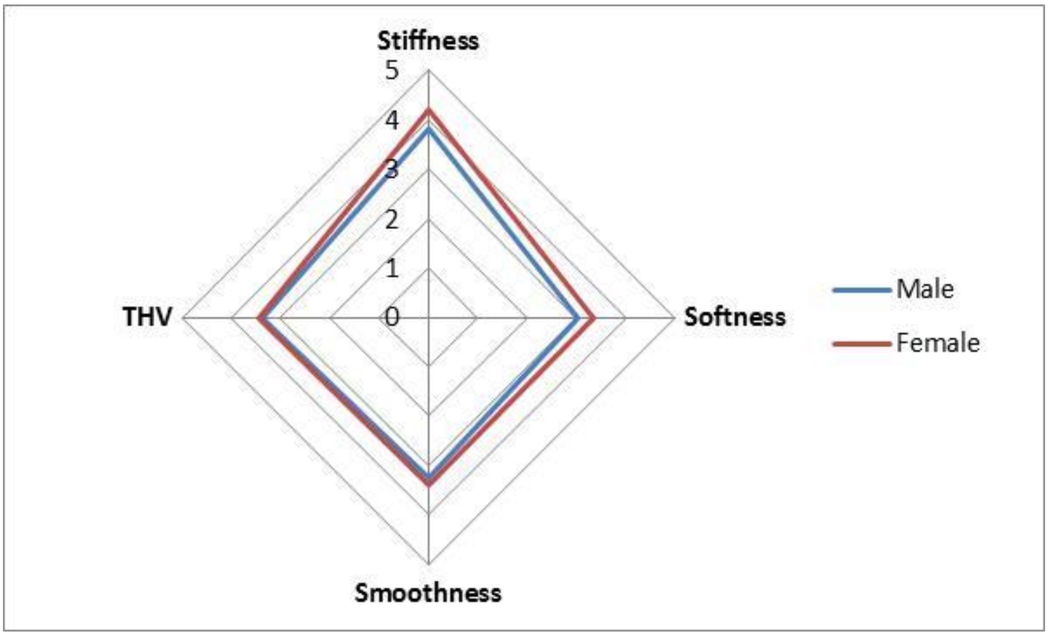


Figure 4. 7 Influence of gender on fabric hand value results by gender influence

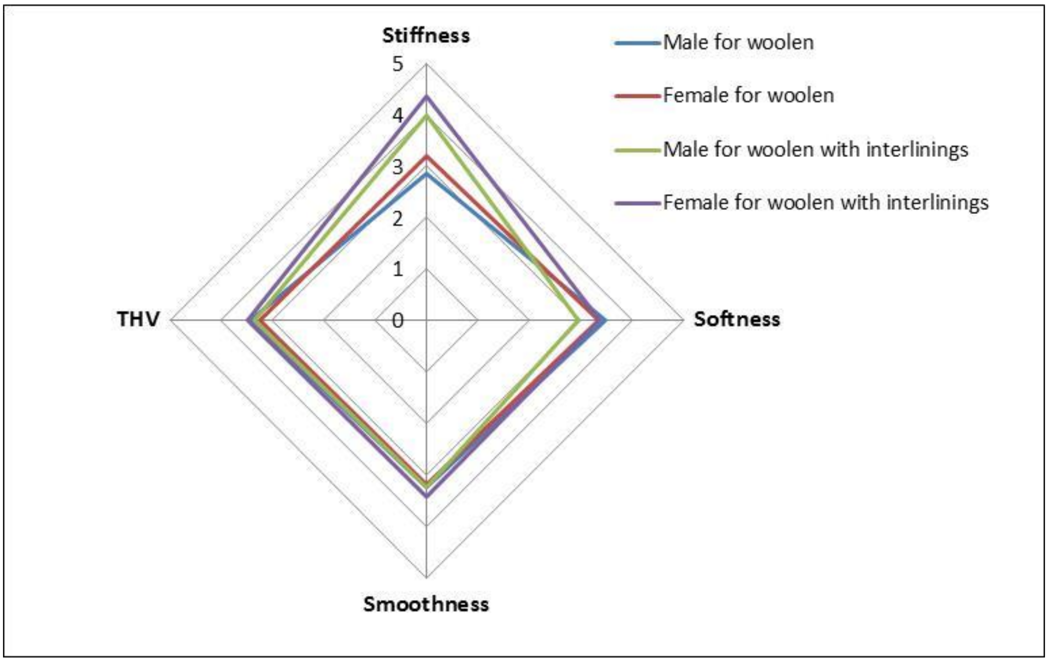


Figure 4. 8 Influence of gender on hand value of woollen fabric with and without interlinings

Table 4. 8 Statistical relationship between gender and hand value

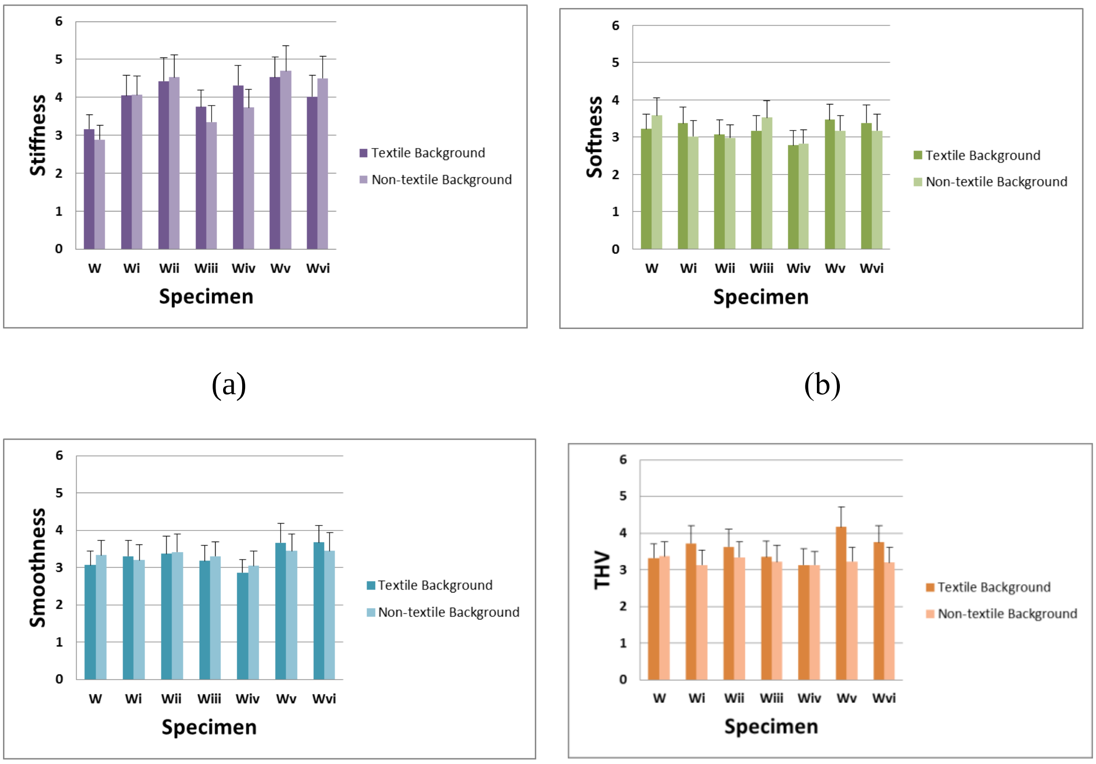
	Stiffness			**Softness**			**Smoothness**			**THV**		
Gender	**Mean**	**T**	**Sig.(2-tailed)**	**Mean**	**T**	**Sig.(2-tailed)**	**Mean**	**T**	**Sig.(2-tailed)**	**Mean**	**T**	**Sig.(2-tailed)**
Male	3.814	-1.248	0.236	3.019	-2.457	**0.030**	3.236	-1.140	0.276	3.364	-0.766	0.459
Female	4.190	-1.248	0.236	3.363	-2.457	**0.030**	3.383	-1.140	0.276	3.449	-0.766	0.459

4.6.5 Education background influence

In terms of judge's education background influence on subjective hand value evaluation, 20 textile and 20 non-textile background judges were invited and their average ratings on the specimens are analyzed and shown in Table 4.9. The evaluation results of this group's rating are similar with less than 0.4 score difference. Figure 4.9 (a-d) shown the primary hand value and total hand value by education background influence, the results are valid and consistency on both education backgrounds. Stiffness values are obviously changed after fusing interlinings in comparison with other primary hand values. Figure 4.10 shows that both textile and non-textile background judges have the similar score and non-textile background judges rate a little bit higher on the softness value. All the results are around 3 and stiffness has the highest score while THV has the lowest value. Figure 4.11 reflects that there are significant differences in terms of the stiffness, softness and THV before and after fuse interlinings on woollen fabric. The stiffness value has obviously increasing, while softness value decreases. Judges with textile background give a higher value comparing with the non-textile background judges. The relationship between judge education background and hand value is shown in Table 4.10. T-test reflects that only total hand value has the significant correlation with education background evaluation by 0.024 which is less than 0.05. Furthermore, the T-test value of stiffness, softness and total hand value are positive which implicates that judges with textile background have higher sores for fabric hand value evaluation. This is because judges have the textile background are more sensitive than the judges without textile background for fabric hand value evaluation.

Table 4. 9 Influence of education background on subjective hand rating by judge

Attributes	**Stiffness**			**Softness**			**Smoothness**			**THV**		
Specimen	Textile	Non-Textile	Difference	Textile	Non-Textile	Difference	Textile	Non-Textile	Difference	Textile	Non-Textile	Difference
W	3.17	2.89	0.28	3.22	3.58	0.36	3.07	3.33	0.26	3.32	3.37	0.05
Wi	4.05	4.07	0.02	3.37	3.02	0.35	3.30	3.20	0.10	3.72	3.13	0.59
Wii	4.43	4.53	0.10	3.07	2.98	0.09	3.37	3.42	0.05	3.63	3.34	0.29
Wiii	3.75	3.35	0.40	3.17	3.52	0.35	3.18	3.3	0.12	3.35	3.22	0.13
Wiv	4.32	3.73	0.59	2.78	2.83	0.05	2.87	3.05	0.18	3.13	3.13	0.00
Wv	4.53	4.70	0.17	3.47	3.17	0.30	3.67	3.45	0.22	4.17	3.23	0.94
Wvi	4.02	4.50	0.48	3.38	3.17	0.21	3.68	3.45	0.23	3.75	3.20	0.55
Mean	4.04	3.97	0.07	3.21	3.18	0.03	3.31	3.31	0.01	3.58	3.23	0.35



(a) (b)

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Figure 4. 9 Fabric hand value results by education background influence (a-d)

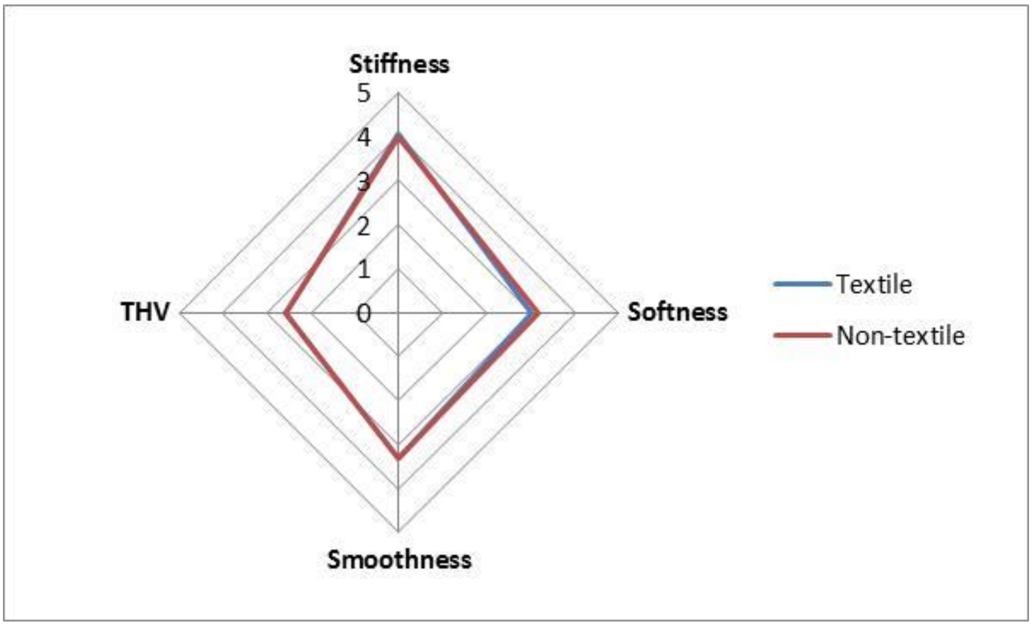


Figure 4. 10 Influence of education background on fabric hand value results

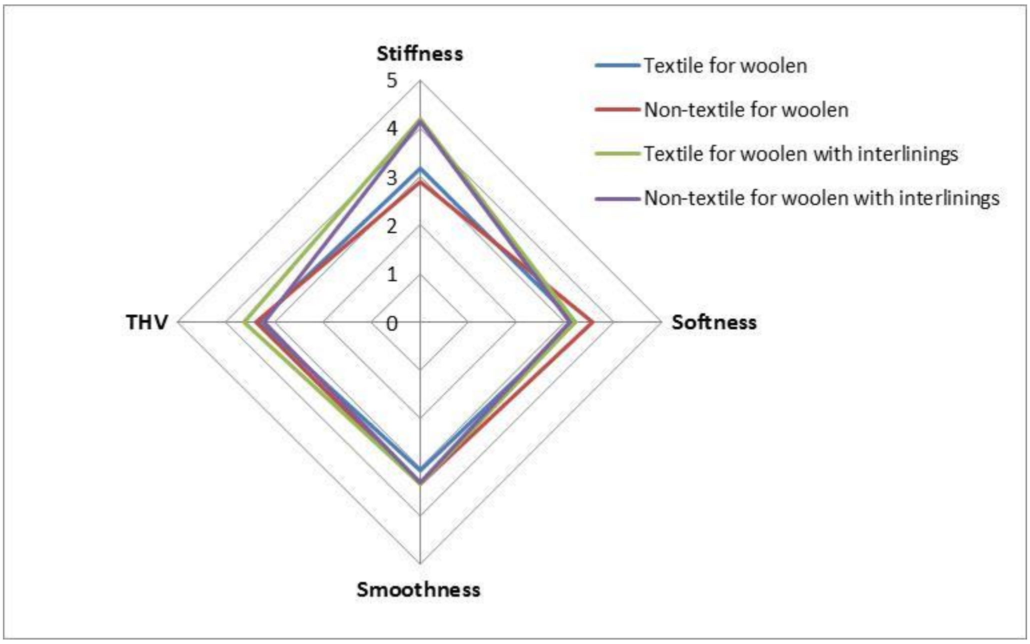


Figure 4. 11 Influence of education background on hand value of woollen fabric with and without interlinings

Table 4. 10 Statistical Relationship between the education background and hand value

	Stiffness			**Softness**			**Smoothness**			**THV**		
Education Background	**Mean**	**T**	**Sig.(2-tailed)**	**Mean**	**T**	**Sig.(2-tailed)**	**Mean**	**T**	**Sig.(2-tailed)**	**Mean**	**T**	**Sig.(2-tailed)**
Textile	4.039	0.230	0.822	3.021	0.198	0.847	3.306	-0.068	0.947	3.581	2.577	**0.024**
Non-Textile	3.967	0.230	0.822	3.181	0.198	0.847	3.314	-0.068	0.947	3.231	2.577	**0.024**

4.7 Objective Test Correlations

This chapter analyses the relationships between fabric physical properties and low-stress mechanical properties in order to find the implications in terms of fabric hand value evaluation. KES-F has been used to measure low-stress mechanical properties in terms of tensile, bending, shearing, surface and compression.

4.7.1 Tensile properties

Table 4. 11 Pearson's correlation between the physical properties and tensile

Tensile	Correlations on	Adhesive density	Thickness	Weight
EM	Pearson Correlation	0.438	-0.590	-0.650
	Sig. (2-tailed)	0.385	0.218	0.162
LT	Pearson Correlation	**-0.899***	0.747	0.697
	Sig. (2-tailed)	**0.015**	0.088	0.124
WT	Pearson Correlation	0.386	-0.346	-0.479
	Sig. (2-tailed)	0.450	0.501	0.337
RT	Pearson Correlation	-0.417	0.191	0.383
	Sig. (2-tailed)	0.410	0.718	0.454

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

LT is the linearity of load extension curve. This parameter is a measure of the deviation of the extension curve straight line. LT determines the tensile strength along with the change in fabric extension treatment and reflects the elasticity of the fabric. A lower value of LT is supportive to have a better tensile strength and stiffer fabric (Deshmukh and Shetty, 2008, Sun and Stylios, 2005, Lam et al., 2011). Table 4.11 shows the correlation results, the interlining adhesive density is negatively related with LT value with R= -0.899. It reflects that the larger is the adhesive density, the less is the LT value while elasticity and stiffness are higher. This may indicate that fabric has a better fusing contact with the increased adhesive points, which makes the fabric stiffer. The increased yarn interaction develops yarn force which makes the fabric have higher elasticity. Table 4.11 indicates that the relationships are significant at the 0.01 level (two-tailed). This implies that the fabric adhesive density affects the tensile property; the less is the adhesive density of interlinings, the more extensible woollen fabric with interlining is. However, WT, RT and EMT do not show a significant relationship with fabric physical properties. Comparing with these four tensile properties, LT has an integrated tensile evaluation. This may be because tensile property is not the significant low-stress mechanical property affected by these three physical properties.

4.7.2 Bending Properties

Table 4. 12 Pearson's correlation between the physical properties and bending

Bending	Correlations on	Adhesive density	Thickness	Weight
B	Pearson Correlation	**-0.842**[*]	0.773	0.764
	Sig. (2-tailed)	**0.036**	0.071	0.077
2HB	Pearson Correlation	-0.808	0.920**	0.981**
	Sig. (2-tailed)	0.052	0.009	0.001

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Bending properties of woollen fabric with and without interlinings, such as bending rigidity (B) and bending hysteresis per unit length (2HB) are measured (Lam et al., 2011). Bending rigidity is the ability of a fabric to resist the bending moment, which is related to the quality of stiffness when a fabric is handled (Lam et al., 2011). A higher value indicates greater resistance to bending. 2HB refers to the recovery ability of a fabric after being bent. The smaller the value of 2HB, the better the bending recovery of the fabric will be (Kan and Lam, 2013b, Yang et al., 2013). Table 4.12 presents the correlation between the physical properties and bending. It reflects that adhesive density, thickness and weight affect bending property. Adhesive density has a negative correlation with bending rigidity by R= -0.842. It also has a significant correlation with p=0.036 (less than 0.05). Adhesive density affects the ability of resistance to bending, the greater adhesive density, the softer is the woollen fabric with interlinings. This is due to because the increased adhesive contact at yarn crossover points (Avinc et al., 2011). It leads to enhance the fabric structure to make better robustness and have a soft handle. Table 4.12 shows positive correlation between 2HB and thickness with R=0.920 and weight with R=0.981. The significant correlations are 0.009 and 0.001 (less than 0.01). This is assumed that thickness and weight are important factors to affect the bending recovery ability. This is primarily attributed to enhance the inter-yarn friction with the thickness and weight increase.

4.7.3 Shearing Properties

Table 4. 13 Pearson's correlation between the physical properties and shearing

Shearing	Correlations on	Adhesive density	Thickness	Weight
G	Pearson Correlation	0.298	-0.086	-0.024
	Sig. (2-tailed)	0.567	0.872	0.964
2HG	Pearson Correlation	0.268	0.029	0.075
	Sig. (2-tailed)	0.607	0.956	0.888
2HG5	Pearson Correlation	0.067	0.180	0.242
	Sig. (2-tailed)	0.900	0.734	0.644

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The study of shearing properties of woollen fabric with interlinings includes shear stiffness (G), shear stress at 0.50 (2HG) and shear stress at 50 (2HG5). G refers to the ability of the fabric to resist shear stress which is the ease of the fibers slide against each other (Kan and Lam, 2013b). 2HG and 2HG5 indicate the ability of the fabric to recover after applying a shear stress of 2.50 and 0.50 shear angles. Table 4.13 shows there are no correlation between interlining physical properties and shearing properties. In general, shear hysteresis 2HG and 2HG5 represent the energy that the fabric loses during shear deformation. The energy loss is caused primarily by friction occurring at points where warp and weft yarns cross each other (Geršak, 2004). Shear properties may be more related to fabric weave (Lam et al., 2011); adhesive density, thickness and weight are not significant impact factors to affect the shear of woollen fabric with interlinings.

4.7.4 Surface properties

Table 4. 14 Pearson's correlation between the physical properties and surface

Surface	Correlations on	Adhesive density	Thickness	Weight
MIU	Pearson Correlation	0.004	0.232	0.126
	Sig. (2-tailed)	0.993	0.658	0.812
MMD	Pearson Correlation	-0.408	0.351	0.417
	Sig. (2-tailed)	0.422	0.495	0.411
SMD	Pearson Correlation	**-0.899***	**0.823***	0.782
	Sig. (2-tailed)	**0.015**	**0.044**	0.066

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Surface properties include MIU, which is the coefficient of friction between the fabric surface and measuring contactor. Geometrical roughness (SMD) is the variation in surface geometry of the fabric. SMD refers to the fabric surface evenness (Fontaine et al., 2005). Table 4.14 shows there are correlations between SMD and adhesive density with R= -0.899 and thickness with R= 0.823. This reflects that interlining affects the surface evenness of the woollen fabric. This shows that the higher is the adhesive density and thinner are the interlinings, the smoother is the woollen fabric with interlining. This can be interpreted by the interaction between the interlining and woollen fabric. The surface of the woollen fabric is penetrated by fused adhesive points through cracks in the surface (Yang et al., 2013). The significant coefficients of SMD and adhesive density and thickness are 0.015 and 0.044 respectively (less than 0.05). This shows that adhesive density and thickness are two significant important factors of surface property.

4.7.5 Compression Properties

Table 4. 15 Pearson's correlation between the physical properties and compression

Compression	Correlations on	Adhesive density	Thickness	Weight
LC	Pearson Correlation	0.128	0.343	0.342
	Sig. (2-tailed)	0.809	0.505	0.507
WC	Pearson Correlation	**-0.916***	**0.961****	**0.986****
	Sig. (2-tailed)	**0.010**	**0.002**	**0.000**
RC	Pearson Correlation	**-0.815***	0.529	0.601
	Sig. (2-tailed)	**0.048**	0.281	0.207

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The study of compression properties includes compressional linearity (LC), compressional energy (WC) and compressional resilience (RC). LC is the linearity of compression thickness curve. The WC value represents the fluffy feeling of the fabric.

RC indicates the recoverability of the fabric after the compression force is removed (Kan and Lam, 2013b). Table 4.15 reflects the thickness and weight properties positively affect WC value with R= 0.961 and R= 0.986. A higher WC means greater fluffy feeling of the fabric. This reveals that increased thickness and weight improve the fluffy feeling of woollen fabric. This can be interpreted by the increased yarn density request more recovering energy when given by the pressure in the measurement process. The significant correlations between them are 0.002 and 0.000 (less than 0.01) which means that thickness and weight significantly affect the compression property of woollen fabric with interlinings. However, adhesive density has a negative coefficient with WC and RC with R= -0.916 and R= -0.815. The significant coefficient values are p= 0.010 and p= 0.048 (less than 0.05). This reflects that adhesive points increase the inter-yarn friction which makes the woollen fabric not fluffy and springy. The analysis indicates adhesive density, thickness and weight significantly impact compression of woollen fabric with interlinings. In brief, the thicker and heavier the fabric is, the fuller and elastic it is. The less is the adhesive density, the fluffier the fabric is.

4.8 Conclusion

This study reported two important calculations of subjective evaluation and objective measurement in terms of two relationships: physical properties and hand value; physical properties and low-stress mechanical properties of woollen fabric with and without interlinings. Subjective evaluation was performed to reviewed physical properties, including thickness, weight and adhesive density, and statistical analysis is conducted to find significant correlations of these properties with hand value of woollen fabric with interlinings. Thickness and weight properties were highly related with stiffness, softness, smoothness and THV. Adhesive density of interlining affected fabric stiffness and softness. In addition, the comprehensive evaluation of hand values, the respondents shown that both gender and education background of judges affected the fabric hand value evaluation results. The T-test analysis was conducted to evaluate the answers given in the subjective hand value evaluation. Judge’s gender and education background affected the fabric hand value evaluation. Judge gender affected on softness evaluation through the statistical analysis, however, judges gender did not have significant correlation with stiffness, smoothness and total hand value evaluation. Female have higher tactile sensation on fabric handle by giving higher rating. Judges education background did effect in THV evaluation, however, it did not have significant correlation with stiffness, softness and smoothness evaluation statistically. Judges with textile background have higher tactile sensation on fabric handle by giving higher score.

In objective measurement by the KES-F system, adhesive density and thickness properties were found to play an important role in affecting the fabric low-stress mechanical properties, weight properties was also a significant factor. In terms of the low-stress mechanical properties, the severity of the impact properties were bending, compression, surface and tensile in sequence, details are shown in Table 4.16. The study had the implications of the appeal design, manufacture and retailing in terms of woollen fabric in men's suits.

Table 4. 16 Physical properties and low-stress mechanical properties correlation

Physical properties	Adhesive density	Thickness	Weight
Correlative low-stress mechanical properties	Tensile Bending Surface Compression	Bending Surface Compression	Bending Compression

CHAPTER 5 INVESTIGATION OF EFFICIENT OF PRINTABLE INTERLINING IN PLACE OF FUSIBLE INTERLINING ON LOW-STRESS MECHNICAL PROPERTIES AND HANDLE OF WOOLLEN FABRICS

5.1 Introduction

To improve the fabric processing aspects of garment production systems, the textile and apparel industries have in recent years trying to develop various techniques. Printing is a cost-effective process for garment manufacture. In this study, printing technique applied to substitute the fusing technique on woollen fabrics in suit making. In this chapter, the woollen fabrics with fusible interlinings and printable interlinings have been evaluated and compare the low-stress mechanical properties and hand values. It finds that printable interlinings can in place of the fusible interlinings with similar low-stress mechanical properties and better hand value performances evaluated by Kawabata Evaluation System of Fabric (KES-F).

KES-F is a popular objective fabric evaluation method. It includes 16 low-stress mechanical properties and primary hand value, total hand value (THV) as well. Low-stress mechanical properties involve tensile, bending, shearing, surface and compression properties. Primary hand value has a various combination, such as men's suit in winter concludes stiffness, smoothness, fullness & softness and men's suit in summer includes stiffness, anti-drape, fullness, crispness. THV is evaluated based on mechanical properties and primary hand value.

Two groups of fabrics which are woollen fabric with fusible interlinings and printable interlinings have compared. The purpose of this chapter is explored the printing method in place of traditional fusing interlinings on woollen fabrics. Printing is process and cost efficient technique applying for garment manufacture, especially for the mass garment manufacture.

5.2 Experimental

5.2.1 Woollen fabric (Fabric 1)

There are three kinds of fabrics which are woollen fabrics (Fabric 1); woollen fabrics with fusible interlinings (Fabric 2); and woollen fabrics with printable interlinings (Fabric 3). Each fabric has three different fabric weights which are light, medium and heavy weight. Specification of woollen fabrics shows in Table 5.1 Specification of woollen fabrics.

Table 5. 1 Specification of woollen fabrics

Samples	Thickness (mm)	Weight (mg/cm^2)	Component woollen	Structure
Light Weight	0.30	13.823	100%	plain weave
Medium Weight	0.58	20.248	100%	plain weave
Heavy Weight	0.69	23.865	100%	plain weave

5.2.2 Woollen fabric with fusible interlining (Fabric 2)

Woollen fabrics fused different fusible interlinings were examined. Fusible interlinings supported from two brands which were CO. KG Vileseline and KUFNER.

All the fusible interlining substrates are woven and polyethersulfone (PES) glue is used on the polyester fabric. According to the suitability, interlinings selections based on the respective brand's recommendation. The specification of fusible interlinings has shown in Table 5.2.

Table 5. 2 Specification of fusible interlinings

Samples	**Thickness (mm)**	**Weight (mg/cm^2)**	**Component**	**Structure**	**Adhesive Density (dots/cm^2)**
MBB60	0.380	6.2	100%PES	Cross Twill 3/1	66
FW2048	0.38	4.8	100% PES	Cross Twill 2/2	110
MBB80	0.593	8.4	100%PES	Cross Twill 3/1	52
FW2065	0.40	6.3	100% PES	Cross Twill 2/2	42
MBB95	0.492	9.3	100%PES	Cross Twill 3/1	52
FW2080	0.50	8.2	100% PES	Cross Twill 2/2	52

Fusible interlinings are fabrics coated with some form of resin or adhesive that serves as bonding resin to hold the interlining to the woollen fabric. Fusing is the process of bonding fabric layers by application of heat and pressure for a specific amount of time. In this experiment, fusing parameters of the woollen fabric were: 115°C; speed: 3m/min; pressure: 5N/cm2. A continuous fusing machine (PPS-L600, Maschinenfabrik Herbert Meyer GmbH, Germany) was used with a straight conveyor belt. Figure 5.1 shows the fusible interlining before and after the fusing procedure where the adhesive point fuses on woollen fabric.

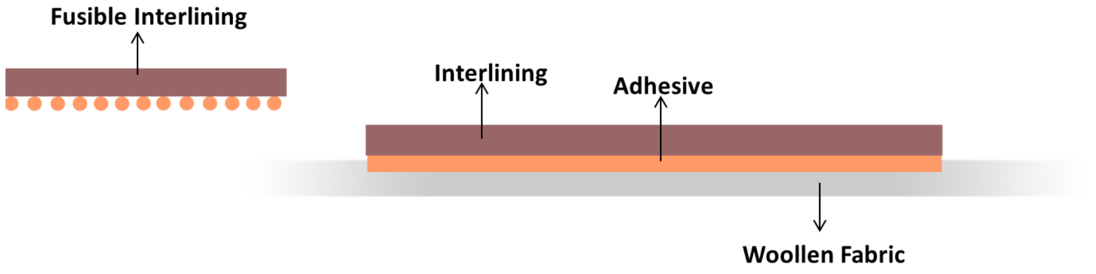


Figure 5. 1 Fusible interlining illustration

5.2.3 Woollen fabric with printable interlining (Fabric 3)

In this experiment, there were three kinds of meshes, 100T, 160T and 200T. The images on transparent acetate sheets were transferred on the screen through a photographic process, on a specimen of size 20×20 cm square. Agents were formulated in a liquid state with proper viscosity and flow characteristics suitable for the screen-printing process. Printable interlining adopted three kinds of crosslinking resins with different components which were A (Acrylic copolymer: 40.5%; Paraffin Wax: 4.2%; Silica 1.8%; Mineral spirit 8.7%; Ethylene glycol 4.5%; Water 40.3%); B (Copolymer of acrylate: 49%; Water: 51%); and C (Polyethyleneglycol stearate: 3.6%; Polyoxyethylene nonylphenol ether: 5.2%; Methanol 67-56-1: 0.7%; Benzyl alcohol 100-51-6: 0.7%; Polyurethane: 2%; Water: 87.8%) and their combinations. All the resins supplied by Shin-Nakamura Chemical Co., Ltd. Japan. The chemical information details as Table 5.3.

Table 5. 3 Chemical information

Chemical	**A**	**B**	**C**
Appearance	White paste	White paste	Clear paste
Non-volatile Components	46%±4%	49%	12%
PH	7.5	8.5	7
Viscosity (mPa.s/25ºC)	162000	172000	12800

Considering the physical properties of woollen fabrics that light and medium weight fabrics were not suitable for dilute viscosity resins and low-density screen mesh, which may due to the resin stroke through. The experiment design based on different printing technique conditions, which were shown in Table 5.4 concluding resin viscosity, screen mesh density and squeegee stroke frequency.

Table 5.4 Printing technique condition

	Light Weight	**Medium Weight**	**Heavy Weight**
Resin Viscosity (mPa.s/25ºC)	116000; 172000	12800; 162000	12800; 96000; 116000; 162000; 172000
Mesh (T)	160; 200	160; 200	100; 160; 200
Frequency (Times)	3; 6	3; 6	2; 4; 6

During printing, a single pass of the squeegee was sufficient to transfer the agent to the woollen fabric. The squeegee forced the agent through the stencil while simultaneously pressing the stencil. In front of the squeegee edge, the agent was moved and penetrated into the openings of the stencil (filling zone). After the squeegee edge passed the openings, the agent in the openings adhered to woollen fabric. Finally, the stencil was lifted up, leaving the ink on the woollen fabric (release zone). Figure 5.2 depicts a schematic cross-sectional view of the stencil during printing, illustrating the equivalent mechanics of screen printing with a stencil and a conventional screen.

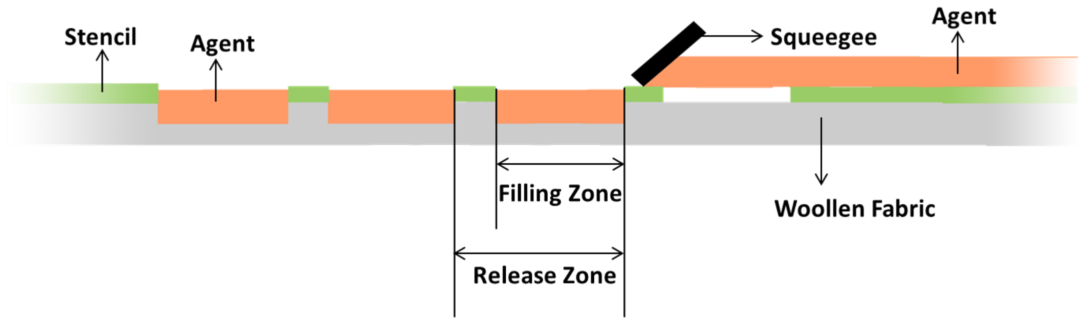


Figure 5. 2 Screen-printing illustration

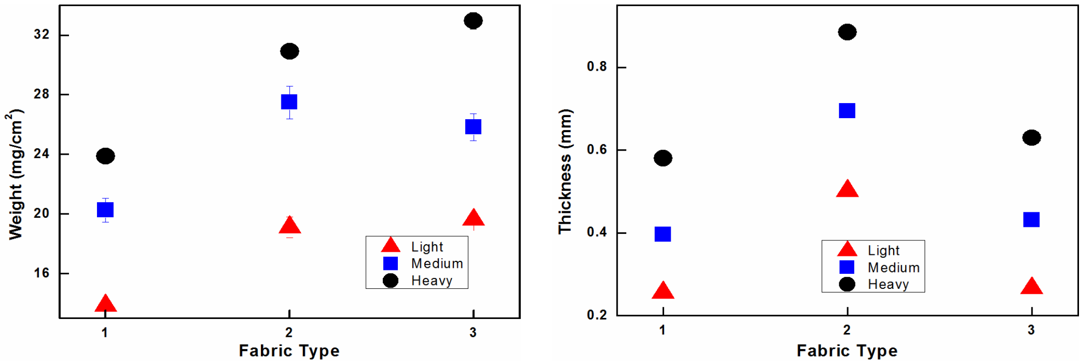
5.2.4 Evaluation testing

Samples were measured from each of the entire piece of fabrics (20 cm × 20 cm). Kawabata Evaluation System of Fabric (KES-F) in a standard laboratory condition (21±2°C temperature, 65±2% relative humidity) was carried out. The results of tensile, bending, shearing, surface, compression, primary hand value and total hand value of three groups' treatment are reported and discussed below. Fabrics air-permeability was tested by KES-FB-AP1 automatic air permeability tester (KATO TECH CO.LTD.).

5.3 Results and Discussion

5.3.1 Fabric thickness and weight

Changes of fabric thickness and weight in the three weight categories (light, medium and heavy weight) in terms of three types of fabrics (Fabric 1, 2 and 3) are shown in Figure 5.3. There is a dramatic increase in fabric weight and thickness for woollen fabric (Fabric 1) with fusible (Fabric 2) and printable interlinings (Fabric 3) in all their weights. Fabric 2 (woollen fabric with fusible interlinings) exhibits 38.2%, 35.8%, and 29.6% weight increase and Fabric 3 (woollen fabric with printable interlinings) shows 41.8%, 27.5% and 38.1% weight increase in light, medium and heavy weight respectively. In terms of thickness, Fabric 2 has 96.7%, 75.3%, and 52.6% thickness increase and Fabric 3 have 4.2%, 8.9% and 8.6% thickness increase. It can be seen that the weight increases on both fusible interlinings and printable interlinings have the similar level. However, the thickness of woollen fabrics with fusible interlinings is almost twice that of woollen fabrics with printable interlinings. The increase of both fusible and printable interlinings on weight and thickness may be due to the fact that the lamination of woollen fabrics at both treatment stages. The marked increase of fusible interlinings compared with printable interlinings should be due to the base shell of fusible interlinings which increases the thickness of fabric. Figure 5.4 illustrates the woollen fabric with fusible interlinings which has the substrate fabric on the surface increasing fabric thickness. However, printable interlinings do not have the extra layer shown in Figure 5.5.



(a) (b)

Figure 5. 3 Changes of weight (a) and thickness (b) of three types of samples 1 (woollen fabric); 2 (woollen fabric with fusible interlining); and 3 (woollen fabric with printable interlining)

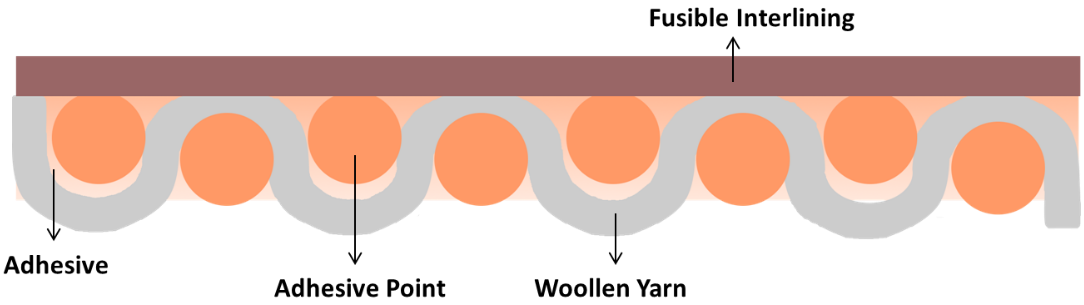


Figure 5. 4 Fusible interlining

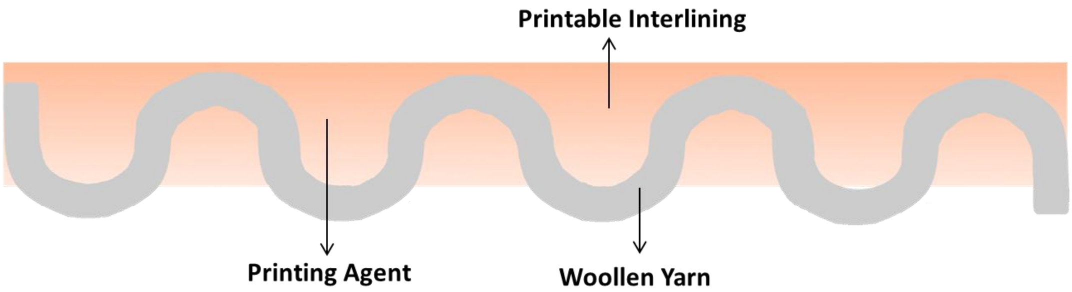


Figure 5. 5 Printable interlining

5.3.2 Total hand value

Total hand value (THV) is the total fabric quality measured from the optimum combination of HVs. The evaluation of light weight woollen fabric focused on the men's summer suit, medium and heavy weight woollen fabric was evaluated the men's winter suit (Kawabata, 1980b).

Figure 5.6 shows THV of three types of fabrics in three weight levels. All the woollen fabrics with printable interlinings (Fabric 3) show a dramatically increase of THV comparing with woollen fabric with fusible interlinings (Fabric 2). It reflects that woollen fabric with printable interlining can in place of traditional fusible interlinings. For light weight woollen fabric, THV of woollen with fusible interlinings and printable interlinings are increased ordinal, printable interlinings show the dramatically function of improving the total hand value. For medium and heavy weight fabrics, THV of woollen fabric with fusible interlinings were decreased while printable interlinings reflect a better THV comparing with the fusible interlinings.

Both fusible interlinings and printable interlinings have functions to affect the total hand value of fabrics, and printable interlinings have the significant advantages. Total hand value of fabrics is based on fabric low-stress mechanical properties, in order to explore details of the low-stress mechanical properties of the three types of fabrics which will discuss in the following parts.

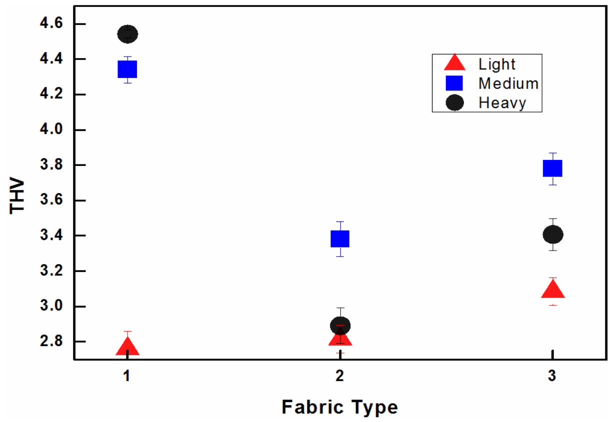


Figure 5. 6 Changes of total hand value of three types of three types of samples 1 (woollen fabric); 2 (woollen fabric with fusible interlining); and 3 (woollen fabric with printable interlining)

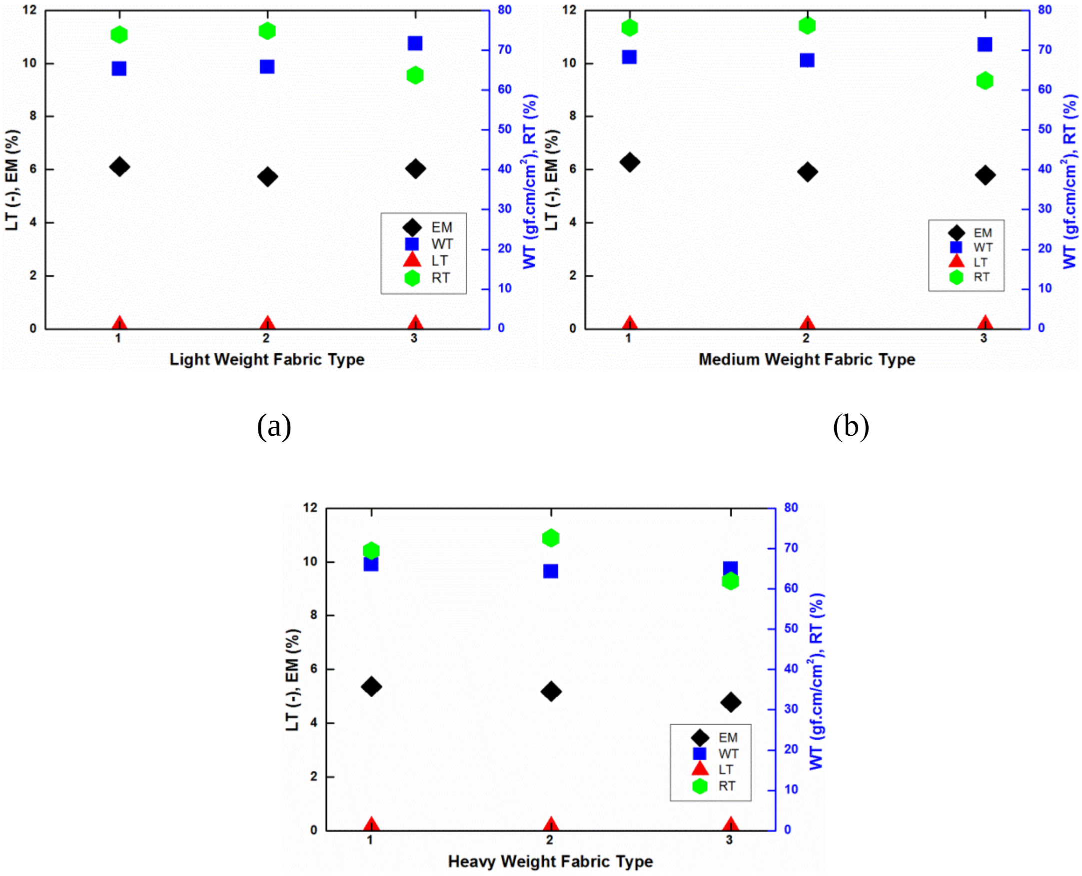
5.3.3 Tensile properties

Tensile properties of woollen fabrics obtained from KES-FB are presented in Figure 5.7 (a,b,c), which include tensile linearity LT, tensile energy WT, tensile resilience RT and elongation EMT. Tensile linearity LT reflects the elasticity of the fabric, the higher the LT value the stiffer the material will be (Sun and Stylios, 2006). There is an increase of woollen fabric with both fusible and printable interlinings. It reflects that printable interlinings have a significant efficiency to improve the stiffness of the woollen fabric. This maybe due to because the printable interlinings increases the thickness which changes the fabric structure. In addition, the resins go through into the fiber intervals, which increase the density of the fabric.

Tensile energy is the work done by extending of the fabric, and a greater WT value responds to a higher tensile strength of the fabric. WT increased for all the three weights woollen fabric with printable interlinings when compared with woollen fabrics with fusible interlinings. Generally speaking, fiber type and fabric structure influence fabric tensile strength (Wemyss and De Boos, 1991). In this study, both fusible and printable interlinings increase the inter-force of fibers that cause an increase in fabric tensile strength.

Tensile resilience reflects the recovery ability of a fabric after being extended. There is decreases in RT of woollen fabric with printable interlinings, however, there is a little bit increase in woollen fabric with fusible interlinings. This may be due to the increase of interaction between fibers and yarns after printing, however, fusible interlinings have a base cloth (substrate) which increases the fabric recovery.

Fabric extensibility EM is the percentage strain at maximum applied force (500 gf/cm in this experiment). Both fusible and printable interlinings decrease the EM value compared with woollen fabrics. This can be explained by the increase in yarn crimp after fusing or printing which results in a decrease in extensibility (Garcia et al., 1994, Lam et al., 2011). In addition, fusing or printing cause degradation and bond breakage of the molecule chains of the woollen fabrics, resulting in a decrease in EM.



(a)

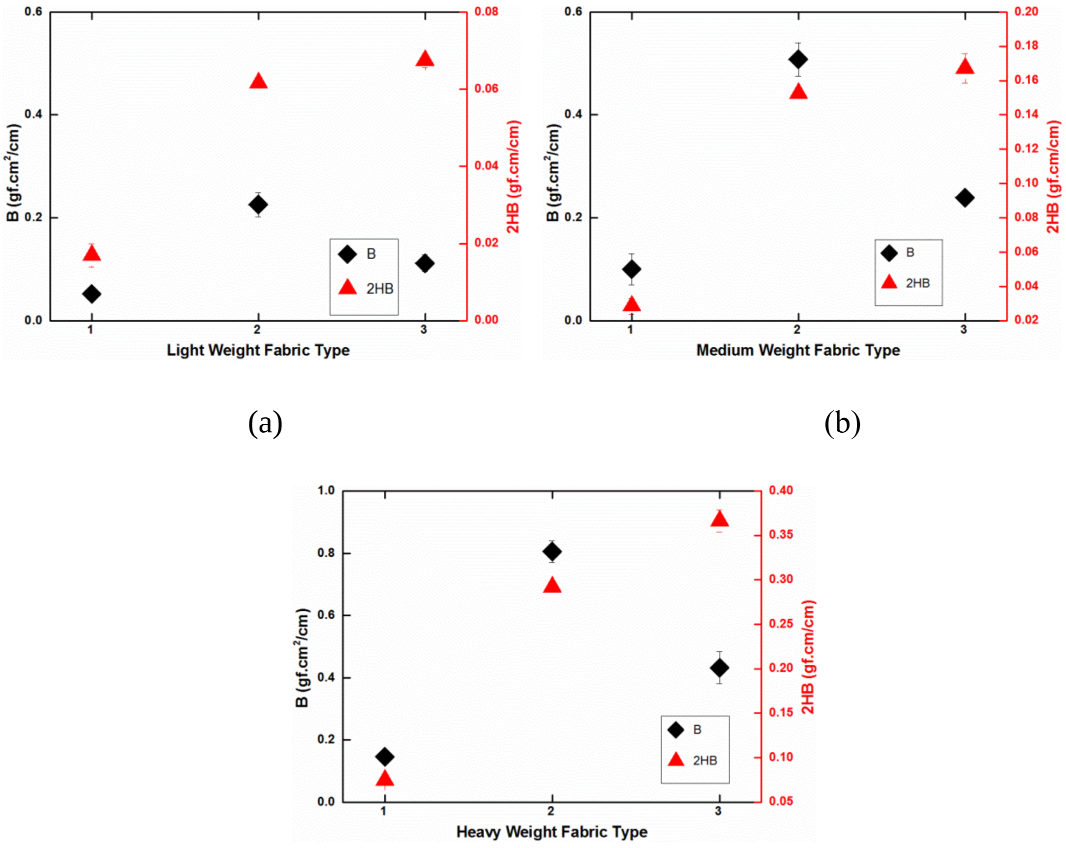
(b)

(c)

Figure 5. 7 Changes of tensile properties of three weights of samples 1 (woollen fabric); 2 (woollen fabric with fusible interlining); and 3 (woollen fabric with printable interlining)

5.3.4 Bending properties

The results of the bending properties of woollen fabrics with fusible interlinings and printable interlinings are shown in Figure 5.8 (a,b,c), which include bending stiffness B and bending hysteresis 2HB. Bending rigidity reflects the flexibility of the fabric and higher B values indicate greater resistance to bending motions. Bending hysteresis indicates the ability of the fabric to recover after being bent (Sun and Stylios, 2005). The smaller the 2HB value, the better the bending recovery ability of the fabric will be. There is a remarkable increase in bending stiffness B and bending hysteresis 2HB after fusing or printing interlinings on woollen fabrics. It shows 224.4%, 267.9%, and 323.8% increase in B and 282.0%, 491.1% and 340.5% increase in 2HB of woollen fabric with fusible and printable interlinings for three weights fabrics respectively. This is due to the treatment of fusing or printing which enhance the interaction of the constituent yarns and fibers. After the treatment, the bending resistance increases, however, the recovery of resistance decreases.



(a) (b)

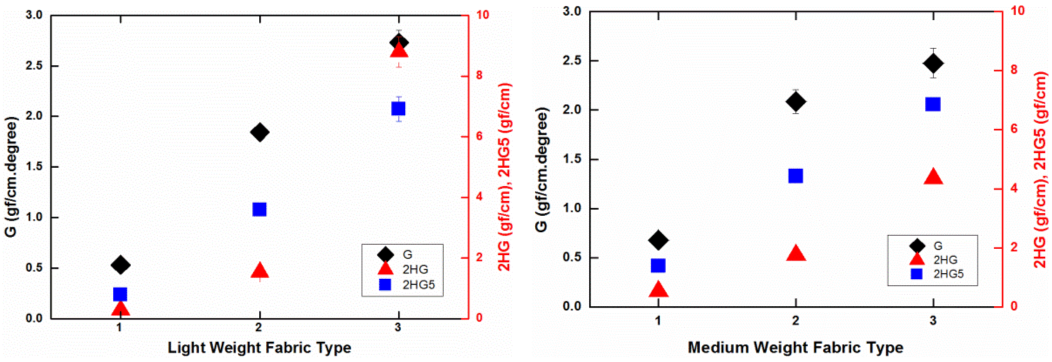
(c)

Figure 5. 8 Changes of bending properties of three weights of samples 1 (woollen fabric); 2 (woollen fabric with fusible interlining); and 3 (woollen fabric with printable interlining)

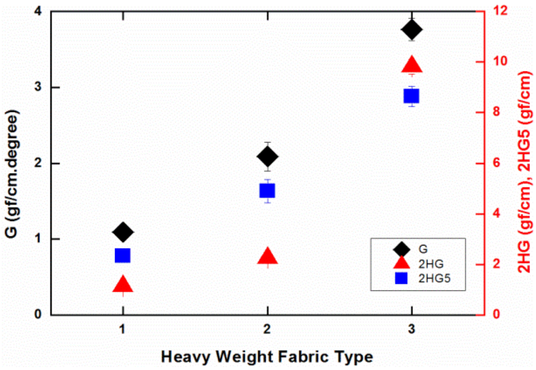
5.3.5 Shearing properties

Results of shear properties are shown in Figure 5.9 (a,b,c), containing shear stiffness G, shearing hysteresis at 0.5 degree angle 2HG and shear hysteresis at 5 degree angle 2HG5. G is the resistance of a material to deformation at various angles to the direction of the individual yarns to pull against one another. 2HG and 2HG5 are the energy loss in the final shear deformation in cooperation with the initial part of the deformation. The easier the yarns glide over each other, the smaller the fabric hysteresis will be.

The results of shear properties of woollen fabrics with interlinings have dramatically increase compared with woollen fabric. These results may due to interlinings increase the fiber friction of woollen fabrics. The increased interlining lamination also enhances the interaction of yarn. The woollen fabric becomes stiffer, the higher shear rigidity and shear hysteresis of the fusible and printable interlinings which can be attributed to modification of fabric (Kan and Lam, 2013).



(a) (b)

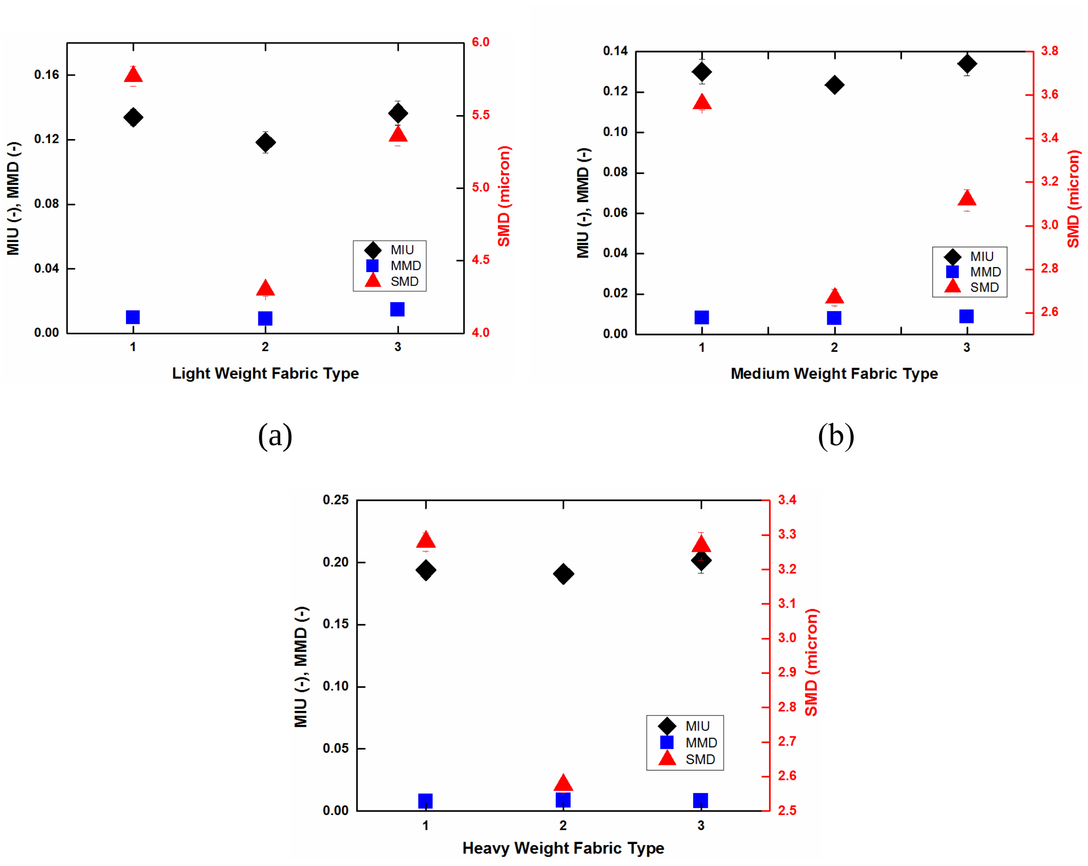


(c)

Figure 5. 9 Changes of shearing properties of three weights of samples 1 (woollen fabric); 2 (woollen fabric with fusible interlining); and 3 (woollen fabric with printable interlining)

5.3.6 Surface properties

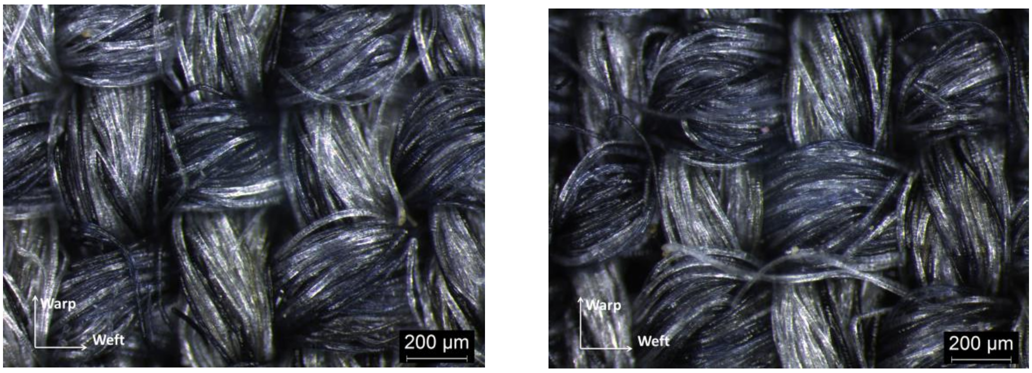
Surface properties of the fusible interlinings and printable interlinings of woollen fabrics are shown in Figure 5.10 (a,b,c). Surface properties conclude the friction coefficient MIU, the mean deviation of friction MMD and the geometrical roughness SMD. MIU indicates fabric smoothness, roughness, and crispness. Higher MIU values correspond to greater friction or resistance to drag. Figure 5.11 illustrates the electron micrographs of the surface performance of Fabric 2 and Fabric 3. The figures show the change of MIU values for woollen fabrics with and without interlinings is quite small. This is caused by both fusible interlinings and printable interlinings are on the back side of woollen fabrics and resins do not go through the woollen fabric.



(a) (b)

(c)

Figure 5. 10 Changes of shearing properties of three weights of samples 1 (woollen fabric); 2 (woollen fabric with fusible interlining); and 3 (woollen fabric with printable interlining)

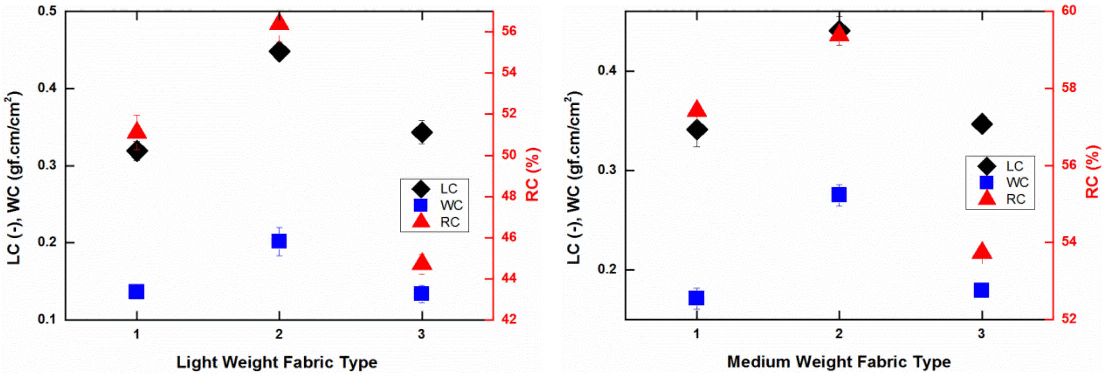


(a) (b)

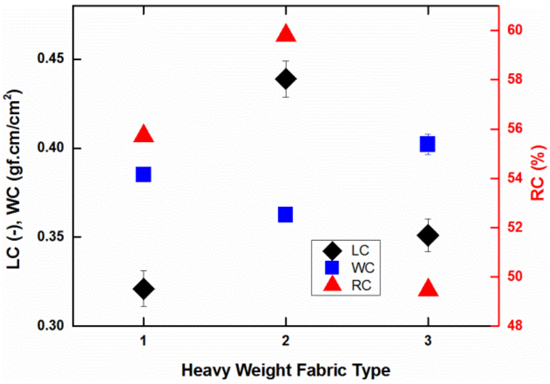
Figure 5. 11 Electron micrographs of fabric surface: (a) woollen fabric with fusible interlining; (b) woollen fabric with printable interlinings

5.3.7 Compression properties

The compressional properties of woollen fabric after various printing resin resins are presented in Figure 5.12 (a,b,c) containing compression linearity LC, compression energy WC, and compression resilience RC. The change of LC between the woollen fabric and woollen fabric with printable interlinings stage is small. The compression energy WC reflects the fluffy feeling of the fabric; the fabric will appear fluffier when the value of compression energy is increased (Kan et al., 1998). In this study, WC increases for woollen fabrics with interlinings. Compression resilience RC is the percentage of the extent of recovery, or the regain in fabric thickness when the applied force is removed. The greater the value RC, the better retention ability of the fullness of the fabric after compression is. However, RC of woollen fabric with fusible interlinings increases for light weight and heavy weight fabrics. This may be due to the resins of printable interlining go into the gap of yarns and stick them together, which enhances the yarn interaction of woollen fabrics.



(a) (b)



(c)

Figure 5. 12 Changes of compression properties of three weights of samples 1 (woollen fabric); 2 (woollen fabric with fusible interlining); and 3 (woollen fabric with printable interlining)

5.3.8 Air permeability

Figure 5.13 shows the air permeability of three weight level specimens for three kinds of fabrics. The less result value, the better air permeability the fabric has. From the bar chart below, we can see the woollen fabric with interlinings could reduce the fabric air permeability. For light weight fabric, woollen fabric with printable interlining decrease the property compared with fusible interlinings, it may because the yarn distance is small and resin fill the gap between yarns which decrease the air permeability. For medium and heavy weight, woollen fabrics with printable interlinings have a better performance compared with woollen fabric with fusible interlinings. This may because the yarn distance is large, however, the substrate of fusible interlinings resists the air flow and printable interlinings show a better air permeability.

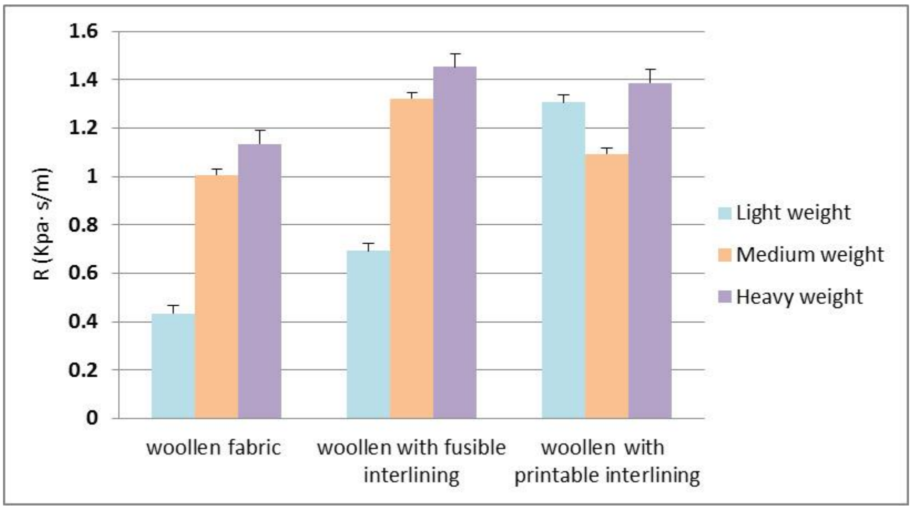


Figure 5. 13 Air permeability of three weights of samples

5.4 Conclusion

Fusible interlinings and printable interlinings affect woollen fabric in terms of hand values and low-stress mechanical properties. The printable interlinings obviously can achieve the performance or even better than fusible interlinings. Printable interlinings show a significant development of total hand value of woollen fabric for men’s suits compared with fusible interlinings. Especially, there was a marked increase in terms of fabric stiffness. There was a dramatic increase in shearing, bending and tensile properties for printable interlinings compared with fusible interlinings. Surface properties were found similar for all woollen fabrics and with and without fusible interlinings and printable interlinings. The printable interlinings have similar compression performance as woollen fabric without interlinings. In brief, printable interlinings were effective for the woollen fabric used for men’s suit manufacture.

This invent of printable interlining not only has the potential of substitute for traditional fusible interlining but also develop the hand value and low-stress mechanical properties of woollen fabric for suit manufacture.

CHAPTER 6 PRINTABLE INTERLININGS HAND VALUES OPTIMIZATION OF WOOLLEN FABRICS BY ORTHOGONAL EXPERIMENT DESIGN

6.1 Introduction

The fusible interlining utilized an adhesive on the fabric surface and it specifically is used to improve garment hand (Marler, 1977). In recent years some attempts have been made to bypass the operation of fusing the interlining on to the garment parts. However, the adhesive paste could be printed directly onto garment parts with a suitable density, it can achieve the support and control that interlining provide and to do it more economically, which named it printable interlining. In order to use the printable interlining in place of fusible interlining could be achieve. This chapter develops an efficient printing technique for printable interlining on woollen fabrics and analyzes that hand values. An orthogonal experiment design has been developed based on data obtained from experiments. The results showed that squeegee frequency is significant for light and medium weight fabrics; screen mesh is important for light weight fabrics; resin viscosity is significant for medium and heavy weight fabrics. The correlation analysis of primary hand value reflected that all the hand values have linear regression relationships each other and the hand value performances correlated with the woollen fabric weight. The optimization and analyzing of impact factors of printable interlining could be an implication in garment manufacture.

Interlinings to the shell fabrics can improve the garment formability for a beautiful silhouette and elasticity of the deformed fabric during wearing, and also can enhance the appearance and wearing properties of the garment (Kim et al., 2007). Currently, fusing an interlining to the shell fabric is widely used. However, this technology is costly in terms of manufacture, process, and the material cost. In addition, the fusing operational process is complicated one is a restriction in a temperature range, the other is time-consuming. The inapposite adhesive conditions would cause bubbles, strike through and strike back phenomenon (Raj Sharma et al., 2005). To improve the fabric processing technique of garment production systems has been paying much attention (Chuter, 1995). Screen printing is a printing technique that uses a woven mesh to support an ink-blocking stencil which can be pressed through the mesh as a sharp edged image on to a substrate (Li dong and Lugscheider, 2002). The technology is now widely used as it can satisfy people’s requirement in clothing and textile and clothing personalized production with advantages such as mass-production, high-speed and versatility (Walter et al., 2009). Screen printing is used as a new method for printable interlining which is more versatile and higher speed than traditional fusible interlinings and the advantage of screen printing is that large quantities can be produced rapidly with new automatic presses (Chuter, 1995). The performance of the printable interlining and its hand values are studied in detail. In this chapter, the printable interlining process optimization has been investigated by orthogonal experimental design, which is carried out to study the effect factors of printing technique on the primary hand value and total hand value of woollen fabric with printable interlining. The mixed orthogonal matric $L_8(2^3)$, $L_8(2^3)$ and $L_{25}(5^1 \times 3^2)$ are for light, medium and heavy weight respectively. In addition, the different primary hand value correlations of the printable interlinings on the woollen fabric have been explored.

6.2 Materials and methods

6.2.1 Materials

Three kinds of 100% woollen fabric with different weights were purchased from Tai Tung Textile Company, Hong Kong were used for experiments. The specifications are detailed as Table 6.1.

Table 6. 1 Specifications of fusible woollen fabrics

Samples	Thickness (mm)	Weight (mg/cm^2)	Component woollen	Structure
Light Weight	0.30	13.823	100%	plain weave
Medium Weight	0.58	20.248	100%	plain weave
Heavy Weight	0.69	23.865	100%	plain weave

6.2.2 Printing resin

Three kinds of crosslinking resins with different components A (Acrylic copolymer: 40.5%; Paraffin Wax: 4.2%; Silica 1.8%; Mineral spirit 8.7%; Ethylene glycol 4.5%;

Water 40.3%); B (Copolymer of acrylate: 49%; Water: 51%); C (Polyethyleneglycol stearate: 3.6%; Polyoxyethylene nonylphenol ether: 5.2%; Methanol 67-56-1: 0.7%; Benzyl alcohol 100-51-6: 0.7%; Polyurethane: 2%; Water: 87.8%) which were supplied by Shin-Nakamura Chemical Co., Ltd. Japan. The chemical composition details as following Table 6.2.

Table 6. 2 Chemical information

Chemical	**A**	**B**	**C**
Appearance	White paste	White paste	Clear paste
Non-volatile Components	46%±4%	49%	12%
PH	7.5	8.5	7
Viscosity (mPa.s/25°C)	162000	172000	12800

6.2.3 Orthogonal Experiment Design (OED) method

An orthogonal experiment design was adopted for printing resin and technique optimization. SPSS (IBM Corp., Armonk, NY) has been used for experiment design and analysis. The influences of the printing resin and operating parameters on the printing procedure were investigated. The three independent variables were defined as resin viscosity (A), screen mesh (B) and squeegee frequency (C), and the response variable were defined as the primary hand value and total hand value. The selected printing technique parameters and variable levels in the experiment have for OED method.

6.2.4 Experimental arrangement

Table 6. 3 Printing technique condition

	Light Weight	**Medium Weight**	**Heavy Weight**
Resin Viscosity (mPa.s/25°C)	172000; 116000	12800; 162000	162000; 172000; 12800; 96000; 116000
Mesh (T)	160; 200	160; 200	100; 160; 200
Frequency (Times)	3; 6	3; 6	2; 4; 6

The resin viscosities contained from 12800 to 172000 (mPa.s/25°C) for light, medium, and heavy weight woollen fabric. Printing screen meshes were 160T and 200T for light and medium weight fabrics. 100T, 160T, and 200T screen mesh were used for heavy weight fabrics. The stroke frequency was three and six times for light and medium weight fabrics; and two, four, and six stroke times for heavy weight fabrics. As the light and medium weight woollen fabrics are thin and resins can easily strike through, the viscosity of resins could not be dilute and screen mesh should not be low density. The experiment design is based on the fabric properties and there are various printing technique condition of light weight, medium weight and heavy weight woollen fabrics. Details have shown in Table 6.3.

The experiment arrangement has shown in Table 6.4 to Table 6.6. Screen printing gauzes were made from synthetic fibers which are polyamide (Nylon) and polyester (Terylene). A squeegee was used to force the ink through the screen mesh and stencil on to the printing stock below. The squeegee was pressed down into contact with the screen, whilst held at an angle of about 75°.

Table 6. 4 Arrangements of experiment of light weight fabrics

S. No	Resin / Viscosity (mPa.s/25°C)	Mesh (T)	Frequency (Times)
	A	B	C
1	a	a	a
2	a	a	b
3	a	b	a
4	a	b	b
5	b	b	a
6	b	a	b
7	b	b	b
8	b	a	a

Table 6. 5 Arrangements of experiment of medium weight fabrics

S. No	Resin / Viscosity (mPa.s/25°C)	Mesh (T)	Frequency (Times)
	A	B	C
1	I	I	I
2	I	I	II
3	I	II	I
4	I	II	II
5	II	II	I
6	II	I	II
7	II	II	II
8	II	I	I

Table 6. 6 Arrangements of experiment of heavy weight fabrics

S. No	Resin / Viscosity (mPa.s/25°C)	Mesh (T)	Frequency (Times)
	A	B	C
1	3	1	3
2	5	1	2
3	4	1	1
4	4	2	1
5	5	1	1
6	1	1	1
7	5	2	2
8	1	1	2
9	2	2	2
10	2	1	2
11	1	3	2
12	5	3	1
13	3	2	1
14	4	3	2
15	3	3	1
16	4	2	2
17	1	2	3
18	2	1	1
19	3	1	2
20	4	1	3
21	1	2	1
22	2	2	1
23	3	2	2
24	4	2	3
25	2	3	3

6.2.5 KES-F testing

Primary hand value and total hand value were evaluated by the KES-F testing. There was a little different for light weight fabric in terms of men's summer suit while medium and heavy weight fabric adapted to men’s winter suit evaluation. In details, stiffness (KOSHI), smoothness (NUMERI), crispness (SHARI), fullness & softness (FUKURAMI), anti-drape stiffness (HARI) evaluated for light weight woollen fabric, in addition, stiffness (KOSHI), smoothness (NUMERI), fullness & softness (FUKURAMI) were evaluated for medium weight and heavy weight fabrics. Total hand value (THV) was explored for all the fabrics.

6.3 Results and discussion

6.3.1 Orthogonal analysis

Variable effects on process technique were studied base on OED method which shown in Table 6.7 to 6.9 clearly. Analysis of range was used to calculate average response and impact level for each factor. During the printing process, some primary parameters were selected as the factors of the orthogonal experiment, including resin viscosity, screen mesh density, and squeeze frequency. The Mixed-level $L_8(2^3)$ and $L_{25}(5^1\times3^2)$ matrix were used to determine the optimal printing parameters with the maximum primary hand value and total hand value.

Eight sets of experimental trials were pre-designed based on the mixed-level $L_8(2^3)$ array for light and medium weight woollen fabric； $L_{25}(5^1\times3^2)$ array for heavy weight woollen fabric, furthermore, the corresponding hand value was obtained. In order to verify the improvement of hand value in the printing process, OED method optimized the experiment condition. Where T is the sum of the evaluation indexes; T_{mn} refers to the sum of the evaluation indexes of all levels (n, n=1, 2, 3) in each factor (m, m=A, B, C), X indicates the mean value of T_{mn}. $R=Max(X_{mn})-Min(X_{mn})$ indicates the function of the corresponding factor. The larger value of R corresponds to a greater impact of the level of the factor on the experimental index.

According to light weight fabric performance, it is found that the order of importance of the variables for hand value which include stiffness, smoothness, crispness, fullness & softness, and anti-drape stiffness. Based on the OED method, Table 6.7 shown R value [mesh] > [frequency] > [viscosity] for total hand value performance. Meanwhile, the optimum total hand value correspond to [viscosity] = 116000 mPa.s/25°C; [mesh] = 160T; and [frequency] = 3 times. The experiment is conducted under the optimum conditions $A_bB_aC_a$ for total hand value. In the same way, conditions $A_bB_bC_b$ for stiffness, $A_bB_bC_b$ for crispness, $A_aB_aC_a$ for fullness, and $A_bB_bC_b$ for anti-drape performance are the optimum conditions.

According to medium weight fabric performance, it is found that the order of importance of the variables for hand value which include stiffness, smoothness, and fullness & softness. Based on the OED method, Table 6.8 shows R value [viscosity]> [frequency] > [mesh] for total hand value performance. Meanwhile, the optimum total hand value correspond to [viscosity] = 162000 mPa.s/25ºC; [mesh] = 200T; and [frequency] = 6 times. The experiment is conducted under the optimum conditions $A_{II}B_{II}C_{II}$ for total hand value. In the same way, conditions $A_{I}B_{II}C_{II}$ for stiffness, $A_{II}B_{I}C_{II}$ for smoothness and $A_{II}B_{I}C_{II}$ for fullness and softness performance are the optimum conditions.

According to heavy weight fabric performance, it is found that the order of importance of the variables for hand value which include stiffness, smoothness, and fullness & softness. Based on the OED method, Table 6.9 shows R value [viscosity] > [frequency] > [mesh] for total hand value performance. Meanwhile, the optimum total hand value correspond to [resin viscosity] = 12800 mPa.s/25ºC; [mesh] = 160T; and [frequency] = 2 times. The experiment is conducted under the optimum conditions $A_3B_2C_1$ were obtained according to the total hand value evaluation. In the same way, conditions $A_2B_1C_3$ for stiffness, $A_3B_2C_2$ for smoothness and $A_3B_2C_2$ for fullness & softness performance are the optimum conditions.

Table 6. 7 Average response and range for each factor on light weight fabric based on orthogonal experiment

	S. No	**resin / Viscosity**	**Mesh (T)**	**Frequency**	**Stiffness** KOSHI	**Crispness** SHARI	**Fullness & Softness** FUKURAMI	**Anti-drape stiffness** HARI	**THV**
		A	**B**	**C**					
	1	a	a	a	5.48	4.1	5.07	5.3	3.15
	2	a	a	b	6.45	4.33	5.04	6.35	3.09
	3	a	b	a	6.78	5.06	4.12	6.95	3.1
	4	a	b	b	7.53	5.08	4.68	7.81	3
	5	b	b	a	6.15	4.24	4.99	6.15	3.08
	6	b	a	b	7.1	5.26	4.76	7.3	3.22
	7	b	b	b	7.63	5.36	4.27	7.9	3
	8	b	a	a	6.4	4.49	4.85	6.46	3.11
KOSHI	X1	6.56	6.36	6.20					
	X2	**6.82**	**7.02**	**7.18**					
	R	0.26	0.67	**0.98**					
SHARI	X1	4.64	4.55	4.47					
	X2	**4.84**	**4.94**	**5.01**					
	R	0.20	0.39	**0.54**					
FUKURAMI	X1	**4.73**	**4.93**	**4.76**					
	X2	4.72	4.52	4.69					
	R	0.01	**0.42**	0.07					
HARI	X1	6.60	6.35	6.22					
	X2	**6.95**	**7.20**	**7.34**					
	R	0.35	0.85	**1.13**					
THV	X1	3.09	**3.14**	**3.11**					
	X2	**3.10**	3.05	3.08					
	R	0.02	**0.10**	0.03					

Table 6. 8 Average response and range for each factor on medium weight fabric based on orthogonal experiment

	S. No	**resin / Viscosity**	**Mesh (T)**	**Frequency**	**Stiffness** KOSHI	**Smoothness** NUMERI	**Fullness & Softness** FUKURAMI	**THV**
		A	**B**	**C**				
	1	I	I	I	5.22	6.53	6.74	4.03
	2	I	I	II	7.97	5.91	6.32	3.74
	3	I	II	I	8.7	5.41	5.34	3.36
	4	I	II	II	8.22	5.9	5.74	3.69
	5	II	II	I	7.74	6.02	5.93	3.81
	6	II	I	II	8.16	5.67	5.91	3.6
	7	II	II	II	6.62	6.42	6.56	4.07
	8	II	I	I	8	5.75	6.49	3.65
KOSHI	X1	**7.53**	7.34	6.13				
	X2	5.97	**7.82**	**7.74**				
	R	1.56	0.48	**1.61**				
NUMERI	X1	5.94	**5.97**	5.93				
	X2	**5.97**	5.94	**5.98**				
	R	0.03	0.03	**0.05**				
FUKURAMI	X1	6.04	**6.37**	6.13				
	X2	**6.22**	5.89	6.13				
	R	0.18	**0.48**	0				
THV	X1	3.71	**3.76**	3.71				
	X2	**3.78**	3.73	**3.78**				
	R	0.07	0.03	0.07				

Table 6. 9 Average response and range for each factor on heavy weight fabric based on orthogonal experiment

	S. No	**resin / Viscosity**	**Mesh (T)**	**Frequency**	**Stiffness** KOSHI	**Smoothness** NUMERI	**Fullness & Softness** FUKURAMI	**THV**
		A	**B**	**C**				
	1	3	1	3	9.65	6.39	8.3	3.46
	2	5	1	2	9.7	6.24	8.9	3.22
	3	4	1	1	9.77	6.04	7.22	3.41
	4	4	2	1	8.61	6.32	7.94	3.71
	5	5	1	1	9.79	6.28	7.72	3.47
	6	1	1	1	9.57	5.77	6.6	3.37
	7	5	2	2	8.86	6.49	8.54	3.63
	8	1	1	2	10.05	5.94	6.84	3.31
	9	2	2	2	9.88	6.15	8.2	3.29
	10	2	1	2	10.59	5.85	7.55	3.02
	11	1	3	2	9.41	5.92	6.76	3.48
	12	5	3	1	9.98	5.68	6.97	3.2
	13	3	2	1	7.16	7.12	9.79	3.83
	14	4	3	2	9.09	5.95	7.02	3.55
	15	3	3	1	7.06	6.89	9.07	3.93
	16	4	2	2	9.1	6.01	7.79	3.48
	17	1	2	3	9.84	5.7	6.9	3.25
	18	2	1	1	9.29	5.65	7.45	3.32
	19	3	1	2	9.82	6.01	7.81	3.31
	20	4	1	3	9.59	5.51	7.43	3.18
	21	1	2	1	8.94	5.9	7.07	3.55
	22	2	2	1	9.06	5.94	7.91	3.44
	23	3	2	2	8.1	6.54	9.04	3.65
	24	4	2	3	10.36	5.3	7	2.91
	25	2	3	3	10.88	6.05	6.91	3.08
KOSHI	X1	9.56	**9.78**	8.92				
	X2	7.82	8.99	9.46				
	X3	6.43	9.28	**10.06**				
	X4	9.23						
	X5	**9.74**						
	R	**3.31**	0.791	1.14				

NUMERI	X1	5.85	**9.78**	8.92				
	X2	4.76	8.99	9.46				
	X3	5.31	9.28	**10.06**				
	X4	5.97						
	X5	**6.00**						
	R	**1.15**	0.79	1.14				
FUKURAMI	X1	6.83	7.58	7.77				
	X2	6.09	**8.02**	**7.85**				
	X3	7.14	7.35	7.31				
	X4	7.48						
	X5	**7.83**						
	R	**1.74**	0.67	0.54				
THV	X1	3.39	3.31	**3.52**				
	X2	2.63	**3.47**	3.39				
	X3	2.94	3.45	3.18				
	X4	**3.47**						
	X5	3.29						
	R	**0.84**	0.17	0.35				

6.4 Correlation analysis

In order to study the effects of factors, ANOVA and regression analysis are applied. The printing technique conditions have a correlation with primary hand values in terms of different weight fabrics. R square has checked the linear regression relationship which R square around 0.5 or more than 0.5 shows the regression was established. DW and VIF value checked the variable factors collinearity performance. ANOVA reflected the correlation level of each independent variable factors with the Sig. a value less than 0.1. Detail explanations of results are shown below.

6.4.1 Light weight –Stiffness performance

For the light weight fabrics, the correlations of variable factors and stiffness have been explored. For the model summary (Table 6.10), R square is 0.797 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which shows that data has not collinearity. From ANOVA analysis (Table 6.11), Sig. is 0.072 which is less 0.1 that means the independent factors affect the dependent variable stiffness. From the coefficients Table 6.12, it shows the frequency and mesh dependent variable has the correlation level with the stiffness which coefficients are 0.033 and 0.094 respectively. In addition, the collinearity statistics VIF value is 1(<10) which show the independent variable is not collinearity.

Table 6. 10 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.893[a]	0.797	0.646	0.43067	0.797	5.249	3	4	0.072	2.020

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Stiffness

Table 6. 11 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.921	3	0.974	5.249	0.072[b]
	Residual	0.742	4	0.185		
	Total	3.663	7			

a. Dependent Variable: Stiffness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 12 Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	2.904	1.650		1.760	0.153	-1.678	7.485		
	Viscosity	-4.643E-6	0.000	-0.192	-0.854	0.441	0.000	0.000	1.000	1.000
	Mesh	0.017	0.008	0.491	2.184	0.094	-0.005	0.038	1.000	1.000
	Frequency	0.325	0.102	0.720	3.202	0.033	0.043	0.607	1.000	1.000

a. Dependent Variable: Stiffness

6.4.2 Light weight – crispness performance

For the light weight fabrics, the correlations of variable factors and crispness have been explored. For the model summary (Table 6.13), R square is 0.540 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.14), Sig. is 0.329 which is more than 0.1 which means the independent, not factors affect the dependent variable crispness. In addition, the collinearity statistics VIF value is 1(<10) which show the independent variable is not collinearity (Table 6.15).

Table 6. 13 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.735[a]	0.540	0.196	0.45008	0.540	1.568	3	4	0.329	2.748

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Crispness

Table 6. 14 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.953	3	0.318	1.568	0.329[b]
	Residual	0.810	4	0.203		
	Total	1.763	7			

a. Dependent Variable: Crispness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 15 Coefficients

		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	2.684	1.725		1.556	0.195	-2.104	7.472		
	Viscosity	-3.482E-6	0.000	-0.208	-0.613	0.573	0.000	0.000	1.000	1.000
	Mesh	0.010	0.008	0.415	1.225	0.288	-0.012	0.032	1.000	1.000
	Frequency	0.178	0.106	0.570	1.681	0.168	-0.116	0.473	1.000	1.000

a. Dependent Variable: Crispness

6.4.3 Light weight – fullness & softness performance

For the light weight fabrics, the correlations of variable factors and fullness & softness have been explored. For the model summary (Table 6.16), R square is 0.403 (<0.5) that means the degree of fitting linearity is not feasibility of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.17), Sig. is 0.516 which is more than 0.1 that means the independent factors not affect the dependent variable fullness and softness. In addition, the collinearity statistics VIF value is 1(<10) which show the independent variable is not collinearity (Table 6.18).

Table 6. 16 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.635[a]	0.403	-0.045	0.36259	0.403	0.899	3	4	0.516	2.162

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Fullness & Softness

Table 6. 17 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.354	3	0.118	0.899	0.516[b]
	Residual	0.526	4	0.131		
	Total	0.880	7			

a. Dependent Variable: Fullness & Softness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 18 Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	6.669	1.389		4.800	0.009	2.812	10.527		
	Viscosity	1.786E-7	0.000	0.015	0.039	0.971	0.000	0.000	1.000	1.000
	Mesh	-0.010	0.006	-0.626	-1.619	0.181	-0.028	0.007	1.000	1.000
	Frequency	-0.023	0.085	-0.106	-0.273	0.798	-0.261	0.214	1.000	1.000

a. Dependent Variable: Fullness & Softness

6.4.4 Light weight – anti-drape stiffness performance

For the light weight fabrics, the correlations of variable factors and anti-drape stiffness have been explored. For the model summary (Table 6.19), R square is 0.769

(>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which shows that data has not collinearity. From ANOVA analysis (Table 6.20), Sig. is 0.092 which is less than 0.1 which means the independent factors affect the dependent variable anti-drape stiffness. From the coefficients table (Table 6.21), it shows the frequency dependent variable has the correlation level with the anti-drape stiffness which coefficient is 0.048. In addition, the collinearity statistics VIF value is 1(<10) which shows the independent variable is not collinearity (Table 6.21).

Table 6. 19 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.877[a]	0.769	0.596	0.56301	0.769	4.439	3	4	0.092	2.160

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Anti-drapeStiffness

Table 6. 20 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.221	3	1.407	4.439	0.092[b]
	Residual	1.268	4	0.317		
	Total	5.489	7			

a. Dependent Variable: Anti-drape Stiffness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 21 Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	2.165	2.157		1.004	0.372	-3.824	8.154		
	Viscosity	-6.250E-6	0.000	-0.211	-0.879	0.429	0.000	0.000	1.000	1.000
	Mesh	0.021	0.010	0.513	2.135	0.100	-.006	0.049	1.000	1.000
	Frequency	0.375	0.133	0.679	2.826	0.048	0.007	0.743	1.000	1.000

a. Dependent Variable: Anti-drape Stiffness

6.4.5 Light weight – THV performance

For the light weight fabrics, the correlations of variable factors and total hand value have been explored. For the model summary (Table 6.22), R square is 0.585 (>0.5) that means the degree of fitting linearity is feasibility of this method. DW value is around 2 which shows that data is not collinearity. From ANOVA analysis (Table 6.23), Sig. is 0.275 which is more than 0.1 that means the independent factors have not affected the dependent variable THV. From the coefficient table (Table 6.24), it shows screen mesh correlated with THV which Sig. is 0.091. In addition, the collinearity statistics VIF value is 1(<10) which shows the independent variable is not collinearity (Table 6.24).

Table 6. 22 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.765[a]	0.585	0.273	0.06215	0.585	1.876	3	4	0.275	2.127

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: THV

Table 6. 23 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.022	3	0.007	1.876	0.275[b]
	Residual	0.015	4	0.004		
	Total	0.037	7			

a. Dependent Variable: THV

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 24 Coefficients

		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	3.626	0.238		15.228	0.000	2.965	4.287		
	Viscosity	-3.125E-7	0.000	-0.128	-0.398	0.711	0.000	0.000	1.000	1.000
	Mesh	-0.002	0.001	-0.715	-2.219	0.091	-0.005	0.001	1.000	1.000
	Frequency	-0.011	0.015	-0.238	-0.740	0.501	-0.052	0.030	1.000	1.000

a. Dependent Variable: THV

6.4.6 Medium weight –Stiffness performance

For the medium weight fabrics, the correlations of variable factors and stiffness have been explored. For the model summary (Table 6.25), R square is 0.826 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.26), Sig. is 0.053 which is less than 0.1 that means the independent factors affect the dependent variable smoothness. From the coefficients table (Table 6.27), it shows resin viscosity, and squeeze frequency correlated with the stiffness which Sig. is 0.037, and 0.037 respectively. In addition, the collinearity statistics VIF value is 1(<10) which show the independent variable is not collinearity (Table 6.27).

Table 6. 25 Model Summary

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	0.909[a]	0.826	0.696	0.42559	0.826	6.336	3	4	0.053	1.796

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Stiffness

Table 6. 26 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.443	3	1.148	6.336	0.053[b]
	Residual	0.724	4	0.181		
	Total	4.167	7			

a. Dependent Variable: Stiffness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 27 Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1 (Constant)	5.671	1.446		3.921	0.017	1.655	9.686					
Viscosity	6.200E-6	0.000	0.641	3.074	0.037	0.000	0.000	0.641	0.838	0.641	1.000	1.000
Mesh	0.001	0.008	0.021	0.100	0.925	-0.020	0.022	0.021	0.050	0.021	1.000	1.000
Frequency	0.310	0.100	0.644	3.090	0.037	0.031	0.589	0.644	0.840	0.644	1.000	1.000

a. Dependent Variable: Stiffness

6.4.7 Medium weight –Smoothness performance

For the medium weight fabrics, the correlations of variable factors and smoothness have been explored. For the model summary (Table 6.28), R square is 0.920 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.29), Sig. is 0.012 which is less than 0.1 that means the independent factors affect the dependent variable the smoothness. Table 6.30 shows resin viscosity and screen mesh correlated with smoothness which Sig. is 0.000 and -0.006 respectively. In addition, the collinearity statistics VIF value is 1(<10) which show the independent variable is not collinearity (Table 6.30).

Table 6. 28 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.959[a]	0.920	0.860	0.12743	0.920	15.366	3	4	0.012	1.479

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Smoothness

Table 6. 29 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.749	3	0.250	15.366	0.012[b]
	Residual	0.065	4	0.016		
	Total	0.813	7			

a. Dependent Variable: Smoothness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 30 Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	6.804	0.433		15.713	0.000	5.601	8.006					
	Viscosity	-2.430E-6	0.000	-0.568	-4.023	0.016	0.000	0.000	-0.568	-0.895	-0.568	1.000	1.000
	Mesh	0.000	0.002	0.027	0.194	0.855	-0.006	0.007	0.027	0.097	0.027	1.000	1.000
	Frequency	-0.164	0.030	-0.772	-5.466	0.005	-0.248	-0.081	-0.772	-0.939	-0.772	1.000	1.000

a. Dependent Variable: Smoothness

6.4.8 Medium weight –Fullness & Softness performance

For the medium weight fabrics, the correlations of variable factors and fullness & softness have been explored. For the model summary (Table 6.31), R square is 0.911 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.32), Sig. is 0.014 which is less than 0.1 that means the independent factors affect the dependent variable fullness and softness. Table 6.33 reflects resin viscosity correlated with fullness and softness which Sig. is 0.004. In addition, the collinearity statistics VIF value is 1(<10) which shows the independent variable is not collinearity (Table 6.33).

Table 6. 31 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.954[a]	0.911	0.844	0.19180	0.911	13.623	3	4	0.014	1.514

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Fullness & Softness

Table 6. 32 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.503	3	0.501	13.623	0.014[b]
	Residual	0.147	4	0.037		
	Total	1.651	7			

a. Dependent Variable: Fullness & Softness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 33 Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	7.847	0.652		12.040	0.000	6.037	9.657					
	Viscosity	-5.429E-6	0.000	-0.892	-5.972	0.004	0.000	0.000	-0.892	-0.948	-0.892	1.000	1.000
	Mesh	-0.005	0.003	-0.215	-1.438	0.224	-0.014	0.005	-0.215	-0.584	-0.215	1.000	1.000
	Frequency	-0.080	0.045	-0.264	-1.770	0.152	-0.206	0.046	-0.264	-0.663	-0.264	1.000	1.000

a. Dependent Variable: Fullness & Softness

6.4.9 Medium weight –THV performance

For the medium weight fabrics, the correlations of variable factors and total hand value have been explored. For the model summary (Table 6.34), R square is 0.881 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which shows that data has not collinearity. From ANOVA analysis (Table 6.35), Sig. is 0.026 which is less than 0.1 that means the independent factors affect the dependent variable THV. Table 6.36 shows screen mesh has the correlation with THV which coefficients is 0.006. In addition, the collinearity statistics VIF value is 1(<10) which show the independent variable is not collinearity (Table 6.36).

Table 6. 34 Model Summary

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	0.938[a]	0.881	0.791	0.10542	0.881	9.837	3	4	0.026	1.399

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: THV

Table 6. 35 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.328	3	0.109	9.837	0.026[b]
	Residual	0.044	4	0.011		
	Total	0.372	7			

a. Dependent Variable: THV

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 36 Coefficients

		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	4.352	0.358		12.150	0.000	3.358	5.347					
	Viscosity	-1.726E-6	0.000	-0.597	-3.455	0.026	0.000	0.000	-0.597	-0.865	-0.597	1.000	1.000
	Mesh	6.250E-5	0.002	0.006	0.034	0.975	-0.005	0.005	0.006	0.017	0.006	1.000	1.000
	Frequency	-.104	0.025	-0.724	-4.192	0.014	-0.173	-0.035	-0.724	-0.903	-0.724	1.000	1.000

a. Dependent Variable: THV

6.4.10 Heavy weight –Stiffness performance

For the heavy weight fabrics, the correlations of variable factors and stiffness have been explored. For the model summary (Table 6.37), R square is 0.656 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.38), Sig. is 0.000 which is less than 0.1 that means the independent factors affect the dependent variable smoothness. From the coefficients table (Table 6.39), it shows resin viscosity, screen mesh and squeeze frequency correlated with the stiffness which Sig. is 0.000, 0.003 and 0.077 respectively. In addition, the collinearity statistics VIF value is 1(<10) which show the independent variable is not collinearity (Table 6.39).

Table 6. 37 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.810[a]	0.656	0.606	0.57255	0.656	13.326	3	21	0.000	2.403

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Stiffness

Table 6. 38 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.105	3	4.368	13.326	0.000[b]
	Residual	6.884	21	0.328		
	Total	19.989	24			

a. Dependent Variable: Stiffness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 39 Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	8.347	0.566		14.749	0.000	7.170	9.524					
	Viscosity	9.121E-6	0.000	0.581	4.535	0.000	0.000	0.000	0.581	0.703	0.581	1.000	1.000
	Mesh	-0.007	0.003	-0.307	-2.396	0.026	-0.013	-0.001	-0.307	-0.463	-0.307	1.000	1.000
	Frequency	0.283	0.077	0.473	3.697	0.001	0.124	0.442	0.473	0.628	0.473	1.000	1.000

a. Dependent Variable: Stiffness

6.4.11 Heavy weight –Smoothness performance

For the heavy weight fabrics, the correlations of variable factors and smoothness have been explored. For the model summary (Table 6.40), R square is 0.496 (<0.5) that means the degree of fitting linearity is not feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.41), Sig. is 0.002 which is less than 0.1 that means the independent factors affect the dependent variable smoothness. Table 6.42 reflects resin viscosity and squeeze frequency correlated with the smoothness which Sig. is 0.001 and 0.06 respectively. In addition, the collinearity statistics VIF value is 1(<10) which shows the independent variable is not collinearity (Table 6.42).

Table 6. 40 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.705[a]	0.496	0.424	0.31105	0.496	6.900	3	21	0.002	2.233

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Smoothness

Table 6. 41 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.003	3	0.668	6.900	0.002[b]
	Residual	2.032	21	0.097		
	Total	4.034	24			

a. Dependent Variable: Smoothness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 42 Coefficients

		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	6.596	0.307		21.453	0.000	5.956	7.235					
	Viscosity	-4.314E-6	0.000	-0.611	-3.948	0.001	0.000	0.000	-0.611	-0.653	-0.611	1.000	1.000
	Mesh	0.002	0.002	0.167	1.078	0.293	-0.002	0.005	0.167	0.229	0.167	1.000	1.000
	Frequency	-0.083	0.042	-0.308	-1.987	0.060	-0.169	0.004	-0.308	-0.398	-0.308	1.000	1.000

a. Dependent Variable: Smoothness

6.4.12 Heavy weight –Fullness & Softness performance

For the heavy weight fabrics, the correlations of variable factors and fullness & softness have been explored. For the model summary (Table 6.43), R square is 0.454 (<0.5) that means the degree of fitting linearity is not feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.44), Sig. is 0.005 which is less than 0.1 that means the independent factors affect the dependent variable fullness and softness. Table 6.45 indicates resin viscosity correlated with fullness and softness which Sig. is 0.001. In addition, the collinearity statistics VIF value is 1(<10) which shows the independent variable is not collinearity (Table 6.45).

Table 6. 43 Model Summary

					Change Statistics					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	0.674^a	0.454	0.376	0.67025	0.454	5.825	3	21	0.005	2.772

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: Fullness & Softness

Table 6. 44 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.850	3	2.617	5.825	0.005^b
	Residual	9.434	21	0.449		
	Total	17.284	24			

a. Dependent Variable: Fullness & Softness

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 45 Coefficients

		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	9.100	0.662		13.736	0.000	7.723	10.478					
	Viscosity	-9.520E-6	0.000	-0.652	-4.044	0.001	0.000	0.000	-0.652	-0.662	-0.652	1.000	1.000
	Mesh	9.787E-5	0.003	0.005	0.028	0.978	-0.007	0.007	0.005	0.006	0.005	1.000	1.000
	Frequency	-0.095	0.090	-0.171	-1.058	0.302	-0.281	0.091	-0.171	-0.225	-0.171	1.000	1.000

a. Dependent Variable: Fullness & Softness

6.4.13 Heavy weight –THV performance

For the heavy weight fabrics, the correlations of variable factors and total hand value have been explored. For the model summary (Table 6.46), R square is 0.636 (>0.5) that means the degree of fitting linearity is feasibility and validity of this method. DW value is around 2 which show that data has not collinearity. From ANOVA analysis (Table 6.47), Sig. is 0.000 which is less than 0.1 that means the independent factors affect the dependent variable THV. From the coefficients table (Table 6.48), it shows all the independent factors have the correlation with THV which coefficients of resin viscosity, screen mesh, and squeeze frequency are 0.001, 0.041 and 0.001 respectively.

In addition, the collinearity statistics VIF value is 1(<10) which shows the independent variable is not collinearity (Table 6.48).

Table 6. 46 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.797[a]	0.636	0.584	0.15648	0.636	12.208	3	21	0.000	2.078

a. Predictors: (Constant), Frequency, Mesh, Viscosity

b. Dependent Variable: THV

Table 6. 47ANOVA

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	0.897	3	0.299	12.208	0.000[b]
	Residual	0.514	21	0.024		
	Total	1.411	24			

a. Dependent Variable: THV

b. Predictors: (Constant), Frequency, Mesh, Viscosity

Table 6. 48 Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	3.694	0.155		23.884	0.000	3.373	4.016					
	Viscosity	-2.191E-6	0.000	-0.525	-3.986	0.001	0.000	0.000	-0.525	-0.656	-0.525	1.000	1.000
	Mesh	0.002	0.001	0.287	2.182	0.041	0.000	0.003	0.287	0.430	0.287	1.000	1.000
	Frequency	-.084	0.021	-0.526	-3.997	0.001	-0.127	-0.040	-0.526	-0.657	-0.526	1.000	1.000

a. Dependent Variable: THV

6.4.14 Correlations of primary hand value

The primary hand values have some relations shown from Figure 6.1 to Figure 6.5.

There are linear regression relationships between each primary hand value in terms of different weight fabrics. However, there are linear relationship between stiffness and fullness/softness for heavy weight fabric. In addition, there are linear regression relationship between stiffness & crispness, stiffness & anti-drape stiffness, crispness & anti-drape stiffness and crispness & fullness/softness. Furthermore, there are linear relationship between anti-drape stiffness and fullness/softness.

For stiffness and fullness & softness, with increasing the stiffness, fullness and softness will decrease which the light, medium, and heavy weight show an incremental performance. For stiffness and smoothness, with the stiffness increasing, smoothness decreases in terms of medium and heavy weight fabrics. For smoothness and fullness and softness, with the smoothness increase, the fullness & softness increase, and heavy fabrics have a significant performance compare with the medium weight fabrics. Figure 6.4 shows stiffness has a positive relationship with crispness and anti-drape stiffness respectively in terms of light weight fabric. With light weight fabric stiffness increase, fabric crispness has a significant increase compared with anti-drape stiffness performance. Figure 6.5 shows the relationships among crispness, anti-drape stiffness and fullness and softness. Fullness & softness has a negative correlation with crispness and anti-drape stiffness. However, crispness has a positive relationship with anti-drape stiffness.

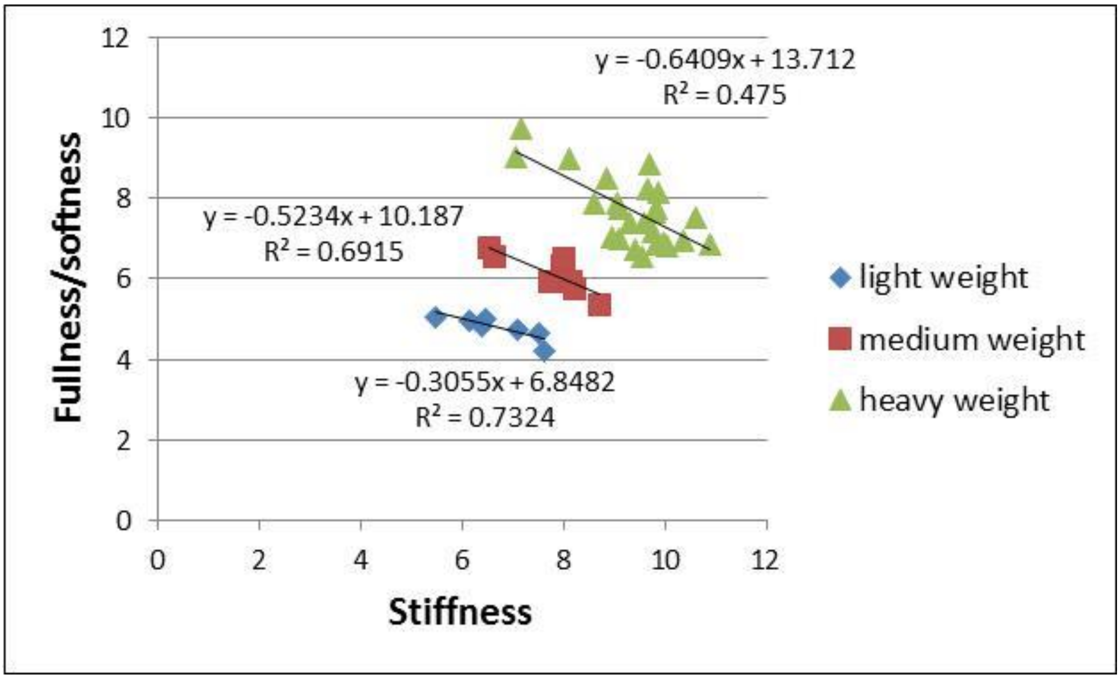


Figure 6. 1 Stiffness and fullness/softness

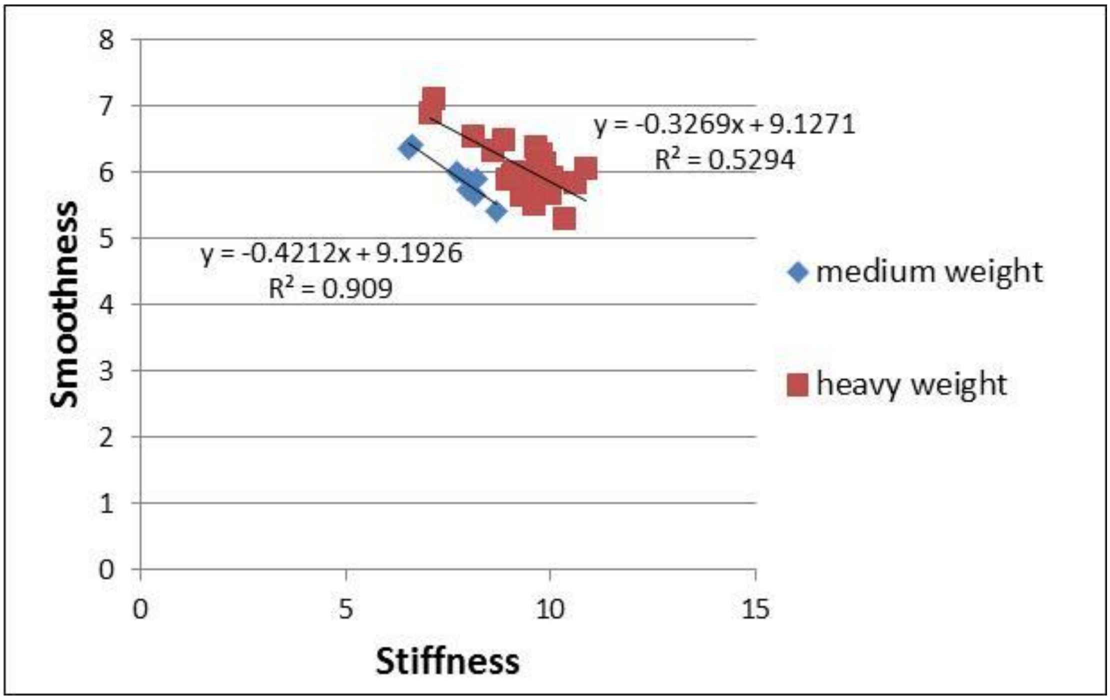


Figure 6. 2 Stiffness and smoothness

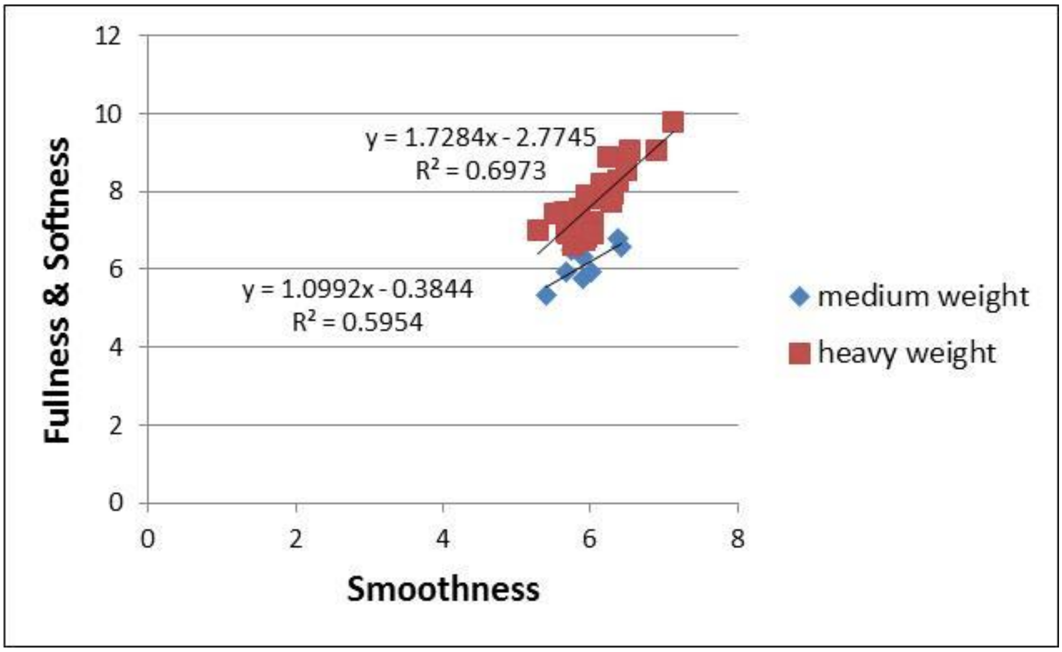


Figure 6. 3 Smoothness and fullness/softness

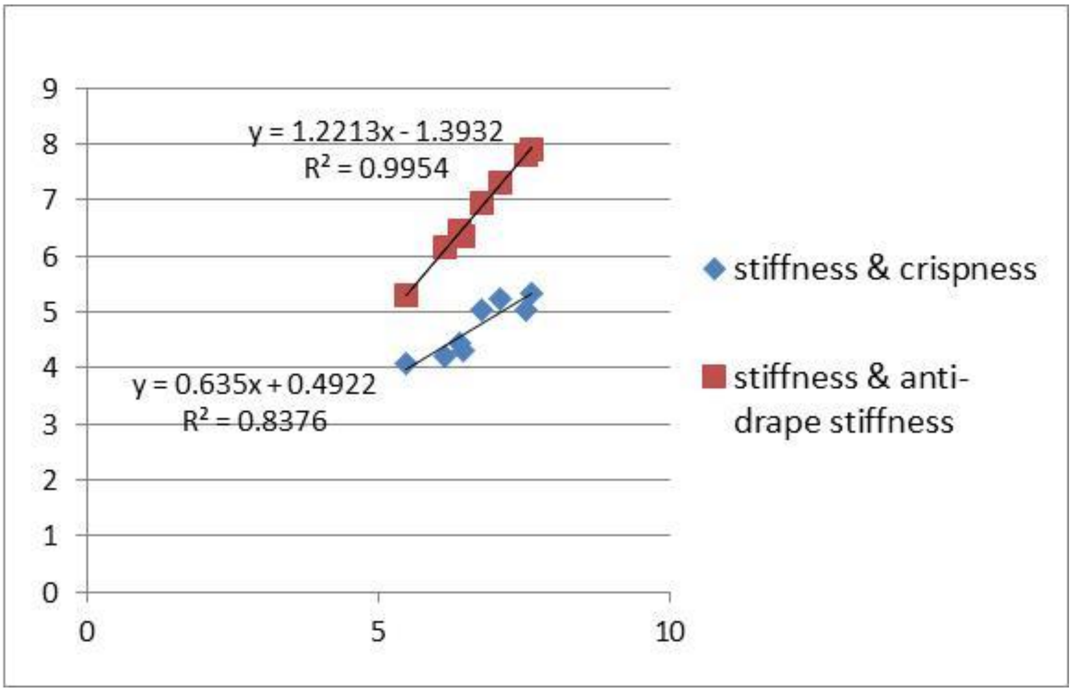


Figure 6. 4 Stiffness and crispness and anti-drape stiffness

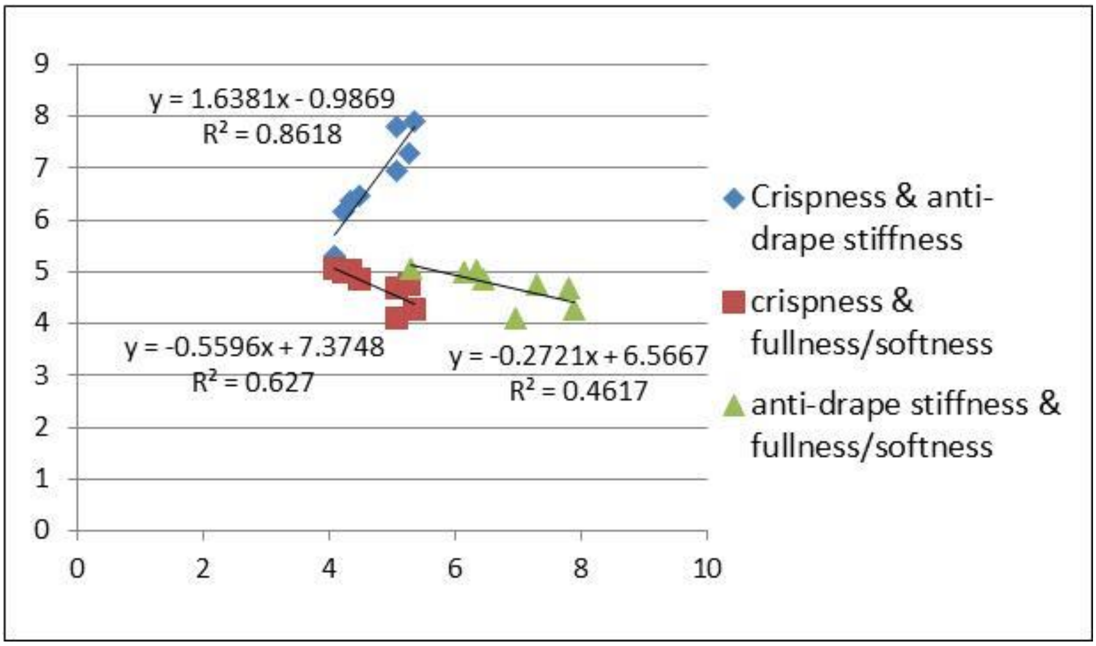


Figure 6. 5 Crispness, anti-drape stiffness, and fullness/softness

6.5 Conclusion

This chapter explored the hand values of printable interlinings to develop an efficient technique. In this study, printable interlining hand value of different weight woollen fabrics were optimized by OED method. According to the previous result, the resin viscosity, screen mesh, and squeeze frequency have significant influences on the hand value of woollen fabric with printable interlinings. For total hand value, the optimum conditions correspond to light weight fabric were [viscosity] = 116000mPa.s/25°C; [mesh] = 160T; and [frequency] = 3 times; for medium weight fabrics were [viscosity] = 162000mPa.s/25°C; [mesh] = 200T; and [frequency] = 6 times; for heavy weight fabrics were [viscosity] = 12800mPa.s/25°C; [mesh] = 160T; and [frequency] = 2 times. The detail optimum combinations of all the hand values have shown in Table 6.49. The optimized printing technique demonstrated as an effective method for evaluating and improving a request hand value of woollen fabrics in terms of the printing process.

Table 6. 49 Optimum condition for fabric hand value in three different weight levels

			Factor		
	Hand Value	**Optimum Condition levels**	**Viscosity (mPa.s/25˚C)**	**Mesh (T)**	**Frequency (Times)**
Light Weight	**Stiffness**	$A_bB_bC_b$	116000	200	6
	Crispness	$A_bB_bC_b$	116000	200	6
	Fullness & Softness	$A_aB_aC_a$	172000	160	3
	Anti-drape stiffness	$A_bB_bC_b$	116000	200	6
	THV	$A_bB_aC_a$	172000	160	3
Medium Weight	**Stiffness**	$A_IB_{II}C_{II}$	12800	200	6
	Fullness & Softness	$A_{II}B_IC_{II}$	162000	160	6
	Smoothness	$A_{II}B_IC_{II}$	162000	160	6
	THV	$A_{II}B_{II}C_{II}$	162000	200	6
Heavy Weight	**Stiffness**	$A_2B_1C_3$	172000	100	6
	Fullness & Softness	$A_3B_2C_2$	12800	160	4
	Smoothness	$A_3B_2C_2$	12800	160	4
	THV	$A_3B_2C_1$	12800	160	2

The relationships of factors and hand values show that three factors have different efficiency levels for different weight fabrics. For light weight fabric, resin squeegee frequency and screen mesh were more significant than resin viscosity. In addition, for medium weight fabric, resin viscosity and squeegee frequency were more significant than screen mesh. Furthermore, the heavy weight fabric showed that the resin viscosity was the most important factor compared with the other two factors. In addition, the primary hand values have linear regression. The analysis and comparison of impact factors of printable interlinings could be an implication in manufacture.

CHAPTER7 CONCLUSION AND RECOMMENDATION

7.1 Conclusion

This section provides a major results and finding screen printing technique used on woollen fabrics which is in place of the fusing method, we so called printable interlining in place of fusible interlinings. This thesis attempted to present a comprehensive and systematic study of traditional fusible interlinings and investigate screen printing interlining on woollen fabrics.

In Chapters 3 and 4, the attainment of fusible interlining on woollen fabrics was evaluated and analyzed. Physical properties, low-stress mechanical properties and hand value were evaluated by KES-F and analyzed the correlated relationship among them. In Chapter 5, the printable interlining was studied which could achieve the hand value and low-stress mechanical properties of fusible interlinings on woollen fabrics, which could be defined that printable interlinings in place of fusible interlinings. In Chapter 6, the printable interlining technique has been optimized based on different hand value and low-stress mechanical properties.

7.1.1 Study of fusible interlinings on woollen fabrics

Nowadays, woollen fabrics are widely used in suit making. Fusible interlining was an important accessory for suit manufacture. The low-stress mechanical properties and hand value reflected different performance for the same woollen fabrics. Three kinds of thickness levels of woollen fabrics with fusible interlinings were explored. Experiment results revealed that most important low-stress mechanical properties were bending and shearing which changed more than hundred percentage sorting after woollen fabrics fused interlinings. Compression and tensile properties had obvious change and surface of woollen fabrics with fusible interlinings were slight affected. Fusible interlinings on woollen fabrics had a dramatically efficiency in terms of hand value. The most influenced primary hand value was stiffness with a rapid increase. Fullness and crispness had slightly increase, however smoothness decreased after woollen fabrics fused interlinings.

In addition, this study explored fusible interlining and woollen fabric physical properties correlated with low-stress mechanical properties and hand value of woollen fabrics with fusible interlinings respectively. Fabric thickness and weight properties were highly related with stiffness, softness, smoothness and THV. Adhesive density of interlining affected fabric stiffness and softness. Interlining adhesive density and thickness properties affected fabric low-stress mechanical properties, the severity of the impact properties were bending, compression, surface and tensile in sequence. Not only objective measurement, but also subjective evaluation was explored. The subjective questionnaire results shown both gender and education background of judges affected the fabric hand value. Judge gender affected on fabrics softness evaluation, and judge education background did effect in fabric THV evaluation.

7.1.2 Study of printable interlinings on woollen fabrics

Printing is a cost-effective process for garment manufacture. In this study, printing technique applied to substitute the fusing technique on woollen fabrics in suit making. Printable interlinings obviously could achieve the hand value or even increased performance comparing with fusible interlinings on woollen fabrics. Woollen fabrics with printable interlinings were dramatically increased in shearing, bending and tensile properties and fabric stiffness as well. Printable interlinings were effective for the woollen fabric used for men's suit. Resin viscosity, screen mesh, and squeeze frequency have significant influence on hand value of woollen fabric with printable interlinings. In order to develop the efficiency of printable interlinings on woollen fabrics, the printing technique was optimized based on orthogonal analysis. For total hand value, the optimum conditions correspond to light weight fabric were [viscosity] = 116000mPa.s/25°C; [mesh] = 160T; and [frequency] = 3 times; for medium weight fabrics were [viscosity] = 116000mPa.s/25°C; [mesh] = 200T; and [frequency] = 3 times; for heavy weight fabrics were [viscosity] = 12800mPa.s/25°C; [mesh] = 160T; and [frequency] = 2 times. The optimized printing technique would develop the printing process with a various hand value requirement.

7.2 Recommendations for future work

Although the objectives have been achieved in the study, it is recognized that more research works in the area of printable interlinings. It would be conducted in the future to produce aesthetic and effective printable interlinings.

7.2.1 Printing pattern affect woollen hand value

The optimization of printable interlining was based on printing technique which were resin viscosity, screen mesh and squeegee frequency. This technique control was mainly about volume and distribution of resin. However, printing pattern also an important factor to affect the resin volume and distribution, which would affect the fabric low-stress mechanical properties and hand values. Printing pattern would refer to different dot or striped and so on.

7.2.2 Printable interlinings used for different fabrics

In the present work, woollen fabrics were treated for fused interlinings and invested printable interlinings. Although interlinings were widely used in woollen fabrics for suit manufacture, interlinings are also used on various fabrics, such as cotton and polyesters. Different fusible interlinings can be used to various fabrics, printable interlinings would also achieve the fusible interlinings function for garment manufacture.

7.2.3 Printable interlining mechanism

Printable interlining would develop the production process especially for the mass ready-to-wear manufacture. A competitiveness mechanism could match the printing technique in terms of resin viscosity, screen mesh, squeegee frequency and so on. Printable interlining mechanism would control the process automatically.

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