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EVALUATION OF SHAPE MEMORY FABRICS

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CERTIFICATE OF ORIGINALITY

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Dedicated to My Family and Brian Liu for their continuous encouragement and support

ABSTRACT

Shape memory fabrics in this research are novel and temperature sensitive products prepared by applying waterborne thermally sensitive shape memory polymers (SMP) onto fabrics through specific finishing processes. This thesis concerns the evaluation of shape memory effects of fabrics using modified evaluation methods. There are three thermally sensitive shape memory effects for fabrics. They are flat appearance, crease retention and bagging recovery.

A subjective evaluation method for evaluating the fabric shape memory effects in water was developed based on the AATCC Test Method 124 and 88C. The experimental procedures were newly designed. The effect of water temperature, recovery method and drying method on fabric shape memory effects were investigated. The results show that the shape memory fabrics possess shape memory effects of flat appearance and crease retention in water at 60℃. Moreover, tumble dry could enhance the shape memory effects of fabrics. In addition, washing in the recovery stage of fabrics can give a higher fabric shape memory effect compared with immersing samples in water.

An objective evaluation method was also established to evaluate the fabric shape memory effects of flat appearance and crease retention in water. This newly designed method was modified from the AATCC Test Method 66. The Wrinkle Recovery Tester was used to measure the Original Angles and Shape Memory Angles. These parameters were used in newly developed equations of Shape Memory Coefficient of flat samples (Sf%) and Shape Memory Coefficient of creased samples (Sc%). Since it was found that the Shape Memory Coefficients were complicated and has a limitation,

their equations were then further simplified and modified respectively. A Flat Recovery % (FRec%) and Crease Recovery % (CRec%) were developed to give a better representation of the fabric shape memory effects.

After investigating the fabric shape memory effects in water, the fabric shape memory effects in air at various temperatures and relative humidities were determined using both subjective and objective evaluation methods. It is discovered that high relative humidity can enhance the fabric shape memory effect of flat appearance. However, the fabric shape memory effect of crease retention is lowered if the relative humidity is too high. Furthermore, an optimum condition for the recovery of fabrics in air is found.

The relationship between the fabric shape memory effects in water and air was compared, using a subjective evaluation method. It is shown that the fabric shape memory effects of flat appearance and crease retention in water are higher than that in air. It is easier for samples to recover their original flat and creased shapes in water than in air.

Apart from the flat appearance and crease retention, the fabric shape memory effect of bagging recovery was also evaluated. The Bagging Recovery Percentages for the warp direction (BPR%) and the weft direction (BTR%) of a fabric were established. The experimental procedures were designed in order to measure the bagging recovering ability of samples after immersing in water at various temperatures. In addition, a Bagging Recovery Rating (BRR) was set up to integrate the ability of fabric bagging recovery in warp and weft directions to determine the fabric shape memory effect.

The finding shows that a knitted fabric has a higher bagging recovery effect when putting in water at switch temperature compared with woven fabrics.

Study on the evaluation of shape memory fabrics by using new characterization methods can help to understand the fabric shape memory effects under various conditions clearly. As a result, designing evaluation methods and analysing evaluation results for the shape memory fabrics are very significant.

LIST OF PUBLICATIONS

(I) Refereed Journal Papers

Jinlian Hu, Siuping Chung and **Yuenkei Li, "**Characterizing the Shape Memory Effect of Woven Fabrics", *The Transactions of the Institute of Measurement and Control*. (Accepted)

Yuenkei Li, Jinlian Hu, Siuping Chung and Laikuen Chan**, "**Subjective Evaluation of Shape Memory Effect of Fabrics in Water", *Research Journal of Textile and Apparel.* (Accepted)

(II) Non-Refereed Journal Papers

Yuenkei Li, Siuping Chung, Laikuen Chan and Jinlian Hu, "Characterization of Shape Memory Fabrics", *Textile Asia*, Vol.35 (6), pp. 32-37, June (2004).

Yuenkei Li, Siuping Chung, Laikuen Chan and Jinlian Hu, Characterization of Shape Memory Fabrics, *Asian Textile Journal*, Vol. 65, pp. xxiv-xxv, July (2005).

(III) Conference Papers

Jinlian Hu, **Yuenkei Li**, Siuping Chung and Laikuen Chan, "Subjective Evaluation of Shape Memory Fabrics", *Proceeding of the International Conference on " High Performance Textiles & Apparels" HPTEX 2004*, July 2004, Kumaraguru College of Technology, Coimbatore, India, pp. 597-604, ISBN:81-7296-085-9 (2004).

Jinlian Hu, Siuping Chung, Hung Zhu, **Yuenkei Li** and Laikuen Chan, "The Effect of Finishing Methods on Shape Memory Fabrics", *Proceeding of the International Conference on "High Performance Textiles & Apparels" HPTEX 2004*, July 2004, Kumaraguru College of Technology, Coimbatore, India, pp. 605-611, ISBN:81-7296-085-9 (2004).

Yuenkei Li, Lapyan Yeung, Siuping Chung and Jinlian Hu, "Evaluation Method of Innovative Shape Memory Fabrics", *NTCTIAWC 2005 (13th National Textile Center Annual Forum and the 84th Textile Institute Annual World Conference), Raleigh, North Carolina, USA,* Technical Program, Session 1, Wednesday, 1:50, ISBN: 1 870 372 67 0 (2005).

(IV) Patents

Jinlian Hu, Siuping Chung, Edward Newton and **Yuenkei Li**, Methods of Determining Shape Memory Coefficients of Fabrics, US Patent, Filing no. 11/485480, Filing date: 13 July 2006.

(V) Book Chapters

Siuping Chung, Jinlian Hu and **Yuenkei Li**, "Chapter 9, Evaluation Methods of Shape Memory Fabrics", in Shape Memory Material for Textiles, China Textile and Apparel Press, pp. 375- 403, ISBN: 750643860 (June 2006).

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Symbol	Description
Tm(h)	The melting temperature of hard segments of a shape memory polymer
Tm(s)	The melting temperature of soft segment crystals in a shape memory polyurethane and it is the switch temperature of recovering an original shape of fabrics
Of	Original Angle of a flat sample
Oc	Original Angle of a creased sample
Mf	Shape Memory Angle of a flat sample
Mc	Shape Memory Angle of a creased sample
Sf %	Shape Memory Coefficient of a flat sample
Sc %	Shape Memory Coefficient of a creased sample
FRec%	Flat Recovery % of a flat sample
CRec%	Crease Recovery % of a creased sample
Op	Original Warp Length of a bagged sample
Ot	Original Weft Length of a bagged sample
Dp	Deformed Warp Length of a bagged sample
Dt	Deformed Weft Length of a bagged sample
Rp	Recovered Warp Length of a bagged sample
Rt	Recovered Weft Length of a bagged sample
BPR%	Bagging Warp Recovery %
BTR%	Bagging Weft Recovery %
BRR Rating	Bagging Recovery Rating
CR Rating	Crease Retention Rating of a creased sample
SA Rating	Smoothness Appearance Rating (Flat Appearance Rating) of a flat sample

CHAPTER 1: INTRODUCTION

1.1 Research Background

1.1.1 Study on Shape Memory Fabrics

Shape memory fabrics studied in this research are novel and temperature-sensitive products prepared by applying waterborne shape memory polymers (SMP) onto fabrics through specific finishing processes. These shape memory fabrics were first prepared in 2004 by the project team led by Prof. Jinlian Hu of The Hong Kong Polytechnic University. There are three thermally sensitive fabric shape memory effects which are flat appearance, crease retention and bagging recovery.

The shape memory effect of flat appearance refers to the ability of shape memory fabric recovering an original flat shape from a deformed shape upon application of a thermal stimulus. The shape memory effect of crease retention refers to the ability of shape memory fabric recovering an original creased shape from a deformed shape. Furthermore, the shape memory effect of bagging recovery refers to the ability of shape memory fabric recovering an original flat shape from a deformed shape which likes a bag.

The shape memory polymers used are a class of polyurethanes (PU) which are stimuli-responsive materials and they are capable of changing their shapes upon application of an external stimulus. Thermo-responsive shape memory polymers, which have the capability of changing their shapes caused by temperature stimulation, are used for treating fabrics in this project. These polymers are conventionally processed to receive their permanent shape. Afterwards, they can be deformed and their intended temporary shape is fixed by heating up the samples, deforming and cooling the samples or drawing samples at a low temperature. Then, the deformed shape can be recovered by heating up the shape memory polymer above a transition temperature. This is called a thermally sensitive shape memory effect [6, 15, 40, 46]. As a result, fabrics applied with shape memory polymers can acquire the unique shape memory effects of shape memory polymers.

1.1.2 Application of Thermo-responsive Shape Memory Polymers to Textiles

In the past decade, many researchers investigated the properties of shape memory polymers (temperature-sensitive polyurethane) because of their unique characteristics [9, 23, 55, 66]. In addition, a number of patent applications of shape memory polymers on medical products and toys which take advantage of shape memory effects have been developed.

In recent years, the applications of temperature-sensitive polyurethane to textiles have been researched. As mentioned in Section 1.1.1, the preparation of shape memory fabrics is the first of its kind in applying shape memory polymers onto fabrics as a finishing to achieve the above mentioned effects. Thus the technology and products so developed under this project are considered to be a breakthrough in the academic and the industry communities.

1.1.3 Importance of Evaluation of Novel Fabrics

Shape memory fabrics refer to novel and temperature-sensitive products. As a consequence, specific evaluation methods are required to test shape memory effects of fabrics under various conditions. In this study, the flat shape and creased shape of fabrics were evaluated for determining the shape memory effects using both subjective and objective evaluation methods.

1.2 Statement of Problems

The following problems lead to this research:

1. The shape memory fabrics so produced are novel fabrics which respond to the temperature stimulation. Because the concept of shape memory fabric is new, there is no specific evaluation method for this kind of the textile product. Thus, developing methods are required for a better understanding of fabric shape memory effects.

2. There are some related evaluation methods but the problem is that they do not take into consideration of the parameters of temperature sensitivity, shape deformation and shape recovery in their tests. Their experimental procedures cannot be used to evaluate the fabric shape memory effects specifically.

3. No report has been found regarding the relationship between fabric shape memory effects under various testing conditions such as temperature and relative humidity in previous studies. This relationship should be examined in order to further understand the application and improve the properties of shape memory fabrics.

1.3 Objectives

To address the problems as mentioned in Section 1.2, this research shall consider evaluating fabric shape memory effects using specific evaluation methods. The objectives of my study were as follows:

1. To evaluate the thermally sensitive fabric shape memory effects in water or air using subjective methods.
2. To evaluate the thermally sensitive fabric shape memory effects in water or air using objective methods.
3. To investigate the relationship of fabric shape memory effects under various conditions.

1.4 Definition

The fabric shape memory effects of flat appearance, crease retention and bagging recovery can be defined and are given in the following Sections (1.4.1 - 1.4.3).

1.4.1 Fabric Shape Memory Effect of Flat Appearance

The fabric shape memory effect of flat appearance could be defined as the ability of recovering an original flat shape from a deformed shape, after stimulation at switch temperature in different media.

1.4.2 Fabric Shape Memory Effect of Crease Retention

The fabric shape memory effect of crease retention could be defined as the ability of recovering and retaining an original creased shape from a deformed shape, after stimulation at switch temperature in different media.

1.4.3 Fabric Shape Memory Effect of Bagging Recovery

The fabric shape memory effect of bagging recovery could be defined as the ability of recovering an original flat shape from a deformed shape which likes a bag, after stimulation at switch temperature in different media.

1.5 Significance

The shape memory fabric is a new concept. As a result, specific evaluation methods for the testing of these novel fabrics are required. Based on the evaluation results and analysis, the fabric shape memory effects can be further improved. Moreover, the shape memory fabrics may be commercialized in the near future. Thus, evaluation of these novel fabrics can determine the existence of fabric shape memory effects before launching them to the market.

1.6 Outline of Thesis

This thesis is divided into nine chapters. Chapter 1 introduces the research background, objectives, significance and a brief outline of this thesis.

Chapter 2 provides the literature review, which explores the historical study of shape memory polymers and the previous existing evaluation methods. The limitations in the previous studies are discussed.

Chapter 3 is the research methodology. It demonstrates the specific evaluation methods for the testing of fabric shape memory effects. The principle of evaluation methods is stated and the details of both subjective evaluation methods and objective evaluation methods are examined.

Having discussed the research methodology, the thesis will move on to investigate the fabric shape memory effects of crease retention and flat appearance in water using a subjective method in Chapter 4. Different fabric types for producing shape memory fabrics are examined. Furthermore, the effect of water temperature, recovery method and drying method on the fabric shape memory effects is explored.

Chapter 5 analyzes the fabric shape memory effects of crease retention and flat appearance in water using an objective method. New equations are established to evaluate the fabric shape memory effects effectively.

Chapter 6 investigates the fabric shape memory effects of crease retention and flat appearance in air using both subjective and objective methods. The effect of air temperature and relative humidity in a Conditioning Chamber is explored.

In Chapter 7, the relationship of fabric shape memory effects in water and air is examined and the effect of tumble dry on fabrics is determined.

In Chapter 8, the fabric shape memory effect of bagging recovery in water is explored using a developed objective evaluation method. New equations and a rating system are established to evaluate the bagging recovery effect of fabric. The effectiveness of this method is accessed.

Finally, Chapter 9 summarizes the major results and findings of the present work and draws conclusions. Recommendation on further studies is also included.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the historical development of shape memory polymers and their applications. The previous evaluation methods of crease retention, flat appearance and bagging recovery on textile fabrics are discussed.

The first section introduces the development and unique properties of shape memory polymers of the polyurethane series. These polymers are the essential and functional materials which are applied onto fabrics to produce the novel shape memory fabrics in this study. The second section investigates the applications of shape memory polymers to textiles. Having discussed the background and applications of the main polymeric materials, the chapter moves on to review the existing methods for evaluating the crease retention, flat appearance and bagging recovery. The limitations of these previous methods on the evaluation of shape memory fabrics are explored. Finally, this chapter concludes with a description of objectives to fill these gaps.

2.2 Thermally Sensitive Shape Memory Polymers

The shape memory fabrics were treated with the thermally sensitive shape memory polyurethanes in this study. The polyurethanes have large reversible changes in an elastic modulus and offer unique shape memory properties. The major unique property of these polymeric materials is that they can exhibit the ability of recovering a previously defined permanent shape from a temporary deformed shape, under the appropriate thermal conditions.

2.2.1 Chemical Structure of Shape Memory Polymers

Shape memory polyurethanes are polymeric materials which could fix the deformation without external force and recover the original shape after a series of thermo-mechanical treatments [47]. The most common and basic formulation of shape memory polyurethanes are based on three materials that are reacted with no or very little catalysts [44]. These three key materials include (1) Isocyanate, (2) Polyol and (3) Chain Extender.

The basic chemical reaction of a urethane group in shape memory polyurethane is shown in Figure 2.1 and the chemical structure of a urethane group is given in Figure 2.2. The principle of the isocyanate reaction is that the hydrogen atom presented in a hydroxyl group attaches itself to the nitrogen atom of an isocyanate (NCO) group [57].

$$\mathbf{R \cdot NCO} \quad + \quad \mathbf{HO \cdot R'} \quad \rightarrow \quad \mathbf{-R \cdot NH \cdot CO_2\,R'-}$$

(Isocyanate group) *(Hydroxyl group in Polyol)* *(Urethane)*

Figure 2.1 Basic chemical reaction of urethane group in polyurethane

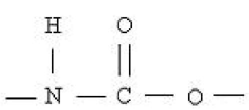

Figure 2.2 Chemical structure of urethane group

A urethane (**$-R \cdot NH \cdot CO_2\ R'-$**) is a reaction product of a hydroxyl group of a polyol and an isocyanate. Thus, a polyurethane indicates a polymer wherein the reactants have produced a repeating urethane linkage **$-R \cdot NH \cdot CO_2\ R'-$** along the polyurethane molecular chain [57]. The thermo-responsive polyurethanes contain di-functional groups. The di-functionality is required because the formation of high molecular weight and linear long chain polyurethane molecules is encouraged. The long polyurethane molecules can provide a product which has high physical strength characteristics with high degree of toughness and high thermoplastic characteristic at the same time. Figure 2.3 indicates the chemical reaction of thermoplastic polyurethane.

Figure 2.3 Chemical reaction of thermoplastic polyurethane

In order to perform the mechanical act of fixing and recovering deformation, the shape memory polymers consist of at least two distinct segments. Takahashi states that the shape memory polyurethane was a functional segmented polyurethane (PU) which contains alternating sequences of hard and soft segments [64]. They are an amorphous soft segment domain as a reversible phase and a crystalline hard segment domain as a fixed phase [30, 31, 33, 34]. The phase separation was derived from the thermodynamic incompatibility of the hard and soft segments [31].

The isocyanate groups can form the hard segment while the polyol groups can form the soft segment. Besides, chain extenders can facilitate a polymer chain growth to raise the crystallization in a hard segment. Hu maintains that, soft segments should be large enough to allow considerable free rotation of molecules for recovering from deformations when temperature changes [30]. Figure 2.4 shows the schematic representation of the thermoplastic polyurethane composed of diisocyanate, long-chain diol and chain extender [27].

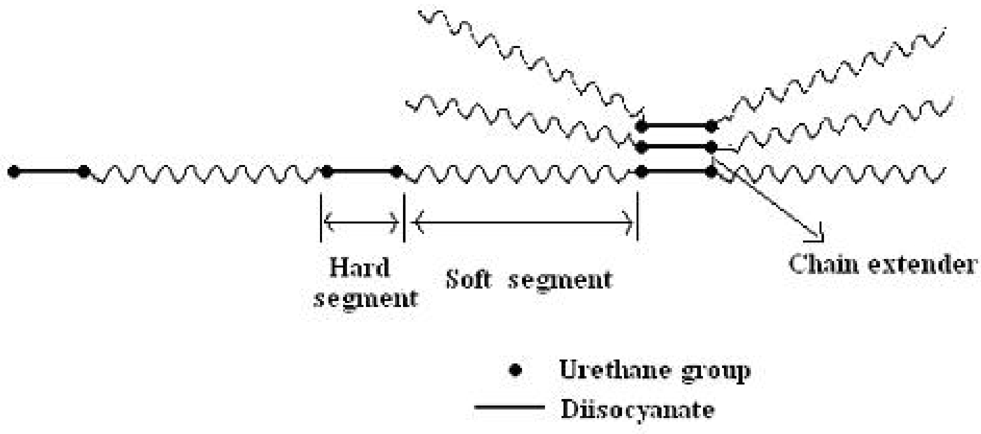

Figure 2.4 Hard segment and soft segment of thermoplastic polyurethane

2.2.2 General Shape Memory Mechanism

There are two types of shape memory polymers including the Tg type and Tm type. Tg type shape memory polymers mean that they recover their original shapes by stimulating the glass transition temperature in soft segments or hard segments. Tm type shape memory polymers mean that they are stimulated by the melting temperature in soft segments or hard segments leading to recover their original shapes. In this study, Tm type polyurethane was applied onto fabrics for making shape memory fabrics.

The shape memory polymers have various elasticities from hard one like a glass, to soft one like a rubber. The elastic modulus of Tg type polymers performs a reversible change with the glass transition temperature [Tg(s)], which is a switch temperature of a soft segment for the recovery. As a result, the shape memory could repeat the shape change and shape retention depending on the temperature change [22, 25, 31, 40]. The glass transition temperature in soft segments [Tg(s)] of shape memory polyurethanes generally depends on the strength of intermolecular forces (hydrogen bond and polarization), stiffness and symmetry of backbone chains and also geometrical factors such as the side chains and functional groups [22]. Figure 2.5 presents the shape memory mechanism of Tg type polyurethanes by indicating the temperature dependency of elastic modulus of SMPs.

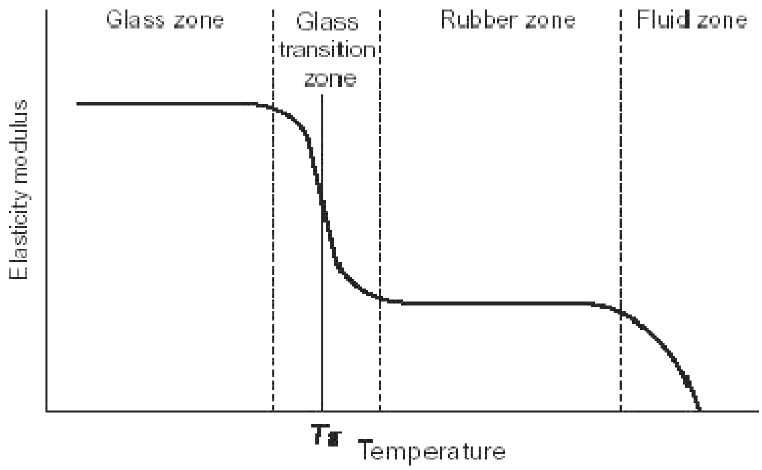

Figure 2.5 Elasticity modulus against temperature of SMP

Hayashi, S. demonstrated that when the temperature was increased above the glass transition temperature of soft segment [Tg(s)] and below the melting temperature of hard segment [Tm(h)], the material entered a rubbery state and got soften like a rubber where it could be easily deformed into any free shapes in the soft segment. When the environment was cooled below Tg(s), the deformation would be fixed and a new temporary shape retained. At this stage, the material becomes rigid and lacks its rubbery elasticity. If the temperature is kept permanently below Tg(s), the material will never recover its original shape. However, when it is heated up again above Tg(s) and below Tm(h), the deformed shape could be returned to its original shape automatically due to loosing the orientations of temporary molecular chains. This process can be repeated again and again, and that is the reason why this material is named ‘Shape Memory’ [15, 22].

2.2.3 Molecular Movement during Shape Shifting

In the seminal study of Hayashi, he believed that the molecular chains of polymers could undergo Micro-Brownian movement when the temperature is increased to Tg(s). This meant that the elastic modulus of the material was lowered. With gradual increase in temperature, the material becomes molten.

In the glassy state, the entanglement networks or crosslinking networks in the hard segment can be used as fixed structures to memorize original shapes. The material entered a rubbery state when the temperature was increased above Tg(s). In the rubbery state, the shape of the material could be changed to any shape when the amorphous region or soft segment inside this material was sufficiently large. The molecular chains could be re-structured in the direction of tension.

When the temperature was cooled below Tg(s) and the deformation remained constant, the Micro-Brownian motion would be frozen. Then, the chain orientation and deformation would be fixed. If the temperature was kept below Tg(s), the material would not recover its original shape from the deformation. When the temperature was increased again to Tg(s), the micro-Brownian movement started again and the molecular chains become mobile.

The shape memory material would recover its original shape due to the crosslinking or partial crystallization [25].

2.2.4 Shape Memory Mechanism of Shape Memory Fabric

In this study, the thermo-responsive shape memory polymers of polyurethane series were selected. The shape memory polyurethane emulsions used as the finishing agent are the Tm type, which means that the switch temperature of recovering the original shape of polymers depends on the melting temperature of soft segment crystals [Tm(s)] in the polyurethane. To perform the mechanical fixing and recovering deformation, shape memory polyurethanes should consist of at least two unique segments including hard and soft segments.

The shape memory mechanism of shape memory fabrics shows in Figure 2.6. The shapes of shape memory fabrics are heat set by a curing step in a finishing process. The hard segments of shape memory polyurethanes have a specific melting temperature [Tm(h)]. The fabrics are cured at a temperature which is higher than Tm(h), for setting the permanent shape. During this period, molecular chains within the polyurethanes will loose their original orientations. When the temperature of polymers is cooled below Tm(h), the molecular chains in polyurethanes create new orientations due to re-crystallization. The permanent flat shape and creased shape of shape memory fabrics can be set consequently.

The shape memory fabrics may be deformed when the external temperature is below the switch temperature, Tm(s). For example, the creased shape of fabrics may become flat, the flat shape of fabrics may be wrinkled and the bagged shape may be formed on fabrics temporarily when a force is applied to fabrics.

The external thermal stimulation can recover the deformed shape to the original shape of shape memory fabrics. When the external temperature such as water and air temperature is above Tm(s), the temporary fabric shape could return to their original permanent shapes automatically. At this moment, the molecular chains in the soft segments of shape memory polymers will have greater mobility and recover to their original orientations. The hard segments of polymer act as fixing points for memorizing their original shapes which are heat-set during the curing process. As a result, shape memory fabrics can be simulated by heat.

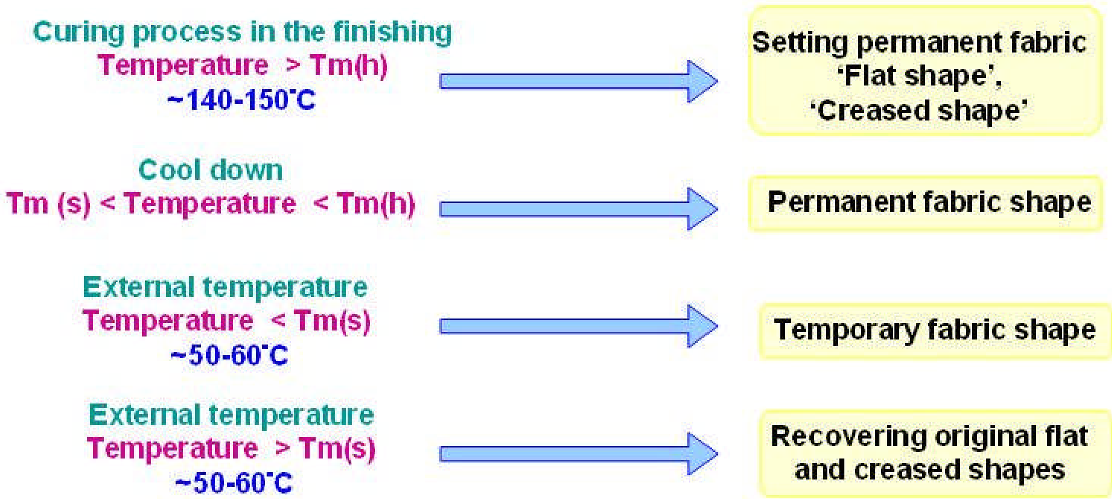

Figure 2.6 Shape memory mechanism of shape memory fabric

2.3 Chemical Nature of Cotton

Cotton is the main fabric type for treating with shape memory polyurethanes in this research. It is the most important cellulosic fibre and it accounts for about 50% of total fibre production in the world. In our daily life, many of our textile fabrics are made from cotton [8, 53] which holds 75% of the market for apparels [28]. Cotton is composed of many linear cellulose polymers. The most important chemical group on the cellulose polymer is the hydroxyl group (-OH). Cotton also contains the carbon, hydrogen and oxygen. Its molecular chains are in a spiral form, as shown in Figure 2.7.

Figure 2.7 Spiral structure of cotton

Hydrogen bonding will occur between the molecular chains of cotton. The chemical structure of cotton is given in Figure 2.8. Hydrogen bonding involves the oxygen atom located between rings and the hydroxyl groups attached to the sixth carbon atom. This hydrogen bonding confers strength and additional rigidity to the fibre. In addition, the hydroxyl groups can be reactive and they will attract and hold water in a fibre.

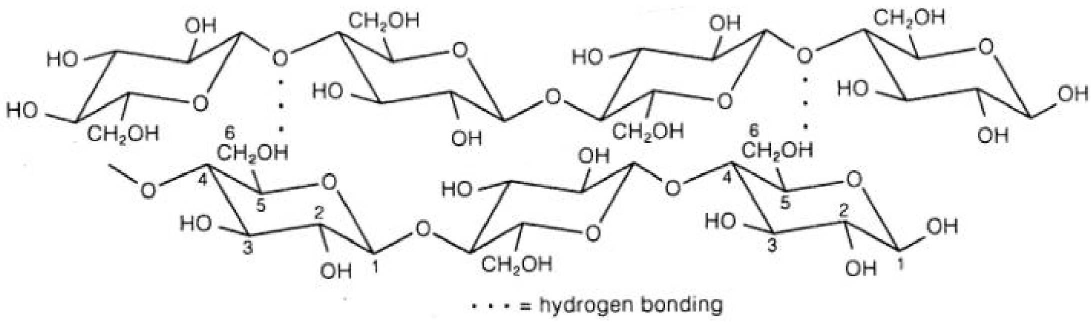

Figure 2.8 Chemical structure showing hydrogen bonding of cotton

Cotton has very low resiliency and the hydrogen bonds holding the molecular chains together are weak. Therefore, when the fabrics are bent or crushed, particularly in the presence of moisture, the molecular chains in cotton move freely to new positions as the polymers slide by one another. Then, new hydrogen bonds form when the fibre is in the bent position and these hydrogen bonds prevent the fibre from recovering after the bending force is removed. When the stress is removed from the fibre polymer system, the polymers stay bonded in their new locations. As a result, the cotton is wrinkled easily during use or the original shape will disappear easily.

When the cotton fabric is placed in an atmosphere of high relative humidity, water molecules enter the polymer system in its amorphous regions but not in its crystalline regions, as the inter-polymer spaces in the crystalline regions are too small. Cotton becomes less rigid because the fibres swell when it absorbs moisture [21, 28, 32, 36]. In addition, water molecules can interact with the hydroxyl groups in the molecular chains. Thus, the hydrogen bonds between chains can be broken and therefore, the cotton fibre will be softened.

2.4 Application of Shape Memory Polyurethane to Textiles and Other Areas

In the past decades, there has been growing interest in investigating the development and application of polymers with shape memory characteristic. Shape memory polymers were first developed in Japan in 1984. These shape memory polymers can be a class of polyurethanes which are stimuli-responsive materials. They can change their shapes upon application of an external stimulus such as temperature. Thermo-responsive shape memory polymers have the capability of changing their shapes caused by temperature sensitivity. This is called a thermally sensitive shape memory effect [6, 46].

There were some publications and patents researching these shape memory polymers [39, 45, 54, 58, 59, 66]. The researchers explored the parameters affecting the shape memory effects and the availability of various applications of shape memory polymers [18, 25, 30, 64, 71].

Shape memory alloys which contain certain metallic compounds that exhibited the unique shape memory effect in the 1930s. For instance, the nickel-titanium alloy (Nitinol) was used in actuators and medical devices. Compared with the shape memory polyurethane, they are more difficult to be applied to textiles since these alloys have some serious drawbacks which were suggested by Andreas Lendline [46]. They have a maximum deformation of only about eight percent and their programming was time-consuming and also involved a high temperature [33].

In contrast, shape memory polyurethane can exhibit much greater deformation capabilities and easier shaping procedures. They have high shape stability. Their transition temperatures and mechanical properties can be varied in a wide range even when there is only a little change in their chemical structure and composition [33]. There have a great potential in the development of smart textiles by applying shape memory polymers [30].

In the landmark study of Tobushi, H., the researchers developed shape memory polymers and the recovery temperature of these polymers could be set anywhere between room temperature and 50K. This contribution could increase the applications of shape memory polymers [66].

One of textile properties which have become steadily important, as informed by consumers, was breathability of the material [22]. According to the seminal study of

Hayashi, S., et al. who worked in Mitsubishi Heavy Industry Limited in New York, they explored the properties and applications of these shape memory polymers for a period of time [23, 24, 41, 66, 67]. In 1993, Hayashi developed polyurethane which has a high permeable property at warm temperature and a thermal insulation property at cold temperature. This polyurethane would be applied to textiles for developing a breathable and waterproof sportswear with a higher level of comfort. Hayashi maintained that this polyurethane was prepared by a solution polymerisation process and the polyurethane has high permeability above the Tg in the rubbery state, while low permeability below the Tg in the glassy state [23].

One of the most significant inventions from Mitsubishi in the application of these materials is the ‘Diaplex Fabric’, which was successfully commercialised. This fabric was laminated with a nonporous, temperature-sensitive, waterproofing and permeability intelligent membrane. In order to commercialise this revolutionary shape memory polymer technology developed by Mitsubishi Heavy Industry Limited, the DiAPLEX Co. Ltd. was established in November 1988 [20, 22, 26, 65, 66].

Diaplex membrane is made using shape memory polyurethane. This membrane would have a Micro-Brownian motion that is the thermal vibration when the temperature is increased above Tg. This motion leads to the creation of micro-pores in the Diaplex membrane. Therefore, water vapour and body heat can escape through these micro-pores. When the temperature is decreased, its permeability is lowered and body heat is retained. It can respond to changes in the wearer’s environment and body temperature intelligently. The membrane can self-regulate since it is able to sense environmental changes and adjust itself to maintain its comfort. The Diaplex fabric can be applied to active outdoor sportswear and outerwear [25, 30].

In 1999, Hayashi and the organization of DCTA developed the clothing that could provide the function of cold protection and hot protection. The clothing for cold protection was applied to the leisurewear while the clothing for heat protection which could protect against hot surfaces and hot fluids would be used to make coveralls, gloves, and head protection accessory. They achieved these functions by inserting a polyurethane film between two layers of fabrics. For the cold protective clothing, the glass transition temperature was about 25°C and hence, the thermal insulation value of a garment could alter depending on the external temperature. When the environmental temperature is lower than 25°C, the polyurethane layer would shrink 3% of its length and became rigid. For the heat protective clothing, the glass transition temperature of the polyurethane layer was 55℃ and the film layer would be recovered its pre-textured shape from the flat shape between two fabric layers. This air gap becomes larger and then the fabric afforded the thermal insulation function. Thus, it would protect the wearer from steam, boiling water, cooking oil and so on [59].

Indeed, there is little research to examine the applications of shape memory polyurethanes to textiles. Some researchers explored the applications of other types of polyurethanes with no shape memory effect to textiles.

In 2001, Lomax [48] developed an interactive clothing by coating the polyurethane onto fabrics. He investigated the relationship between diffusing water molecules and polyurethane chains and he stated that hydrophilic polyurethane membranes have a tendency to absorb moisture and swell during use. The degree of swelling could be controlled and limited to maximise breathability.

C. Hu prepared a water-soluble bi-functional polyurethane and applied for wash-and-wear finishing of silk fabrics. He found that the wet resiliency of finished silks improved greatly whilst retaining the soft handle and presenting no danger to human health. Physical properties such as breaking strength, elongation, moisture regain and the whiteness of finished silk fabrics have slightly worsened [29].

In 2003, Hall et al. developed a multilayer compression support sleeve by laminating a thin polyurethane film coated on both surfaces of clothing with an adhesive. The type of clothing was to provide support to limbs and joints which have been injured or weakened. The advantages of this compression support sleeve were thinner and have higher permeability compared with the traditional Neoprene [19]. Vogt et al. conducted research to analyse a method to improve the washing fastness of metallic fabric by coating with specific polyurethane finishes. The main significant finding from the investigation was that it could prevent the metal coatings, like aluminium, from easily washing out of and from fabrics upon standard laundering [69].

According to the mentioned previous studies, only a limited body of research has been conducted on the application of shape memory polymers to textiles and clothing. Their applications of shape memory polymers to clothing were only concentrated on the function of permeability and breathability. They did not consider using the shape memory polyurethane as a finishing agent to treat the fabrics. Their textile products which contain the shape memory polyurethanes did not show the fabric shape memory effects of recovering their original fabric shapes from their deformed shapes. In this study, the shape memory fabrics so produced are novel textile products.

2.5 Characterization Methods of Crease Retention, Flat Appearance and Bagging Recovery

In this thesis, the creased shape, flat shape and bagged shape for the recovery have been selected and they act as significant parameters for presenting the fabric shape memory effects. The evaluation of crease retention of fabrics could represent the fabric shape memory effect of crease retention. The evaluation of flat appearance could represent the fabric shape memory effect of flat appearance. The characterization of bagging recovery could be used for showing the bagging recovery effect of fabrics.

The creased shape and flat shape were used as the permanent shape of shape memory fabrics in this research. It is because the property of crease retention and flat appearance can satisfy the requirements of garments. Adding creases to a fabric can produce desirable features like fashionable appearance, usefulness and minimum care [74]. On the other hand, the wrinkle free technology has thoroughly liberated the house-wife from the hard labour of ironing [14].

The shape memory fabrics are evaluated based on existing methods for evaluating flat appearance, crease retention and bagging recovery. However, the existing methods could not be used for testing the shape memory fabrics and they did not consider the parameters of temperature sensitivity, shape deformation and shape recovery in their experimental designs. Therefore, new methods should be developed to evaluate the fabric shape memory effects effectively in this study. These existing evaluation methods will be discussed in the following sections.

2.5.1 Evaluation of Crease Retention

Pressing makes a large contribution to a finished appearance of garments and it can make creases for designing and fashioning of garments. A number of researchers investigated how the finishing process can be used to improve and give the most advantages to durable press property of fabrics [38, 68, 70] and how the wrinkle resistant finishing could keep the crease [62, 72]. In the past decades, some researchers studied the pressing performance of fabrics instead of the evaluation methods of crease retention [11, 13].

An AATCC Test Method 88C-2003, ‘Retention of Creases in Fabrics after Repeated Home Laundering’, from the American Association of Textile Chemists and Colorists has traditionally been used for testing the retention of creases since 1967. The well trained observers evaluate the test specimen with the use of six sets of 3-D Crease Retention (CR) replicas [3]. However, this traditional standard method does not take into account any temperature stimulus to fabric samples. The deformation of creased shape is also not included in this standard. As a result, this traditional method cannot be applied to the evaluation of fabric shape memory effects. The shape memory fabrics can be evaluated based on its Crease Retention (CR) replicas but the procedures of the method should be adjusted.

In 1978, Pharo et al. mainly explored the crease retention of wool, polyester and their blended fabrics after the pressing under various steaming times. They measured the creased yarn angles of creased yarns which were removed from the fold of fabrics and then placed on a transparent reference grid. A circular protractor was used to measure the creased yarn angle. Their analysis showed that the creased angles in degrees would be decreased if the steaming time was increased. In their study, they did not consider the effect of pressing temperature on crease retention. Their evaluation method was problematic as the angle on the folding position could be affected by the action of taking out the creased yarn. Therefore, the results would be affected to a certain extent [56].

In 2000, Shu et al. developed a theoretical model which could be used to predict experimental results of the relationship of creasing [61]. Another study was conducted by Laird, he developed an image analysis system to evaluate the creasing properties of fabrics using a laser with cylindrical and collimating lenses [42]. Fan determined the interrelationship between the fabric crease recovery and pressing performance. He suggested that a fabric could have both high crease recovery angle and small press angle at the same time [12].

Researchers did not concentrate to develop the evaluation methods of crease retention in the previous studies. The existing AATCC Test Method 88C and previous methods were not suitable to apply to the testing of fabric shape memory effect of crease retention. They did not consider the temperature sensitivity in their experiments. Moreover, there was no shape deformation and shape recovery in their experimental design. Thus, it is required to develop new evaluation method for the evaluation of the novel shape memory fabrics effectively. The fabric shape memory effect of crease retention could be evaluated based on the replicas of AATCC Test Method 88C in this study. However, the test procedures were modified to characterize the fabric shape memory effect effectively.

2.5.2 Evaluation of Flat Appearance

Some researches have been conducted to explore the new technology to make wrinkle free clothes or special fabrics with the function of wrinkle free instead of investigating the evaluation methods [17, 26, 51, 60]. Numerous studies examined how the wrinkle free treatment could improve the wrinkle free ability and make clothing more comfortable to wear. After using these wrinkle free treatments, the garments or clothing would become flat and the wrinkles would not be formed easily. However, wrinkle free finishing caused a great reduction in strength of treated fabrics. Higher initial fabric strengths could compensate for the strength reduction [73]. In 1997, some researchers explored the effect of wrinkle free treatment on the comfort sensations of polo shirts [43].

Other than studying the wrinkle free technology, a traditional evaluation method and some methods were used for the testing of flat appearance of fabrics in previous studies. Even though there were some researches which explored the evaluation methods of flat appearance, these characterization methods might not be suitable for testing the shape memory fabrics specifically.

In 1970, an AATCC Test Method 124-2001, ‘Appearance of Fabrics after Repeated Home Laundering’, from American Association of Textile Chemists and Colorists was developed. It is traditionally used for testing the smoothness appearance of fabrics. It allows the well trained observer to evaluate the test specimen with the use of five sets of 3-D Smoothness Appearance (SA) replicas [1]. However, this traditional standard method does not take into account the stimulus of temperature to the fabric samples, to test the response of fabrics at different temperatures. In addition, the deformations of flat shape are not taken into consideration. Thus, this traditional method cannot be used for the evaluation of fabric shape memory effect of flat appearance. The shape memory fabrics can be evaluated based on its Smoothness Appearance (SA) replicas and the procedures of this method should be modified.

In 1951, an AATCC Test Method 66-1998, ‘Wrinkle Recovery of Woven Fabrics: Recovery Angle’, from American Association of Textile Chemists and Colorists was developed [2]. This method is used to determine the wrinkle recovery of woven fabrics. The Wrinkle Recovery Tester is used to measure the wrinkle recovery angle of fabrics to investigate how the fabrics can be recovered to its flat appearance from a folding deformation. However, there is no temperature stimulation to samples in this method. Therefore, this traditional standard method cannot be applied on the evaluation of fabric shape memory effect directly. The shape memory fabrics can be evaluated based on the measurement of wrinkle recovery angles but the procedures of this method should be modified.

The study of Dong, et al. explored a regression equation of the strain relaxation curve to verify the crease recovery angle [10]. Subramanian, et al. have used three different crease recovery testers to evaluate crease recovery angles of textile fabrics [63]. Although, these researches have discussed the crease recovery angles, they did not consider the temperature stimulations of water or air in their testing processes.

Some previous researches revealed the wrinkle appearance using image analysis methods. Na et al. developed a digital image processing method which was applied to grade the fabric wrinkle recovery. They used a combination of texture and profile analysis techniques in order to analyse the degree of fabric wrinkling of AATCC replicate standards [52]. A great deal of researchers investigated the wrinkle appearance using image scanner, stereo vision technique and image processing system indicating the grey level distribution [7, 37, 49, 75, 76].

Regarding the previous evaluation methods of flat appearance, the existing AATCC Test Method 124 and previous methods could not be used to test the fabric shape memory effect of flat appearance. It is because the testing of shape memory fabrics must involve the temperature stimulation in the test procedures. However, previous researches did not consider the temperature sensitivity and they did not have the procedures to deform and recover the shape of samples in their experiments. As a result, the fabric shape memory effect of flat appearance could be evaluated based on the replicas of AATCC Test Method 124 and the measurement of wrinkle recovery angles in AATCC Test Method 66 in this research. In the meantime, the test procedures were modified in order to evaluate the fabric shape memory effect specifically.

2.5.3 Evaluation of Bagging Recovery

Bagging of garments arises from the lack of recovery when pressure or stress is exerted on a fabric by the body like the elbow or knee. It occurs during sitting or squatting down for long periods or from repeated movement. The forced area in the fabric or garment would be fixed in a protruded and swollen state and bagging seems to affect the appearance of garments. Therefore, studying on the bagging recovery behaviour of fabrics becomes more important. There were only limited researches on the investigation of the evaluation of bagging recovery of woven and knitted fabrics.

Grunewald et al. developed an artificial arm with an elbow to simulate the motion of bending of an arm. The sample was made into tubular form and drawn into the bagging tester. After bending of the testing arm for several times, the bagging height was measured to determine the bagging behaviour. They concluded that a fabric was judged to be wearable when the degree of bagging measured in the laboratory was below 5 mm [16].

In 1985, Matsuoka H. et al. developed a new objective evaluation method for the prediction of the bagging propensity of fabrics. A new test apparatus was developed to simulate the actual bagging behaviour and the volume of the bagged shape was measured. Then, the correlation between the bagging propensity of fabrics, volume, and the initial mechanical properties of fabrics was examined. The correlation coefficients between the bagging volume and the values of the tensile, bending and, shearing were found. They discovered that the bagging propensity of fabrics correlated with their mechanical properties [50].

Yokura et al. analyzed the bagging behaviour of woven fabrics in terms of increased volume. Samples were deformed under a constant load and the bagging volume was determined. The relationship between the bagging volume of woven fabrics and the mechanical properties was found and predicted [77].

Later on, Zhang et al. studied the bagging behaviour of fabrics by measuring the relative residual bagging height. The samples were loaded by an Instron tensile tester repeatedly. Then, the bagging height was measured and they used a multiple regression analysis to predict the bagging height of woven fabric as a function of bagging resistance and bagging fatigue [78, 79].

In 2004, the test method of JIS L 1061 from Japanese Industrial Standard was developed to test the bagging of woven and knitted fabrics [35]. This method was to test the bagging of woven and knitted fabric. A repeated bending type tester or tensile testing machine was used. The bagging height or the residual deformation value was measured.

However, the above evaluation methods could not be applied to the measurement of bagging recovery effect of fabrics. It is because the previous methods did not consider the parameter of temperature stimulation in water or air. In addition, they did not measure the recovering ability of fabric bagging after the external stimulation. Measuring the bagging height and bagging volume may not be applied to the evaluation of fabric bagging recovery effect. The reason is that the fabric samples should be immersed in water or put in air at various temperatures for the bagging recovery. Therefore, the fabric strength or other properties may be changed and the fabrics may be softened due to the water molecules. Then, the bagging height and volume will be affected easily during the drying process. As a result, it is difficult to measure these parameters accurately. Therefore, it is required to develop a new method with new parameters to evaluate the bagging recovery effect of fabrics.

2.6 Conclusions

In this study, the novel shape memory fabrics which are temperature sensitive were produced. There is no evaluation method for this product specifically. Previous evaluation methods could not be used for the evaluation of fabric shape memory effects as they did not consider the temperature stimulation, shape deformation and shape recovery in their experimental designs. In addition, no research has been conducted on the relationship between fabric shape memory effects under various conditions. Thus, it is necessary to develop some specific methods to evaluate the shape memory fabrics for understanding the shape memory effects.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter introduces the methodology of this research. In Section 3.2, the sample preparation process is described. Due to the new concept of shape memory fabric, there is no specific evaluation method for this fabric. Thus, in the section that follows, the new evaluation methods of crease retention and flat appearance of fabrics are explored. Within this section, both developed subjective and objective evaluation methods are described. Furthermore, the evaluation method of fabric bagging recovery is also explored. The new equations for characterizing the fabric shape memory effects of flat appearance, crease retention and bagging recovery, and new specific procedures are presented in this chapter. In addition, the statistical inferences including the estimation and confidence interval are applied to decide the precision of the measurements in the modified and new evaluation methods. Some statistical methods such as confidence level, error bar, ANOVA and regression are used to analyse the experimental results.

3.2 Preparation of Shape Memory Fabrics

The shape memory fabrics were created by treating with the waterborne shape memory polyurethanes on grey fabrics via specific finishing processes. Over three hundreds of shape memory fabrics treated with different shape memory chemicals were produced for this study. Some significant results were reported.

3.2.1 Fabric Specification

Three types of fabrics were used in the earlier stage of this study. They were cotton, silk and ramie. In this research, the results showed that cotton has the highest potential for developing the shape memory fabrics. In addition, cotton is the most important cellulosic fibre and many of our textile fabrics are made from cotton. Therefore, mainly 100% cotton woven and knitted samples were used for making shape memory fabrics in this research. The fabric specifications are described in Table 3.1.

Table 3.1 Fabric specification

Fabric Code	Fabric Type	Fabric Specifications	Type of Shape Memory Effects
S	Silk	14654 white crepe-back satin	Flat appearance and crease retention
R	Ramie	Plain, 21s, density 60 X 60 bleached	Flat appearance and crease retention
C1	Cotton	100% Cotton Sheeting, 68 X 68, 30s X 30s	Flat appearance and crease retention
C3	Cotton	100% Cotton Twill, 108 X 58, 20S X 20S, 43/44"	Flat appearance, crease retention and bagging recovery effect
C7	Cotton	100% Cotton Poplin, 133 X 100, 40s X 40s	Bagging recovery effect
K1	Cotton	100% Cotton, 60" X 320g/y, White	Bagging recovery effect

3.2.2 Shape Memory Chemicals

Shape memory chemicals used in this project were based on polyurethanes and they were prepared by using different recipes. The shape memory polyurethanes in this research belong to Tm(s) type with a switch temperature (The melting temperature of the soft segment crystals of the shape memory polymers) between 50°C and 60°C. This means that the shape memory polymers can recover its original shape within this temperature range.

In this study, there were many shape memory chemicals produced for preparing shape memory fabrics. Polyurethane emulsions used as a finishing agent were prepared by dispersing shape memory polyurethane solution in water. The polyurethane solutions were produced by the condensation polymerization reaction between polyols, diisocyanate, blocking agent, crosslinking agent and chain extenders in a solvent. A polyurethane can be prepared using Methylene Diisocyanate (MDI), Poly (propylene glycol) of molecular weight 4000 (PPG4000) and 1,4-butanediol (BDO), as shown in Figure 3.1. The polymerisation method employed was solution polymerisation. After the polymerisation, water and emulsifying agent were added to the polyurethane solution. Thus, an emulsion of shape memory chemicals could be produced for the finishing process.

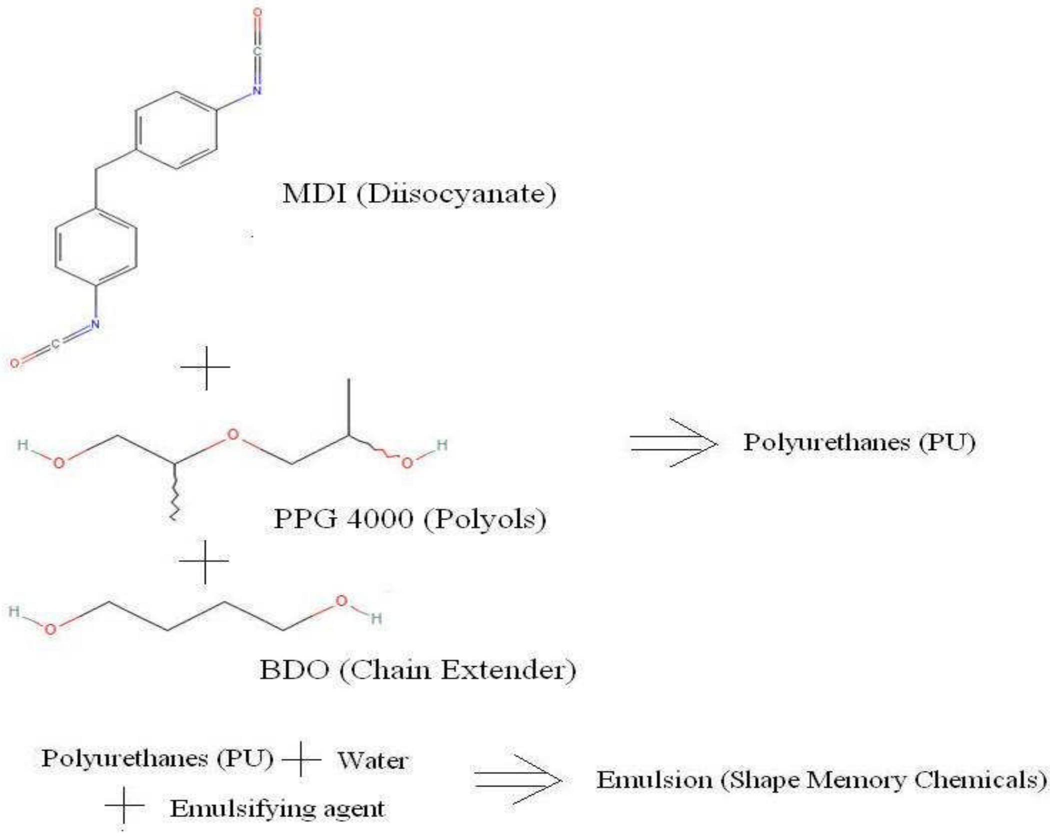

Figure 3.1 Shape memory chemicals

3.2.3 Finishing Process

Shape memory fabrics were prepared via various finishing processes using different shape memory chemicals. Two original fabric shapes were made in the finishing processes and they were the flat shape and creased shape. The flat shape memory fabric has the shape memory effect of flat appearance and bagging recovery, and the creased shape memory fabric has the shape memory effect of crease retention. Different types of fabrics were treated by the specific finishing processes with different parameters, which were adjusted in order to make shape memory fabrics with satisfactory shape memory effects.

3.2.3.1 Flat Shape Memory Fabrics

A calculated amount of shape memory polymer was added to a bath tank at room temperature. The semi-finished fabrics were padded twice through a finishing bath containing shape memory chemicals with a pick-up of 55%. The weight of the original fabrics (G_0) and the treated fabrics (G_1) were recorded. The padded fabric was dried at 80℃ for 2.5 – 3.0 minutes, and then ironed at 140℃ – 150℃ (higher than the softening temperature of the hard segment for fixing the permanent fabric shape) for 30 seconds on each face in a flat shape under $100 g/m^2$ of pressure. After that, the fabric was cured at 150℃ - 160℃ (higher than the softening temperature of the hard segment for fixing the permanent fabric shape) for 3.0 – 3.5 minutes. The finishing process is shown in Figure 3.2 and the treated cotton flat fabric is given in Figure 3.3.

Untreated fabric → **Padding** (Pressure: 2.5kg/cm^2), Velocity: 7.5m/min) → **Drying** (80ºC for 2.5 – 3.0 mins) → **Pressing** (Press a flat shape, Pressure: 100g/m^2, 140ºC-150ºC for 30s on each side) → **Curing** (150ºC - 160ºC for 3.0 - 3.5 mins)

Figure 3.2 Finishing process for flat sample

Top View Side View

Figure 3.3 Flat shape memory fabric

3.2.3.2 Creased Shape Memory Fabrics

The finishing procedures for padding, drying and curing were the same as above for flat fabric, except the pressing. After drying, the fabrics were pressed to form a creased shape in center instead of a flat shape at 140°C – 150°C for 30 seconds on each fabric face. The finishing process is presented in Figure 3.4 and the treated cotton creased fabric is shown in Figure 3.5.

Untreated fabric → **Padding** (Pressure: 2.5kg/cm^2), Velocity: 7.5m/min) → **Drying** (80ºC for 2.5 - 3 .0 mins) → **Pressing** (Press a creased shape, Pressure: 100g/m^2, 140ºC - 150ºC for 30s on each side) → **Curing** (150ºC - 160ºC for 3.0 - 3.5 mins)

Figure 3.4 Finishing process for creased sample

Top View Side View

Figure 3.5 Creased shape memory fabric

After the finishing process, the fabrics were tested and evaluated by various new fabric evaluation methods. The fabric shape memory effects of flat appearance, crease retention and bagging recovery were found.

3.3 Principle of Evaluation and Sample Size

3.3.1 Evaluation Principle for Evaluating Fabric Shape Memory Effects

Shape memory fabrics were prepared via various finishing processes using different shape memory chemicals. Two original fabric shapes were made in the finishing. Shape memory fabrics should have the ability to recover their original shapes from the deformed shape after thermal stimulation in different media. There are three types of fabric shape memory effects and they are given in Figure 3.6, Figure 3.7 and Figure 3.8 respectively.

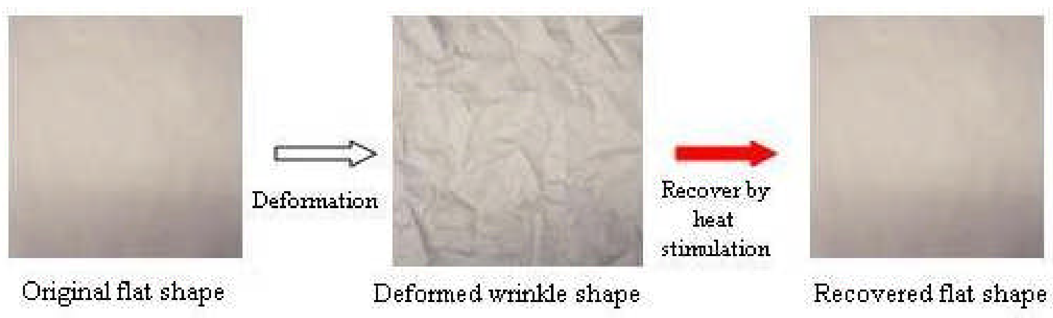

Figure 3.6 Fabric shape memory effect of flat appearance

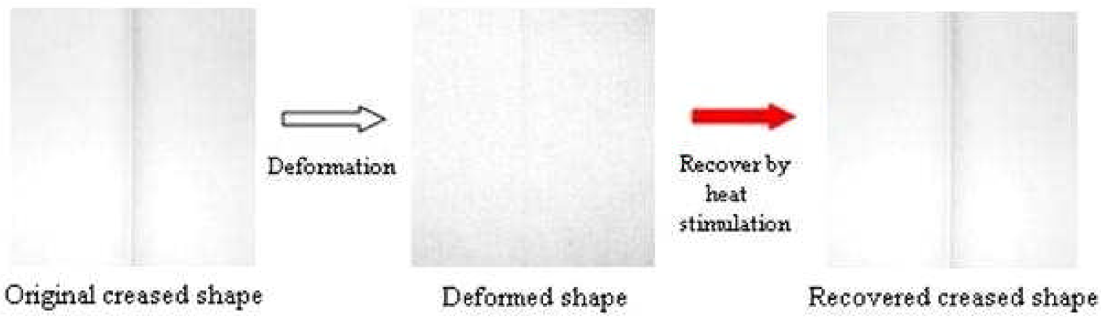

Figure 3.7 Fabric shape memory effect of crease retention

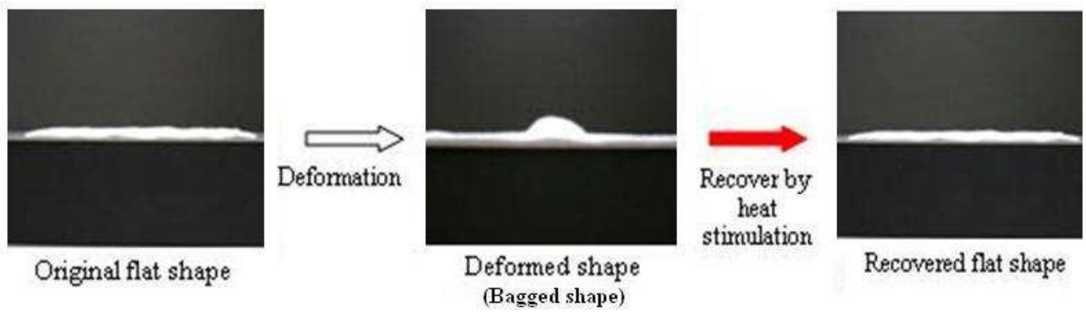

Figure 3.8 Fabric shape memory effect of bagging recovery

Thus, the experimental design should include a shape deformation and recovery process for incurring of fabric shape memory effect. The principle of evaluating the fabric shape memory effects is indicated in Figure 3.9.

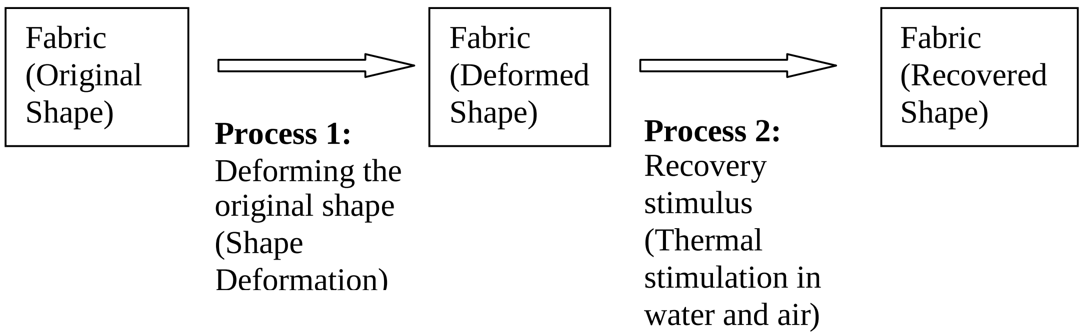

Figure 3.9 Principle of evaluation of shape memory fabric

3.3.2 Determination of Sample Size using Statistical Inference

In this study, the modified and newly evaluation methods were developed. In the experimental process, any variations due to the test itself are kept to the minimum by careful design of the test and correct operation of the instruments. Also, the random error may be found when repeated measurements of the same quantity. Then, the error bar which shows the 95% confidence limits for each mean to estimate from a study group that is highly likely to include the true value are used to analyse the experimental data. The confidence interval extends in each direction by a distance calculated from the standard error of the mean multiplied by a critical value $t_{\alpha/2}$ from the Student t Distribution.

Furthermore, it is important to determine how large of sample sizes required to estimate the population mean. When solving for the sample size, n, the standard deviation of population (σ) from which we are to select the samples should be known. In reality, it is usually unknown and it is a lack of this information. Therefore, a pilot study was conducted and a preliminary sample of size $n \geq 30$ was selected to estimate of σ . Then, in this study, the sample standard deviation s was calculated and use it in place of σ . So, a required sample size was determined approximately to provide the desired degree of accuracy.

In addition, the coefficient of variation (CV) of each experimental method was found in the preliminary study. The CVs of all experimental methods were below 5% which means that the variation of a group of samples was very small.

For all evaluation methods in my thesis, I want to be 95% confident that the sample mean will be within a specific value of the population mean μ. Formula of sample size for estimating population mean μ:

$$n = \left[\frac{Z_{\alpha/2}\ \sigma}{E} \right]^2$$

Where $Z_{\alpha/2}$ = critical z score based on the desired confidence level

E = desired margin of error

σ = population standard deviation

For the $\mathbf{Z}_{\alpha/2,}$ 1.96 was used by converting the 95% confidence level to $\alpha = 0.05$. Also, the desired margin of error was set to a specific value. The population standard deviation σ was estimated by the sample standard deviation.

The detailed results of the pilot study are listed in Appendix A.

3.3.2.1 Sample Size of Subjective Evaluation of Flat Appearance and Crease Retention in Water

(i) Flat samples:

The preliminary sample of size 10 (90 Observations/Ratings) was used as an approximation for σ . The number of trained observers was three and nine observations were made on each test fabric (three grades on each of three test specimens). Therefore, the actual sample size should be 90.

Sample standard deviation s = 0.127 (obtained from 90 observations)

Then

$$n = \left[\frac{(1.96)\,(0.127)}{0.1} \right]^2 = 6.20 = 7 \text{ (rounded up) (represents 7 observations)}$$

That is 3 fabrics (9 observations) are required in this test.

Therefore, it will be 95% confident that a random sample of size 7 (observations) will provide an estimate sample mean $\bar{x}$ that differs from the population mean μ by an amount not to exceed 0.1. Since the number of trained observers to rate the sample was three and nine observations were made on each test fabric (three grades on each of three test specimens), and therefore, it means that the sample size of 3 fabrics (9 observations) is sufficient to show that the sample mean $\bar{x}$ is within 0.1 of the true population mean μ for the 95% confidence level.

As a result, the required sample size n = 3.

(i.e., three flat fabrics were required and then three observers gave the ratings to the samples, which meant that 9 observations/ SA Ratings were obtained on each test fabric as three grades on each of three test specimens)

In the subjective evaluation method for evaluating the fabric shape memory effects of flat appearance, the sample size of 3 flat samples (total 9 observations made on each test fabric) was used in the experiment. Moreover, in some experiments, there were 6 observers giving the ratings to samples and that means 18 observations made on each test fabric were averaged.

Therefore, the **sample size of three** of each flat sample was used in the modified evaluation method and it was also the same as the required number of sample of AATCC Test Method 124.

(ii) Creased samples:

The preliminary sample of size 10 (90 Observations/Ratings) was used as an approximation for σ. The number of trained observers was three and nine observations were made on each test fabric (three grades on each of three test specimens). So, the actual sample size should be 90.

Sample standard deviation s = 0.151 (obtained from 90 observations)

Then

$$n = \left[\frac{(1.96)\,(0.151)}{0.1} \right]^2 = 8.81 \;=\; 9 \;\; \text{(rounded up)} \qquad \text{(represents 9 observations)}$$

As a result, it will be 95% confident that a random sample of size 9 (observations) will provide an estimate sample mean $\overline{x}$ that differs from the population mean μ by an amount not to exceed 0.1. Similar to the flat sample, since the number of trained observers to rate the sample was three and nine observations were made on each test fabric (three grades on each of three test specimens). Therefore, it means that the sample size of 3 fabrics (9 observations) is sufficient to show that the sample mean $\overline{x}$ is within 0.1 of the true population mean μ for the 95% confidence level.

Then, the required sample size n = 3.
(i.e., three creased fabrics were required and then three observers gave the ratings to the samples, which meant that 9 observations/ CR Ratings were obtained on each test fabric as three grades on each of three test specimens)

In the subjective evaluation method for evaluating the fabric shape memory effects of crease retention, the sample size of 3 creased samples (total 9 observations made on each test fabric) was used in the experiment.

Therefore, the **sample size of three** of each creased sample was used in the modified evaluation method and it was also the same as the required number of sample of AATCC Test Method 88C.

3.3.2.2 Sample Size of Subjective Evaluation of Flat Appearance and Crease Retention in Air

(i) Flat samples and (ii) Creased samples:

The preliminary study for flat and creased samples was conducted which was similar to the Section 3.3.2.1. The details are shown in Appendix A. After calculating, the required sample size of flat and creased samples is n = 3 respectively.

Therefore, it will be 95% confident that a random sample of size 3 will provide an estimate sample mean $\overline{x}$ that differs from the population mean μ by an amount not to exceed 0.1.

In the subjective evaluation method of evaluating shape memory effects of flat appearance and crease retention in air, the **sample size 3** was selected in the experiment and the sample size is sufficient to evaluate the samples.

3.3.2.3 Sample Size of Objective Evaluation of Flat Appearance and Crease Retention in Water

(i) Flat samples:

The preliminary sample size (35) of sample with their long dimension parallel to the warp direction and weft direction was used as an approximation for σ respectively.

Sample standard deviation s = 1.973 (obtained from 35 samples in warp direction)

Sample standard deviation s = 2.037 (obtained from 35 samples in weft direction)

Then

$$n = \left[\frac{(1.96)\,(1.973)}{2} \right]^2 = 3.74 = 4 \quad \text{(rounded up)}$$

$$n = \left[\frac{(1.96)\,(2.037)}{2} \right]^2 = 3.99 = 4 \quad \text{(rounded up)}$$

Therefore, it will be 95% confident that a random sample of size 4 will provide an estimate sample mean $\bar{x}$ that differs from the population mean μ by an amount not to exceed 2.0. Therefore, the required sample size of samples with their long dimension parallel to the warp direction and weft direction is 4.

In the objective evaluation method for evaluating the fabric shape memory effects of flat appearance, the sample size of 6 flat samples with their long dimension parallel to the warp direction and the sample size of 6 flat samples with their long dimension parallel to the weft direction were used in the experiment. Therefore, the **total sample size of twelve of each flat sample** was use in the modified evaluation method and it was also the same as the required number of sample of AATCC Test Method 66.

(ii) Creased samples:

The preliminary sample size 35 was used as an approximation for σ.

Sample standard deviation s = 1.884 (obtained from 35 samples)

Then

$$n = \left[\frac{(1.96)\,(1.884)}{2} \right]^2 = 3.41 = 4 \quad \text{(rounded up)}$$

Therefore, it will be 95% confident that the sample mean $\bar{x}$ is within 2 of the true population mean μ when the sample size 4 is selected. In the objective evaluation method for evaluating the fabric shape memory effects of crease retention, **the sample size of 12** creased samples was used in the experiment.

3.3.2.4 Sample Size of Objective Evaluation of Flat Appearance and Crease Retention in Air

(i) Flat samples and (ii) Creased samples:

The preliminary study for flat and creased samples was conducted which was similar to the Section 3.3.2.3. The details are shown in Appendix A. By calculating the required sample size, the required sample size of flat samples with their long dimension parallel to the warp direction is 4 and the required sample size of flat samples with their long dimension parallel to the weft direction is 6. Also, the required sample size of creased samples is n = 4.

In the objective evaluation method of evaluating shape memory effects of flat appearance and crease retention in air, the **total sample size of 12 for each flat and creased sample** was selected in the experiment and the sample size is sufficient to evaluate the samples.

3.3.2.5 Sample Size of Objective Evaluation of Bagging Recovery Effect

The preliminary sample size (35) of sample for measuring recovered warp length (Rp) and the sample for measuring recovered weft length (Rt) respectively was used as an approximation for σ .

Sample standard deviation s = 0.382 (obtained from 35 samples - Rp)

Sample standard deviation s = 0.343 (obtained from 35 samples - Rf)

Then

$$n = \left[\frac{(1.96)\,(0.382)}{0.3} \right]^2 = 6.24 = 7 \quad \text{(rounded up)}$$

$$n = \left[\frac{(1.96)\,(0.343)}{0.3} \right]^2 = 5.02 = 6 \quad \text{(rounded up)}$$

Therefore, it will be 95% confident that a random sample (Rp) of size 7 will provide an estimate sample mean $\bar{x}$ that differs from the population mean μ by an amount not to exceed 0.3. In addition, it can be 95% confident that the sample mean $\bar{x}$ is within 0.3 of the true population mean μ when the sample (Rt) of size 6. Therefore, the required sample size of samples for measuring the recovered warp and weft length is 7 and 6 respectively.

In the objective evaluation method for evaluating the fabric bagging recovery effect, the **sample size of 10** for each fabric sample was used in the experiment and it is sufficient to evaluate the samples.

3.4 Specific Evaluation Methods of Fabric Shape Memory Effects

There were five sections in this part. In the first two sections, the evaluation methods of fabric shape memory effects of flat appearance and crease retention in water was described. The first section refers to the subjective evaluation method and the second section refers to the objective evaluation method. Then, in the next two sections, the subjective and objective evaluation methods in air were presented. In the final section, the fabric bagging recovery effect in water was evaluated by a new objective method. New equations established in these new methods for representing the fabric shape memory effects were described.

3.4.1 Subjective Evaluation of Flat Appearance and Crease Retention in Water

3.4.1.1 Principle

The subjective evaluation method is to evaluate the fabric shape memory effects of flat appearance and crease retention in water. This method is based on the AATCC Test Method 88C-2003 [3] and AATCC Test Method 124-2001 [1] to determine the recovering ability to the original creased shape and flat shape of fabrics. The procedures of these standards were modified to evaluate the fabric shape memory effects specifically. The new test method consists of a deformation stage and a recovery stage with temperature stimulation to samples. Then, the ratings of fabric shape memory effects were based on the 3-D Smoothness Appearance (SA) replicas and the 3-D Crease Retention (CR) replicas. The effects of water temperatures, recovery methods (water immersion and washing) and drying methods (flat dry, line dry and tumble dry) on the fabric shape memory effects of flat appearance and crease retention in water were investigated.

3.4.1.2 Samples

There were over four sets of samples which were treated with different shape memory polymers for this test. Based on the Section 3.3.2.1, the sample size of flat and creased sample was 3 respectively. Each set of sample contained three flat samples and three creased samples that were the same as the requirement of AATCC Test Method 88C and 124. The dimension of sample was 20cm X 20cm which was smaller than the size in the above standards. It was the largest fabric size that we could produce due to the limitation of the size of a pinned frame used in the finishing process. However, this sample size was also acceptable for the testing in the commercial laboratory (Specialized Technology Resources (H.K.) Ltd.) according to these two standards. All specimens were pre-conditioned in the standard condition (21 ± 1 °C and 65 ± 2 % RH) for 24 hours before conducting the tests.

3.4.1.3 Test Apparatus

The apparatuses for this test include an automatic washing machine (Whirlpool 3XGSC9455JQ Washer) and an automatic tumble dryer (Whirlpool 3XLER54327). These two apparatuses followed the requirement of the standard AATCC Test Method 88C and 124.

3.4.1.4 Experimental Design

The testing procedures were modified from the above mentioned standards. In order to examine the fabric shape memory effects, the procedures contain four stages including (1) Deformation Stage, (2) Recovery Stage, (3) Drying Stage and (4) Evaluation Stage. The main differences of this new subjective method were that this method has a deformation stage and the meaning of the smoothness appearance (SA) rating and crease retention (CR) rating was specified. The experimental procedures are shown in Figure 3.10 and Figure 3.11 and the details were described below these figures.

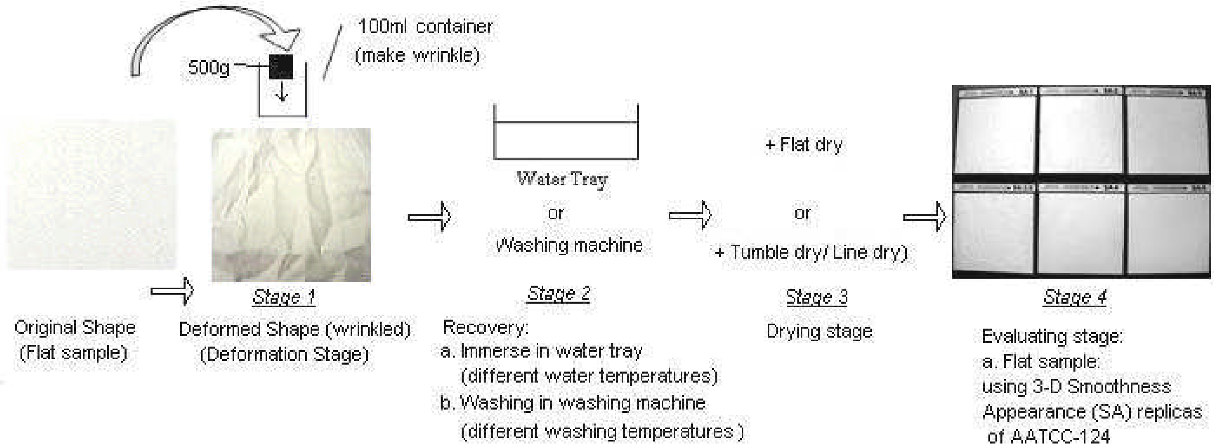

Figure 3.10 Experimental stages of subjective evaluation of flat sample

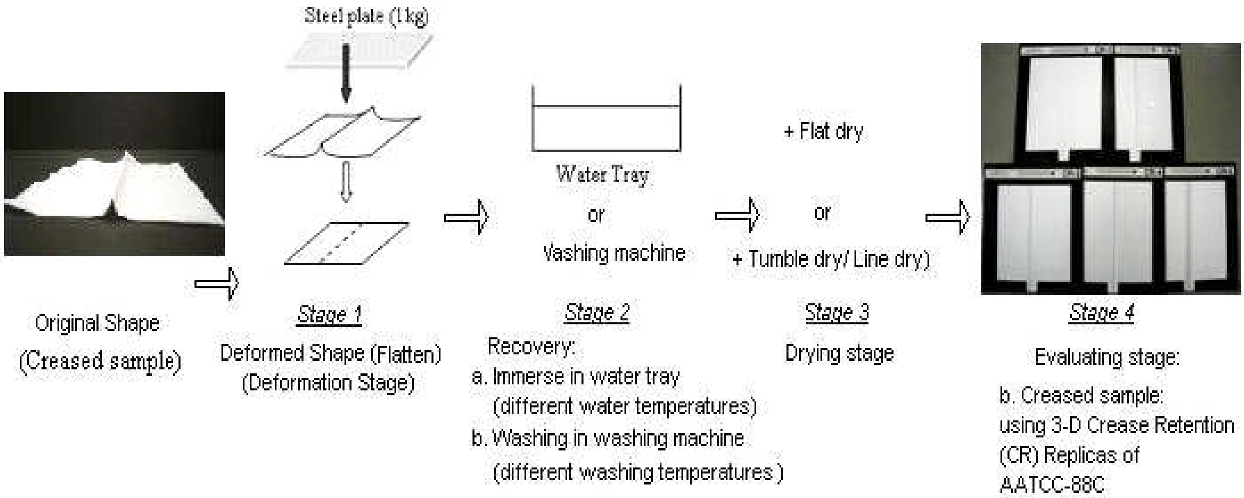

Figure 3.11 Experimental stages of subjective evaluation of creased sample

<u>**(1) Deformation Stage**</u>

a) Flat sample

The flat sample was wrinkled by crumpling and placing into a 100ml beaker and a 500g weight was placed on top of the fabric for 1 hour. Then, the fabric was allowed to relax for 1 hour. In the early period of this research, the pressing time and the relaxation time were 5 minutes in this test.

The 500g weight was selected due to the reference from the AATCC Test Method 66 [2]. This standard is used to evaluate the wrinkle recovery of woven fabrics and the 500g weight is used to press the folded sample. Therefore, the parameters in the deformation stage followed this standard. In order to make irregular wrinkles on flat samples, a 500g weight was put into a 100ml beaker which held the sample. The 100ml beaker and 500g weight were used as they have similar diameter. (Diameter of the 500g weight: 4.2 cm, Inside diameter of 100ml beaker: 4.6 cm). The pressing time and the relaxation time were adjusted to 1 hour because 5 minutes was only sufficient to deform thin fabrics but not thick fabrics. Therefore, after several trials, one hour was sufficient to deform the thicker woven fabric (fabric code: C3) in this research. In addition, the whole washing process was also taken around one hour. Therefore, one hour was selected for the pressing and relaxation time in this stage.

b) Creased sample

The creased sample was deformed by opening the crease and laying the fabric on a flat surface, and placing a 1kg steel plate (15 cm X 20 cm) on top of the fabric for 1 hour. Then, the steel plate was removed and the fabric was allowed to relax for 1 hour. In the early period of this study, the pressing and relaxation time were 4 hours.

There was no standard test to flatten the creased shape of fabrics. In the initial trial, a weight below 1kg was difficult to flatten the creased shape and 1kg plate was sufficient to flatten the creased fabric shape. Thus, 1kg steel plate was used in this test. In addition, after several trials, it was found that 1 hour was sufficient to flatten the samples. Then, the time for making flat on creased samples was changed from 4 hours to 1 hour for the sake of consistency with the deformation time of flat samples.

<u>(2) Recovery Stage</u>

This step was important for the samples to recover from their deformed shapes to original shapes. The samples could be immersed in water or washed in a washing machine with the temperature stimulation.

a) Water immersion

The samples were put into a water tray [30cm(L) X 30cm(W) X 5cm(H)] with water filled in 3/4 volume of the tray at various temperatures, e.g. 15°C, 25°C, 40°C, 50°C and 60°C respectively for 5 minutes for their recovery. The 5 minutes was selected because it was sufficient for the recovery of fabrics after some observations.

Based on the AATCC Test Method 88C and 124, hand wash can be used in this test instead of washing. However, in order to evaluate the fabric shape memory effect, the main parameters should be the temperature stimulation in water and any distortions to the fabric shape should be minimized. Therefore, the standard should be modified and the water immersion was used for their recovery.

b) Washing

Washing followed the AATCC Test Method 88C for creased sample and AATCC Test Method 124 for flat sample. The washing conditions are as follows:

Water level : Medium (18 ± 1 gal)

Machine Cycle : Normal/Cotton Sturdy

Water Temperature : 25°C ± 3 °C and 60°C ± 3 °C

(The temperature (60 °C) was selected in order to reach the switch temperature of shape memory polymers in fabrics and the temperature (25 °C) was used to compare with the results using higher water temperature.)

Wash load ballast : 50/50 polyester/cotton bleached and mercerized poplin (Type2)

Washing cycle : One

(According the mentioned standards, four washing and drying cycles are used. However, in our test, one cycle could be easier to evaluate the effect of water temperature, recovery method and drying method on the fabric shape memory effects. Therefore, one washing and drying cycle was used in our test.)

(3) Drying Stage

a) Flat dry and line dry

The sample which immersed in water was dried by flat dry or line dry. For flat dry, both flat and creased samples were dried by placing on a plate flatly, in order not to distort the pre-set fabric shape. A thin cotton fabric on the plate was used to absorb excess water. Therefore, the physical interaction between the specimen and the plate would not affect the shape of specimen directly. Line dry was to hang each specimen by two corners with the fabric length in a vertical direction and allowed the test specimen to hang in still air at room temperature until dry.

According to the two mentioned standards, the sample was dried by drip dry if the sample was washed by hand wash. However, it was found that drip dry distorted the recovered shape as there was a high gravity of water to the sample. Therefore, flat dry and line dry were used. In the later period this research, line dry was selected in the drying stage as it allowed the sample to dry more naturally and reduced the distortions of its recovered shape. Also, line dry is a very common method of drying in our daily life.

b) Tumble dry

The samples which were washed in a washing machine were tumble dried or line dried. The normal (cotton sturdy) cycle was used in the tumble dry. For this kind of cycle, the exhaust temperature was high (66 $\pm$ 5 °C) and the cool down time was 10 minutes. The condition of tumble dry followed the two mentioned standards.

<u>(4) Evaluation Stage</u>

All samples were conditioned in the standard condition for 24 hours before evaluation.

a) Flat sample and creased sample

Three to six trained observers assigned ratings to each test sample independently and the number of observers might be more than that in the AATCC Test Method 88C and 124. The rating method and condition followed these two standards. The creased samples were evaluated using the 3-D Crease Retention (CR) replicas of AATCC Test Method 88C and the flat samples were evaluated using the 3-D Smoothness Appearance (SA) replicas of AATCC Test Method 124. At most eighteen observations made on each test fabric were averaged if each sample was rated by six observers.

3.4.1.5 New Meaning of SA and CR Ratings

The meaning of the SA Rating and CR Rating was changed to represent the fabric shape memory effects, as illustrated in Table 3.2. Higher SA rating and CR rating represent higher fabric shape memory effects of flat appearance and crease retention respectively.

Table 3.2 New meaning of SA Rating and CR Rating

Creased Specimens			Flat Specimens		
CR Rating (Crease Retention in AATCC 88C)	**Traditional Meaning**	**New Defined Meaning**	**SA Rating (Smoothness of Appearance in AATCC 124)**	**Traditional Meaning**	**New Defined Meaning**
CR-5	The best crease retention	**The best shape memory effect of crease retention**	SA-5	The smoothest appearance	**The best shape memory effect of flat appearance**
CR-4			SA-4		
CR-3			SA-3		
CR-2			SA-2		
CR-1	The poorest crease retention	**The poorest or no shape memory effect of crease retention**	SA-1	The poorest appearance	**The poorest or no shape memory effect of flat appearance**

Assumption

After finishing process, the flat samples were in a smooth flat shape and the creased samples have a sharp creased line in the centre. Therefore, it was assumed that the flat sample with an original flat shape has the SA Rating of 5.0 and the creased sample with an original creased shape has the CR Rating of 5.0.

3.4.2 Objective Evaluation of Flat Appearance and Crease Retention in Water

3.4.2.1 Principle

The test method was based on the AATCC Test Method 66-1998 [2]. The Wrinkle Recovery Tester in this standard was used to measure the fabric angle. Moreover, a new apparatus was designed and used. The testing procedure was developed and new equations were established using the fabric angles to determine the fabric shape memory effects of flat appearance and crease retention in water specifically.

3.4.2.2 Samples

There were twenty-four samples which treated with different shape memory chemicals and one untreated sample. Based on the Section 3.3.2.2, the sample size of flat and creased sample was 12 respectively. Each set of sample contained flat samples and creased samples and the dimension of each sample was 40mm X 15mm. For each flat sample, six samples with their long dimension parallel to the warp direction and six samples with their long dimension parallel to the weft direction were cut. For each creased sample, twelve samples with their long dimension parallel to the weft direction were cut and then the center line of the creased sample was placed in the center of the cut sample, as shown in Figure 3.12.

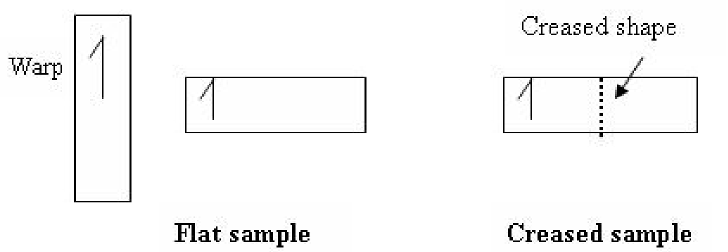

Figure 3.12 Flat and creased samples of objective evaluation in water

According to the AATCC Test Method 66, there are only flat samples. However, in the new objective method, the creased samples were also measured to investigate the crease retention of fabrics. As a result, twelve creased samples in weft direction were prepared for this test. All specimens were conditioned in the standard condition (21 ± 1 °C and 65 ± 2 % RH) for 24 hours before testing. These samples were also tested using the subjective evaluation method as described in Section 3.4.1. The SA Rating and CR Rating of samples were found for the comparison in Chapter 5.

3.4.2.3 Test Apparatus

A Wrinkle Recovery Tester (Option 2) in AATCC Test Method 66, as shown in Figure 3.13, was used to measure the wrinkle recovery angles (fabric angles). In addition, the new designed frame and the hanger for holding samples are given in Figure 3.14 and Figure 3.15 respectively.

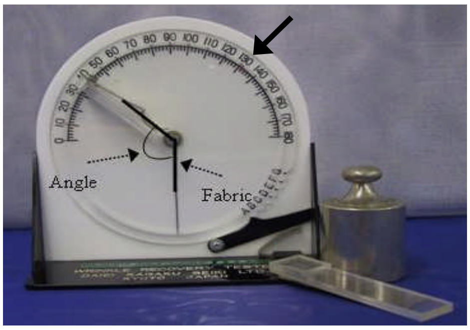

Figure 3.13 Winkle Recovery Tester

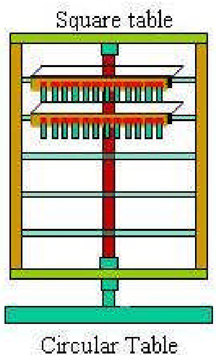

Figure 3.14 Frame for holding hangers

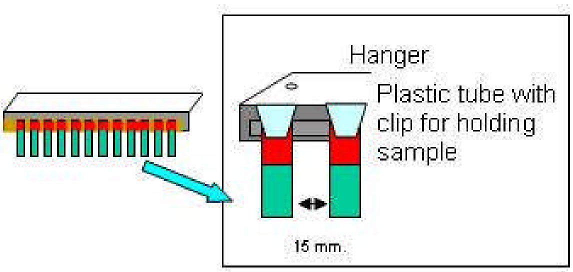

Figure 3.15 Hanger for holding samples

3.4.2.4 Experimental Design

The new testing procedures were designed for evaluating the fabric shape memory effects and modified from the AATCC Test Method 66. Figure 3.16 shows the concept of evaluation of this objective method. It contained four steps and the testing procedures of each step were described below.

(1) Evaluation of the original shape

(2) Shape deformation

(3) Recovery process (water immersion)

(4) Evaluation of shape recovery

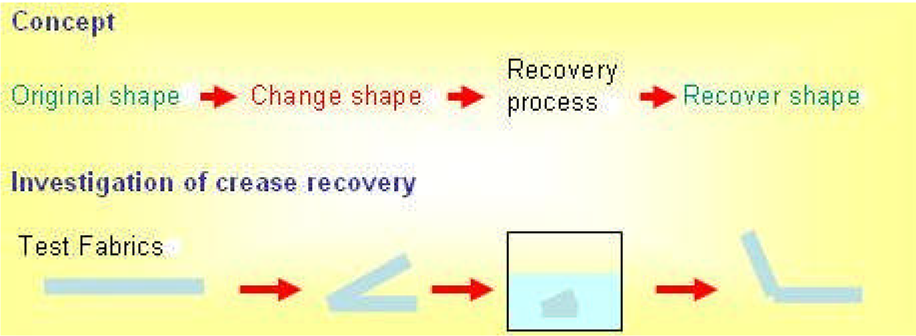

Figure 3.16 Concept of evaluation of fabric shape memory effects

(1) <u>Evaluation of the original shape</u>

The samples were hold by hangers on the flame for 24 hours for fabric relaxation in a standard condition before the measurement. It was required to let the samples to become more stable for the measurement of the fabric angle. Especially for creased samples, the creased shape would become larger during relaxation due to the gravity. After several trials, it was found that 24 hours was sufficient to make them to be stable for the measurement.

a) Flat sample

- Six warp and six weft specimens were cut (40 mm x 15 mm)
- The fabric angle named **Original Angle (Of)** was measured using the Wrinkle Recovery Tester. Twelve readings were averaged.

b) Creased sample

- Twelve weft specimens were cut (each 40 mm x 15 mm)
- The fabric angle named **Original Angle (Oc)** was measured using the Wrinkle Recovery Tester. Twelve readings were averaged.

The AATCC Test Method 66 does not need to measure an original angle. In addition, twelve readings were averaged in the new method instead of reporting in warp and weft angles. It was because the main aim of measuring the original fabric angle was to use the value to calculate the fabric shape memory effects by comparing the fabric angle (Shape Memory Angle) of fabric which was immersed in water for recovery.

(2) <u>Shape deformation</u>

a) Flat sample

- A line at the centre of each specimen was drawn and folded to deform the fabric, as shown in Figure 3.17. The specimen was put into a plastic holder with six plastic flat bags to keep the crease in position.

b) Creased sample

- The sample was laid flat and put into the plastic holder to keep the flat in position. The flat and creased sample in the plastic holder were pressed by a weight of 1 kg steel plate for 24 hours and then taken out after 24 hours. Then, samples were clipped on the hangers which placed on the flame, as illustrated in Figure 3.14 and Figure 3.15.

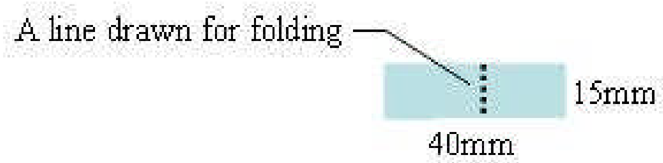

Figure 3.17 A line drawn on flat sample

The tweezers, metal holders, platform and a 500g weight in AATCC Test Method 66 were not used. It was because the aim of this step was to deform the flat sample to make a crease and flatten the creased sample at the same time. All samples should be clipped on hangers and then put into a water tray later. Thus, all samples were put into the plastic folder and then pressed by a 1kg steel plate for the deformation. Pressing for 24 hours can make sure that the shapes can be deformed well. The 1kg steel plate used in this step was the same as the steel plate used in the subjective method (Section 3.4.1) for the sake of consistency.

(3) Recovery process (water immersion)

a) Wetting Process

- A water tank with water at 60°C was prepared.
- The hanger which contained 12 specimens was put into the water tank for 5 minutes for recovery. Then the flat and creased samples were picked up.

b) Drying Process

- The hanger with wet specimens was held onto the frame which was placed in standard condition room for 24 hours for drying.

According to AATCC Test Method 66, it does not involve water and temperature stimulus. However, in order to evaluate the fabric shape memory effects, water at various temperatures was required to stimulate the fabric. After several observations, 5 minutes was enough for the fabric recovery. Moreover, drying for 24 hours is to make sure that the sample can be dried thoughtfully.

4) Evaluation of shape recovery

The hangers with samples were taken out from the frame and the fabric angles of all samples were measured.

a) Flat sample

- The fabric angle named **Shape Memory Angle (Mf)** was measured by using the Wrinkle Recovery Tester. Twelve readings were averaged. The Shape Memory Angle (Mf) and the Original Angle (Of) were compared and new equations were established to evaluate the fabric shape memory effect of flat appearance.

b) Creased sample

- The fabric angle named **Shape Memory Angle (Mc)** was measured by using the Wrinkle Recovery Tester. Twelve readings were averaged. The Shape Memory Angle (Mc) and the Original Angle (Oc) were compared and new equations were used to evaluate the fabric shape memory effect of crease retention.

For AATCC Test Method 66, it does not have any steps to compare the angles or use any equations for the evaluation.

3.4.2.5 New Equations for Evaluating Fabric Shape Memory Effects in Water

After measuring the angles including Original Angle (Of and Oc) and Shape Memory Angle (Mf and Mc), new equations were established to evaluate the fabric shape memory effect of flat appearance and crease retention respectively.

(I) Shape Memory Coefficients

Shape Memory Coefficient was developed using the Original Angles and Shape Memory Angles to determine the fabric shape memory effects.

a) Shape Memory Coefficient of Flat Sample (Sf%)

It was used to determine the fabric shape memory effect of flat appearance. If the difference between the Shape Memory Angle (Mf) and the Original Angle (Of) is small, the Sf% is larger. This means that the ability of flat sample to recover its original flat shape and the fabric shape memory effect of flat appearance are larger. The Shape Memory Coefficient (Sf %) of flat sample is expressed as:

$$Sf\% = [1 - (\frac{|Of - Mf|}{180})]*100$$

(Equation 3.1)

b) Shape Memory Coefficient of Creased Sample (Sc %)

It was used to determine the fabric shape memory effect of creased retention. If the difference between the Shape Memory Angle (Mc) and the Original Angle (Oc) is small, the Sc is larger. This means that the ability of creased sample to recover its original creased shape and the fabric shape memory effect of crease retention are larger. The Shape Memory Coefficient (Sc %) of creased sample is expressed as:

$$Sc\% = [1 - (\frac{|Oc - Mc|}{180})]*100$$

(Equation 3.2)

In shorts, the fabric shape memory effect is larger while the Shape Memory Coefficients (Sf % and Sc %) are larger. In Chapter 5, Section 5.4 showed the results of Shape Memory Coefficients and the fabric shape memory effects were determined using these equations.

(II) Improved Equations of Shape Memory Coefficients

After further using the Shape Memory Coefficients (Sf% and Sc%) for evaluating the fabric shape memory effects, it was found that there is a limitation of the equation of Sc%. Also, the equation of Sf% could be simplified.

a) Simplification of Shape Memory Coefficient of Flat Sample (Sf %)

(1)Flat Recovery % (FRec%):

The Sf% can be simplified to Flat Recovery % (FRec%) and Figure 3.18 shows the parameters of this equation in a diagram. The simplified equation of Flat Recovery Percentage (FRec%) is expressed as:

$$\textbf{Flat Recovery \% (FRec\%)} = \frac{\textbf{Mf}}{\textbf{Of}} \textbf{ X 100\%}$$

(Equation 3.3)

- ✓ It represents the recovering ability of a flat sample from a deformed shape (fabric angle = 0°) to an original flat shape (fabric angle = 180°).
- ✓ Higher FRec% of a sample represents that the sample has a higher fabric shape memory effect of flat appearance.

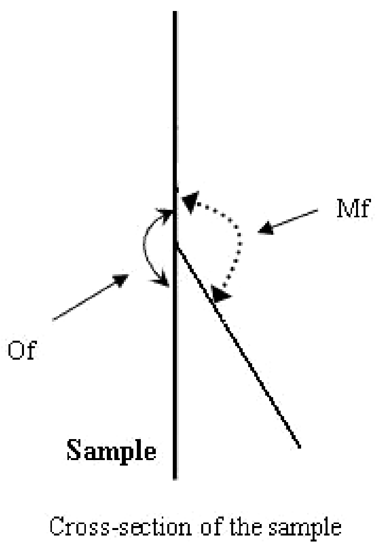

Figure 3.18 Parameters of Flat Recovery % (FRec%)

b) Limitation of the Shape Memory Coefficient of Creased Sample (Sc %)

It was found that when the retention ability of Oc was very low and the Mc was near to the value of Oc, the Sc% cannot show the actual performance of shape memory fabric since it ignored the crease setting ability of the sample in the calculation. For example, the Oc of a sample was 170° and the Mc was 175°, the Sc% was still very high since the difference of Oc and Mc was very small. Similarly, when the Oc of a sample was 30° and the Mc was 35°, the Sc% was also the same as the previous example.

Therefore, the actual performance of a sample was not apparent if the Sc% was used and the actual crease recovery cannot be represented by using Sc%. As a result, the new equation was developed to give a better representation of what is taking place. This example was explained in Section 5.5.1.

(1) <u>Crease Recovery % (CRec%)</u>

The equation of Crease Recovery % (CRec%) is expressed as follows and Figure 3.19 shows the parameters of this equation in a diagram.

$$\text{Crease Recovery \% (CRec\%)} = \frac{(180 - Mc)}{(180 - Oc)} \text{ X } 100\ \%$$

(Equation 3.4)

- ✓ It represents the recovering ability of a creased sample from a deformed shape (fabric angle = 180°) to an original creased shape (fabric angle = depending on the finishing process).
- ✓ Higher CRec% of a sample represents that the sample has a higher fabric shape memory effect of crease retention.

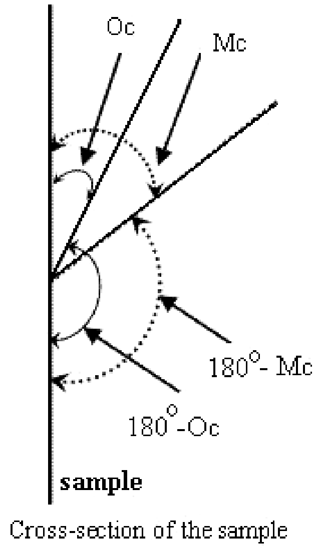

Figure 3.19 Parameters of Crease Recovery % (CRec%)

3.4.3 Subjective Evaluation of Flat Appearance and Crease Retention in Air

3.4.3.1 Principle

The subjective evaluation method in air was similar to the subjective evaluation method in water in Section 3.4.1. The main difference of subjective evaluation method in air was the equipment in the recovery stage. Furthermore, there was no drying stage required in this method as the samples were not wet fully. The effects of air temperatures and relative humidities on the fabric shape memory effects of flat appearance and crease retention in air were investigated.

3.4.3.2 Samples

Many samples were tested and some significant results were presented in this thesis. There were three sets of samples (20cm X 20cm) which were treated with different shape memory polymers and one set of sample was untreated for this test. Based on the Section 3.3.2.3, the sample size of flat and creased sample was 3 respectively. Each set of sample contained three flat samples and three creased samples that were the same as the requirement of AATCC Test Method 88C and 124. Three trained observers gave ratings to samples. All specimens were pre-conditioned under the standard condition (21 ± 1 °C and 65 ± 2% RH) for 24 hours before testing.

3.4.3.3 Test Apparatus

The apparatus is a Conditioning Chamber (HOTPACK, Model: 435314), as shown in Figure 3.20. It was used in the recovery stage so as to supply air at various temperatures and relative humidities to samples. The Conditioning Chamber can be set to specific temperature and relative humidity. The claimed temperature range is between 5°C and 95°C and the claimed relative humidity range is between 25 % RH and 95 % RH

Figure 3.20 Conditioning Chamber (outside view)

<u>a) Modified Sample Holder</u>

The Conditioning Chamber was modified to evaluate fabric shape memory effects. The original steel plates in the Conditioning Chamber were changed to plastic rods with clips for holding samples. This modification was required to prevent the samples from contacting the steel plates and thus, with the direct heat. It was because the hot air was the stimulus for the recovery of fabrics. If the samples contacted the steel plates, the effect of air temperature on samples would be affected. Therefore, the plastic rods which could withstand a high temperature replaced the original steel plates. Figure 3.21 shows the sample holder for this subjective evaluation.

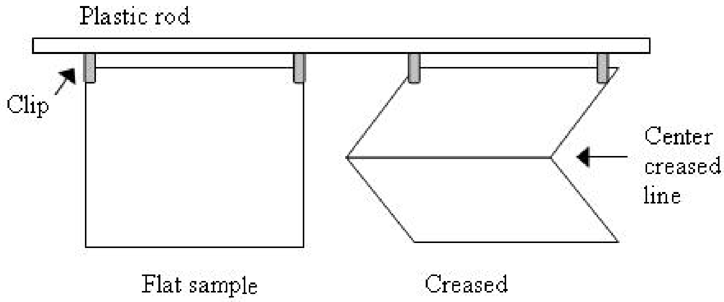

Figure 3.21 Sample holder in Conditioning Chamber for subjective evaluation

3.4.3.4 Experimental Design

The subjective evaluation method in air is the same as the subjective method in water which was described in Section 3.4.1, except for the recovery stage and drying stage. In this method, there were three stages in the experimental procedures. They were (1) Deformation Stage (2) Recovery Stage and (3) Evaluation Stage. The drying stage was not used in this experiment as the sample was not washed or immersed in water in the recovery stage. The Conditioning Chamber was used to provide the specific temperature and relative humidity to the samples for their recovery and the fabric shape memory effects of flat appearance and crease retention were evaluated by giving the ratings as in Section 3.4.1.

Assumption

The flat samples were in a smooth flat shape and the creased samples have a sharp creased line in the centre of fabrics after the finishing process. As a result, it was assumed that the flat sample with original flat shape has the SA Rating of 5.0 and the creased sample with original creased shape has the CR Rating of 5.0. Experimental Procedures were described as follows:

(1) <u>Deformation Stage</u>

The procedure was the similar to that in Section 3.4.1.4. The flat sample was wrinkled by crumpling and placing into a 100ml beaker and then a 500g weight placed on top of the fabrics for 1 hour. Also, the creased shape was deformed by using 1kg steel plate acting on the sample for 1 hour. After that, two corners of each sample were clipped on a plastic rod for the relaxation for 1 hour in a standard condition.

(2) <u>Recovery Stage</u>

The Conditioning Chamber was used instead of using a washing machine and a water tray. The recovery process depended on the air temperature and relative humidity. The plastic rod which clipped samples was hanged in the Conditioning Chamber with specific temperature and relative humidity for 1 hour in the recovery stage. The air temperature was 25°C and 60°C and the relative humidity was 35, 65 and 90 % RH.

One hour was selected for the recovery of sample in the Conditioning Chamber as the deformation and the relaxation time were also one hour. In order to provide the same time period in each stage, one hour for the recovery was selected. In addition, one hour was sufficient to let the samples for the recovery after the heat stimulation.

(3) <u>Evaluation Stage</u>

After the recovering process, the samples were taken out from the Conditioning Chamber and evaluated using the subjective method immediately. The creased samples were evaluated using the Crease Retention (CR) replicas, while the flat samples were evaluated using the Smoothness Appearance (SA) replicas. This evaluation stage was the same as that in Section 3.4.1.5. Three trained observers assigned the ratings and nine observations of each sample were averaged.

3.4.3.5 New Meaning of SA and CR Ratings

The evaluation was the same as that in Section 3.4.1.5.

3.4.4 Objective Evaluation of Flat Appearance and Crease Retention in Air

3.4.4.1 Principle

The objective evaluation method in air was similar to the objective evaluation method in water in Section 3.4.2. The main difference of objective evaluation method in air was the equipment in the recovery. Also, there was no drying stage required in this method as the samples were not wet fully. The effects of air temperatures and relative humidities on the fabric shape memory effects of flat appearance and crease retention in air were explored.

3.4.4.2 Samples

Many samples were tested and some significant results were presented in this thesis. There were three sets of samples which were treated with different shape memory polymers and one set of sample was untreated for the comparison. The sample finishing treatment in this objective evaluation was the same as that in Section 3.4.3 (Subjective evaluation in air). The sample preparation was the same as that in Section 3.4.2.2 (Objective evaluation in water). Based on the Section 3.3.2.4, the sample size of flat and creased sample was 12 respectively. Each set of sample contained flat samples and creased samples and the size of each sample was 40mm X 15mm. Twelve flat samples and twelve creased samples for each set of samples were prepared, as shown in Figure 3.22. The samples were conditioned under 21 ± 1°C and 65 ± 2 % RH for 24 hours before testing.

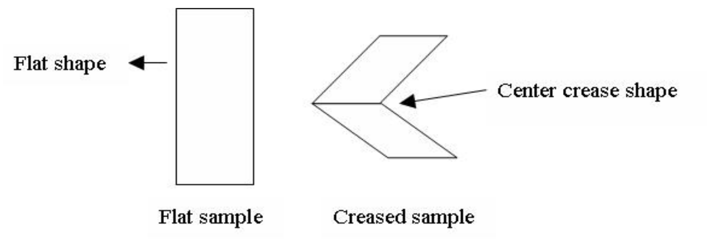

Figure 3.22 Flat and creased sample for hot air test

3.4.4.3 Test Apparatus

The Conditioning Chamber and the sample holder were used, as shown in Figure 3.23.

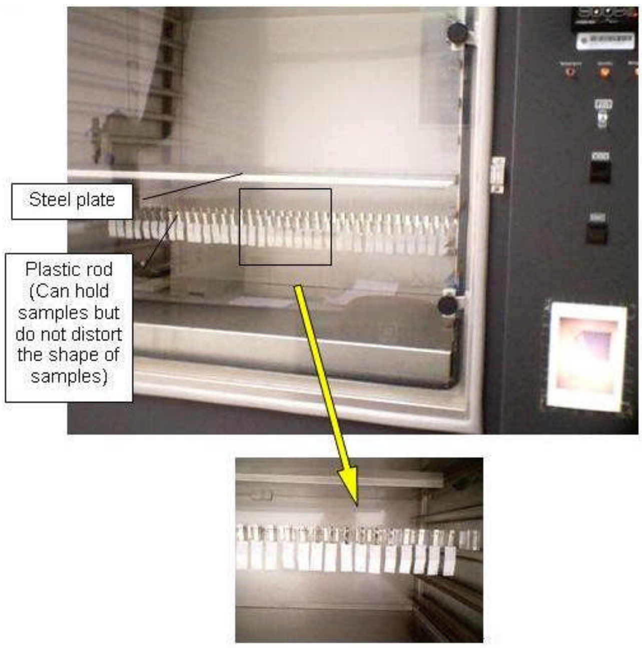

Figure 3.23 Sample holder for objective evaluation in air

3.4.4.4 Experimental Design

The testing procedures in air were similar to the testing procedures in water (Section 3.4.2.4) and the fabric angles were measured using the Wrinkle Recovery Tester in

AATCC Test Method 66. The main difference was that the Conditioning Chamber was used instead of using a water tray in the recovery stage. There were four steps in this experiment and they were (1) Evaluation of the original shape, (2) Shape deformation, (3) Recovery process (hot air) and (4) Evaluation of shape recovery.

<u>(1) Evaluation of the original shape</u>

The procedure was the same as that in Section 3.4.2.4. **Original Angle (Oc)** for a creased sample was measured and it was averaged from twelve readings. The **Original Angle (Of)** for a flat sample could be assumed as 180° as the flat sample is in flat shape originally.

<u>(2) Shape deformation</u>

The deformation process was similar to that in Section 3.4.2.4. The pressing time was changed from 24 hours to 1 hour since it was discovered that 1 hour was sufficient to deform the fabric shape.

a) Flat sample

- The specimen was folded symmetrically and put in a plastic bag for holding in position and the sample was pressed using 1kg steel plate for 1 hour.

b) Creased sample

- The specimen was laid flat and pressed using 1kg steel plate in order to remove the original creased shape for 1 hour.

Then, all specimens were clipped on the plastic rod for the relaxation for 1 hour.

(3) Recovery process (hot air)

The plastic rods with deformed samples were put into the Chamber for 1 hour (Various relative humidities and hot air temperatures were set). Then, the plastic rods were taken out and the fabric angles of recovered samples were measured right away.

(4) Evaluation of shape recovery

- The fabric angle of recovered sample was measured called **Shape Memory Angle (Mf)** for flat sample and **Shape Memory Angle (Mc)** for creased sample. Twelve readings of each sample were averaged and reported.
- The new equations including Flat Recovery % (FRec%) and Crease Recovery % (CRec%) which mentioned in Section 3.4.2.5 were used.

3.4.5 Specific Evaluation Method of Fabric Bagging Recovery Effect in Water

3.4.5.1 Principle

The aim of the bagging recovery test was to explore the recovery ability of an original flat shape of a fabric from a deformed shape which likes a bag (bagged shape) after immersing in water at various temperatures. The evaluation procedures have been designed and original lengths, deformed lengths and recovered lengths of yarns in warp and weft directions of samples were measured. The equations of the Bagging Recovery Percentage were set up. Moreover, the new Bagging Recovery Rating for evaluating the fabric shape memory effect of bagging recovery was developed.

In the previous researches, the bagging height, immediate distortion, other parameters of bagging propensity were measured [16, 35, 50, 77, 78, 79]. However, measuring the height of the bagging recovery of samples was tried previously in order to determine the fabric bagging recovery effect. It was found that measuring height may not be the best method to show the bagging recovery effect, as shown in Figure 3.24. It may be because the height of the bagged shape was deformed easily after immersing in water. Therefore, in this experiment, measuring the yarn length was selected to calculate the bagging recovery of fabrics.

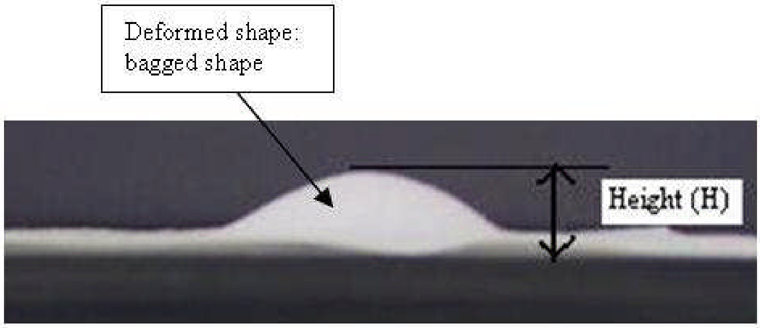

Figure 3.24 Bagging height (H)

3.4.5.2 Samples

Many samples were produced for this study and some significant results were presented. Three types of fabrics were used in the bagging recovery test. Each type of fabric has one untreated sample for comparison and the other samples were treated. Based on the Section 3.3.2.5, each sample has 10 specimens and ten readings were averaged. The original shape of the bagging samples was flat and the dimension of sample was 9 cm X 9 cm. All samples were conditioned under 21 $\pm$ 1°C and 65 $\pm$ 2 % RH for 24 hours before testing. This size of sample was selected as it was the most appropriate size to fit into the apparatus. Too large sample would affect the tightness of a steel ring which held a sample and too small sample would lead to the slippage between the steel rings.

3.4.5.3 Test Apparatus

a) Instron

An Instron – 4411 Tensile Testing Machine as shown in Figure 3.25 was used to set make a bagged shape on a sample. The crosshead of the Instron machine was modified with an attachment to provide a larger deformation. The crosshead was attached a larger ball outside. Thus, the original diameter of the crosshead changed from 25mm to 41mm, as illustrated in Figure 3.26. The reason of adding an attachment for making a larger bagged shape was to increase the deformation of fabrics and make the recovering results to be seen more easily. The crosshead speed for making the bagged shape was 20mm per minute.

The Tensile Testing Machine was selected to deform the fabric as similar to Zhang's researches [78, 79]. The crosshead speed was 20mm per minute based on the Zhang's research and the JIS L 1061 [35]. The circular plastic ring (Inside diameter: 45mm, Outside diameter: 77mm) was put between the upper and lower steel ring. Then, the samples were put between both plastic rings preventing slippage from the samples.

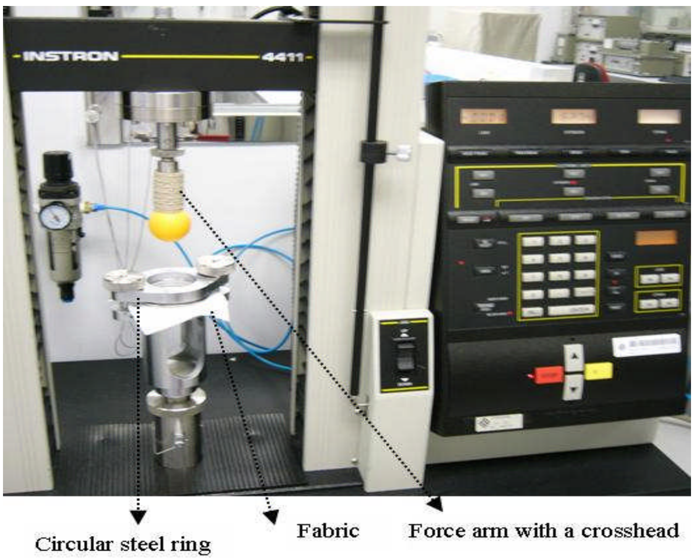

Figure 3.25 Instron machine for making a bagged shape on sample

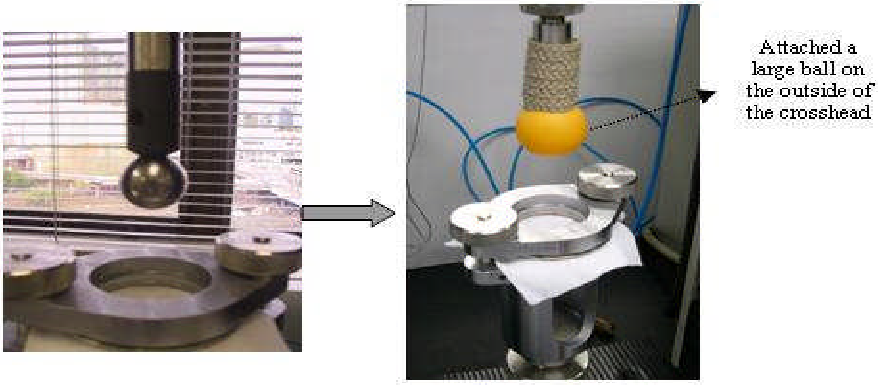

Figure 3.26 Attachment for making a larger bagged shape

b) Displacement (Depth) of a Bagged Shape

The displacements of the crosshead starting from the fabric surface to the head of the bagged shape of fabrics were set to 25 mm, 13mm and 11mm for K1 fabric, C3 fabric and C7 fabric respectively, as shown in Figure 3.27.

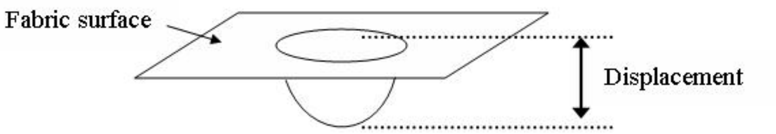

Figure 3.27 Displacement of a bagged shape

The setting of displacement is quite important. It is because the bagged shape of an untreated fabric may be recovered at a certain extend due to its relaxation if the displacement is too small. If the displacement is too large, the bagged shape may burst or it cannot be recovered to flat even it was a treated sample. After several trials on many samples, the displacements of fabric K1, C3 and C7 were selected as 25mm, 13mm and 11mm respectively.

3.4.5.4 Experimental Design

The evaluation process contained four steps: (1) Evaluation of original shape, (2) Shape deformation, (3) Recovery process and (4) Evaluation of shape recovery.

(1) Evaluation of original shape

- Draw a vertical and horizontal line on samples, as show in Figure 3.28. The length of both lines is the same as the diameter of the inside steel ring.
- Measure the **Original Warp Length (Op)** and **Original Weft Length (Ot)** using a flexible curve ruler. The unit of length was in millimetres. For the woven fabric sample, the Warp Length represented the length in a warp direction of a fabric and the Weft Length represented the length in a weft direction of a fabric. For the knitted fabric sample, the Warp Length represented the length of a wale in vertical row of a fabric and the Weft Length represented the length of a course in a horizontal row of a fabric.

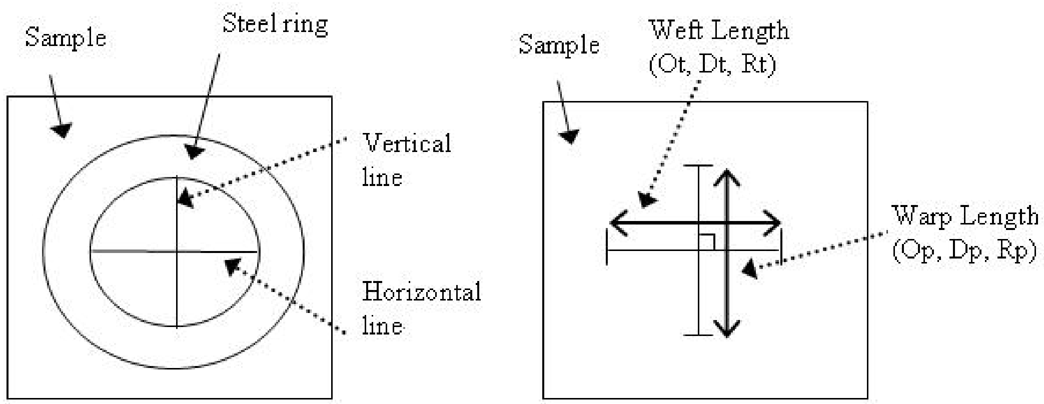

Figure 3.28 Vertical line and horizontal line of a bagging sample

(2) Deformation Stage

- The specimen with original flat shape was clipped between the upper and lower steel rings with the plastic rings. An attachment, a large ball, was attached on outside of the crosshead at the end of the force arm.
- When the Instron machine was started, the force arm moved down with specific displacement to the fabric with a speed of 20 mm/min. After the force arm was moved down to 25mm, 13mm and 11mm (displacement) for K1, C3 and C7 fabric respectively, the force arm was held in position for 5 minute.

- The original flat fabrics could be deformed to a bagged shape on the fabric surface. Then, the samples were relaxed for 5 minute. The holding time for the bagged shape was 5 minute which referred to the JIS L 1061 [35].
- After that, the **Deformed Warp Length (Dp)** and **Deformed Weft Length (Dt)** were measured.

(3) Recovery Stage

- The samples were taken out and immersed in water at 25°C and 60°C respectively for 5 minute for its recovery.
- After immersing for 5 minute, the samples were taken out and then dried by a line dry for 24 hours. The sample was immersed in water for 5 minute for the sake of consistency with the evaluation of samples in water in Section 3.4.1 and 3.4.2.

(4) Evaluation Stage

- Measure the **Recovered Warp Length (Rp)** and **Recovered Weft Length (Rt)** of samples using a flexible curve ruler.
- The **Bagging Warp Recovery % (BPR%)** and the **Bagging Weft Recovery % (BTR%)** were calculated using the newly developed equations.
- The **Bagging Recovery Rating (BRR Rating)** was used for the evaluation of the fabric bagging recovery effect by integrating the value of BPR% and BTR%.

3.4.5.5 New Equations for Evaluating Fabric Bagging Recovery

The new equations of the Bagging Recovery Percentage and the Bagging Recovery rating for the evaluation of fabric bagging recovery were designed. Two equations were developed in order to calculate the Bagging Recovery % in warp and weft direction respectively. It was defined that the Bagging Recovery % (Warp or Weft) was equal to the Degree of Recovery of a sample over Degree of Extension of a sample, as shown in below.

$$\text{Bagging Recovery \% (Warp or Weft)} = \frac{\text{Degree of Recovery}}{\text{Degree of Extension}} \times 100\ \%$$

The two equations are described below and Figure 3.29 shows the BPR% and BTR% in a schematic diagram.

(1) Bagging Warp Recovery % (BPR%)

The equation of Bagging Warp Recovery % (BPR%) is expressed as:

$$\text{Bagging Warp Recovery \%}\quad (\text{BPR\%}) = \frac{(Dp - Rp)}{(Dp - Op)} \times 100\ \%$$

(Equation 3.5)

- ✓ It represents the ability of a fabric in warp direction to recover its original flat shape from a deformed bagged shape.
- ✓ The higher is the BPR %, the higher is the bagging recovery effect of fabric in warp direction

(2) Bagging Weft Recovery % (BTR%)

The equation of Bagging Weft Recovery % (BTR%) is expressed as:

$$\text{Bagging Weft Recovery \%}\quad (\text{BTR\%}) = \frac{(Dt - Rt)}{(Dt - Ot)} \times 100\ \%$$

(Equation 3.6)

- ✓ It represents the ability of a fabric in weft direction to recover its original flat shape from a deformed bagged shape
- ✓ The higher is the BTR %, the higher is the bagging recovery effect of shape memory fabric in weft direction.

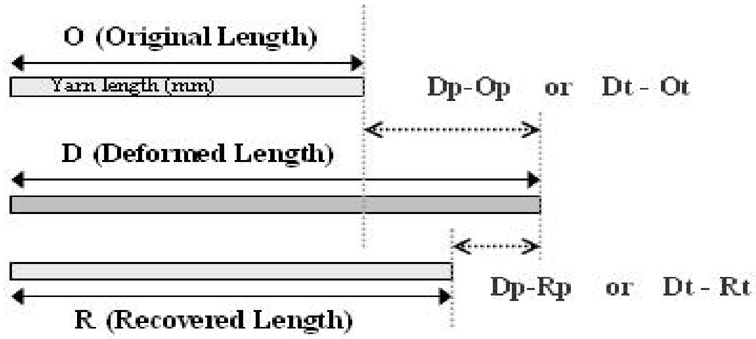

Figure 3.29 Parameters in Bagging Warp Recovery % (BPR%) and Bagging Weft Recovery % (BTR%)

3.4.5.6 Bagging Recovery Rating

As the BPR% and BTR% expressed the bagging recovery effect in warp direction and weft direction of fabrics separately, it was required to integrate these two values into one value to represent the fabric bagging recovery effect. Thus, a Bagging Recovery Rating (BRR) Table was designed to combine the value of BPR % and BTR%, as shown in Table 3.3. In the table, BPR% and BTR% were averaged and divided into ten ranges and a grade was given for each range. Grade (a) referred to BPR% and grade (b) referred to BTR%. Then, the Bagging Recovery Rating (BRR) was averaged from the value of the grade (a) and grade (b). This means that the Bagging Recovery Rating (BRR) is equal to:

$$\textbf{Bagging Recovery Rating (BRR)} = \frac{\mathbf{a} + \mathbf{b}}{\mathbf{2}}$$

Therefore, after calculating the BPR% and BTR%, the Bagging Recovery Rating Table was used to check the corresponding grade (a) for BPR% and grade (b) for BTR%. The Bagging Recovery Rating could be calculated to determine the bagging recovery effect of fabrics.

Table 3.3 Bagging Recovery Rating Table

BPR%	Grade (a)	BTR%	Grade (b)
91-100	10	91-100	10
81-90	9	81-90	9
71-80	8	71-80	8
61-70	7	61-70	7
51-60	6	51-60	6
41-50	5	41-50	5
31-40	4	31-40	4
21-30	3	21-30	3
11-20	2	11-20	2
0-10	1	0-10	1

The Bagging Recovery Rating of 10.0 means that the fabric bagging recovery is very satisfactory and the deformed bagged shape can recover its original flat shape. The Bagging Recovery Rating of 1.0 indicates that the fabric bagging recovery is the worst, meaning that there is very little or no fabric bagging recovery effect. Besides, the deformed bagged shape cannot recover its original flat shape after heat stimulation. The higher is the BRR, the higher is the fabric bagging recovery effect.

3.5 Statistical Method

After conducting all of the above evaluations, testing results were calculated and analysed by statistical methods such as t-test, ANOVA and regression. In addition, error bars were presented to show a range of values estimated from the selected group of samples that is 95% confidence level to include the true value. The confidence interval extends in each direction by a distance calculated from the standard error of the mean multiplied by a critical value $t_{\alpha/2}$ from the Student t Distribution. Furthermore, the standard deviation and coefficient of variation of measured parameters such as Original Angles, Shape Memory Angles, and Original, Deformed, Recovered Warp/Weft Length were shown in appendices.

3.6 Conclusions

This chapter describes the experimental design of subjective evaluation methods and objective evaluation methods for evaluating the fabric shape memory effects of flat appearance, crease retention and bagging recovery effect in water and air. The sample preparation, experimental principle, experimental procedures and new equations are described. In addition, the statistical methods are applied in the process of designing these experiments, and the precision and feasibility of the evaluation methods are discussed in this chapter.

CHAPTER 4: SUBJECTIVE EVALUATION OF FABRIC SHAPE MEMORY EFFECTS IN WATER

4.1 Introduction

This chapter is to report the effect of temperature, recovery method and drying method on the fabric shape memory effects of flat appearance and crease retention in water using a subjective evaluation method. In the first section, different types of fabrics were tested in the early stage of this research. In the sections that follow, shape memory fabrics were treated with different sets of shape memory polymers. Two types of cotton woven fabrics were selected and the fabric shape memory effects in water under various conditions were presented. Then, the chapter moves on to the conclusions.

4.2 Fabric Shape Memory Effect of Different Fabric Types

The aim of this test was to explore the fabric shape memory effects among three types of fabrics. They included a cotton, ramie and silk, as shown in Table 4.1.

Table 4.1 Types of fabrics

Sample No.	Fabric Type	Structure	Specifications (Fabric code)
C1, C2	Cotton	Plain	100% Cotton Sheeting, 68X68, 30sX30s (C1)
S1, S2	Silk	Satin	14654 white crepe-back satin (S)
R1, R2	Ramie	Plain	21S, density 60 x 60 bleached (R)

4.2.1 Sample Details

Nine significant results were selected in this thesis. Each set of sample contained three creased samples (Set A) and three flat samples (Set B). Sample Cu, Su and Ru were untreated samples for comparison and the other samples were treated with different shape memory polymers. The sample details are shown in Table 4.2. During the finishing process, the samples were dried at 80°C for 3.0 minutes, and then ironed at 140°C for 30 seconds on each face. After that, the samples were cured at 150℃ for 3.0 minutes.

Table 4.2 Sample description for testing different fabric types

Sample No.	Set (A)	Set (B)	Fabric Type	Shape Memory Polymer
Cu	Crease	Flat	Cotton	Untreated, no polymer
C1	Crease	Flat	Cotton	P_1
C2	Crease	Flat	Cotton	P_2
Su	Crease	Flat	Silk	Untreated, no polymer
S1	Crease	Flat	Silk	P_3
S2	Crease	Flat	Silk	P_4
Ru	Crease	Flat	Ramie	Untreated, no polymer
R2	Crease	Flat	Ramie	P_5
R3	Crease	Flat	Ramie	P_6

4.2.2 Experimental Parameters (Recovery: Water Immersion)

The details of the subjective method were described in Section 3.4.1. The specific testing parameters of this experiment were given below:

(1) Deformation : Flat samples were wrinkled for 5 minutes and creased samples were flattened for 4 hours.

(2) Recovery : Water immersion (samples were put into a water tray), 50°C

(3) Drying : Flat dry

(4) Evaluation : Samples were rated by six trained observers.

(5) It was assumed that the original shape of crease retention and flat appearance has the rating of 5.0.

4.2.3 Results and Discussions

The detailed test results are listed in Appendix B1.

4.2.3.1 Flat Appearance among Three Types of Fabrics

Figure 4.1 illustrates the fabric shape memory effect of flat appearance of three types of fabrics. As can be seen, the SA Ratings of treated cotton samples were higher than that of the untreated cotton sample. This means that the recovering ability of treated cotton samples is higher than the recovering ability of the untreated sample. However, the SA Ratings of treated silk and ramie sample have the similar ratings compared with their untreated samples. The finding indicates that their fabric shape memory effects are not obvious. It may be because the shape memory polymers are mainly applied to cotton and the finishing process may not be optimum to silk and ramie. It appears that cotton has an obvious shape memory effect of flat appearance compared with the other types of fabrics. Also, the error bars are small and there is 95% confidence that the true value is included within the span of the error bars.

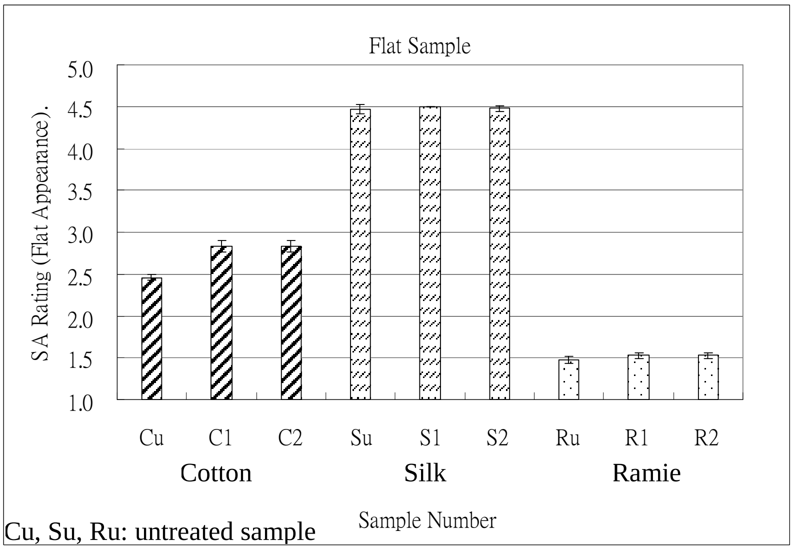

Figure 4.1 Comparison of flat appearance among cotton, silk and ramie

4.2.3.2 Crease Retention among Three Types of Fabrics

A comparison of fabric shape memory effect of crease retention on three types of fabrics is shown in Figure 4.2. It can be seen that the CR Ratings of all untreated fabrics were 1.0 only. The results indicate that there is no crease retention among all untreated fabrics after immersing in water at 50°C.

Comparing the CR Ratings of all treated fabrics, treated cotton fabrics have the higher CR Ratings which was around 3.0 to 4.0 than the other treated samples. The CR Ratings of other treated samples were below 2.0. This point can be interpreted to mean that the treated cotton fabrics have the fabric shape memory effect of crease retention and they have a greater ability to recover their original creased shaped than silk and ramie. It seems that shape memory polymers can exhibit their shape memory effects to cotton more easily compared with the other types of fabrics. There is much confidence that these data are differ significantly.

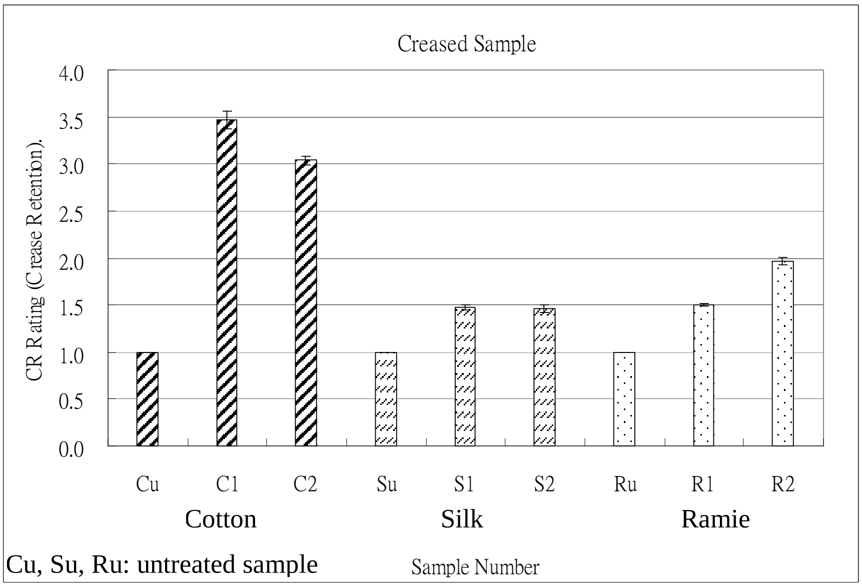

Figure 4.2 Comparison of crease retention among cotton, silk and ramie

4.2.4 Summary

It is obvious from the discussion above that cotton fabric shows a higher fabric shape memory effects among cotton, ramie and silk. These findings suggest that cotton has a large potential to treat with shape memory polymers for making shape memory fabrics.

4.3 Effect of Temperature (Water Immersion, C1 Fabric)

The aim of this test was to investigate the effect of temperature on the fabric shape memory effects of C1 fabric after immersing in water at various temperatures.

4.3.1 Sample Details

A plain fabric (100% Cotton Sheeting, 68X68, 30sX30s, fabric code: C1)) was selected and there were nine samples for this test. Each set of sample contained three creased samples (Set A) and three flat samples (Set B). Sample 0 was an untreated sample for comparison and the other eight samples were treated with different shape memory polymers. The sample details are given in Table 4.3. The finishing process was the same as that in Section 4.2.

Table 4.3 Sample details for temperature test (C1 fabric)

Sample No.	Set (A)	Set (B)	Shape Memory Polymer
0	Crease	Flat	Untreated, no polymer
1	Crease	Flat	P_7
2	Crease	Flat	P_8
3	Crease	Flat	P_9
4	Crease	Flat	P_{10}
5	Crease	Flat	P_{11}
6	Crease	Flat	P_{12}
7	Crease	Flat	P_{13}
8	Crease	Flat	P_{14}

4.3.2 Experimental Parameters

The experimental parameters were the same as that described in Section 4.2.2, except the water temperature in a recovery stage.

(1) Recovery : Water immersion (Temperature: 15°C, 25°C, 40°C and 50°C)

(2) Drying : Flat dry

(3) Evaluation : Samples were evaluated by three trained observers

4.3.3 Results and Discussions

The detailed test results are listed in Appendix B2.

4.3.3.1 Effect of Temperature on Flat Appearance

The influence of water temperature on the fabric shape memory effect of flat appearance after immersing the specimens in water is given in Figure 4.3. The SA Rating of the untreated sample kept at 2.5 at any water temperatures. The results indicate that the untreated sample is not temperature sensitive and it does not respond to the temperature change. Although it can recover from a SA Rating of 1.0 after deforming to the SA Rating of 2.5 in the recovery stage, the SA Rating of 2.5 is not high and some obvious wrinkles could be observed on samples. Therefore, untreated sample did not have fabric shape memory effect.

For the treated samples, the SA Rating increased while the water temperature increased. The results suggest that the treated samples are temperature sensitive and the ability of treated samples to recover their original flat shape increased when the water temperature increased. It is found that the higher is water temperature, the higher is the flat appearance of fabrics. Sample 1, 3 and 4 have higher SA Ratings at 40°C and 60°C compared with the untreated sample and these treated samples have the SA Ratings from 3.0 to 4.0. This lower confidence limit of the sample 1 and 3 in 60°C is higher than the rating of sample 1 in 40°C. This phenomenon shows that the fabric shape memory effect of flat appearance could be existed by treating the samples with shape memory polymers and treated samples are temperature sensitive.

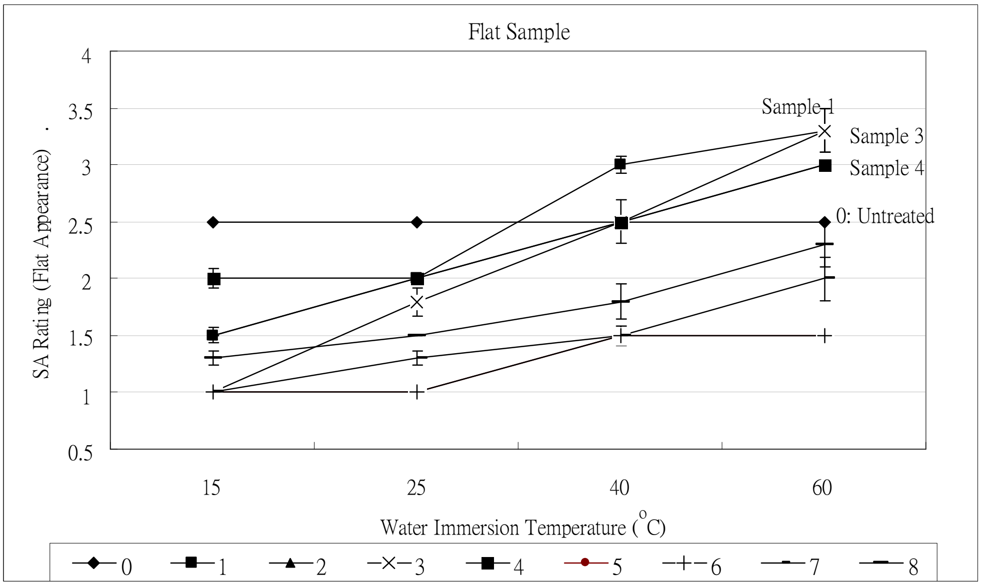

Figure 4.3 Effect of temperature on flat appearance (C1 fabric)

4.3.3.2 Effect of Temperature on Crease Retention

The effect of water temperature on the fabric shape memory effect of crease retention of the specimens after immersing in water at various temperatures is illustrated in Figure 4.4. The untreated sample has the CR Rating of 1.0 at any water temperatures. The finding shows that the untreated sample cannot recover its original creased shape. It is largely true that the untreated sample does not have the fabric shape memory effect and it cannot respond to temperature change. In addition, there is highly significant that there is no variation for the untreated sample in water at different temperature.

On the other hand, the treated samples have higher CR Ratings at any water temperatures compared with the untreated specimen. The finding shows that the treated samples have an ability of recovering their original creased shape and they have significant fabric shape memory effect of crease retention. The CR Ratings of treated samples increased when the water temperature decreased from 60°C to 15°C.

The results demonstrate that the treated creased samples are temperature sensitive and they can respond to water temperature. It is shown that the lower is water temperature, the higher is the crease retention of fabrics. Although these results show interesting trends of temperature sensitive, they do not have the same trend of the results of flat appearance. The effect of temperature on the crease retention and flat appearance are wholly different.

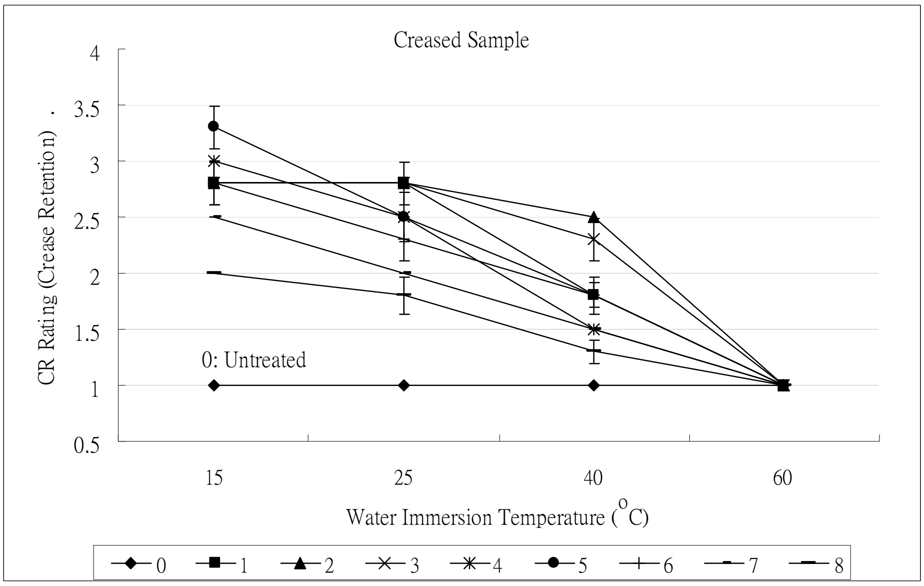

Figure 4.4 Effect of temperature on crease retention (C1 fabric)

4.3.3.3 Comparison of Crease Retention and Flat Appearance

The rating results of flat samples and creased samples in the water temperature of 15°C and 60°C are given in Figure 4.5 and Figure 4.6 respectively. According to Figure 4.5, the CR Ratings of samples were much higher than the SA Ratings of samples at 15°C. It is found that the crease retention of fabrics is higher when the water temperature at 15°C. Unlike the crease retention, the flat appearance of fabrics is lower when the water temperature is 15°C.

Referring to Figure 4.6, the SA Ratings of treated samples were much higher than the CR Ratings of samples at 60°C and the CR Ratings of all samples were 1.0 only. The results reveal that the flat appearance of fabrics is higher when the water temperature at 60°C. However, the crease retention of samples was very lower even the water temperature was high. The results demonstrate that the trend of temperature sensitive of flat samples and creased samples are not the same.

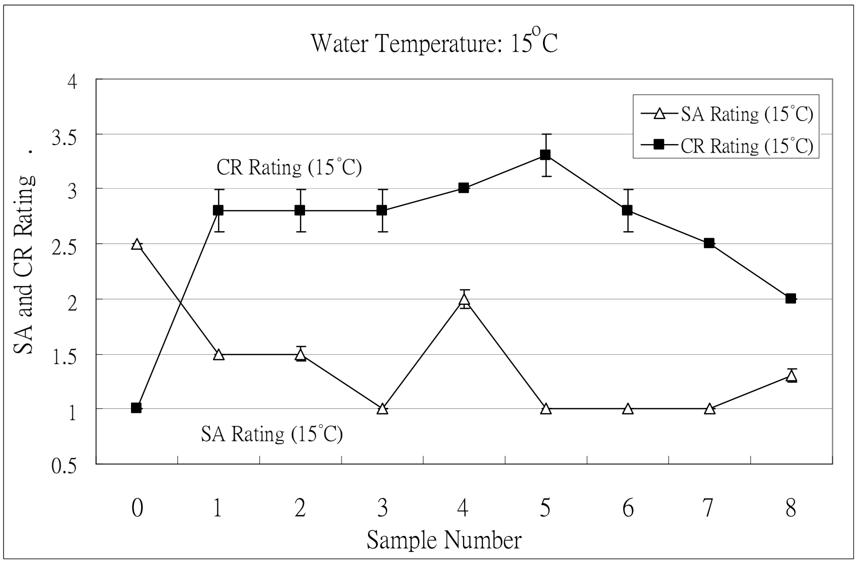

Figure 4.5 **Effect of lower temperature (15°C) on crease retention and flat appearance**

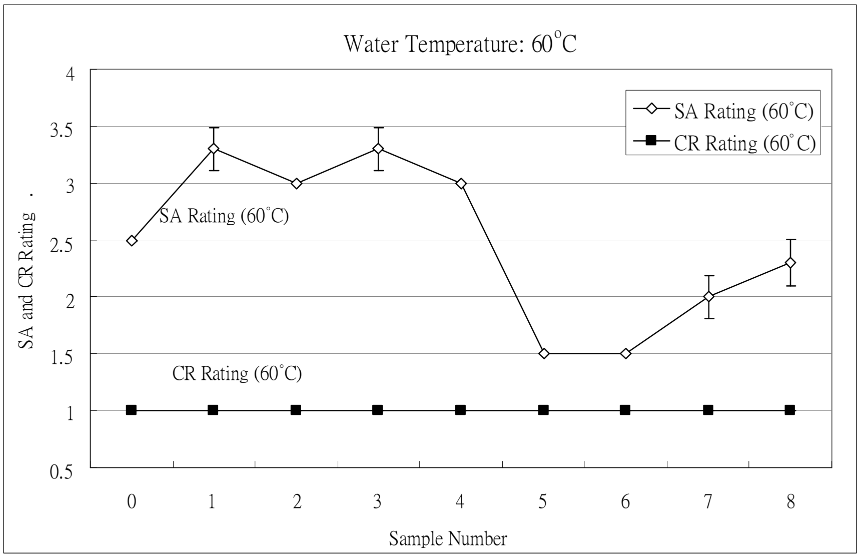

Figure 4.6 **Effect of higher temperature (60°C) on crease retention and flat appearance**

4.3.4 Summary

Shape memory fabrics have the shape memory effects of flat appearance and crease retention when they are stimulated by water at various temperatures. The treated fabrics are temperature sensitive and they can respond to temperature change. However, the untreated samples do not have the fabric shape memory effects at any water temperatures and they are not temperature sensitive.

The temperature response to the shape memory effect of crease retention and flat appearance of woven fabric is wholly different. The crease retention of fabric increases and the flat appearance decreases when the water temperature is low as at 15°C. Conversely, the crease retention of fabric decreases and the flat appearance increases when the water temperature is high as at 60°C. The results can be interpreted to mean that various temperatures can affect the shape memory effects significantly.

However, different trends of temperature response to flat appearance and crease retention of fabrics may not be suitable for making shape memory garments. It is because the fabric shape memory effects of flat appearance and crease retention of woven fabrics may not exist at the same time at a certain water temperature. As a result, another set of shape memory chemicals which are synthesized using new recipes were produced for treating with another cotton woven fabric for making another types of shape memory fabrics. These fabrics were produced and used in this study.

4.4 Effect of Temperature (Water Immersion, C3 Fabric)

The aim of this experiment was to investigate the effect of water temperatures on the fabric shape memory effects of flat appearance and crease retention after immersing in water at various temperatures and drying by a line dry.

4.4.1 Sample Details

Another set of shape memory fabrics which treated with new set of shape memory polymers were tested. A cotton woven fabric (100% Cotton Twill, 108X58, 20sX20s, 43/44”, fabric code: C3) was selected and there were five samples for this test. Each set of sample contained three creased samples (Set A) and three flat samples (Set B). Sample U was an untreated sample for comparison and the other four samples were treated with different shape memory polymers. The sample details are presented in Table 4.4. In the finishing process, the samples were dried at 80°C for 2.5 minutes and then ironed at 150°C for 30 seconds on each face. After that, the samples were cured at 150°C for 3.5 minutes.

Table 4.4 Sample details for temperature test (C3 fabric)

Sample No.	Set (A)	Set (B)	Shape Memory Polymer
U	Crease	Flat	Untreated, no polymer
SM4	Crease	Flat	SMP4
SM11	Crease	Flat	SMP11
SM17	Crease	Flat	SMP17
SM22	Crease	Flat	SMP22

4.4.2 Experimental Parameters

The experimental process was described in Section 3.4.1. Some parameters in the experimental design were shown as below:

(1) Deformation : Flat samples were wrinkled and creased samples were flattened for 1 hour.

(2) Recovery : Water immersion (25°C and 60°C)

The chemical synthesis members recommended that 60°C should be used for the recovery as it is higher than the switch temperature [Tm(s)] of the shape memory chemicals. For comparison, 25°C was also selected.

(3) Drying : Line dry

(4) Evaluation : Samples were evaluated by three trained observers.

4.4.3 Results and Discussions

The detailed test results are listed in Appendix B3.

4.4.3.1 Effect of Temperature on Flat Appearance

The effect of temperature on the fabric shape memory effect of flat appearance is given in Figure 4.7. The SA Rating of untreated sample (U) was 1.0 at any water temperatures. The result indicates that the untreated sample does not have the fabric shape memory effect as it cannot recover its original flat shape after the temperature stimulation and it is not temperature sensitive. Unlike the untreated sample, all treated samples have higher SA Ratings than the untreated one. Their SA Ratings were above 2.0 at 25°C or 60°C. It shows that the fabric shape memory effect of flat appearance exists in treated samples.

As can be seen, the SA Ratings of treated sample were higher while the water temperature was higher as at 60°C. The findings suggest that the treated samples have fabric shape memory effect and they tend to recover their original flat shapes when they were stimulated by hot water at switch temperature. The result implies that they are temperature sensitive. The probable explanation for the recovery of samples at 60°C is that the water at 60°C reaches the switch temperature [Tm(s)] of the shape memory polymers in fabrics. Therefore, the soft segment crystals melt and the molecular chains in the soft segment can move more easily. The deformed shape can change back to the original shape due to the movement of molecular chains in soft segment. The original and permanent flat shape of fabrics was set in the curing process at a very high temperature (160°C). The orientation of molecular chains in the hard segment can keep that permanent shape. Therefore, water at 60°C cannot make the original flat shape to be disappeared but it can make the treated samples to recover their original flat shapes.

According to the figure, the SA Ratings of treated samples at 25°C were around 2.2 and this means that they also tend to recover their original shapes slightly after immersing in water at 25°C. However, the result is not as good as recovering at 60°C. The finding reveals that 25°C is not the optimum temperature for the recovery of fabric shape memory effect and it cannot reach the switch temperature of polymers. Nevertheless, the shape memory fabrics can recover their original shape slightly even the water temperature is 25°C. One possible explanation for this is that water can enhance the fabric recovery. Water molecules are attracted to the numerous hydroxyl groups of cotton and water molecules can enter the polymer system of cotton to break the hydrogen bonding. Then, cotton becomes less rigid and softer. Therefore, the recovery of fabrics at 25°C may be due to the effect of water but not the temperature. It is because the lower temperature as at 25°C cannot reach the switch temperature to stimulate the fabric shape memory effect.

Based on the ANOVA Test, the temperature of treated samples has a highly significant effect on the fabric shape memory effect of flat appearance (SA Rating) at the 0.05 level of significance. However, the water temperatures do not appear to have an effect on the fabric shape memory effect flat appearance of the untreated sample. Also, the error bars are very small and the error bars for 60℃ do not overlap the range of SA Ratings within the error bar of 25°C. There is 95% confidence that the true value is within this range.

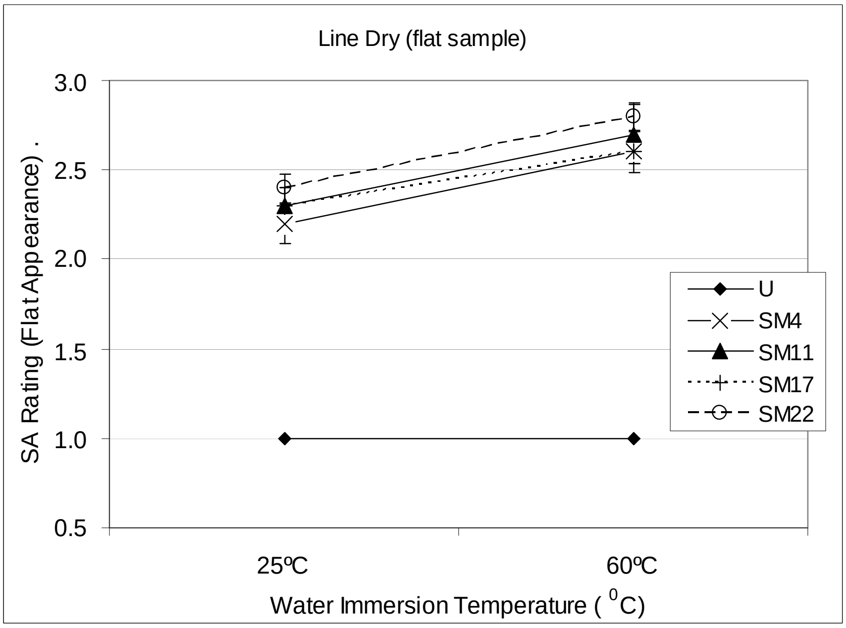

Figure 4.7 Effect of temperature on flat appearance of C3 fabric (water immersion)

4.4.3.2 Effect of Temperature on Crease Retention

Figure 4.8 shows the effect of temperature on the fabric shape memory effect of crease retention. It can be seen that the CR Rating of the untreated sample was 1.0 after immersing in water at 25°C and 60°C and this shows that the untreated sample has no fabric shape memory effect and it does not respond to temperature change of water. The CR Ratings of all treated samples were higher than the CR Rating of the untreated sample at both temperatures. The finding suggests that the fabric shape memory effect of crease retention exists in all treated samples.

According to the figure, the CR Ratings of treated sample were higher while the water temperature was higher as at 60°C. The CR Ratings of SM22 and SM17 were near to 3.0 at 60°C. However, their CR Ratings were lower when the water temperature was lower as at 25°C. The results show that the treated samples are temperature sensitive and they can respond to the temperature change. The reasons for the recovery of treated samples at 60°C obviously and also at 25°C slightly are similar to the explanations of flat appearance in previous Section 4.4.3.1.

According to the ANOVA Test, the temperature effect of treated samples is highly significant on crease retention at the 5% level of significance. The water temperatures do not appear to have an effect on the crease retention of the untreated fabric. The error bars for 60°C do not overlap the range of CR Ratings within the error bar of 25°C. It is 95% confidence that the true value is within this range.

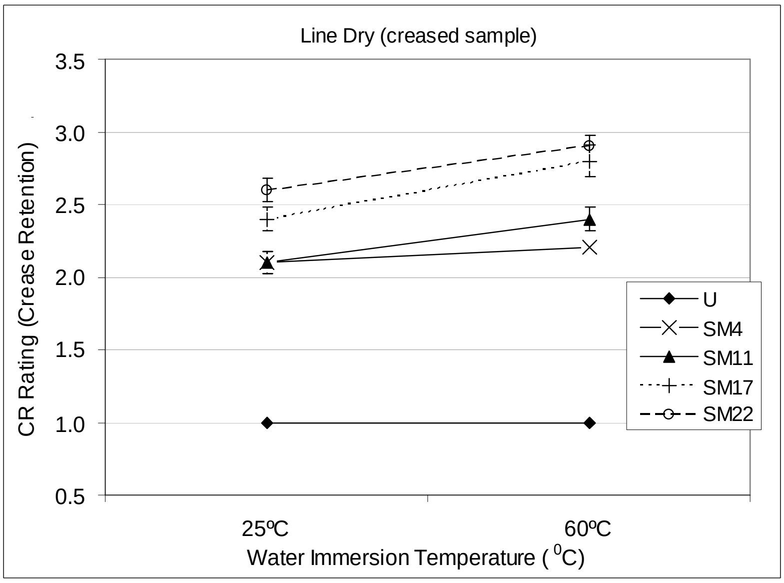

Figure 4.8 Effect of temperature on crease retention of C3 fabric (water immersion)

4.4.3.3 Comparison of Crease Retention and Flat Appearance

After comparing the effect of temperature on the flat appearance with the crease retention of treated samples, the results show interesting trends that both fabric shape memory effects can exist at the same time after stimulating in water at a certain water temperature. Unlike the treated samples in Section 4.3.1, the SA Rating and CR Rating of treated samples in this section are higher while the water temperature is higher as at 60°C. Conversely, the SA Rating and CR Rating of treated samples are lower while the water temperature is lower as at 25°C.

The temperature response to flat appearance and crease retention of this set of shape memory fabrics is wholly different from that of the shape memory fabrics described in Section 4.3.1. It is important for making this type of shape memory fabrics as they can have both fabric shape memory effect of flat appearance and crease retention at the same time.

4.5 Effect of Temperature, Washing and Drying

The aim of this experiment is to explore the effect of washing temperature, recovery method and drying method on the fabric shape memory effects of flat appearance and crease retention. In this experiment, washing replaced water immersion in the recovery stage. In addition, a line dry and a tumble dry were used in the drying stage instead of using the flat dry.

4.5.1 Sample Details

The same samples which were C3 fabrics as in Section 4.4 were used in this experiment.

4.5.2 Experimental Parameters

The experimental process and adjustments were similar to that in the previous Section 4.4. The only difference was the parameters in the recovery stage and the drying stage.

Recovery : Washing by a machine (25°C and 60°C)

Drying : Line dry or tumble dry (High exhaust temperature - 66°C)

Evaluation : Samples were evaluated by three trained observers.

4.5.3 Results and Discussions

The detailed test results are listed in Appendix B4.

4.5.3.1 Effect of Washing Temperature with Line Dry

Figure 4.9 shows the effect of washing temperature on fabric shape memory effect of flat appearance after washing at 25°C and 60°C with a line dry. The SA Rating of the untreated sample was 1.0 at any washing temperatures. The washing temperature does not appear to have an effect on the flat appearance of untreated sample at the 0.05 level of significance. The result indicates that the untreated sample is not temperature sensitive and the fabric shape memory effect does not exist in the untreated fabric.

For the treated samples, their SA Ratings after washing at 60°C was slightly higher than the SA Ratings after washing at 25°C and they were rated between 2.5 and 3.0. Only for SM4 and SM22, washing temperature has significant effect on the flat appearance at 5% level statistically according to the ANOVA analysis. The result reveals that temperature can stimulate some treated samples and they are temperature sensitive. The findings also indicate that fabric shape memory effect exists in treated samples. However, the error bars for samples at 60°C were a little bit larger.

The possible explanation for the higher ratings at higher washing temperature is that higher temperature can reach the switch temperature of polymers and make the soft segment crystals melt more easily. Therefore, the molecular chains in soft segments of polymers can move freely for the fabric recovery. The explanation was described in more details previously in Section 4.4.3.1.

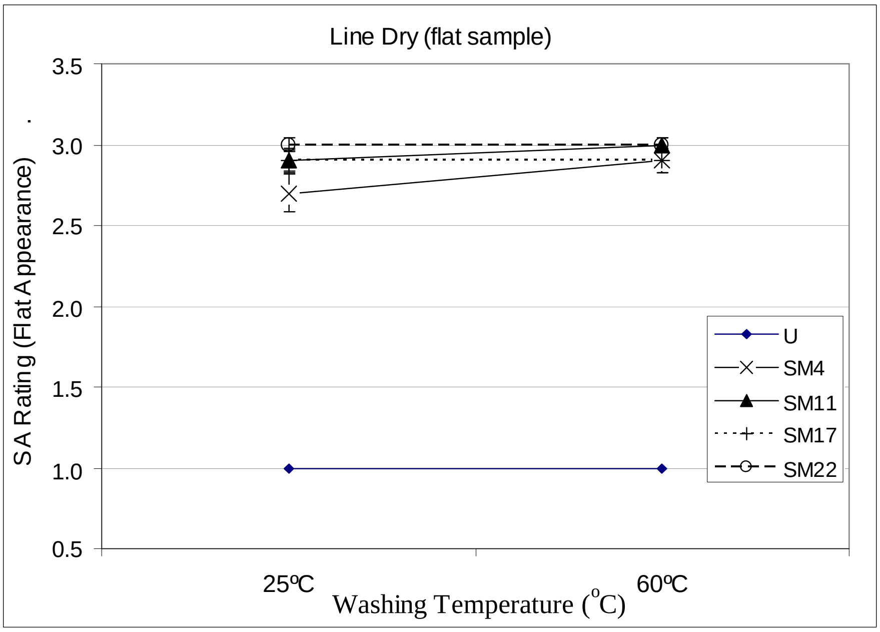

Figure 4.9 Effect of washing temperature of flat appearance (line dry)

The effect of washing temperature on fabric shape memory effect of crease retention after washing at 25°C and 60°C with a line dry is given in Figure 4.10. As can be seen, the CR Rating of the untreated sample was 1.0 at any washing temperatures. This means that the untreated sample is not temperature sensitive and it does not have the fabric shape memory effect.

For the treated samples, the CR Ratings of all samples were between 2.0 to 3.5. The result implies that the fabric shape memory effect exists in creased sample. Comparing the result of washing at 25°C and 60°C, the CR Ratings of samples washing at 60°C were slightly higher than the CR Ratings of samples washing at 25°C. For SM11, washing temperature does appear to have a significant effect on crease retention at the 0.05 level of significance. The findings show that the treated samples can respond to the temperature change. The explanation of the temperature sensitive was explained previously.

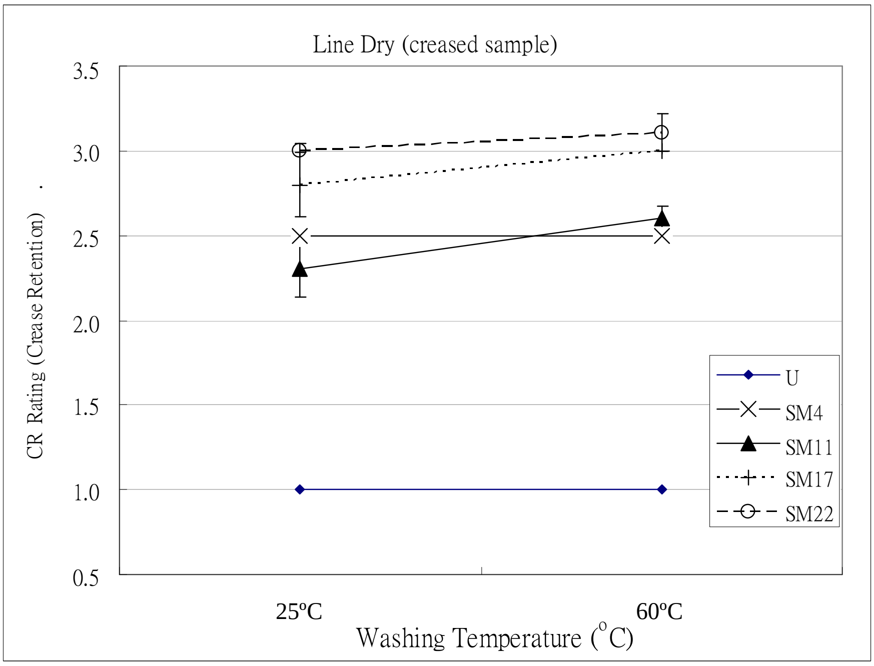

Figure 4.10 Effect of washing temperature of crease retention (line dry)

4.5.3.2 Effect of Washing Temperature with Tumble Dry

Figure 4.11 shows the effect of washing temperature on fabric shape memory effect of flat appearance after washing at 25°C and 60°C with a tumble dry. The SA Rating of the untreated sample was 1.0 at any washing temperatures and the result suggests that the untreated sample does not have fabric shape memory effect and it cannot respond to temperature change. In addition, washing temperature does not appear to have an effect on flat appearance of untreated sample at 5% level of significance.

The SA Ratings of treated samples were above 3.5 after washing at both temperatures with a tumble dry. The results reveal that the treated samples have fabric shape memory effect and they tend to recover their original flat shapes. Comparing the results of washing at 25°C and 60°C, the fabric shape memory effect of treated samples was increased slightly after washing at 60°C. The SA Rating of SM22 after washing at 60°C was considerably higher than the SA Rating of that sample after washing at 25°C. Washing temperature does appear to have a significant effect on flat appearance of most treated samples at the 0.05 level of significance. The finding shows that the treated samples are temperature sensitive and washing temperature can influence the fabric shape memory effect. The error bars are very small and the error bars for 60°C do not overlap the range of SA Ratings within the error bar of 25°C. There is 95% confidence that the true value is within this range and they are differ significantly.

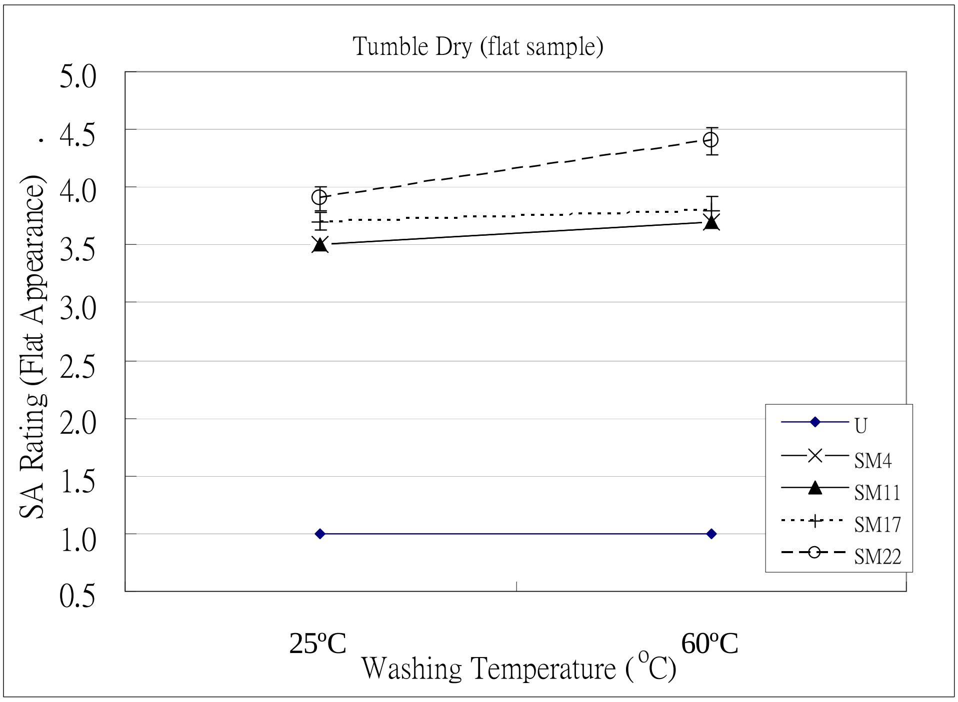

Figure 4.11 Effect of washing temperature of flat appearance (tumble dry)

The effect of washing temperature on the fabric shape memory effect of crease retention after washing at 25°C and 60°C with a tumble dry is presented in Figure 4.12. Similar to the flat appearance, the CR Ratings of treated samples were above 3.5 while the untreated sample was 1.0 after they were washed at 25°C or 60°C. The findings show that fabric shape memory effect only exists in treated samples but not in untreated samples.

Comparing the results of washing at 25°C and 60°C, the CR Ratings of washing at 60°C were higher than that of washing at lower temperature. Based on the ANOVA Test, there is a significant effect of washing temperature on crease retention of most treated samples at 5% level of significance. Also, the variation of data in water at 60°C is very small. The results reveal that the treated creased samples are temperature sensitive. The possible explanation for that is explained in previous section.

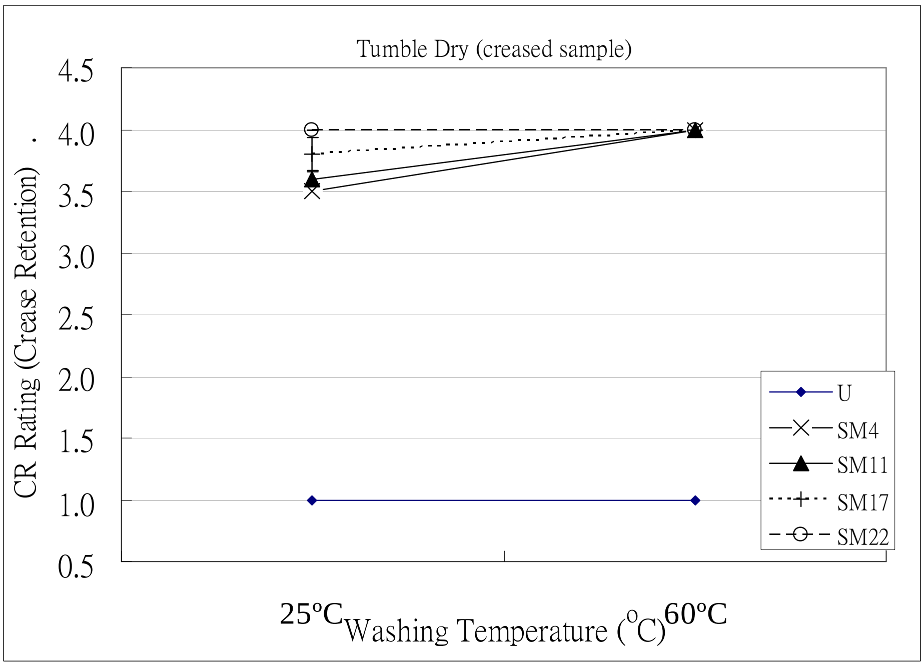

Figure 4.12 Effect of washing temperature of crease retention (tumble dry)

4.5.3.3 Effect of Drying Method

Figure 4.13 shows the effect of drying method on fabric shape memory effect of flat appearance after the samples were washed at 25°C and 60°C respectively. As can be seen, the SA Rating of the untreated sample was 1.0 using any drying methods since it does not have any fabric shape memory effect. There is no significant difference among drying methods on flat appearance and crease retention at the 0.05 level of significance.

For the treated samples, the SA Ratings of treated samples after using a tumble dry were higher than the SA Ratings of treated samples after using a line dry. It is likely that tumble dry is better than the line dry. According to the statistical analysis, the error bars are very small and the error bars for tumble dry do not overlap the range of SA Ratings within the error bars of line dry. There is 95% confidence that the true value is within this range. The drying method does appear to have a highly significant difference on fabric shape memory effect at the 0.05 level of significance. As the P-value is less than 0.001, there is significant effect at the 0.1% level too. Comparing the results of using a tumble dry with washing at 25°C and 60°C, the treated samples which were washed at 60°C and then dried by a tumble dry have the highest SA Ratings. This means that they have the highest fabric shape memory effect of flat appearance.

For example, SM22 has the highest SA Rating of 4.4 after washing at 60°C and then dried by a tumble dry. These data can be interpreted to mean that the temperature (66°C) of tumble drier can influence the fabric shape memory effect. It is likely that the drying temperature is high enough to allow the free movement of shape memory polymer thus facilitating the recovery of the shape memory fabrics. In addition, higher water temperature can reach the switch temperature of polymers in fabrics for the recovery. This can also explain why the treated samples can have a satisfied recovery even if they were washed at 25°C and dried by tumble drying.

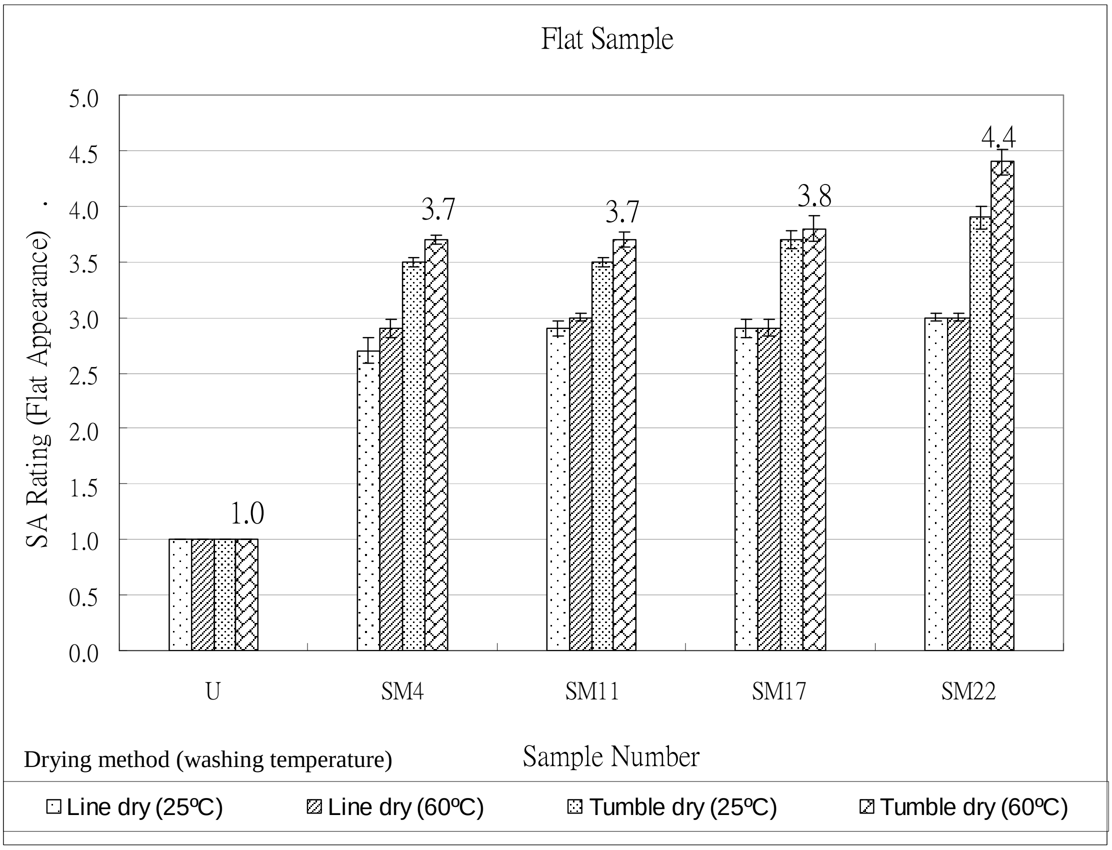

Figure 4.13 Effect of drying method on flat appearance

Figure 4.14 shows the effect of drying method on fabric shape memory effect of crease retention after the samples were washed at 25°C and 60°C respectively. The results were similar to the flat appearance in previous section. It can be seen that the CR Rating of the untreated sample was 1.0 using any drying methods because it does not have any fabric shape memory effect.

The CR Ratings of treated samples after using a tumble dry was higher than the CR Ratings of treated samples after using a line dry. The finding seems to indicate that the tumble dry is the better method to dry the samples and tumble dry can facilitate the fabric shape memory effects. There is a significant difference among drying methods on crease retention at the 5% level statistically. According to the statistical analysis, the error bars for tumble dry do not overlap the range of CR Ratings within the error bars of line dry. Their CR Ratings of samples which were washed at 25°C and then dried by a tumble dry were above 3.5 and the CR Ratings of samples which were washed at 60°C and then dried by a tumble dry were 4.0. The results also suggest that higher washing temperature as at 60°C can stimulate the fabric shape memory effects.

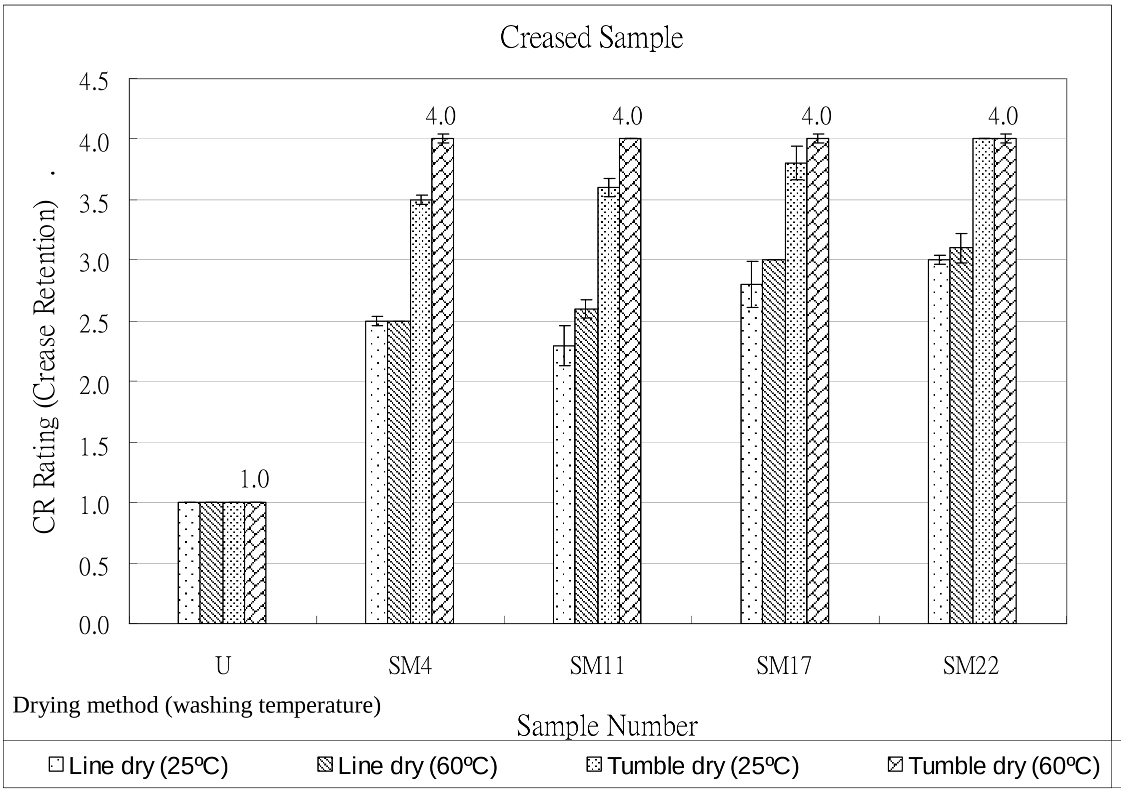

Figure 4.14 Effect of drying method on crease retention

4.5.3.4 Comparison between the Effect of Washing and Water Immersion (Line Dry)

Figure 4.15 shows the comparison between the effect of washing and water immersion at 25°C and 60°C respectively in the recovery stage on the fabric shape memory effect of flat appearance. The SA Rating of untreated sample remained at 1.0 after the samples were washed or immersed in water with a line dry. According to the statistical result, the recovery method does not appear to have an effect on flat appearance at the 5% level. The finding shows that there has no effect of washing and water immersion on flat appearance of the untreated sample.

Regarding the treated samples, the SA Ratings after washing at 25°C or 60°C in the recovery stage were higher than that of samples after immersing in water at 25°C or 60°C in that stage. There is significant difference among recovery methods on flat appearance with a confidence limit of 95% based on the ANOVA result. The findings suggest that the fabric shape memory effect of treated samples is more apparent using the washing machine in the recovery, especially for the comparison between the washing and water immersion at 60°C. The error bars do not overlapped and this shows that they are differ significantly. It seems that washing can influence the fabric shape memory effect as the molecular chains in soft segments have longer time for the recovery due to the longer washing time compared with the immersion time.

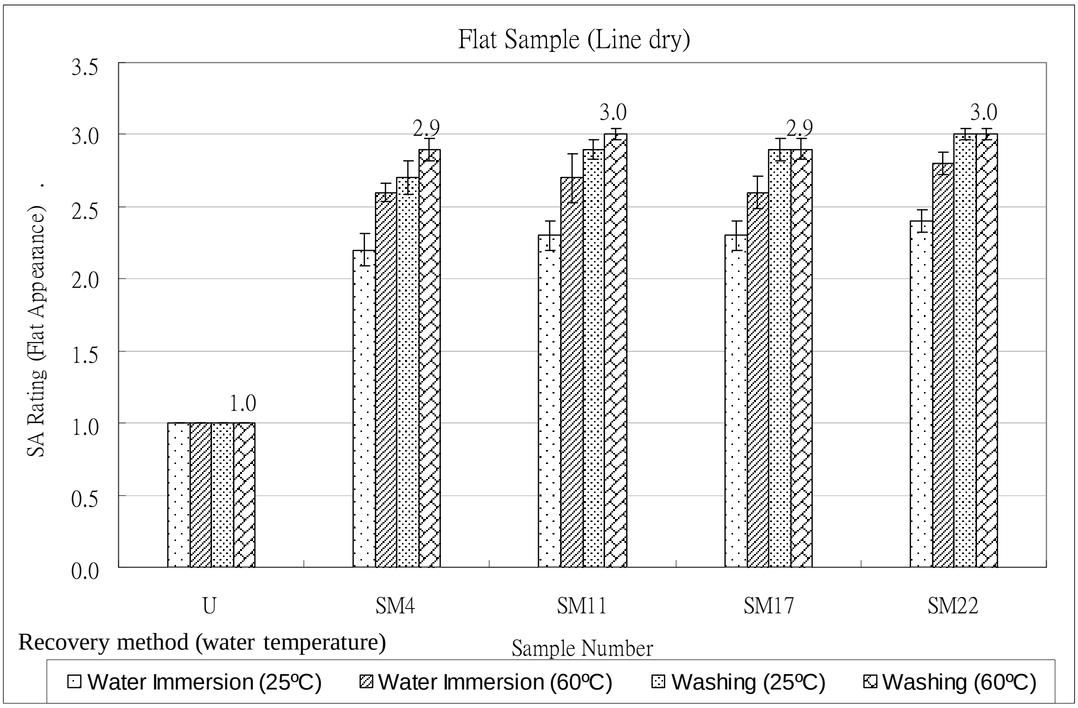

Figure 4.15 Effect of washing and water immersion on flat appearance (line dry)

Figure 4.16 shows the comparison between the effect of washing and water immersion at 25°C and 60°C respectively in the recovery stage on the fabric shape memory effect of crease retention. It can be seen that the CR Rating of untreated sample was 1.0 after the samples were washed or immersed in water with a line dry. The result suggests that no effect between washing and water immersion on fabric crease retention of untreated sample is found.

According to the results, the CR Ratings of treated samples after washing at 25°C in the recovery stage were higher than that of samples after immersing in water at 25°C in that stage. The same results were also obtained if water was at 60°C. Similar to flat samples, the findings indicate that the fabric shape memory effect of treated sample is more apparent using the washing machine. In addition, the effect of recovery method on crease retention is significant based on the statistical analysis.

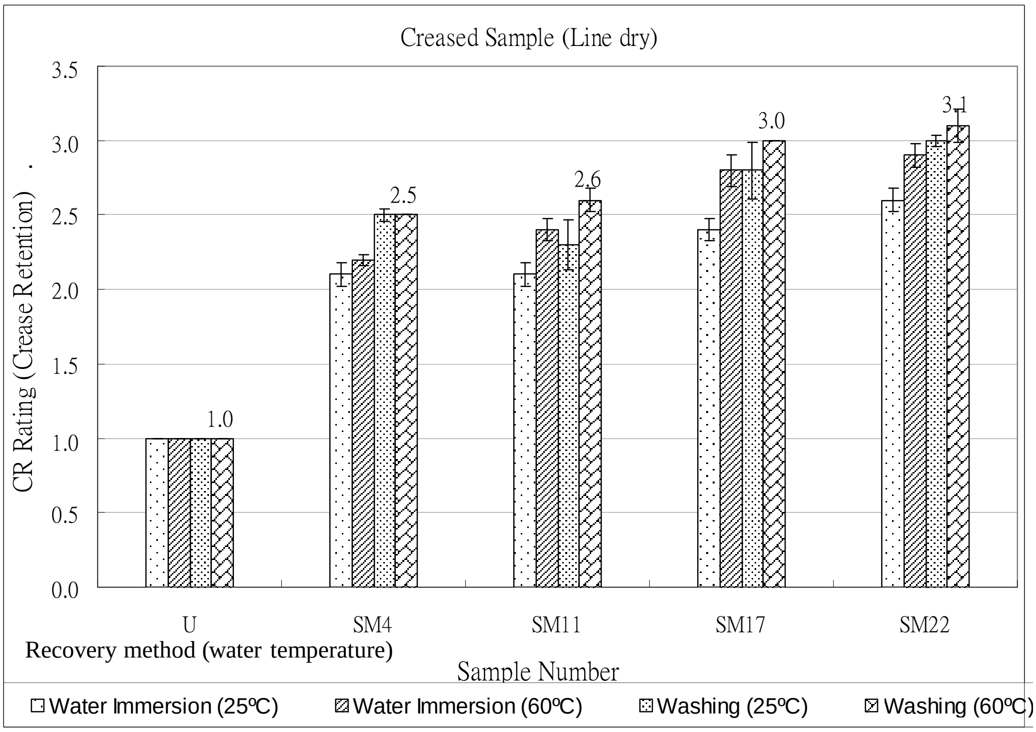

Figure 4.16 Effect of washing and water immersion on crease retention (line dry)

4.6 Conclusions

The subjective evaluation method was modified based on the AATCC Test Method 124 and 88C and used to determine the fabric shape memory effects of flat appearance and crease retention in water effectively. The fabric shape memory effects were tested under various conditions such as water temperature, recovery method and drying method.

It was found that cotton fabric shows a better fabric shape memory effects among cotton, ramie and silk and cotton has the largest potential to treat with shape memory polymers for making shape memory fabrics for this study.

Different shape memory chemicals can make the shape memory fabrics having the wholly different temperature response to flat appearance and crease retention. For the C1 shape memory fabrics, the shape memory effect of flat appearance increases and the crease retention decreases when the water temperature increases to 60°C. Conversely, the fabric shape memory effect of flat appearance decreases and the crease retention increases when the water temperature decreases to 15°C. However, another set of shape memory fabrics (C3 fabric) treated with another set of shape memory chemicals give an opposite result. Their fabric shape memory effect of flat appearance and crease retention increase when they are stimulated by water at the switch temperature as at 60°C. This new set fabrics show the same temperature response to flat appearance and crease retention.

The fabric shape memory effects do not exist in untreated samples as they do not tend to recover their original flat or creased shapes at any water temperatures. Different drying methods and recovery methods such as washing and water immersion cannot stimulate the untreated samples to recover their original shapes. This shows that the untreated samples are not temperature sensitive and they do not have the fabric shape memory effects.

It was discovered that the treated samples are temperature sensitive. Water temperature in the recovery stage can stimulate the fabric shape memory effect of flat appearance and crease retention. The higher temperature as at 60°C which can reach the switch temperature of polymers in treated fabrics in a washing machine and a water tray can stimulate the fabrics to recovery their original shapes.

In terms of the effect of water immersion and washing, the results appeared that the fabric shape memory effects are more apparent if washing is used in the recovery stage.

Other than the recovery condition, the drying method can also influence the shape memory effects. The tumble dry can facilitate the fabric shape memory effects. It is likely that tumble dry is better than the line dry as the temperature of a tumble drier is sufficient to allow the shape memory polymer free movement for the recovery. The result seems to indicate that the optimum condition for the recovery in water is to wash the fabrics at 60°C and dry the fabrics by a tumble dry method.

CHAPTER 5: OBJECTIVE EVALUATION OF FABRIC SHAPE MEMORY EFFECTS IN WATER

5.1 Introduction

This chapter is to investigate the fabric shape memory effects of flat appearance and crease retention in water at a switch temperature of polymers using an objective evaluation method and examine the feasibility of the objective method. In the first section, the Shape Memory Coefficients were calculated using Original Angles and Shape Memory Angles to determine the fabric shape memory effects. The wrinkle recovery angles of samples were found to compare the Shape Memory Angles of fabrics. The objective results were also compared with the subjective ratings. In the next section, the improved equations from Shape Memory Coefficients were used to give a better presentation to fabric shape memory effects and overcome the limitation of Shape Memory Coefficients. Finally, the chapter moves on to the conclusions.

5.2 Sample Details

A woven fabric (100% cotton, 68 X 68, 30s x 30s, fabric code: C1) was selected in this test. For the objective method, one sample was untreated for comparison and twenty-four samples were treated with different shape memory polymers, Nos. 9, 11, 35-58, respectively. Each set of sample contained flat samples and creased samples and the size of samples was 40mm X 15 mm. Twelve readings for each flat sample and creased sample were averaged. The details of the sample preparation are described in Section 3.4.2. In this experiment, the subjective ratings of samples which were immersed in water at 60°C were also found to compare with the objective results. The subjective evaluation method in water is showed in Section 3.4.1.

5.3 Experimental Design

The details of the objective evaluation method are described in Section 3.4.2.

5.4 Evaluation using Shape Memory Coefficients

Based on the objective evaluation method, the Original Angles (Of for flat samples, Oc for creased samples) and Shape Memory Angles (Mf for flat samples, Mc for creased samples) of samples were measured and the equations of Shape Memory Coefficients (Sf% for flat samples, Sc% for creased samples) were used to determine the fabric shape memory effects of flat appearance and crease retention in water.

The details of the calculation are described in Section 3.4.2. In this experiment, the wrinkle recovery angles of samples were also found in order to compare the Shape Memory Angles of samples. The winkle recovery angles were measured following the AATCC Test Method 66 but twelve readings for each sample were averaged.

5.4.1 Results and Discussions

The wrinkle recovery angles (WRA), Original Angles (Of and Oc) and Shape Memory Angles (Mf and Mc) for flat samples and creased samples were measured. The standard deviation and the coefficient of variation (CV) were found and shown in Appendix C. The CV and % Error of almost all measured angles are below 5%. The Shape Memory Coefficient of flat samples (Sf%) and Shape Memory Coefficient of creased samples (Sc%) were calculated using the equations as described in Section 3.4.2.5 to determine the fabric shape memory effects. The subjective ratings were also evaluated according to the subjective evaluation method for the comparison. All calculated data and the ratings are summarized in Appendix C1. The other testing details are listed in Appendix C2.

5.4.1.1 Comparison between Wrinkle Recovery Angle (WRA) and Shape Memory Angle of Flat Samples (Mf)

The comparison between wrinkle recovery angle and Shape Memory Angle (Mf) of flat samples is shown in Figure 5.1. The wrinkle recovery angles were measured using AATCC Test Method 66 and the Shape Memory Angles were measured following the new procedures of objective method. As can be seen, the sample with a large wrinkle recovery angle might not have a large Shape Memory Angle. Based on the regression analysis, the correlation coefficient (r) was 0.01. There is not sufficient evidence to conclude that there is a linear correlation between the wrinkle recovery angles and Shape Memory Angles. The findings indicate that there has no relationship between these two sets of data. Only samples 43 and 44 have both large wrinkle recovery angles of 99° and 101° respectively and then large Shape Memory Angles (Mf) of 170° and 178° at the same time.

According to the figure, the Mf was normally greater than wrinkle recovery angles. This means that the fabric samples can have larger recovery when they were put in hot water as the Mf was measured after the recovery stage. Comparing the Mf between the untreated sample and treated samples, the Mf of most treated samples were larger than the Mf of the untreated sample (152°). Based on the statistical analysis, the coefficient of variation of wrinkle recovery angle and Shape Memory Angle (Mf) are below 5 %. This suggests that the treated samples have a larger recovering ability to recover their original flat shape compared with the untreated one.

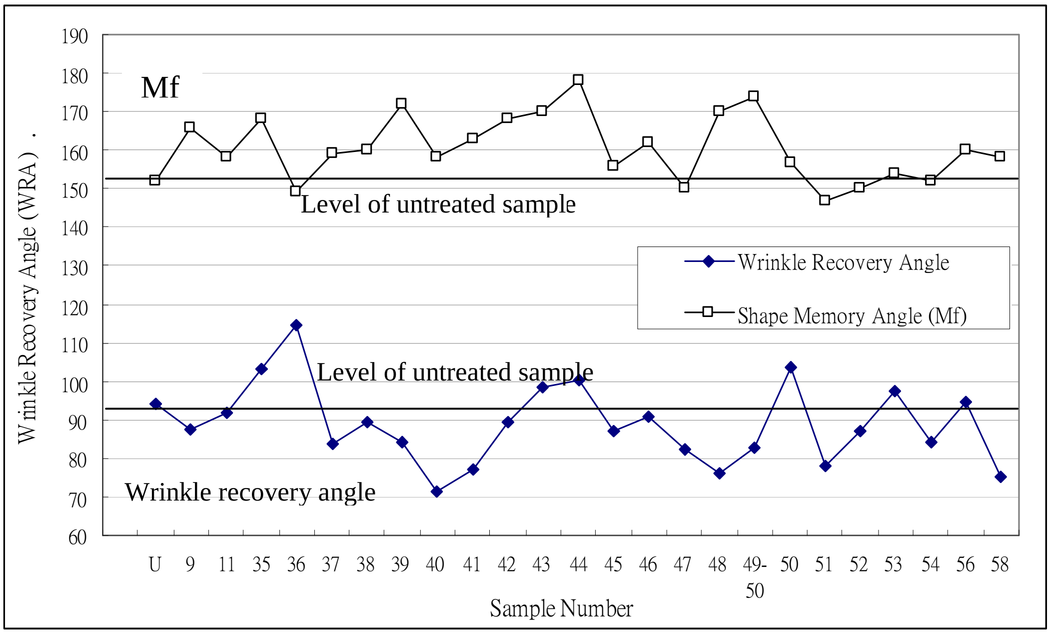

Figure 5.1 Comparison between wrinkle recovery angle and Shape Memory Angle (Mf)

5.4.1.2 Relationship between Shape Memory Angle and Subjective Rating

Figure 5.2 and Figure 5.3 gives the relationship between the Shape Memory Angle and the subjective rating of flat samples and creased samples respectively. Based on the regression analysis, the correlation coefficient (r) of flat samples and creased samples were 0.93 and 0.89 respectively. We can conclude that there is a strong linear relationship between Mf and SA Rating for flat samples and a significant linear correlation between Mc and CR Rating for creased samples at the 0.05 level of significance.

Nevertheless, Shape Memory Angles are not the best indication of the fabric shape memory effect. This is because the higher is the Shape Memory Angle (Mf), the greater is the SA Rating for flat fabrics; but the higher is the Shape Memory Angle (Mc), the smaller is the CR Rating for creased fabrics. In order to determine the fabric shape memory effects in both cases effectively, the Shape Memory Coefficients were developed to determine the fabric shape memory effects.

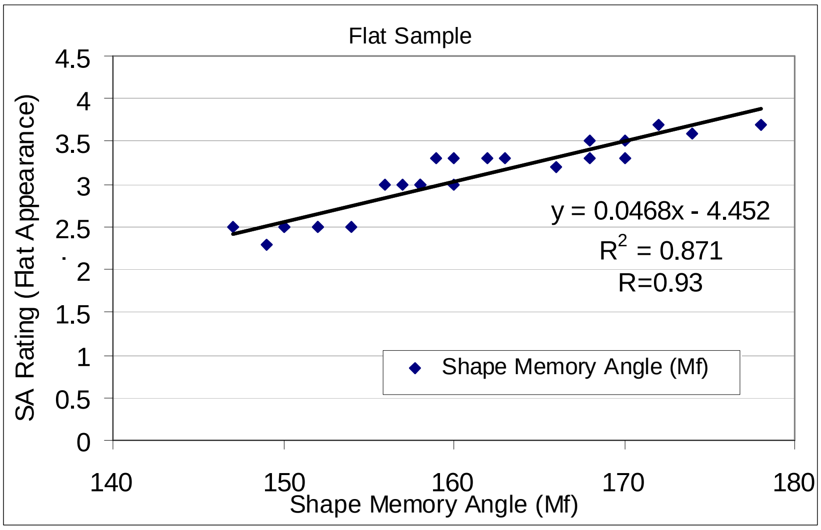

Figure 5.2 Relationship between Shape Memory Angle (Mf) and SA Rating

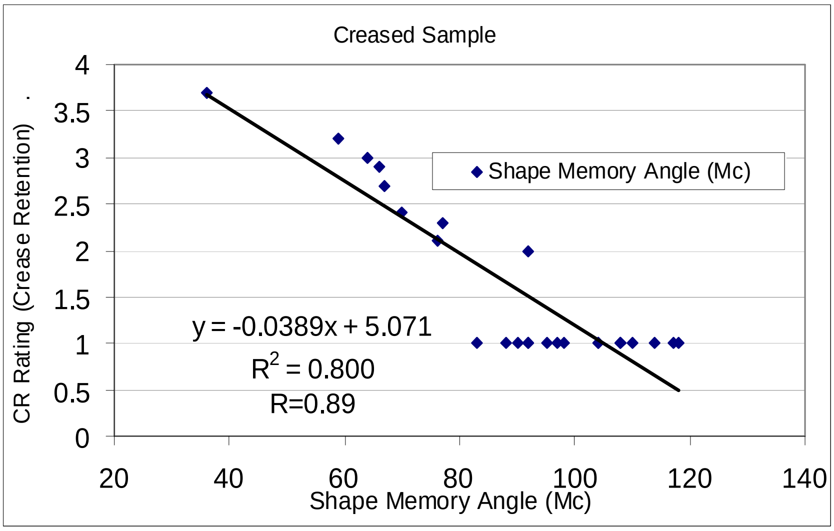

Figure 5.3 Relationship between Shape Memory Angle (Mc) and CR Rating

5.4.1.3 Relationship between Shape Memory Angle and Shape Memory Coefficient

Figure 5.4 and Figure 5.5 shows the relationship between the Shape Memory Angle and Shape Memory Coefficient for flat samples and creased samples respectively. It can be seen that the correlation coefficient (r) of flat samples was 0.99 and there is a strong linear relationship between Mf and Sf%. For the creased samples, the correlation coefficient was 0.96 with a confidence level of 95% and there is also a strong linear relationship between Mc and Sc%. The results indicate that Shape Memory Coefficients have a very strong linear relationship with Shape Memory Angles. As discussed before, the Shape Memory Angles (Mf and Mc) was not the most suitable to indicate the fabric shape memory effects. Therefore, the Shape Memory Coefficients can be used to determine the fabric shape memory effects.

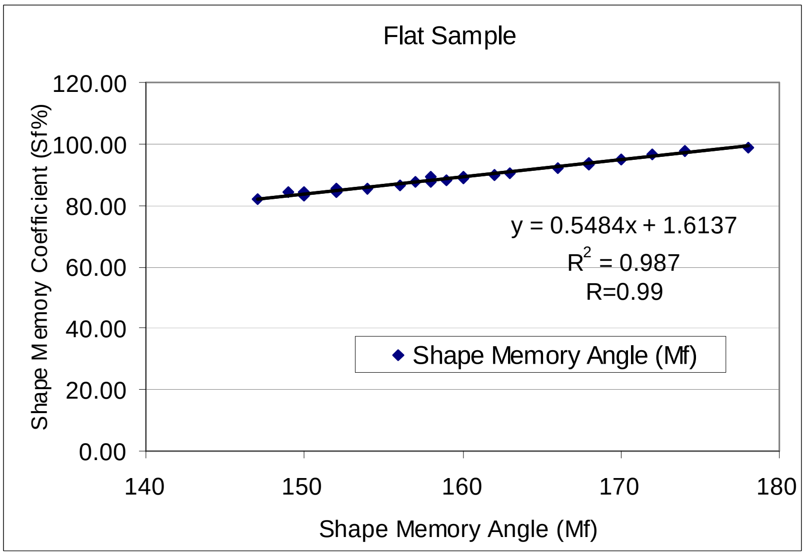

Figure 5.4 Relationship between Shape Memory Angle (Mf) and Shape Memory Coefficient (Sf%)

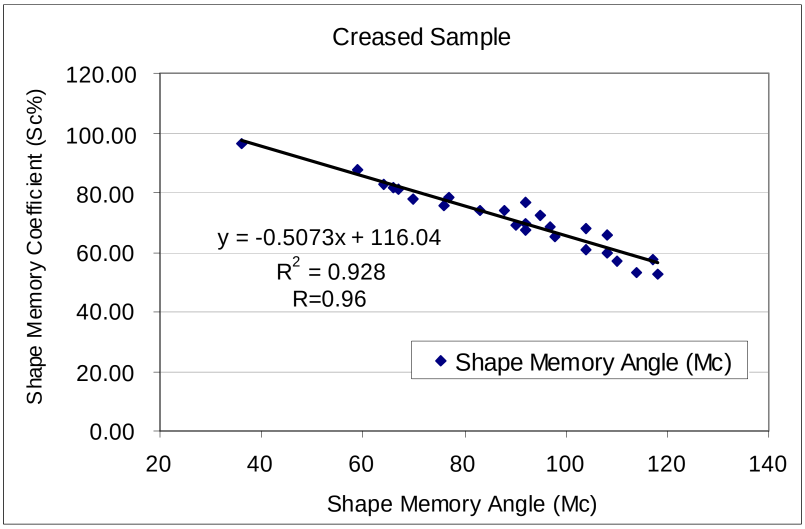

Figure 5.5 Relationship between Shape Memory Angle (Mc) and Shape Memory Coefficient (Sc%)

5.4.1.4 Relationship between Shape Memory Coefficient and Subjective Rating

Figure 5.6 and Figure 5.7 present the relationship between the Shape Memory Coefficients (Sf% and Sc%) and the subjective ratings of flat fabrics and creased fabrics respectively. Based on the correlation analysis, the correlation coefficient (r) of flat samples and creased samples were 0.92 and 0.86 respectively. It can conclude that there is a strong linear relationship between Sf% and SA Rating for flat samples and also a strong linear relationship between Sc% and CR Rating for creased samples at the 0.05 level of significance. The finding implies that the Shape Memory Coefficients can present the fabric shape memory effects effectively. The results suggest that the higher is the Shape Memory Coefficients, the higher the fabric shape memory effect of flat appearance and crease retention they will have.

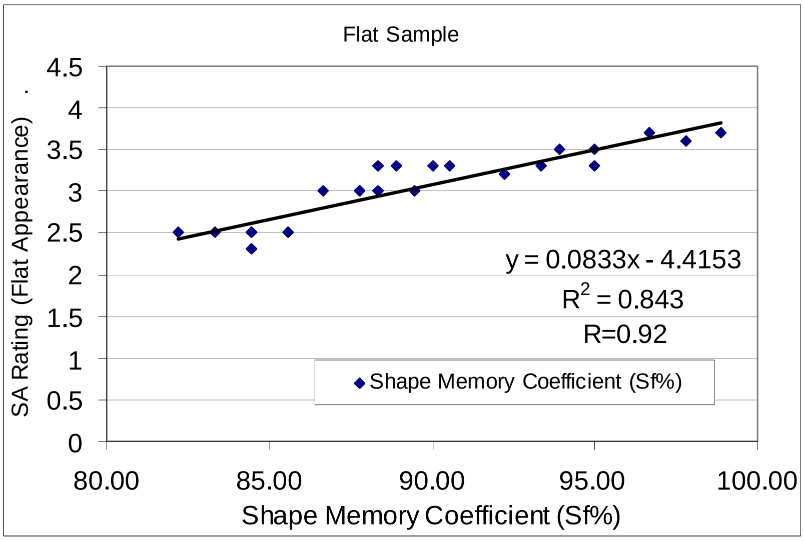

Figure 5.6 Relationship between Shape Memory Coefficient (Sf%) and SA Rating (flat appearance)

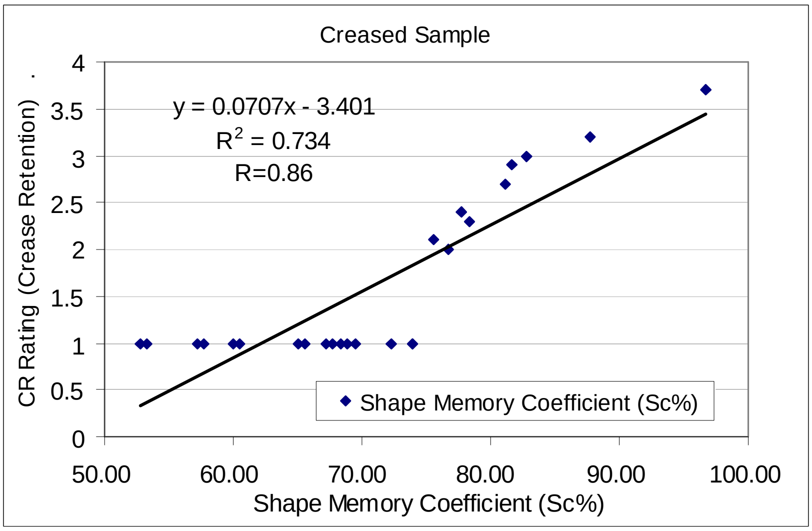

Figure 5.7 **Relationship between Shape Memory Coefficient (Sc%) and CR Rating (crease retention)**

5.4.1.5 Determination of Fabric Shape Memory Effects using Shape Memory Coefficients

The fabric shape memory effects determined using shape memory coefficients are given in Figure 5.8. For both flat samples and creased samples, most treated samples have a higher Shape Memory Coefficients compared with untreated samples. The findings appear that the fabric shape memory effects exist in the treated samples. The treated flat samples tend to recover their original flat shapes and the treated creased samples tend to recover their original creased shapes. As can be seen, not all of treated samples can possess the high fabric shape memory effects of flat appearance and crease retention at the same time.

It was found that only sample 35 has Sf% = 93.89% and Sc%=96.67%, respectively. These values were greater than those of the untreated fabrics of Sf% = 84.44% and Sc%=67.22%. This shows that the sample 35 has the better shape memory effects of flat appearance and crease retention at the same time than other shape memory samples comparatively. For other treated samples, it can be seen that the sample 39, 44 and 49-50 have higher Sf% while sample 49-50, 50, 51 and 52 have higher Sc%. According to the statistical analysis, the coefficient of variations of the parameters such as Of, Oc, Mf and Mc in the equations of Sf% and Sc% are very small and most of them are below 5%.

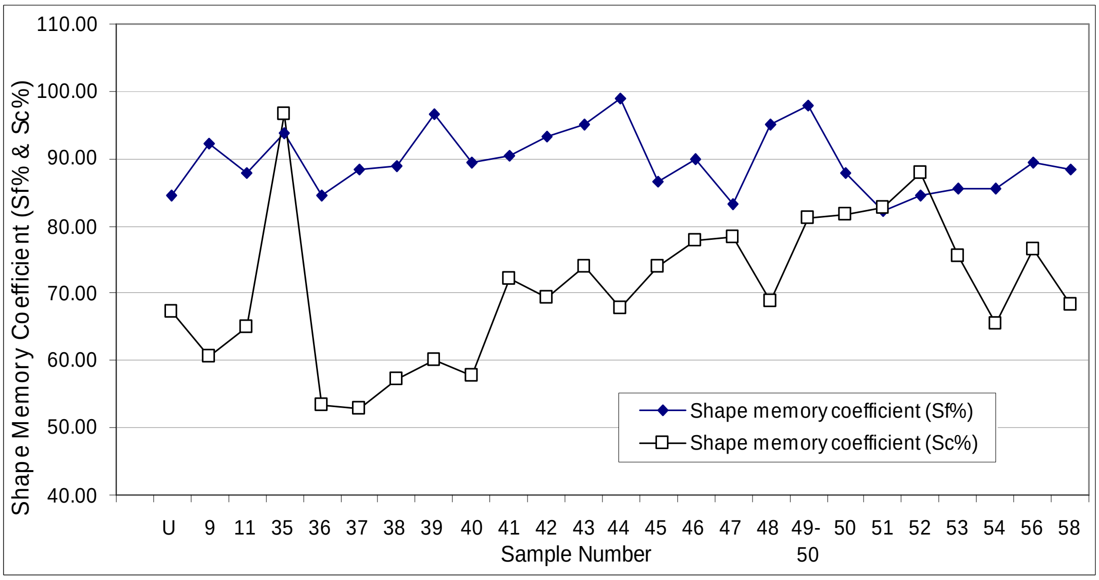

Figure 5.8 Shape Memory Coefficients (Sf% and Sc%) of flat and creased samples

5.5 Evaluation using Improved Equations

As mentioned in Chapter 3, the Shape Memory Coefficient of flat sample (Sf%) was simplified and Shape Memory Coefficient of creased sample (Sc%) was improved to overcome its limitation. The Flat Recovery % (FRec%) and Crease Recovery % (CRec%) were established to provide the better representation of fabric shape memory effects. The limitation and the improved equations are described in Section 3.4.2. The experimental results including the Original Angles and Shape Memory Angles in the previous section 5.4.1 were used to calculate the new values using improved equations to determine fabric shape memory effects. So, the coefficient of variations of the parameters such as Of, Oc, Mf and Mc in the equations of FRec% and CRec% are very small and most of them are below 5%.

5.5.1 Results and Discussions

The detailed test results are listed in Appendix C3.

5.5.1.1 Difference between Flat Recovery % (FRec%) and Shape Memory Coefficient (Sf%)

The equation of Shape Memory Coefficient (Sf%) was simplified to the Flat Recovery % (FRec%). As the calculated value of FRec% is the almost same as that of Sf%, this implies that the FRec% can represent the fabric shape memory effect of flat appearance. This finding implies that the higher is the FRec%, the larger shape memory effect of flat samples will have and they look more flatter and smoother.

5.5.1.2 Overcome Limitation of Shape Memory Coefficient (Sc%) using Crease Recovery % (CRec%)

As mentioned in Section 3.4.2, the Shape Memory Coefficient (Sc%) has a limitation and it was not the best parameter to represent the fabric shape memory effects. Therefore, the Crease Recovery % (CRec%) was established to overcome the limitation. Three virtual samples named Test 1, Test 2 and Test 3 were created to investigate the limitation of Sc%, as given in Table 5.1. The values of Original Angle (Oc) and Shape Memory Angle (Mc) of these three virtual samples were not real experimental values and the difference between Oc and Mc of those three samples was 5°. Figure 5.9 shows the comparison of fabric shape memory effects using CRec% and Sc%.

It was found that the results of Shape Memory Coefficient (Sc%) of sample Test 1, 2 and 3 were the same which was 97.22%. According to the meaning of Sc%, this large value means that the fabric shape memory effect of crease retention is very satisfactory and it can have a sharp crease on fabric after stimulating in hot water. However, in the actual case, the crease retention of these samples is not the same. As compared with the CRec% among three virtual samples, the CRec% of Test 1, 2 and 3 were 96.67%, 83.33% and 50.00% respectively. From this finding, it is clear that the CRec% can represent the actual recovery ability of crease retention of fabrics and the explanations are described below.

In the real case, Test 1 has the highest recovery ability to a creased shape. It is because its Oc is small (30°) which means that it can keep its original crease well before any deformation and recovery. After immersing in hot water in the recovery stage, the Mc was still very small (35°) which was as small as the Oc. This shows that the recovery ability of Test 1 is quite large. Both CRec% and Sc% have a high value to represent its high fabric shape memory effect.

Compared with Test 3, it was only recovered its original creased shape in a small extent. It was because the Oc of Test 3 was very large (170°) which means that it cannot keep its original crease well after the finishing process. After immersing in hot water, the Mc was still very large (175°) which was similar to the Oc. As the Oc was very large and the original creased shape liked a flat shape, it cannot be concluded that Test 3 has a high fabric shape memory effect even the difference between Mc and Oc is also 5°. Compared with the results between CRec% and Sc% for sample Test 3, only CRec% can represent the actual recovery ability of fabrics but Sc% cannot represent it correctly. The CRec% of Test 3 was 50% only but the Sc% of Test 3 was still very high (97.22%) which does not represent the fabric shape memory effect correctly.

It can be seen that the CRec% of Test 2 was smaller than the Test 1 and this shows that the fabric shape memory effect was not so satisfactory compared with that of Test 1.

According to the above analysis, the Crease Recovery % (CRec%) can overcome the limitation of Shape Memory Coefficient (Sc%) and gives a better representation of fabric shape memory effect of crease retention.

Table 5.1 Virtual data for the comparison between CRec% and Sc%

Virtual sample	Original Angle (Oc)	Shape Memory Angle (Mc)	Crease Recovery % (CRec%)	Shape Memory Coefficient (Sc%)
Test1	30	35	96.67	97.22
Test2	150	155	83.33	97.22
Test3	170	175	50.00	97.22

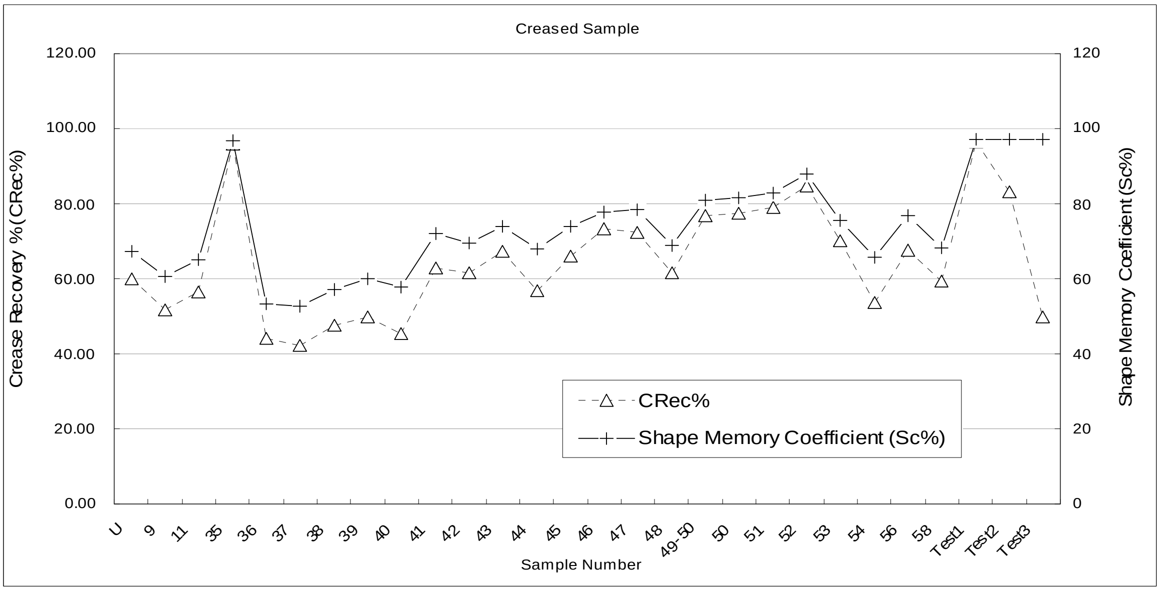

Figure 5.9 Comparison of fabric shape memory performance using CRec% and Sc%

5.5.1.3 Comparison between Flat Recovery % and SA Rating

Figure 5.10 shows the comparison between Flat Recovery % (FRec%) and SA Rating of flat samples. It can be seen that the higher is FRec%, the higher SA Rating will have. It was also found that the correlation coefficient between the FRec% and SA Rating was 0.920 which is higher than the correlation coefficient (0.917) between Sf% and SA Rating slightly. We can conclude that there is a strong linear relationship between FRec% and SA Rating. This means that the FRec% can represent the fabric shape memory effect of flat appearance effectively. This also implies that the flat samples tend to recover their original flat shapes while the FRec% is higher.

According to the figure, the FRec% of the untreated sample was 84.44% and the SA Rating was 2.5. The FRec% of most treated samples was above 84.44% and they also have higher SA Ratings compared with the untreated sample. Sample 44 has the highest FRec% of 98.89% and this suggests that it has the largest fabric shape memory effect of flat appearance. The finding shows that the treated samples have fabric shape memory effects after stimulating by hot water and the FRec% presents the recovering ability of samples to its original flat shape effectively.

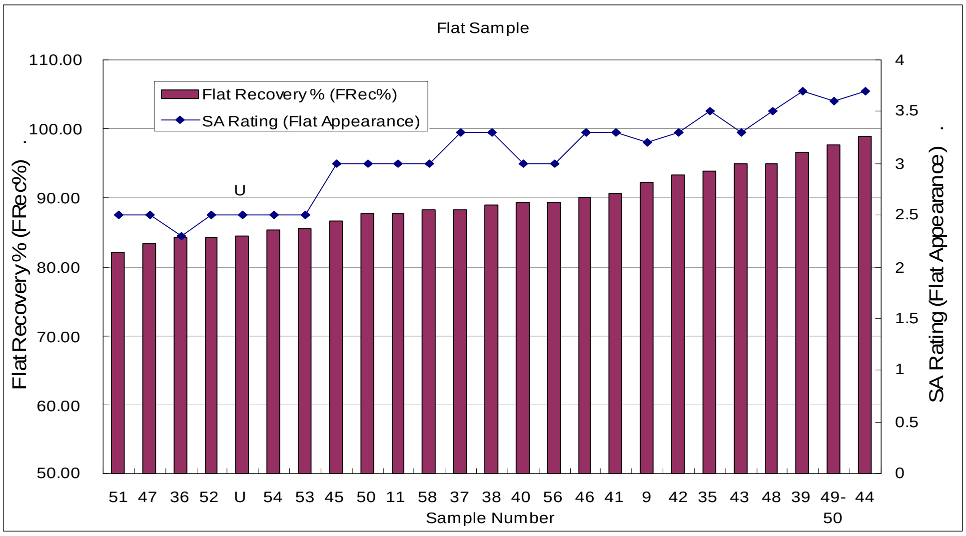

Figure 5.10 Comparison between Flat Recovery % (FRec%) and SA Rating

5.5.1.4 Comparison between Crease Recovery % and CR Rating

Figure 5.11 shows the comparison between Crease Recovery % (CRec%) and CR Rating of creased samples. If the Crease Recovery % (CRec%) was higher, the CR Rating was also higher generally. Based on the regression analysis, the correlation coefficient between them was 0.879 which was higher than the correlation coefficient (0.857) between Sc% and CR Rating.

It can be concluded that there is a very strong linear relationship between CRec% and CR Rating even stronger than the relationship between Sc% and CR Rating. This implies that CRec% can represent the fabric shape memory effect of crease retention effectively. When the CRec% was higher, the creased samples tended to recover their original creased shapes and they have the higher fabric shape memory effect of crease retention.

Referring to the figure, the CRec% of the untreated sample was 59.86% and the CR Rating was 1.0. The CRec% of a quarter of samples was above 70% and they have the CR Ratings over 2.5. The findings show that some treated samples have fabric shape memory effect and some treated samples do not have this effect after stimulating by hot water. Sample 35 has the highest CRec% of 96.00% and it is over 36% recovery compared with the untreated sample. This shows that it has the largest fabric shape memory effect of crease retention.

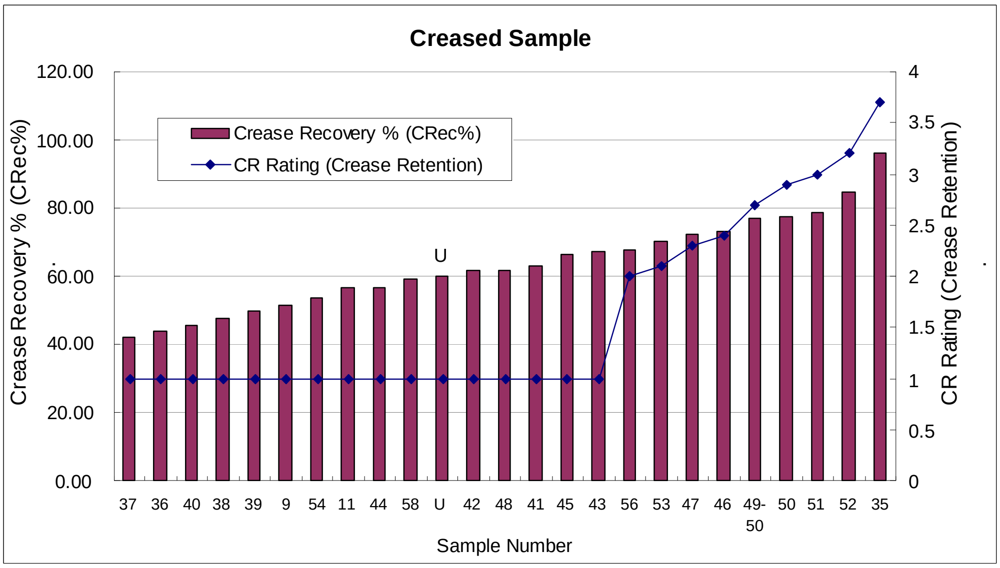

Figure 5.11 Comparison between Crease Recovery % (CRec%) and CR Rating

5.6 Conclusions

An objective evaluation method was designed to determine the fabric shape memory effects of flat appearance and crease retention in water. The new experimental procedures and the new equations were developed to investigate the fabric shape memory effects effectively. The Original Angles (Of and Oc) and Shape Memory Angles (Mf and Mc) were measured and used in the equation of Shape Memory Coefficients (Sf% and Sc%) for flat and creased samples respectively. The Shape Memory Coefficient of flat samples (Sf%) was simplified to Flat Recovery % (FRec%) to evaluate the fabric shape memory effect of flat appearance. Moreover, the Shape Memory Coefficient of creased samples (Sc%) was improved to Crease Recovery % (CRec%) to evaluate the fabric shape memory effect of crease retention more accurately and the limitation of Sc% was overcome.

In terms of fabric angles, it was found that there is no relationship between Shape Memory Angles (Mf and Mc) and wrinkle recovery angles as their correlation coefficient is 0.01 only. It can be concluded that a treated sample with a good wrinkle recovery angle may not have a good Shape Memory Angle at the same time. The results also suggest that treated samples have a larger recovering ability to recover their original flat shape compared with the untreated one after immersing in hot water.

There has a strong relationship between the Shape Memory Angles and the subjective ratings for both flat and creased samples. Nevertheless, Shape Memory Angles are not the best way of indicating the fabric shape memory effects. It is because larger Shape Memory Angles does not mean that both of the SA Rating and CR Rating can have higher values.

It was explored that the Shape Memory Coefficients (Sf% and Sc%) is better to represent the fabric shape memory effects compared with the Shape Memory Angles. A strong linear relationship between the Shape Memory Coefficients (Sf% and Sc%) and subjective ratings was found in both flat and creased samples respectively based on the regression analysis. Higher Shape Memory Coefficients represent higher fabric shape memory effects. The findings revealed that not all of treated samples can possess the high fabric shape memory effects of flat appearance and crease retention at the same time.

With regard to the improved equations, the Flat Recovery % (FRec%) can replace the Shape Memory Coefficient (Sf%) of flat samples to evaluate the flat appearance as the equation of Sf% is simplified only. Regarding creased samples, the limitation of the

Shape Memory Coefficient (Sc%) was revealed and it cannot represent the actual shape memory performance of the crease recovery of samples. As a result, the Crease Recovery % (CRec%) was developed and it can overcome the limitation of Sc% to determine the crease retention of samples in an effective way.

On the other hand, a strong linear relationship was found between the Recovery % and subjective ratings for both flat samples and creased samples respectively. These relationships are slightly stronger than the relationship between the Shape Memory Coefficients and subjective ratings. It can be concluded that the FRec% and CRec% can determine the fabric shape memory effects more effectively. Higher FRec% and CRec% represent higher fabric shape memory effect of flat appearance and crease retention respectively.

In shorts, the equations of Flat Recovery % and Crease Recovery % were established successfully. They can give a better representation of fabric shape memory effects of flat appearance and crease retention.

CHAPTER 6: EVALUATION OF FABRIC SHAPE MEMORY EFFECTS IN AIR

6.1 Introduction

This chapter is to examine the effect of air temperature and relative humidity on the fabric shape memory effects of flat appearance and crease retention in air. The fabric shape memory effects are evaluated using both subjective evaluation method and objective evaluation method.

This chapter is divided into two parts. In the first part, the subjective method is used to evaluate fabrics for determining the fabric shape memory effects. In the second part, the objective method together with the new equations is used to determine the fabric shape memory effect objectively. The effect of air temperature and relative humidity on fabric shape memory effects is explored in each part. After that, the relationship between the objective result and subjective result is investigated. Then, the chapter turns to the conclusions.

6.2 Sample Details

The woven fabric (100% Cotton Twill, 108 X 58, 20s X 20s, fabric code: C3) was selected in this experiment. One sample was untreated (U) and three samples with sample number A10, A13 and A20 which were treated with similar shape memory polymers with no. 10, 13 and 20 respectively were presented in this study. The sample details for the subjective evaluation and objective evaluation are described in Section 3.4.3 and Section 3.4.4 respectively. They were conditioned in the standard condition (21 ± 1°C and 65 ± 2% RH) for 24 hours before testing.

6.3 Experimental Parameters

The details of subjective and objective evaluation method are stated in Section 3.4.3 and Section 3.4.4 respectively. In the recovery stage, samples were recovered in a Conditioning Chamber and they were tested in air at 25°C and 60°C with various relative humidities (35%, 65% and 90%) respectively. The recovering condition in the Conditioning Chamber is given in Table 6.1.

Table 6.1 Conditions of hot air testing

Sample Number	Air Temperature (°C)	Relative Humidity (%RH)
U (untreated) A10 A13 A20	25	35
		65
		90
	60	35
		65
		90

6.4 Subjective Evaluation

The aim of this experiment is to evaluate the effect of air at various temperatures and relative humidities on the fabric shape memory effects of flat appearance and crease retention in air by using subjective method.

6.4.1 Results and Discussions

The detailed test results are listed in Appendix D1.

6.4.1.1 Effect of Air Temperature with Specific Relative Humidity on Flat Appearance

Figure 6.1 shows the effect of air temperature with the relative humidity of 35% RH, 65% RH and 90% RH respectively on fabric shape memory effect of flat appearance. It was found that the SA Ratings of untreated samples were 1.0 or around 1.0 when the samples were put in air at 25 ºC or 60 º C with 35% RH, 65% RH and 90% RH respectively. The finding indicates that air temperature does not stimulate the shape recovery of untreated samples in these conditions. This implies that the fabric shape memory effect does not exist in untreated samples and wrinkles can be seen on untreated samples obviously.

For the treated samples, the SA Ratings of samples were higher if they were recovered at high air temperature as at 60 ºC compared to that at low air temperature as at 25ºC. There is significant effect of air temperature on the flat appearance of treated samples according to the statistical analysis. When the air temperature was 60°C, the SA Ratings of treated samples were around 2.0 at 35% RH, 3.0 at 65% RH and 3.5 at 90% RH. The latter two SA Ratings seem to be satisfactory.

The results suggest that the treated samples can be stimulated by hot air for the recovery and the fabric shape memory effect of flat appearance exists in treated samples. The reason for the sample recovering at high temperature as at 60 ºC is that the high temperature can reach the switch temperature of shape memory polymers in fabrics. Therefore, the soft segment crystals in polymers will melt and the molecular chains of the soft segments can move freely and quickly for the recovery. Furthermore, high temperature can increase the movement of water molecules in air. Water molecules are attracted to the numerous hydroxyl groups of cotton and break the hydrogen bonding between molecular chains in cotton. Therefore, the cotton fabrics become softer ad less rigid more easily at high air temperature as at 60°C compared with the fabrics at low air temperature as at 25°C.

For the treated samples in air at 25°C with the specific relative humidity, they also have the SA Ratings above 1.0. The finding shows that the treated samples in air at 25°C have the recovering ability to their original flat shapes. However, the air temperature cannot reach the switch temperature of polymer in fabrics. Therefore, these samples should not tend to recover their original shape. As a result, it may be explained that the fabric recovery of these samples may be affected by other factors such as relative humidity.

According to the statistical analysis, the error bars are very small and the error bars for treated samples do not overlap the range of SA Ratings within the error bar of untreated samples. There is 95% confidence that the true value is within this range and this shows that the value of untreated and treated samples are differ significantly.

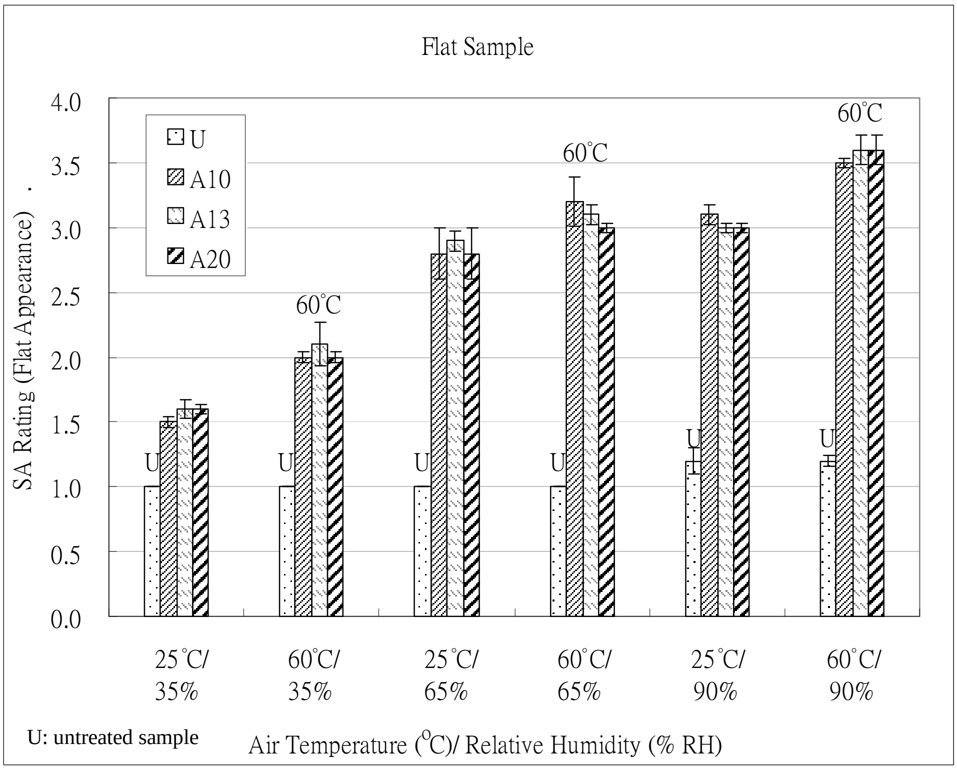

Figure 6.1 Effect of air temperature with specific relative humidity on flat appearance (subjective evaluation)

6.4.1.2 Effect of Air Temperature with Specific Relative Humidity on Crease Retention

Figure 6.2 shows the effect of air temperature with the relative humidity of 35% RH, 65% RH and 90% RH respectively on fabric shape memory effect of crease retention. When the untreated samples were in air at 25 ºC or 60 º C with 35% RH, 65% RH and 90% RH respectively, the CR Rating was 1.0 only. The result shows that the untreated samples cannot be stimulated by air at various temperatures even in hot air. This implies that the untreated samples do not have the fabric shape memory effect of crease retention.

With regard to the treated samples, it was discovered that the CR Ratings of samples were higher when the samples were recovered at high air temperature as at 60 ºC compared to that at low air temperature as at 25ºC. The response to temperature of treated samples on crease retention was similar to that on flat appearance. There is also significant effect among temperatures at the 0.05 level of significance.

When the air temperature was 60°C, the CR Ratings of treated samples were around 3.5 in 35% RH, 3.2 in 65% RH and 1.5 in 90% RH. It is revealed that the treated samples can be stimulated by hot air for recovering their original creased shapes and the fabric shape memory effect exists in creased samples. Their responses to the temperature change of creased samples were explained previously as flat samples.

Based on the statistical analysis, the error bars for treated samples do not overlap the range of CR Ratings within the error bars of untreated samples. There is 95% confidence that the true value is within this range and this indicates that the value of untreated and treated samples are differ significantly.

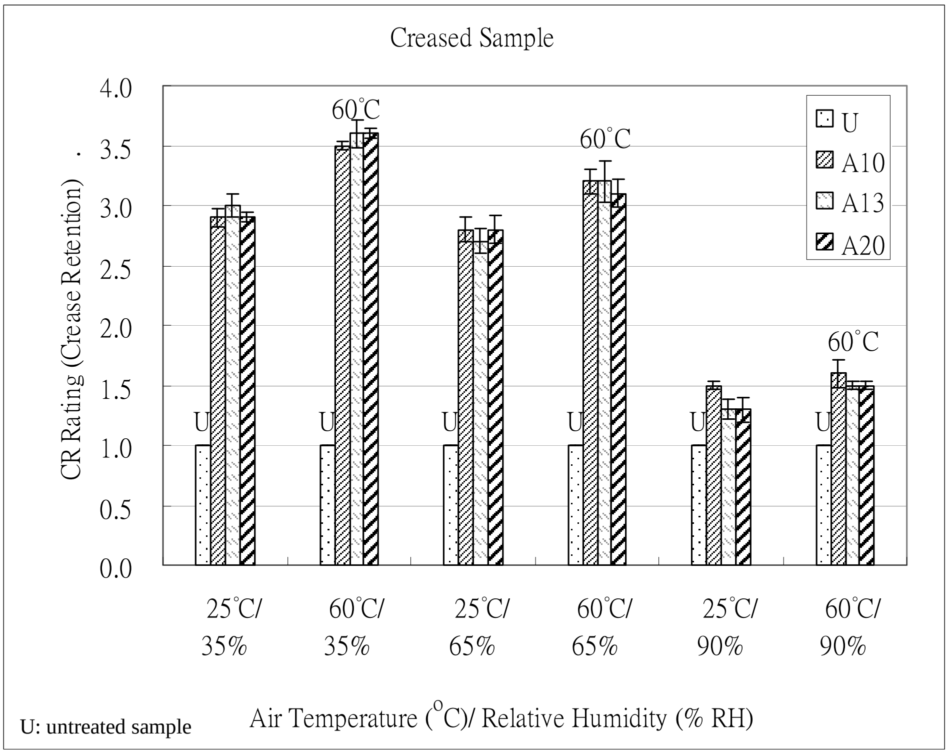

Figure 6.2 Effect of air temperature with specific relative humidity on crease retention (subjective evaluation)

6.4.1.3 Effect of Relative Humidity at Specific Air Temperature on Flat Appearance

The effect of relative humidity at specific air temperature on the fabric shape memory effect of flat appearance is given in Figure 6.3. As can be seen, the SA Ratings of untreated samples were around 1.0 when they were in the air condition at 25 °C or 60 °C with different relative humidities. The finding discovers that relative humidity only affects the fabric recovery of untreated samples slightly.

For treated samples in air at 25 °C or 60 °C, the SA Ratings of samples were higher if the relative humidity was higher. In addition, there is significant effect among relative humidities on treated samples statistically. The findings indicate that the relative humidity can facilitate the fabric shape memory effect of flat appearance.

The probably explanation is that water molecules in air can penetrate into the cellulose network of cotton. They will break the hydrogen bonding between the cellulose molecular chains by reacting with the hydroxyl group of cellulose molecules. Water molecules tend to force the molecules of cellulose apart, reducing the forces that hold the cellulose molecules together. Then, the mass of cellulose is softened and the cotton samples become less rigid. The fabric weight increases and this make the flat sample tend to be more flattening due to the gravity on fabrics. Therefore, the shape memory polymers in fabrics can recover their original flat shape more easily as cotton fabrics become soften. Furthermore, the higher relative humidity may increase the conductivity of heat on fabric. As a result, the fabric shape memory effects of flat appearance can be stimulated easily when the relative humidity is higher.

The treated samples have the highest fabric shape memory effect of flat appearance when they were in the air condition at 60 ℃ and 90% RH compared with the others. The results show that this condition may be the optimum condition for the fabric recovery of flat appearance in air.

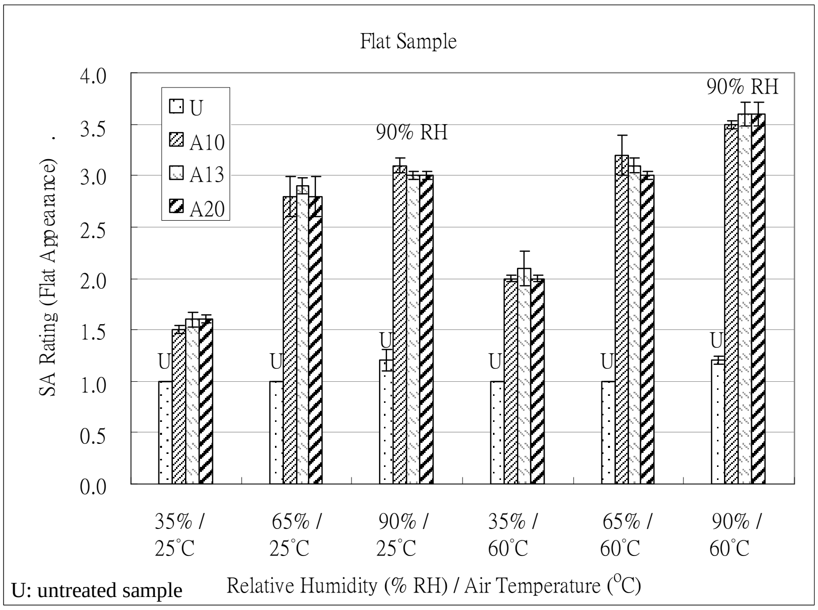

Figure 6.3 Effect of relative humidity at specific air temperature on flat appearance (subjective evaluation)

6.4.1.4 Effect of Relative Humidity at Specific Air Temperature on Crease Retention

The effect of relative humidity at specific air temperature on the fabric shape memory effect of crease retention is shown in Figure 6.4. The CR Ratings of untreated samples were 1.0 when they were in the air condition at 25ºC or 60ºC with different relative humidities. It seems that different relative humidities affect the fabric recovery of untreated samples slightly, as similar to the untreated flat samples. The relative humidity does not appear that to have an effect of untreated samples on crease retention.

Regarding the treated samples in air at 25ºC or 60ºC, their CR Ratings were higher at low relative humidity of 35% and their CR Ratings were lower at high relative humidity of 90%. Based on the statistical analysis, there is also significant effect among relative humidities of treated samples on the crease retention at the 0.05 level of significance. The finding shows that the effect of relative humidity on flat appearance is opposite to the result of crease retention.

The possible explanation is that water molecules are drawn up between the various layers or walls of cotton more easily when the relative humidity is high as at 90% RH. Then, water molecules can enter the polymer system of cotton in its amorphous regions more quickly. As cotton fibre absorbs moisture, it becomes softer as the hydrogen bonding between the cellulose molecular chains are broken. The explanation of this was described previously for flat samples. The creased shapes of the samples may be pulled down because of the effect of gravity and their fabric weights will increase. This gravity force due to water penetration in fabrics may be larger than the recovery force in the soft segment of shape memory polymers in fabrics. Therefore, it is difficult for creased samples to keep their creased shapes on fabrics and recover their original shapes in the Conditioning Chamber when the relative humidity is too high as at 90% RH and at any air temperatures.

The treated samples have the highest fabric shape memory effect of crease retention when they were in the air condition at 60 ºC and 35% RH compared with other samples. These results lead us to infer that this condition may be the optimum condition for the fabric recovery of crease retention in air.

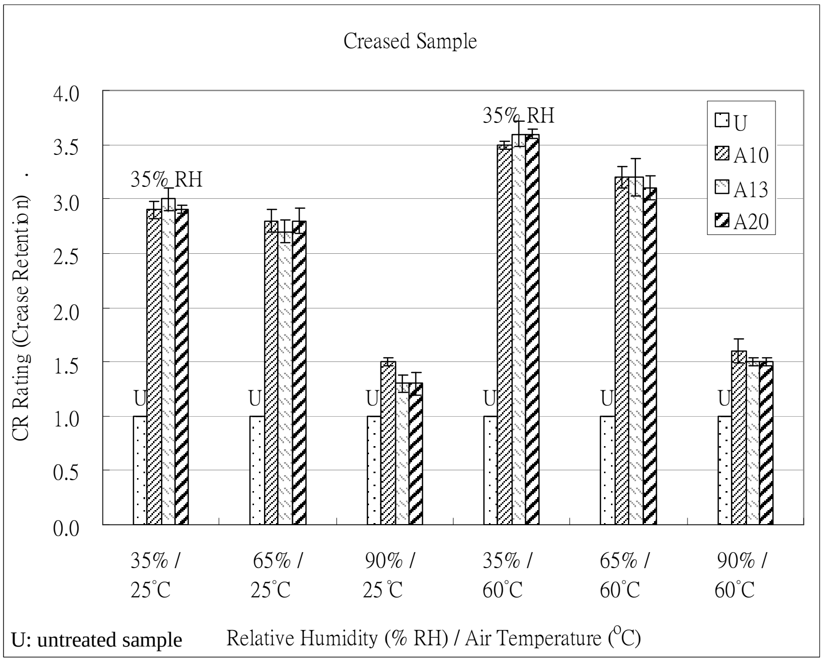

Figure 6.4 Effect of relative humidity at specific air temperature on crease retention (subjective evaluation)

6.4.1.5 Optimum Air Condition for Fabric Shape Memory Effects

Figure 6.5 presents the optimum air condition for both of the fabric shape memory effect of flat appearance and crease retention. The optimum air temperature was in air at 60ºC and at 65% RH for the fabric recovery of flat and creased shape. According to the findings of the effect of air temperature and relative humidity on fabric shape memory effects, it can be concluded that high air temperature as at 60ºC could give a high recovering ability of samples to their original flat and creased shapes respectively compared with the low air temperature as at 25 °C. As a result, 60°C can be the optimum temperature for the flat appearance and crease retention.

On the other hand, it was found that the flat appearance of samples increased and the crease retention of samples decreased when the relative humidity increased. In addition, the flat and creased samples have an opposite response to the relative humidity. However, it was explored that both SA Rating and CR Rating were around 3.0 or above when the relative humidity was 65% RH, as shown in Figure 6.5. This means that the fabric shape memory effects of flat appearance and crease retention have satisfied results when the relative humidity is 65% RH.

Thus, it can be concluded that the optimum air condition for both the fabric shape memory effect of flat appearance and crease retention is at 60°C and at 65% RH. The error bars for treated samples do not overlap the range of SA/CR Ratings within the error bars of untreated samples. This shows that the value of untreated and treated samples are differ significantly at the 95% confidence limit.

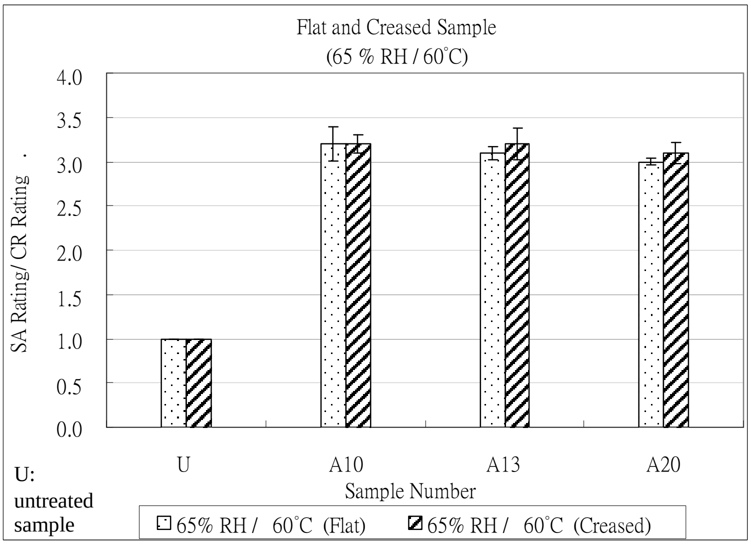

Figure 6.5 Optimum air condition for fabric shape memory effect in air (subjective evaluation)

6.5 Objective Evaluation

This experiment is to evaluate the effect of air temperature and relative humidity on the fabric shape memory effect of flat appearance and crease retention using an objective method. The Original Angle (Of and Oc) and Shape Memory Angle (Mf and Mc) were measured and the equations of Flat Recovery % (FRec%) and Crease Recovery % (CRec%) were used to determine the fabric shape memory effects. According to the statistical analysis, the coefficient of variations of the parameters such as Of, Oc, Mf and Mc in the equations of FRec% and CRec% are very small and most of them are below 5%.

6.5.1 Results and Discussions

The detailed test results are listed in Appendix D2.

6.5.1.1 Effect of Air Temperature with Specific Relative Humidity on Flat Appearance

Figure 6.6 shows the effect of air temperature with the relative humidity of 35% RH, 65% RH and 90% RH in terms of Flat Recovery % (FRec%) on flat appearance. It can be seen that the difference of FRec% of untreated sample in air at 25 ºC and 60 ºC at each specific relative humidities was below 4%. The result indicates that the effect of air temperature on flat appearance was small and the air temperature does not stimulate the shape recovery of untreated samples.

Comparing the treated samples at high temperature as at 60ºC to the treated samples at low temperature as at 25ºC at any relative humidities, the FRec% of treated samples in air at 60ºC with 65% RH and 90% RH was higher than the treated samples in air at 25ºC with these relative humidities slightly. At 65% RH, the FRec% of samples at 60ºC was higher than the FRec% of samples at 25ºC for around 3%. At 90% RH, the

FRec% of samples at 60ºC was higher than the FRec% of samples at 25ºC for around 3 - 9%. However, the FRec% of untreated samples at 60ºC was higher than the FRec% of samples at 25ºC for around 1-2% only.

These findings imply that high air temperature as at switch temperature (60ºC) can stimulate the flat appearance. The likely explanation for the temperature response of samples was described in the subjective evaluation previously.

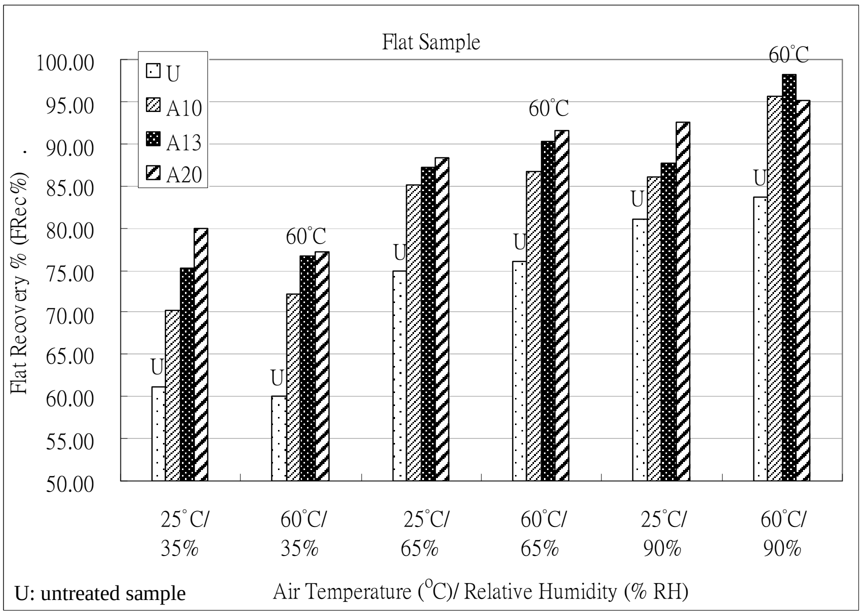

Figure 6.6 Effect of air temperature with specific relative humidity on flat appearance (objective evaluation)

6.5.1.2 Effect of Air Temperature with Specific Relative Humidity on Crease Retention

Figure 6.7 presents the effect of air temperature with the relative humidity of 35% RH, 65% RH and 90% RH in terms of Crease Recovery % (CRec%) on crease retention. Regarding the untreated samples at any relative humidities, the CRec% of untreated samples in air at 60ºC was similar to or below the CRec% of these samples in air at 25ºC. The finding suggests that air temperature cannot stimulate the fabric recovery of untreated samples.

With regard to treated samples at 35% RH and 65% RH, the crease recovering ability of treated creased samples in air at 60ºC was higher than that in air at 25ºC. This seems to be indicated that the shape memory effect of crease retention of treated samples can be stimulated by air temperature as at switch temperature (60ºC).

On the contrary, at 90% RH, the crease recovering ability of creased samples in air at 25ºC was higher than that in air at 60 ºC. This means that the creased sample can recover the creased shape more easily at 25ºC with very high relative humidity as at 90% RH. One likely explanation is that less water molecules can enter to the samples at 25ºC compared with that at 60ºC as water molecules may move slightly slowly in air at 25ºC. As a result, the samples at 25ºC may not contain as much as water compared with the samples at 60ºC. Then, the fabric samples at 25ºC are less soft and the gravity of fabrics may be lower. The shape memory polymer in fabric can keep the crease more easily in air at 25 ºC compared with the sample in air at 60ºC.

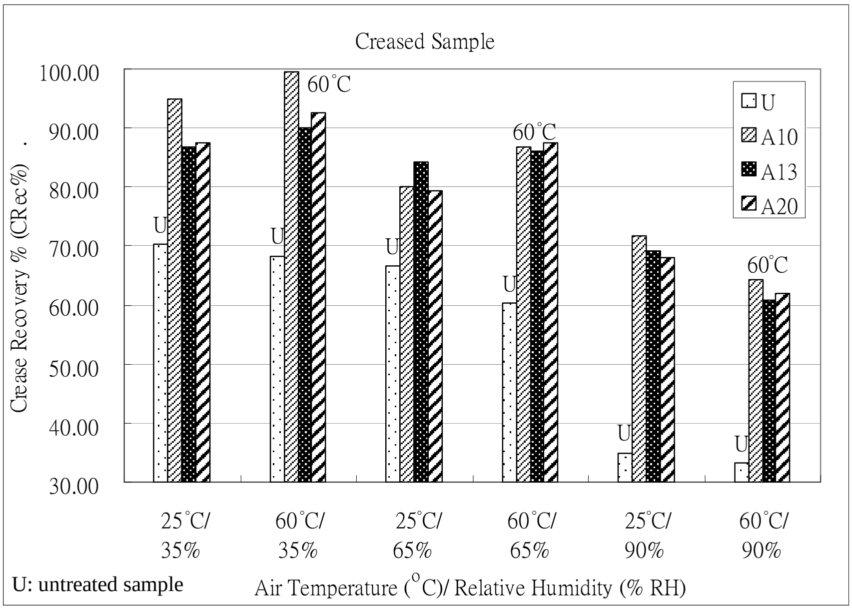

Figure 6.7 Effect of air temperature with specific relative humidity on crease retention (objective evaluation)

6.5.1.3 Effect of Relative Humidity at Specific Air Temperature on Flat Appearance

Figure 6.8 shows the effect of relative humidity of 35% RH, 65% RH and 90% RH at specific air temperature on the fabric shape memory effect of flat appearance. It was found that the FRec% of untreated sample increased while the relative humidity increased at 25 ℃ or 60 °C. The result seems to indicate that there is an effect of relative humidity on untreated samples on flat appearance and it is different from the result of subjective rating. It seems that the findings can show the fabric recovery more clearly as the FRec% was calculated from the Original Angle and Shape Memory Angle.

Regarding the treated samples in air at 25 ℃ or 60 ℃, the FRec% of samples were higher if the relative humidity was higher. In addition, the FRec% of treated samples was much higher than the FRec% of untreated samples in any conditions. The findings indicate that the relative humidity can facilitate the fabric shape memory effect of flat appearance and the recovering ability of flat treated samples increased. The higher relative humidity may increase the conductivity of heat on fabrics. The possible explanation was described previously. As a result, the FRec% of treated samples was much higher than that of untreated one. Based on the figure, the treated samples have the highest fabric shape memory effect of flat appearance when they were in the air condition at 60 ℃ air and 90% RH compared with the others. This result was the same as the result of subjective evaluation.

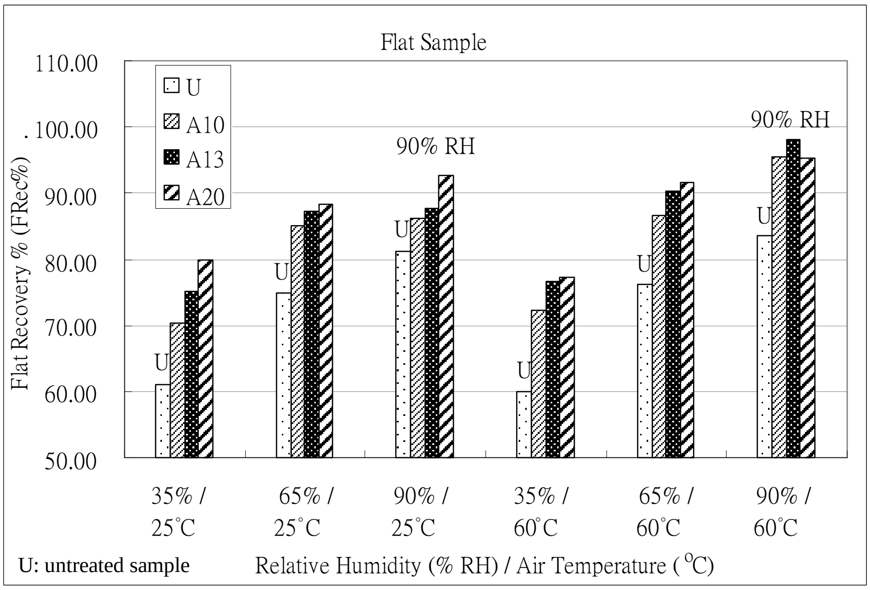

Figure 6.8 **Effect of relative humidity at specific air temperature on flat appearance (objective evaluation)**

6.5.1.4 Effect of Relative Humidity at Specific Air Temperature on Crease Retention

The effect of relative humidity of 35% RH, 65% RH and 90% RH at specific air temperature on the fabric shape memory effect of crease retention is given in Figure 6.9. As can be seen, the CRec% of untreated samples were decreased in air at 25 °C or 60 °C when the relative humidity was increased. It seems that there is an effect of relative humidity on crease retention of untreated creased samples and it is different from the result of subjective rating. The finding implies that FRec% can show the fabric recovery more clearly as the FRec% was calculated from the Original Angle and Shape Memory Angle.

According to treated samples in air at 25°C or 60°C, the treated samples have the highest CRec% when the relative humidity was at 35% RH while the treated samples have the lowest CRec% when the relative humidity was at 90% RH. These results indicate that the effect of relative humidity on crease retention is opposite to the effect of flat appearance. It may be due to the gravity and it was explained previously. Regarding the treated samples in any conditions, the CRec% of treated samples was much higher than the CRec% of untreated samples. The findings imply that the fabric recovering ability of treated samples is much higher than that of untreated samples and the fabric shape memory effect of crease retention of treated samples was very high. At 90% RH and at 25ºC or 60ºC, the CRec% of treated samples was considerably higher than that of untreated samples. It was because the treated creased samples tend to recover their original creased shape but it was not happened to untreated samples.

As can be seen, the treated samples have the highest fabric shape memory effect of crease retention when they were in the air condition at 60 ºC air and 35% RH compared with the others. This result was the same as the result of subjective evaluation.

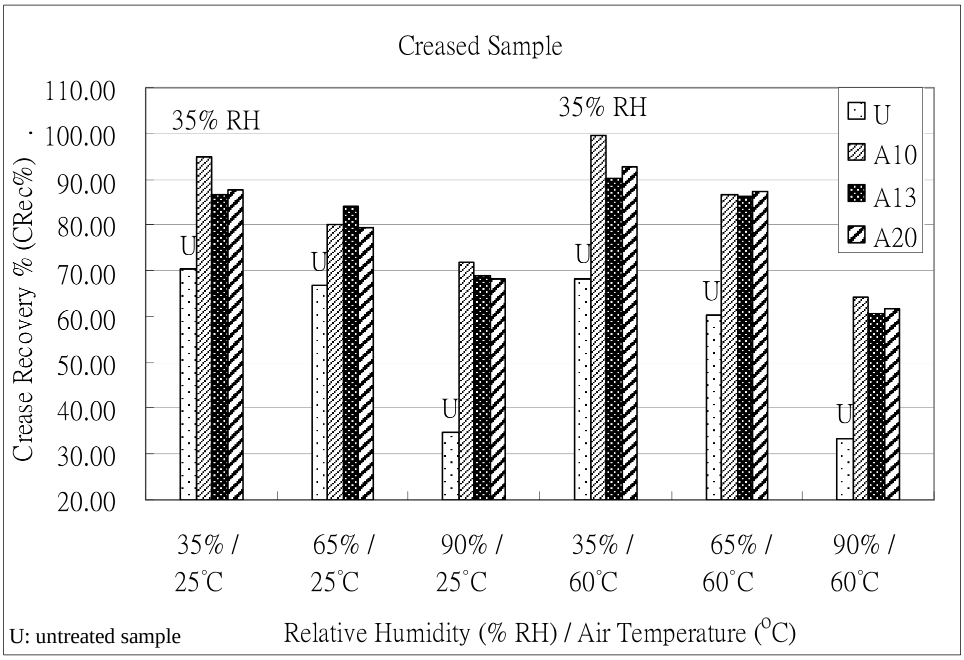

Figure 6.9 Effect of relative humidity at specific air temperature on crease retention (objective evaluation)

6.5.1.5 Optimum Air Condition for the Fabric Shape Memory Effects

Figure 6.10 indicates the optimum air condition at specific air temperature and relative humidity for both of the fabric shape memory effect of flat appearance and crease retention. According to the experimental results, too high relative humidity will decrease the crease retention but it will increase the flat appearance of samples.

In the air condition at 60ºC and 65% RH, it was discovered that both the FRec% of treated flat samples and CRec% of treated creased samples were above 85% which was much higher than the recovery % of untreated samples. For the untreated samples, the FRec% of untreated flat samples and CRec% of untreated creased samples were only 76% and 60% respectively.

Therefore, the findings show that the optimum relative humidity for fabric recovery of flat appearance and crease retention is 65% RH and the optimum air temperature is the high temperature as at switch temperature (60ºC). The findings in the objective evaluation were similar to the findings in the subjective evaluation.

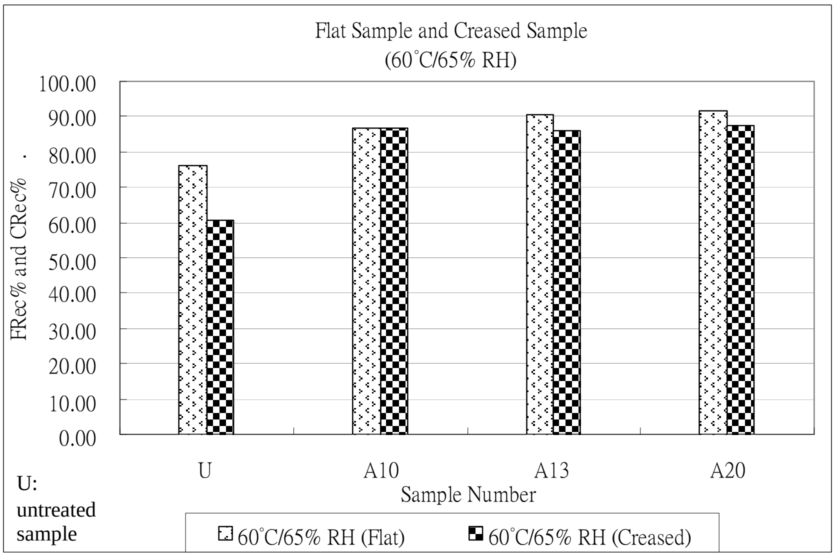

Figure 6.10 Optimum air condition for fabric shape memory effect in air (objective evaluation)

6.6 Comparison of Objective and Subjective Evaluation Results

The detailed test results are listed in Appendix D3.

6.6.1 Correlation between Objective and Subjective Results

Regarding flat samples, the correlation coefficient between Flat Recovery % (FRec%) and SA Rating at various air temperatures and relative humidities was 0.85 at the level of 0.05 significance. For creased samples, the correlation coefficient between Crease Recovery % (CRec%) and CR Rating at various air temperatures and relative humidities was also 0.85 at the 0.05% level. We can conclude that a strong linear relation relationship exists between the FRec% and SA Rating for flat samples and the CRec% and CR Rating for creased samples significantly.

In addition, it is obvious from the above discussions that the FRec% and CRec% can represent the fabric recovering ability more clearly and accurately as they were calculated from the measured values of Original Angles and Shape Memory Angles. This implies that the FRec% can represent the fabric shape memory effect of flat appearance and the CRec% can represent the fabric shape memory effect of crease retention effectively.

6.7 Conclusions

A subjective evaluation method and an objective evaluation method were used to determine the fabric shape memory effects of flat appearance and crease retention in air at various temperatures and relative humidities. A Conditioning Chamber was used to set different air conditions in the experiment.

In terms of subjective evaluation, it was discovered that untreated samples do not have the fabric shape memory effect of flat appearance and crease retention in air and they are not temperature sensitive. The relative humidity affects the flat appearance slightly.

However, it was revealed that the air temperature and the relative humidity can influence of the fabric shape memory effects of treated samples in air in the subjective evaluation. The higher air temperature as at switch temperature (60°C) with various relative humidities can stimulate the fabric shape memory effect of flat appearance and crease retention. It can be concluded that the shape memory effects of fabrics can be stimulated by hot air temperature.

Regarding the effect of relative humidity, a higher relative humidity can give a higher fabric shape memory effect of flat appearance but lower fabric shape memory effect of crease retention. It seems to mean that the relative humidity can facilitate the flat appearance and the recovering ability of treated flat samples was high. Too high relative humidity in air will decrease the fabric recovering ability of crease retention in air.

The treated samples have a moderate performance of shape memory effect of flat appearance and crease retention when the relative humidity was 65% RH compared with the relative humidity of 35% RH and 90% RH. As a result, it can be concluded that the optimum condition for the fabric recovery of flat appearance is in air at 60°C and 90% RH and the optimum condition for the fabric recovery of crease retention is in air at 60°C and 35% RH. These results lead us to infer that the most optimum air condition for a sample to recover its original flat shape and original creased shape together is at 60°C and 65% RH.

In terms of objective evaluation method, the study shows that untreated samples cannot be stimulated by air temperature. However, it was found that the relative humidity affects the flat appearance and crease retention of untreated samples if the samples were evaluated using the FRec% and CRec%. The findings imply that these calculated values can represent the actual fabric recovery more clearly as they were calculated from the Original Angles and Shape Memory Angles.

With regard to treated samples in the objective evaluation method, it was suggested that air temperature and the relative humidity can affect the fabric shape memory effects of flat appearance and crease retention. The result of treated samples in the objective method was similar to the result of treated samples in the subjective method. These findings may indicate that the higher air temperature as at switch temperature (60°C) with various relative humidities can stimulate the flat appearance and crease retention. Based on these findings, it can be concluded that air temperature can stimulate the fabric shape memory effect of flat appearance.

For the effect of relative humidity, the higher relative humidity can give the higher fabric shape memory effect of flat appearance but lower fabric shape memory effect of crease retention. Although the untreated samples have similar trend on the effect of relative humidity of treated samples, the fabric recovering ability of treated samples is much higher than that of untreated samples at various relative humidies.

Comparing between the objective results and subjective results, there is a strong linear relationship between Flat Recovery % and SA Rating for flat samples. Furthermore, the strong relationship was also found between Crease Recovery % and CR Rating for creased samples. As a result, this point can be interpreted to mean that the fabric shape memory effects of flat and creased samples could be evaluated using the objective evaluation method effectively.

CHAPTER 7: RELATIONSHIP OF FABRIC SHAPE MEMORY EFFECTS IN WATER AND AIR

7.1 Introduction

The fabric shape memory effects in water and air were studied in previous chapters. In this chapter, the relationship of fabric shape memory effects in various environments was investigated and the effect of tumble dry in air and water was also examined. The samples were tested using subjective evaluation method. This evaluation method was used because the effect of drying method on fabric shape memory effects between the fabric recovery in water and air was compared. If the objective evaluation method is used, the samples cannot be dried using a tumble dry.

7.2 Sample Details

The woven fabric (100% Cotton Twill, 108 X 58, 20s X 20s, fabric code: C3) was selected. One sample fabric was untreated and another shape memory sample (SM3) was treated with a shape memory polymer. Many samples were tested to find the relationship between water and air and the significant results were presented in this thesis. The preparation of samples for testing the fabric shape memory effects in water and air were described in Section 3.4.1 and 3.4.3 respectively. All specimens were pre-conditioned at 21 $\pm$ 1 °C and 65 $\pm$ 2% RH for 24 hours before testing.

7.3 Experimental Parameters

7.3.1 Fabric Evaluation in Water

The experimental design for evaluating the fabric shape memory effects in water was described in Section 3.4.1. The experimental parameters were as follows:

Recovery: Washing (Temperature: 60°C)

Drying: Line dry and tumble dry

Evaluation: Samples were evaluated by three trained observers

The conditions of washing and tumble dry were described in Section 3.4.1.

7.3.2 Fabric Evaluation in Air

The experimental details were described in Section 3.4.3 and the experimental parameters were as below:

Conditions in a Conditioning Chamber: 60°C and 65% RH

(The optimum condition for the fabric recovery)

Drying: No dry, line dry and tumble dry

Evaluation: Samples were evaluated by three trained observers

The original experimental process in Section 3.4.3 did not have the drying stage and the samples were assigned ratings right away after taking out from the Conditioning Chamber. However, in this experiment, samples were line dried and tumble dried in order to compare the test results in water.

7.3.3 Testing Parameters

In this experiment, the temperature of 60°C in water and air were selected as it was found that this temperature as at switch temperature of polymers in fabric can stimulate the fabric shape memory effects. For testing the samples in air, the relative humidity of 65% RH in a Conditioning Chamber was selected as it has the satisfied fabric shape memory effect of both flat appearance and crease retention at the same time while the air temperature was 60°C.

7.4 Results and Discussions

The detailed test results are listed in Appendix E.

7.4.1 Comparison between the Effect in Water (Tumble Dry) and Air (No Dry)

Figure 7.1 shows the comparison between the fabric shape memory effect of flat appearance and crease retention of samples in air with no dry and in water with tumble dry. It can be seen that the ratings of untreated flat and creased fabrics were 1.0 in water and air. The results show that there is no shape memory effect of untreated samples.

With regard the treated flat and creased samples, the SA Ratings and CR Ratings of samples which recovered in water were much higher than the ratings of samples which recovered in air. The findings seem to indicate the samples have a higher recovering ability of flat shapes and creased shapes in water compared with that in air.

One possible reason is that the heat conductivity in water is better than that in air. There is not as much as water molecules in air compared with that in water. As a result, the heat can have a larger effect on treated fabric for the fabric recovery during washing in the recovery stage. Moreover, water molecules can make the fabrics softer and therefore, samples can be recovered their original shape more easily. The result also shows that water can enhance the fabric shape memory effects.

In addition, there is significant difference among different recovery conditions at the 0.05 level of significance based on the ANOVA analysis. The error bars are very small and the error bars for samples recovered in water do not overlap the range of SA/CR Ratings within the error bars of samples recovered in air. There is 95%

confidence that the true value is within this range and this shows that the value of treated samples recovered in water and air are differ significantly.

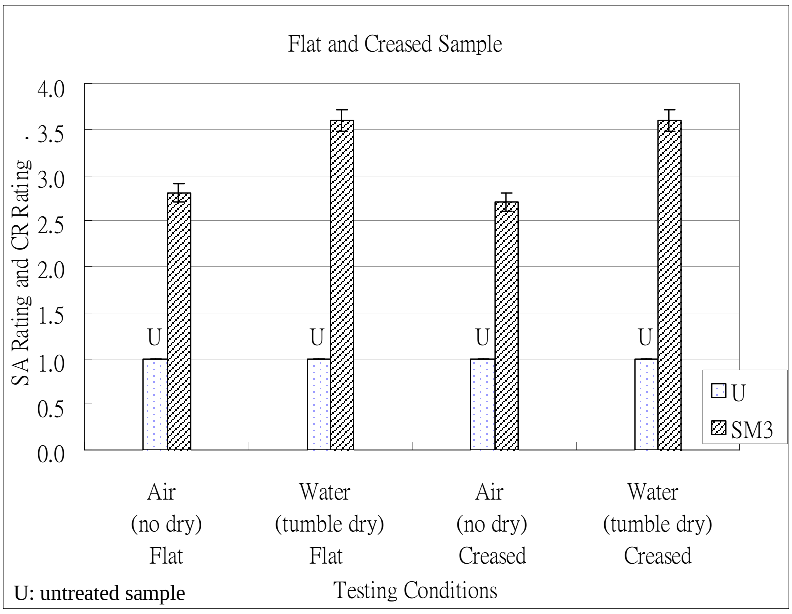

Figure 7.1 **Comparison between the effect in water (tumble dry) and air (no dry)**

7.4.2 Comparison between the Effect in Water and Air with Line Dry

Figure 7.2 shows the comparison between the fabric shape memory effect of flat appearance and crease retention of samples in air and water with line dry. The SA Rating of untreated flat sample and the CR Rating of untreated creased sample in air and water with a line dry were 1.0 only. This means that the recovering conditions do not appear to have an effect on recovering abilities of original flat and creased shape at the 0.05 level of significance based on the ANOVA analysis.

Regarding the treated samples, the SA Rating and CR Rating of samples which recovered in water were higher than the ratings of treated samples which recovered in air slightly. The ratings of samples which recovered in water were above 3.0 whereas the ratings of samples which recovered in air were below 3.0. The finding implies that it is easier for samples to recover their original flat and creased shapes in water rather than that in air. According to the statistical analysis, the error bars for samples recovered in water do not overlap the range of SA/CR Ratings within the error bars of samples recovered in air. There is 95% confidence that the true value is within the span of the error bars.

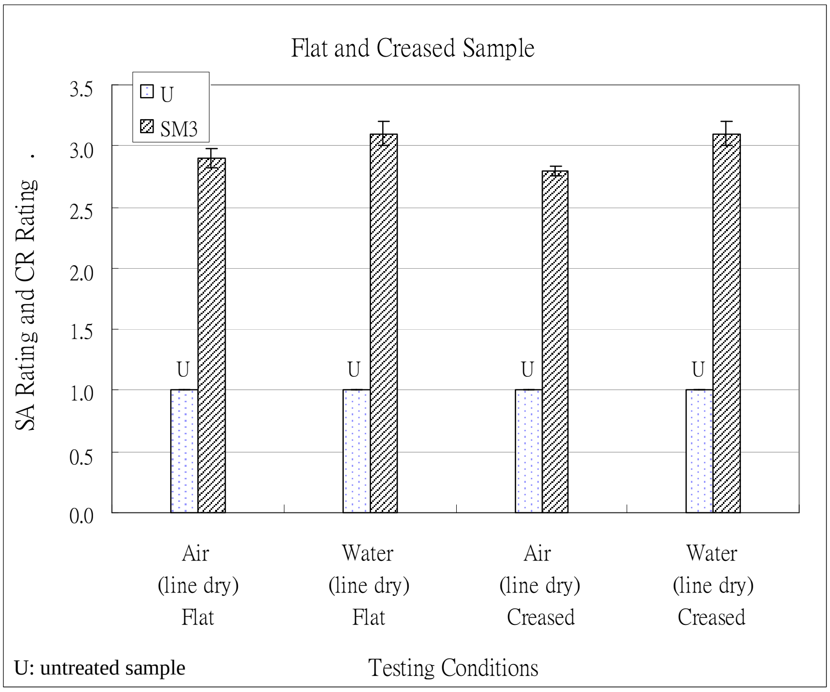

Figure 7.2 Comparison between the effect in water and air with line dry

7.4.3 Comparison between the Effect in Water and Air with Tumble Dry

Figure 7.3 presents the comparison between the fabric shape memory effect of flat appearance and crease retention of samples in water and air with a tumble dry. As can be seen, the untreated samples have the ratings of 1.0 when the samples recovered in water and air. This means that the untreated samples do not affected by different recovering conditions and they do not have fabric shape memory effects.

With regard to treated samples, the SA Rating and CR Rating of samples which recovered in water were higher than the ratings of treated samples which recovered in air. The results show that the fabric shape memory effects of flat appearance and crease retention were higher when the samples recovered in water than in air. The ratings of treated samples in water were above 3.5. In addition, there is significant difference of treated samples among various recovering conditions at the 0.05% level. The possible explanation is that heat conductivity in water is better than that in air. Therefore, the heat can stimulate the fabric shape memory effects in water more easily. These explanations were described previously. Based on the statistical analysis, it shows that the value of treated samples recovered in water and air are differ significantly.

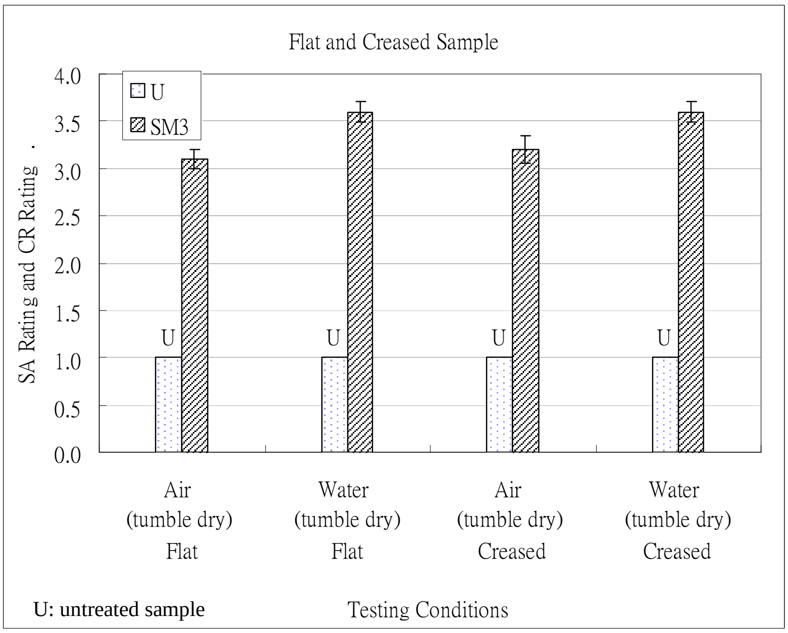

Figure 7.3 Comparison between the effect in water and air with tumble dry

7.4.4 Effect of Drying Method on Samples in Air

Figure 7.4 shows the effect of various drying methods on the shape memory effects of flat appearance and crease retention of samples which recovered in a Conditioning Chamber. For the untreated samples, they have the rating of 1.0 when they were dried by line dry, tumble dry or no dry. This shows that the untreated samples do not have fabric shape memory effects and they do not affected by different drying methods.

Regarding treated samples, it was found that the ratings of samples were higher if they were dried by a tumble dry compared with no dry and line dry. When the samples were dried using a tumble dry, the highest SA Rating of a flat treated sample was 3.1 and the highest CR Rating of a creased sample was 3.2. These data can be interpreted to mean that the temperature (66°C) which is higher than the switch temperature of polymers in fabric in the tumble drier can influence the fabric shape memory effect. It implies that the drying temperature is high enough to allow the shape memory polymer free movement thus facilitating the recovery of the shape memory fabrics.

According to the statistical analysis, the error bars are very small and the error bars for samples dried by tumble dry do not overlap the range of SA/CR Ratings within the error bars of samples dried by line dry and no dry. There is 95% confidence that the true value is within this range and this shows that the value of treated samples dried by tumble dry and other dryings are differ significantly.

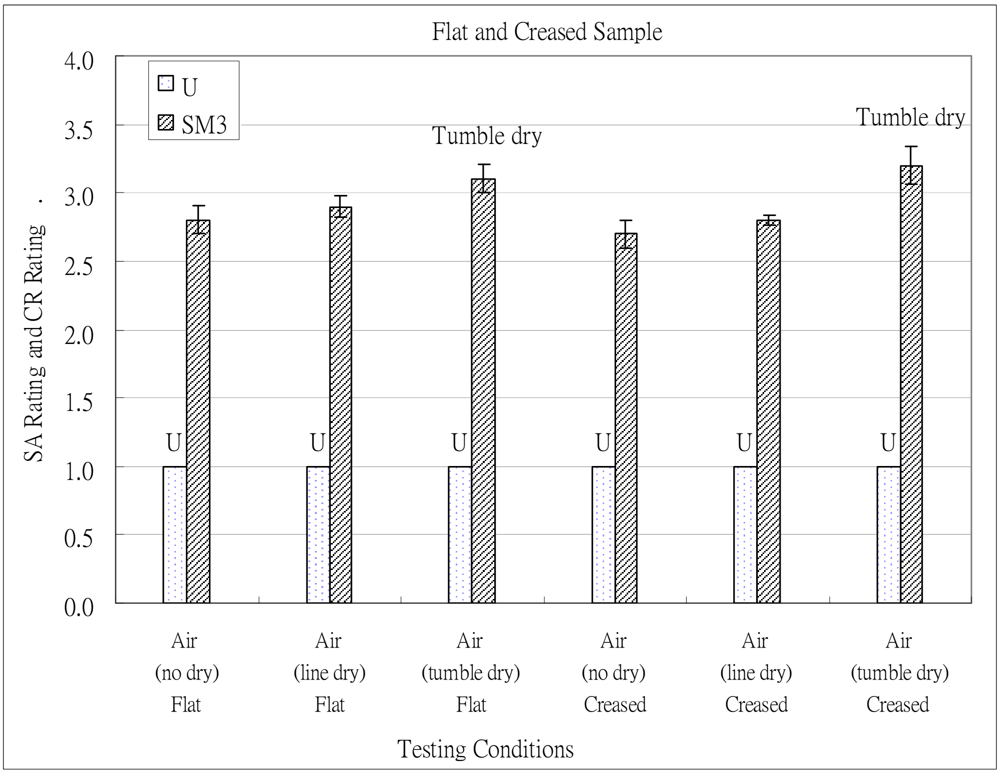

Figure 7.4 Effect of drying method on fabric shape memory effects in air

7.4.5 Effect of Drying Method on Samples in Water

Figure 7.5 presents the effect of various drying methods on the shape memory effects of flat appearance and crease retention of samples which recovered by using a washing machine. As can be seen in the figure, the untreated samples have the rating of 1.0 when they were dried by line dry or tumble dry. The results imply that the untreated samples do not affected by different drying methods.

Similar to the results in air, it was discovered that the ratings of samples were higher if they were dried by a tumble dry compared with a line dry. When the samples were dried by a tumble dry, the highest SA Rating of the treated flat sample and the CR Rating of the treated creased sample were 3.6. The likely explanation was described in the previous section.

Based on the statistical analysis, the error bars are very small and the error bars for samples dried by tumble dry do not overlap the range of SA/CR Ratings within the error bars of samples dried by line dry. This shows that the value of treated samples dried by tumble dry and line dry are differ significantly.

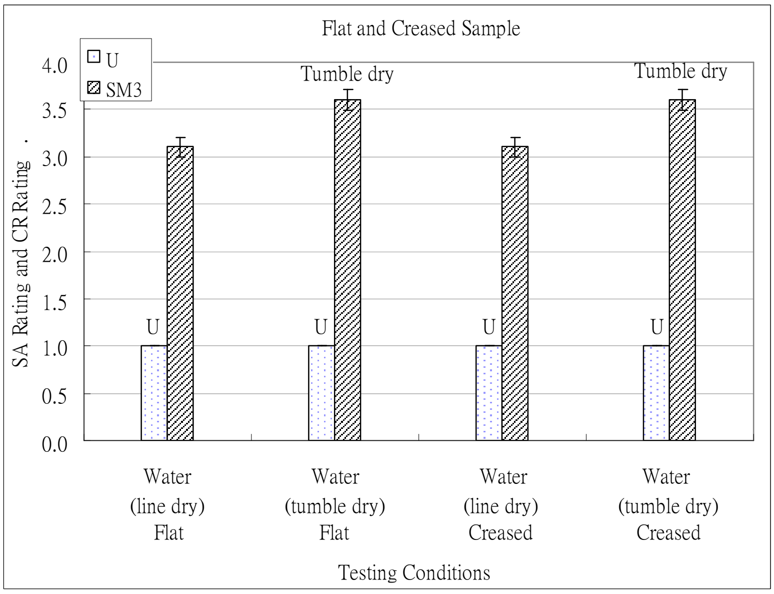

Figure 7.5 Effect of drying method on fabric shape memory effects in water

7.5 Conclusions

The relationship of fabric shape memory effects in water and air was investigated using a subjective evaluation method. There is no effect of the various recovering conditions on the fabric shape memory effects of untreated samples

According to treated samples, it was found that the fabric shape memory effect in water with tumble dry was considerably higher than that in air with no dry. In addition, the fabric shape memory effects of samples which recovered in water with a line dry or tumble dry were higher than the samples which recovered in air with a line dry or tumble dry. It can be inferred from these findings that the recovering ability of samples in water is higher than that in air and it may be due to the larger heat conductivity in water. This implies that water can enhance the fabric shape memory effects.

Moreover, it can be concluded that tumble dry can increase the fabric shape memory effects of treated samples in water and air due to its high drying temperature stimulating the fabrics during drying.

CHAPTER 8: OBJECTIVE EVALUATION OF FABRIC BAGGING RECOVERY EFFECT

8.1 Introduction

This chapter is to examine the effect of water temperature on the bagging recovery effect of three types of fabrics and determine the fabric bagging recovery effect using a new objective evaluation method. The new equations of bagging recovery including the Bagging Warp Recovery % (BPR%) and the Bagging Weft Recovery % (BTR%) were explored to evaluate the fabric bagging recovery effect and the Bagging Recovery Rating (BRR) was designed to integrate the warp and weft recovery of samples. At last, the chapter moves on to the conclusions.

8.2 Sample Details

Many samples were produced for this study and some significant results were presented. Three types of fabrics were used in the bagging recovery test. They were 100% knitted fabric with specification of 60" X 320g/y (Fabric code: K1), 100% woven cotton twill, 108X58, 20sX20s (Fabric Code: C3) and 100% cotton poplin, 133X100, 40sX40s (Fabric Code: C7). The sample preparation is described in Section 3.4.5 and the sample details are described in Table 8.1.

Table 8.1 Sample details of bagging recovery test

Fabric Code	Sample Number	Shape Memory Polymer
K1	K1-U	No polymer
	K1-1	KK1
	K1-2	KK2
C3	C3 -U	No polymer
	C3 -1	CT1
	C3 -2	CT2
C7	C7 -U	No polymer
	C7 -1	CP1

8.3 Experimental Design

The details of evaluation method are described in Section 3.4.5.

8.4 Results and Discussions

The detailed test results are listed in Appendix F. The Original Warp Length (Op), Original Weft Length (Ot), Deformed Warp Length (Dp), Deformed Weft Length (Dt), Recovered Warp Length (Rp) and Recovered Weft Length (Rt) were measured and then these values were used to calculate the Bagging Warp Recovery % (BPR%) and the Bagging Weft Recovery % (BTR%). Moreover, both BPR% and BTR% were integrated to the Bagging Recovery Rating (BRR) using the rating table to evaluate the fabric bagging recovering ability.

The standard deviation and the coefficient of variation (CV) of the parameters including the Dp, Dt, Rp and Rt were found and shown in Appendix F. The CV and % Error of almost all measured lengths are below 3%. That means the variation of each data is small and the precision of the testing is high.

8.4.1 Effect of Temperature (Knitted Fabric: K1)

8.4.1.1 BPR% and BTR% of Fabric K1

Figure 8.1 shows the Bagging Warp Recovery % (BPR%) and Bagging Weft Recovery % (BTR%) of K1 samples in water at 25ºC and 60ºC respectively. It can be seen that the BPR% and BTR% of untreated sample in 60ºC have similar values to the untreated sample in 25ºC and they were below 20%. The result indicates that the untreated sample is unable to recover its original flat shape after immersing in water at 25ºC and 60ºC. It is suggested that the untreated sample does not have the fabric bagging recovery effect and it still has a bagged shape which is the deformed shape after putting into the hot water. In addition, untreated sample is not temperature sensitive.

As can be seen, the BPR% and BTR% of treated samples in 60ºC were much higher than that of treated samples in 25ºC. In water at 25ºC, the BPR% and BTR% of treated samples were around 30% only. The finding shows that bagging recovery effect of treated samples at 25°C is not so satisfactory. The probably explanation is that the water at 25°C cannot reach the switch temperature of polymers in fabrics. As a result, the fabric shape memory effect cannot be stimulated.

When the water was at the switch temperature (60°C), the BPR% and BTR% of treated samples were higher and their values were above 65%. For the recovery in weft direction, the treated samples (K1-1 and K1-2) have the 100% recovery. It is clear that the bagging recovery effect of the treated samples is quite satisfactory if they recovered in hot water as at 60°C. It may be because the high temperature as at 60°C can reach the switch temperature of polymers in fabric. Therefore, the bagged shapes of treated samples tend to be recovered their original flat shapes after immersing in hot water. According to the results, it implies that the treated samples are temperature sensitive and have fabric bagging recovery effect.

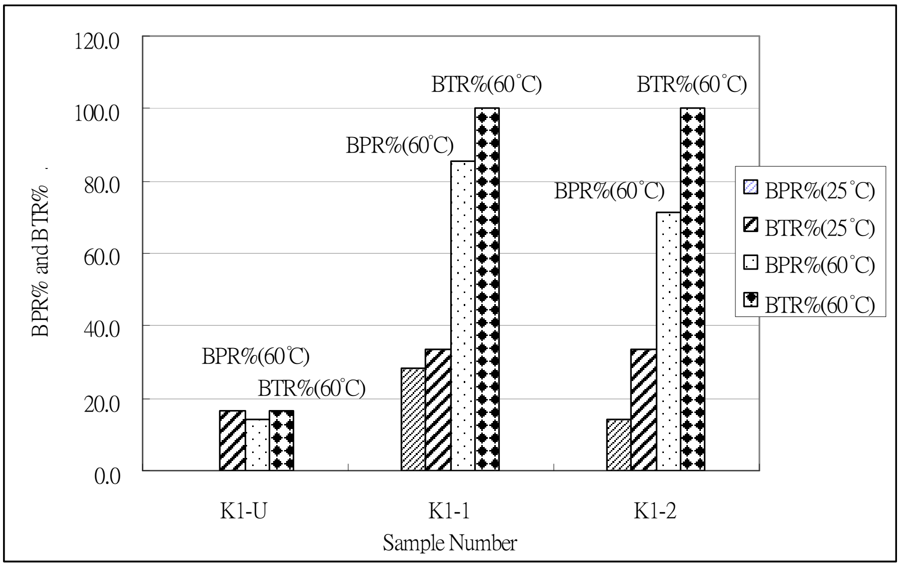

Figure 8.1 Bagging Recovery % of K1 fabric

8.4.1.2 Bagging Recovery Rating (BRR) of Fabric K1

Figure 8.2 shows the Bagging Recovery Rating (BRR) of K1 samples which recovered in water at 25℃ and 60℃ respectively. The BRR of untreated sample was 1.5 and 2.0 at 25°C and 60°C respectively. The ratings were very low and the values of samples in both temperatures were similar. This means that the untreated sample only have slight recovery after putting in water at both temperatures and it was not temperature sensitive.

The BRR of both treated samples was 9.0 and 9.5 respectively when the water temperature was 60°C and the BRR of both treated samples was 3.5 and 3.0 when the water temperature was 25°C. The findings indicate that the fabric bagging recovery effect can be stimulated in water when the water temperature reaches the switch temperature of polymers (60°C). It implies that the treated samples are temperature sensitive and they have the high fabric bagging recovery effect after immersing in hot water as at 60°C.

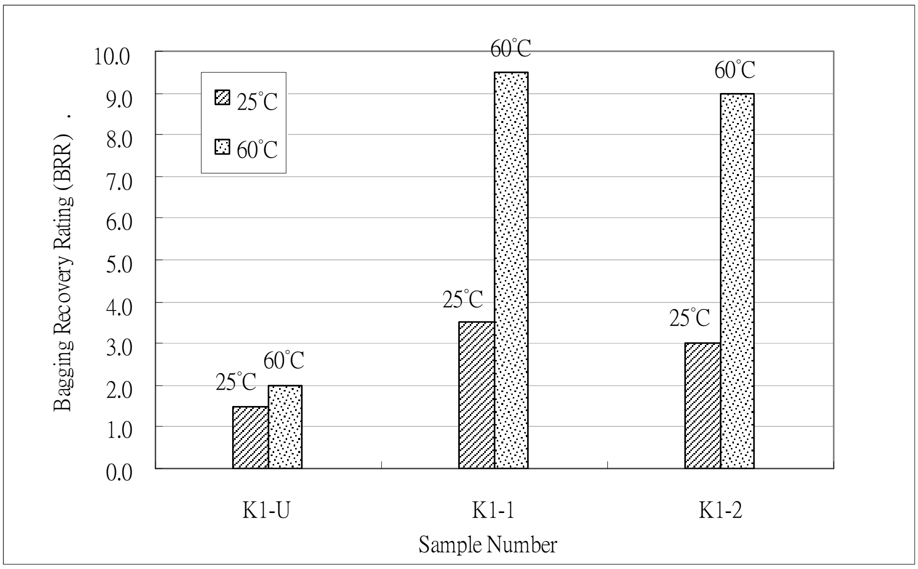

Figure 8.2 Bagging Recovery Rating of K1 fabric at various temperatures

8.4.2 Effect of Temperature (Woven Fabric: C3)

8.4.2.1 BPR% and BTR% of Fabric C3

Figure 8.3 shows the Bagging Warp Recovery % (BPR%) and Bagging Weft Recovery % (BTR%) of C3 samples in water at 25°C and 60°C respectively. The BPR% and BTR% of the untreated sample were 0% which means that the untreated sample does not have the bagging recovery effect after immersing in water at 25°C and 60°C. It can be interpreted to mean that it keeps the deformed shape and cannot recover it original flat shape.

For treated samples, the BPR% and BTR% of samples in 60°C were much higher than that of samples in 25°C. When the water was 25°C, the BPR% and BTR% of both treated samples were only around 33%. This means that the bagging recovery effect of treated samples at 25°C is not satisfied. When the water was 60°C, the BPR% and BTR% of sample C3-1 were quite high and they were above 65%. For sample C3-2, the BPR% was only around 33% but the BTR% was around 66%. This means that their bagging recovery in weft direction is better than that in warp direction. These findings imply that temperature can stimulate the bagging recovery effect of fabrics.

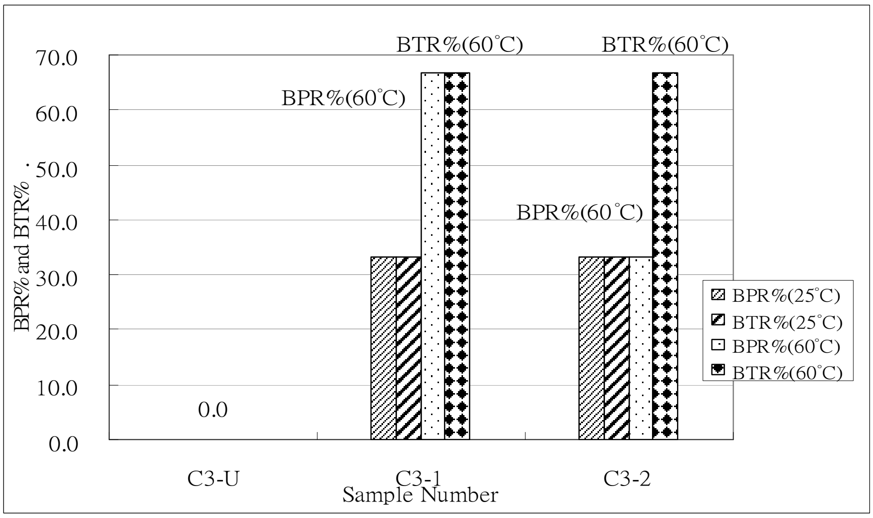

Figure 8.3 Bagging Recovery % of C3 fabric

8.4.2.2 Bagging Recovery Rating (BRR) of Fabric C3

Figure 8.4 shows the Bagging Recovery Rating (BRR) of C3 samples which recovered in water at 25ºC and 60ºC respectively. The BRR of the untreated sample was 1.0 only at 25°C and 60°C. The result shows that the untreated sample has no bagging recovery effect after immersing in water at various temperatures.

However, the BRR of treated samples which recovered at high temperature was higher than that of treated samples which recovered at low temperature. As can be seen, the BRR of the treated sample (C3-1) was 7.0 and the BRR of the treated sample (C3-2) was 5.5 when the water temperature was 60°C. Also, the BRR of both treated samples was 4.0 if they recovered in water at 25°C. It is clear that the bagging recovery effect of fabrics can be stimulated at switch temperature as at 60°C. This is also evident that the treated samples are temperature sensitive.

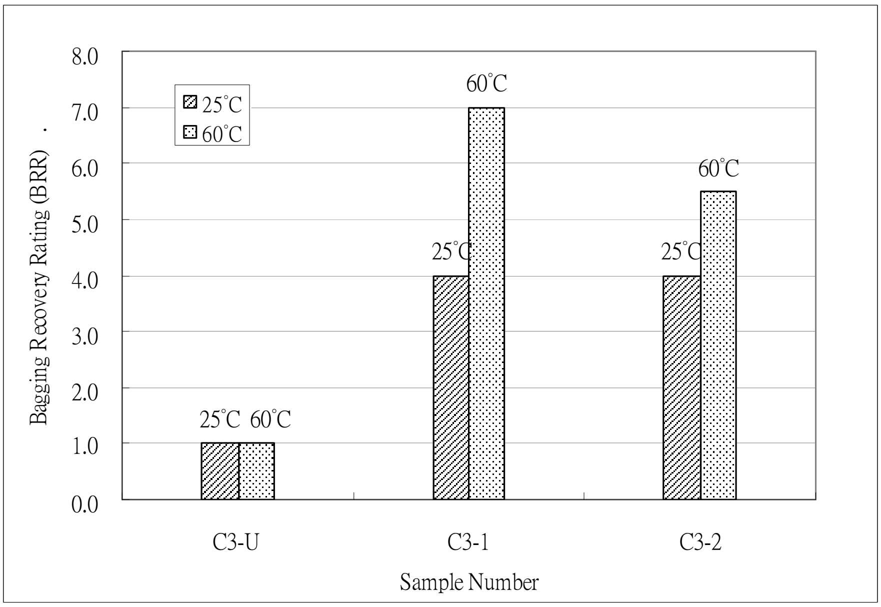

Figure 8.4 Bagging Recovery Rating of C3 fabric at various temperatures

8.4.3 Effect of Temperature (Woven Fabric: C7)

8.4.3.1 BPR% and BTR% of Fabric C7

Figure 8.5 shows the Bagging Warp Recovery % (BPR%) and Bagging Weft Recovery % (BTR%) of C7 samples in water at 25ºC and 60ºC respectively. Regarding the untreated sample, the BPR% and BTR% were 0% which means that the untreated sample does not have the bagging recovery effect after immersing in water at 25ºC and 60ºC. The finding also indicates that the untreated sample keeps the deformed shape and cannot recover its original flat shape.

The BPR% and BTR% of treated samples in 60ºC were much higher than that of treated samples in 25ºC. When the water was 25°C, the BPR% and BTR% of the treated sample were 0%. The result shows that the treated sample (C7-1) does not have the bagging recovery effect at 25ºC and it cannot recover from the deformed shape to the original flat shape. When the water was 60°C, the BPR% and BTR% of sample C7-1 increased to 33%. Although the recovery % of the treated sample at 60°C is higher than that of the treated sample at 25°C, the bagging recovery effect of the treated sample is not satisfactory in 60°C.

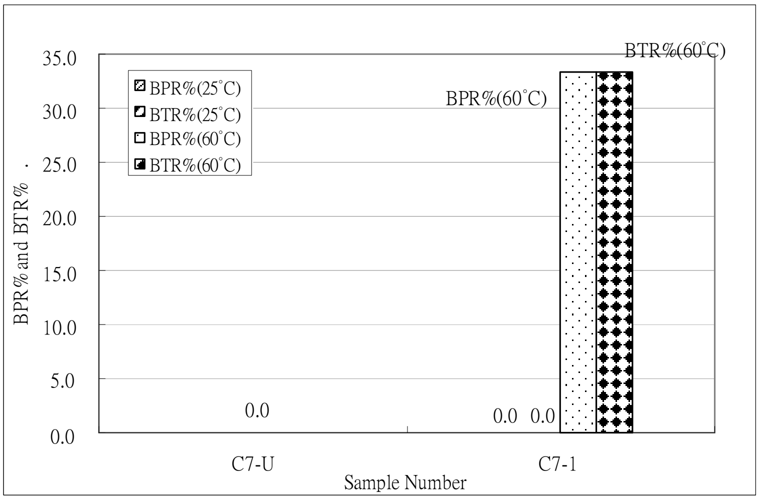

Figure 8.5 Bagging Recovery % of C7 fabric

8.4.3.2 Bagging Recovery Rating (BRR) of Fabric C7

Figure 8.6 shows the Bagging Recovery Rating (BRR) of C7 samples which recovered in water at 25°C and 60°C respectively. The BRR of the untreated sample was 1.0 only at 25°C and 60°C. The result shows that the untreated sample does not have the bagging recovery effect after putting in water at various water temperatures.

According to the treated sample, there was no bagging recovery effect of the treated C7 sample when the water temperature was 25°C. When the sample was at 60°C, the BRR of the treated sample was 4.0. The result shows that the bagging recovery effect of treated sample was higher than that of the untreated sample, but the rating of 4.0 was quite low. This means that the bagging recovery ability of treated C7 woven sample is not high.

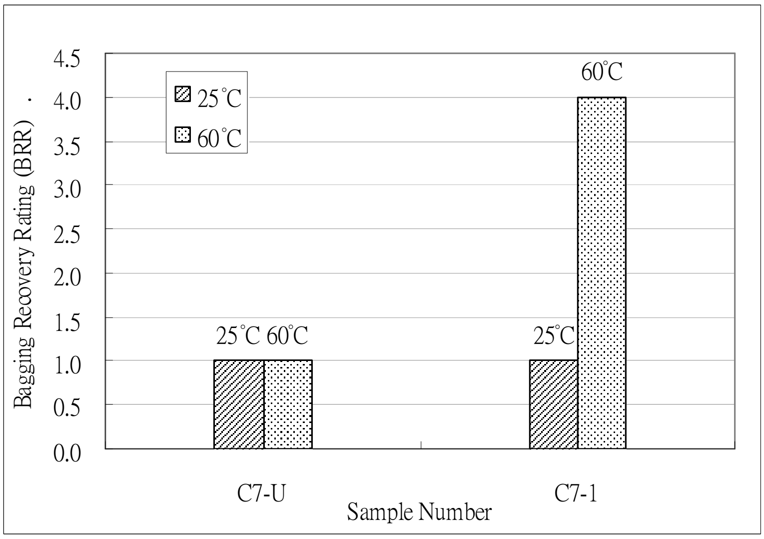

Figure 8.6 Bagging Recovery Rating of C7 fabric at various temperatures

8.4.4 Bagging Recovery Rating Among Three Types of Fabrics

Figure 8.7 shows the Bagging Recovery Rating among K1, C3 and C7 fabric after immersing in water at 25ºC and 60ºC respectively. Referring to the untreated samples of these types of fabrics, their ratings were below 2.0. This means that the untreated samples cannot recover their original flat shapes after putting in water at various temperatures and they do not have any bagging recovery effects.

When the water temperature was 60°C, the result shows that the treated knitted fabrics (K1) have the highest bagging recovery effect as they have the highest Bagging Recovery Rating of 9.5. This shows that the bagging recovery effect of knitted samples is very high. The treated C7 fabric has the lowest Bagging Recovery Rating of 1.0. Regarding the C3 fabrics, they have the moderated result of 7.0. When the water temperature was 25°C, the bagging recovery effect of all treated samples was not very satisfactory and the highest Bagging Recovery Rating among these three types of fabrics was 4.0 only. The findings imply that knitted fabric has the highest bagging recovery effect compared with the other two woven fabrics.

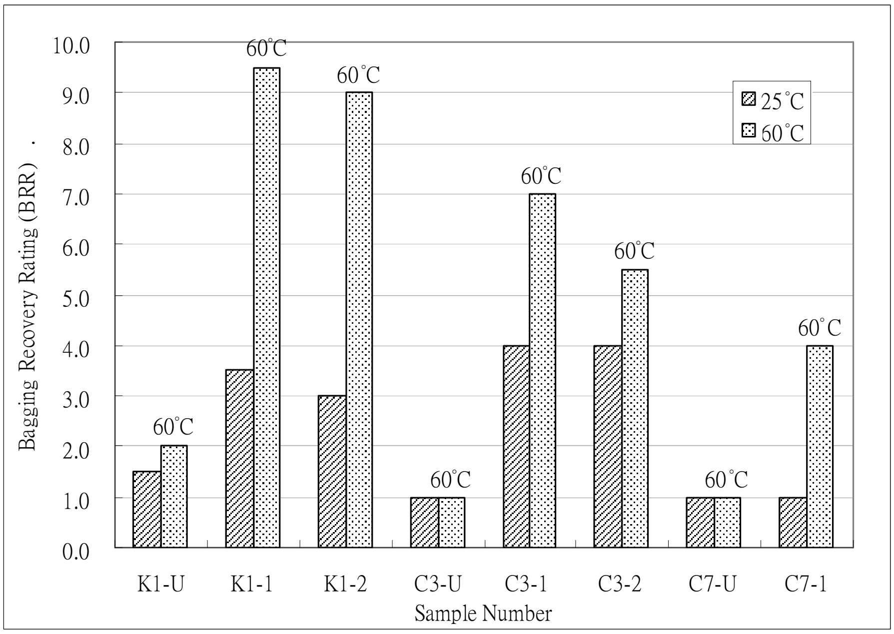

Figure 8.7 Bagging Recovery Rating of different kinds of fabrics

8.5 Conclusions

The bagging recovery effect of fabrics was evaluated using new objective evaluation method and this method can evaluate the fabric bagging recovery effect effectively. The coefficient of variation and % Error of all measured lengths including the Deformed Length and Recovered Length are below 3%. That means the variation of each sample data is small. In addition, the equations of the Bagging Warp Recovery % (BPR%) and Bagging Weft Recovery % (BTR%) were calculated using the parameters of the Original Length, Deformed Length and Recovered Length in warp and weft direction respectively (i.e. Op, Dp, Rp and Ot, Dt, Rt). The Bagging Recovery Rating was also calculated from the data of BPR% and BTR%.

The Bagging Warp Recovery (BPR%) and the Bagging Weft Recovery (BTR%) can represent the bagging recovery % of the warp direction and weft direction of fabrics respectively. The Bagging Recovery Rating (BRR) integrates the BPR% and BTR% into one rating value for the evaluation of the bagging recovery effect of fabrics.

According to the findings, it was found that water temperature can influence the bagging recovery effect of shape memory fabrics significantly. The fabric bagging recovery effect can be stimulated by hot water as at switch temperature (60°C) but the bagging recovery effect cannot be stimulated by cold water (25°C). It may be concluded that the shape memory fabrics are temperature sensitive and the bagging recovery effect exists if the samples recovered in water at switch temperature. They have the ability to recover their original flat shapes from a deformed shape after temperature stimulation.

On the whole, the knitted fabric has the largest bagging recovery effect when putting in high temperature water as at 60°C compared with the woven fabrics of C3 and C7.

CHAPTER 9: CONCLUSIONS

9.1 Introduction

Shape memory fabrics studied in this thesis are novel products prepared by treating with waterborne shape memory polymers via finishing treatments. There are three types of fabric shape memory effects including the flat appearance, crease retention and bagging recovery effect. However, the traditional experiment cannot be used to evaluate the shape memory fabrics as the experimental process and parameters are not suitable for determining the fabric shape memory effects. This thesis attempts to provide a comprehensive investigation on the evaluation of shape memory fabrics. Some modified and new evaluation methods were developed to evaluate the fabric shape memory effects under various testing conditions. This chapter will provide a brief summary of the research results and conclusions.

In this study, cotton was mainly selected in all experiments. Both subjective evaluation and objective evaluation methods were developed to evaluate the fabric shape memory effects of flat appearance and crease retention in water and air. In addition, the fabric bagging recovery effect in water was evaluated using new objective evaluation method. Some new equations were established to evaluate the fabric shape memory effects effectively.

The fabric shape memory effects were revealed in various testing conditions. The effects of temperature, recovery method, drying method and relative humidity on the fabric shape memory effects were examined. Furthermore, the relationship of fabric shape memory effects in water and air was also analyzed in this study.

9.2 Fabric Types for Making Shape Memory Fabrics

Various fabric types may be used for making shape memory fabrics. Cotton fabrics show a large potential for making shape memory fabrics by treating with shape memory polymers as compared to silk and ramie fabrics. In addition, cotton is the most important cellulosic fibre and many of our textile fabrics are made from cotton. Therefore, cotton is our main fabric type in this research.

9.3 Effect of Different Shape Memory Polymers

Different sets of shape memory polymers can be used to make shape memory fabrics with wholly different responses to temperature. One set of shape memory polymers was used to make the shape memory fabrics which have the flat appearance to increase and the crease retention to decrease when the water temperature increases to 60°C. Conversely, the flat appearance of fabrics decreases and the crease retention increases when the water temperature decreases to 15°C. It was found that the fabric shape memory effects of flat appearance and crease retention did not have the same trend of the temperature response.

Another set of shape memory polymers prepared by different recipes were also used to make shape memory fabrics which showed a different response to temperature. It was revealed that both flat appearance and crease retention of fabrics increased when they were stimulated by high temperature as at switch temperature (60°C) in water. It can be concluded that the shape memory fabrics are temperature sensitive and they shows the significant response to temperature.

9.4 Subjective Evaluation of Flat Appearance and Crease Retention in Water

The subjective evaluation method was modified based on the AATCC Test Method 124 and 88C and it was used to determine the fabric shape memory effects of flat appearance and crease retention in water effectively. It appears that the fabric shape memory effects do not exist in untreated samples as they do not tend to recover their original flat or creased shapes at any water temperatures. In addition, different drying methods and recovery methods such as washing and water immersion cannot stimulate the untreated samples for their recovery. We can conclude that the untreated samples are not temperature sensitive. On the contrary, it was revealed that the water temperature, recovery method and drying method can influence the shape memory effects of treated fabrics in water significantly.

9.4.1 Effect of Water Temperature

The shape memory effects of fabrics were stimulated when water temperatures in a washing machine or water tray were high enough for the fabric recovery (60°C). The possible explanation is that the water temperature at 60°C was in the range of switch temperature of soft segments in shape memory polymers. Therefore, the soft segment crystals melt and the molecular chains in soft segments can move easily. Then, the deformed shapes of samples can be recovered the original shapes which were set in the curing process. It can be concluded that the treated samples are temperature sensitive and the fabric shape memory effects of flat appearance and crease retention can be stimulated by the switch temperature (50 - 60°C) of polymer in fabrics.

9.4.2 Effect of Recovery Method

The washing and water immersion in a water tray were used for the fabric recovery in the recovery stage. In terms of the effect of water immersion and washing, the fabric shape memory effects are more apparent if washing is used in the recovery stage compared with the water immersion. One probable explanation is that the soft segment molecular chains may have longer time for recovering their original shapes as the washing time is longer than the immersion time.

9.4.3 Effect of Drying Method

The flat dry, line dry and tumble dry were used in the experiment. Comparing these three drying methods, it is found that tumble dry is the best method to dry the fabric as the tumble dry can facilitate the shape memory effects of fabrics. Compared the line dry and tumble dry, it is likely that tumble dry is better than line dry as the temperature (66°C) of tumble dry is sufficient to allow free movement of molecular chains in soft segments. However, regarding the flat dry and line dry, they do not provide the heat stimulation to samples and then these samples cannot be further stimulated by heat in the drying stage.

Based on these three types of effect on fabric shape memory effects, this conclusion appears to suggest that the optimum condition for the fabric shape memory effects is to wash fabrics at 60°C and dry fabrics using a tumble dry.

9.5 Objective Evaluation of Flat Appearance and Crease Retention in Water

The objective evaluation method was developed and it is more effective compared with the subjective evaluation method as the results were measured and calculated using new equations. The objective evaluation method was established based on the AATCC Test Method 66 and the Wrinkle Recovery Tester was used to measure the Original Angles (Of and Oc) and the Shape Memory Angles (Mf and Mc). These measured values were used in the newly developed equations of Shape Memory Coefficients (Sf% and Sc%) to characterize the fabric shape memory effects.

Later on, it was found that the Shape Memory Coefficient of flat samples (Sf%) can be simplified. In addition, a limitation of Shape Memory Coefficient of creased samples (Sc%) was found. As a result, the Flat Recovery % of flat samples (FRec%) and the Crease Recovery % of creased samples (CRec%) were developed to simplify the equation and overcome the limitation respectively.

9.5.1 Evaluation using Shape Memory Coefficients

The Shape Memory Coefficients (Sf% and Sc%) were established to determine the fabric shape memory effects of flat samples and creased samples respectively. From the findings, it is clear that there is no relationship between the wrinkle recovery angle and the Shape Memory Angle as their correlation coefficient is 0.01. It can be concluded that a shape memory fabric with a good wrinkle recovery angle might not have a good Shape Memory Angle at the same time.

Based on the regression analysis, it concludes that there is a strong linear relationship between Shape Memory Angles and Subjective Ratings for both flat and creased samples respectively at the 0.05 level of significance. However, Shape Memory Angles are not the best indication of the fabric shape memory effects. It is because the higher is the Shape Memory Angle (Mf), the greater is the SA Rating on flat fabrics; but the higher is the Shape Memory Angle (Mc), the smaller is the CR Rating on creased fabrics. As a result, the Shape Memory Coefficients (Sf% and Sc%) were developed to determine the fabric shape memory effects effectively. Shape Memory Coefficients also have a very strong linear relationship with Shape Memory Angles.

There was a good linear correlation between the Shape Memory Coefficients and the Subjective Ratings of both flat and creased samples. The correlation coefficient (r) of flat samples and creased samples were 0.92 and 0.86 respectively. The result implies that the Shape Memory Coefficients can evaluate the fabric shape memory effects effectively.

From the findings, most treated samples have a higher Shape Memory Coefficients compared with untreated samples. This shows that the fabric shape memory effects exist in many treated samples. However, not all of treated samples can possess the high fabric shape memory effects of flat appearance and crease retention at the same time. The results suggested that only sample 35 has Sf% = 94 and Sc%=97 at the same time. Therefore, sample 35 has a comparatively satisfied flat appearance and crease retention than other shape memory samples.

9.5.2 Limitation of Shape Memory Coefficients

Shape Memory Coefficients appear to evaluate the shape memory effects of fabrics effectively according to the mentioned findings. Nevertheless, it was discovered that the Shape Memory Coefficient of flat samples (Sf%) can be simplified to the Flat Recovery % (FRec%). The calculated value of FRec% was the almost same as that of Sf%. This means that the FRec% can represent the fabric shape memory effect of flat appearance. The higher is the FRec%, the larger fabric shape memory effect of flat appearance will have.

With regard to the Shape Memory Coefficient of creased samples, it was found that the Sc% cannot show the actual performance of fabric recovery if the Original Angle (Oc) of samples are quite large and the difference between Oc and Mc is small at the same time. As a result, the Crease Recovery % (CRec%) was established and it can overcome the limitation. It is because the CRec% considers the crease setting ability of creased samples.

9.5.3 Evaluation using Improved Equations

The Flat Recovery % (FRec%) and Crease Recovery % (CRec%) were used to determine the fabric shape memory effect of flat appearance and crease retention. In terms of FRec%, it was indicated that there is a strong relationship between the FRec% and SA Rating and this means that the FRec% can represent the fabric shape memory effect of flat appearance effectively. From the results, the FRec% of many treated samples was higher than the FRec% of the untreated sample and the treated samples also have higher SA Ratings compared with the untreated one. The flat samples tend to recover their original flat shapes while the FRec% is higher.

Regarding the CRec%, the result showed that there is a strong linear relationship between CRec% and CR Rating. This implies that CRec% can represent the fabric shape memory effect of crease retention effectively. The treated creased samples tend to recover their original creased shapes and they have higher fabric shape memory effect of crease retention when the CRec% is higher. Accordingly to the findings, Sample 35 has the highest CRec% of 96.00% and it is over 35% recovery compared with the untreated sample.

9.6 Evaluation of Flat Appearance and Crease Retention in Air

After investigating the fabric shape memory effects in water, it is interesting to explore the shape memory effects of fabrics in another medium, which is the air. The subjective and objective evaluation methods were used to examine the fabric shape memory effects of flat appearance and crease retention in air at various temperatures and relative humidities in a Conditioning Chamber. It was found that both evaluation methods can evaluate the fabric shape memory effects.

9.6.1 Effect of Air Temperature

The air temperature can be kept and adjusted in a Conditioning Chamber. According to the investigation, it was revealed that the fabric shape memory effects of flat appearance and crease retention are higher when the air temperature is high as at 60℃ with various relative humidities. It can be shown that air temperature as at 60°C can stimulate the shape memory effects of fabrics as the high temperature can reach the switch temperature of polymers in fabrics. Then, the soft segment crystals will melt and the molecular chains of the soft segments can move freely and quickly. Thus, the recovering ability of treated samples at 60°C is better than that at 25°C.

9.6.2 Effect of Relative Humidity

Various relative humidities were used in the experiment and they are 25% RH, 65% RH and 90% RH in the Conditioning Chamber. It was revealed that the higher relative humidity can give the higher fabric shape memory effect of flat appearance but lower fabric shape memory effect of crease retention. It may be concluded that the fabric recovering ability in air may be affected by relative humidity significantly.

In terms of flat appearance, higher relative humidity increases the SA Rating of samples. The higher value of flat appearance of fabrics may be caused by an increase of water molecules in air. Much water molecules in air can penetrate into the cellulose network of cotton and break the hydrogen bonding between the cellulose molecular chains. As a result, the mass of cellulose is softened and the cotton samples become less rigid. The fabric weight and the gravity on fabrics increase and this makes the flat sample to become flat. In addition, the conductivity of heat may increase when the relative humidity increases. Thus, the shape memory polymers in fabrics can recover their original flat shape more easily. It can be concluded that water may enhance the shape memory effects of fabrics.

In terms of crease retention, higher relative humidity decreases the CR Rating of samples. When the relative humidity was 90% RH, the fabric shape memory effect of crease retention was quite small. It may be because water molecules are drawn up between the various layers or walls of cotton more easily and cotton fibre becomes softer. The creased shape of fabrics may be pulled down due to the gravity and the increase of the fabric weight. The effect of water may be larger than the recovery force in the soft segment of shape memory polymers in fabrics. Therefore, the creased line in a horizontal direction of treated fabrics cannot be kept well in the Conditioning Chamber even they have fabric shape memory effects. The deformed shapes of treated fabrics cannot recover their original creased shape easily if the humidity is too high.

In shorts, it may be concluded that the optimum condition for the fabric recovery of flat appearance is in air at 60°C and 90% RH and the optimum condition for the fabric recovery of crease retention is in air at 60°C and 35% RH. These results lead us to infer that the most optimum air condition for a sample to recover its original flat shape and original creased shape together is at 60°C and 65% RH as both results of SA Rating and CR Rating are satisfactory in this condition.

9.6.3 Evaluation using New Equations

The Flat Recovery % (FRec%) and Crease Recovery % (CRec%) were used in the objective evaluation in the air test. It was discovered that the effect of air temperatures and relative humidities on the fabric shape memory effects in the objective evaluation was similar to that in the subjective evaluation. However, the FRec% and CRec% can represent the fabric recovering ability more clearly and accurately since they were calculated from the measured values of Original Angles and Shape Memory Angles. There is also a strong linear relationship between the FRec% and SA Rating for flat samples and the CRec% and CR Rating for creased samples significantly.

Moreover, it was discovered that both the FRec% of treated flat samples and CRec% of treated creased samples were above 85% which was much higher than the recovery % of untreated samples in the air condition at 60ºC and 65% RH. For the untreated samples, the FRec% of flat samples and CRec% of creased samples were only 76%

and 60% respectively. We can conclude that the optimum relative humidity for fabric recovery of flat appearance and crease retention is 65% RH and the optimum air temperature is the high temperature as at switch temperature (60ºC). Therefore, the findings in the objective evaluation are similar to that in the subjective evaluation.

9.7 Relationship of Fabric Shape Memory Effects in Water and Air

After examining the fabric shape memory effects in water and air separately, the relationship of fabric shape memory effects in water and air was also explored under the condition of 60ºC in water or air and 65% RH in air. The results indicated that the recovering ability of flat and creased samples in water with tumble dry were much higher than that in air with no dry. It can be concluded that the fabric shape memory effects of flat appearance and crease retention in water is larger than that in hot air. The findings imply that water can enhance the shape memory effects of fabrics and it may be because the conductivity of heat in water is higher than that in air.

Comparing between the samples which recovered in air with line dry and the samples which recovered in water with line dry, it was discovered that the fabric shape memory effects in water is also better than that in air. The result shows that line dry may not help in the shape recovery of samples in air.

However, if the tumble dry was used in the air and water test, the finding shows that tumble dry can increase the fabric shape memory effects and it can enhance the shape recovery of samples in air and water. Generally speaking, the shape memory effects of fabrics are different if they are recovered in various media for the shape recovery and dried by different drying methods.

9.8 Objective Evaluation of Fabric Bagging Recovery Effect in Water

Other than the fabric shape memory effect of flat appearance and crease retention, the fabric bagging recovery effect was evaluated using the new objective method. The Original Length (Op, Ot), Deformed Length (Dp, Dt) and Recovered Length (Rp, Rt) were measured from the samples and these values were used in the new equations including the Bagging Warp Recovery % (BPR%) and the Bagging Weft Recovery % (BTR%). Furthermore, the Bagging Recovery Rating (BRR) was developed to integrate the BPR% and BTR% in a single value.

The bagging recovery percentages of fabrics in warp and weft direction were found and the method can represent the fabric bagging recovery effects in both warp and weft direction instead of the bagging height. On the whole, the evaluation method for evaluating the bagging recovery effect is developed successfully.

From the findings, the bagging recovery effect does not exist in untreated samples. For the treated samples, it was found that the BPR% and BTR% of samples in hot water as at switch temperature (60ºC) was higher than that in cold water as at 25ºC. This means that the bagging recovery effect exists in treated samples and they are temperature sensitive. In addition, the fabric bagging recovery effect can be stimulated by hot water as at switch temperature (60ºC) but it cannot be stimulated by cold water (25ºC).

Comparing the fabric bagging recovery effect between the knitted and woven fabrics, it was explored that the knitted treated samples (K1) have a much higher BPR% and BTR% compared with the values of woven treated fabrics (C3 and C7) when the samples were put in hot water as at 60°C. The BRR of knitted fabrics in hot water was also much higher than the BRR of woven fabrics. We can conclude that the knitted fabric has higher bagging recovery effect than the woven fabrics.

9.9 Summary

From the above conclusions, it is clear that both subjective and objective evaluation methods were developed to evaluate the fabric shape memory effects of flat appearance, crease retention and bagging recovery under various testing conditions successfully. Some equipment, the experimental processes and the new equations were established in this research.

In conclusion, this study revealed that the shape memory fabrics are the temperature sensitive products which can respond to temperature changes and they can be stimulated in water and air at switch temperature. The results imply that there are many factors that can influence the fabric shape memory effects. Apart from the temperature, other factors such as the washing, relative humidity and tumble dry can also affect the shape memory effects of fabrics. On the whole, a comprehensive evaluation of shape memory fabrics was achieved successfully.

9.10 Recommendation for Future Work

The major objectives of the research project have been achieved. However, further work is necessary in order to improve and further develop evaluation techniques for new researches and industrial applications as the shape memory fabrics may be commercialized in the near future.

The developed evaluation methods in the present research will be useful in the evaluation of shape memory fabrics which are spun by shape memory filaments. It is because the current developed methods consider the parameters of temperature sensitivity, shape deformation and shape recovery in the experimental design. Therefore, applying the current developed methods to another type of shape memory fabrics is highly recommended in the future.

It is also recommended to develop new evaluation method to characterize the shape memory fibre instead of the shape memory fabric only. Then, the shape memory effect of fibres can be discovered.

APPENDICES

Appendix A

Determination of sample size of subjective evaluation of flat appearance and crease retention in water:

Testing conditions:
Water temperature = 60 °C
Recovery: washing
Drying: tumble dry

Pilot study:

(i) Flat sample

Preliminary sample of size: (observations)	90 observations
No. of observers for each sample	3
Sample Mean ($\bar{x}$)	3.5
Standard Deviation	0.127
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.013
Upper Confidence Limit (UCL)	0.026
Lower Confidence Limit (LCL)	0.026
Coefficient of variation (CV)	3.587
% Error: (E/ $\bar{x}$) *100	0.741
Required sample size (n)	3 (as 7 observations)

(ii) Creased sample

Preliminary sample of size: (observations)	90 observations
No. of observers for each sample	3
Sample Mean ($\bar{x}$)	3.7
Standard Deviation	0.151
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.016
Upper Confidence Limit (UCL)	0.031
Lower Confidence Limit (LCL)	0.031
Coefficient of variation (CV)	4.055
% Error: (E/ $\bar{x}$) *100	0.838
Required sample size (n)	3 (as 9 observations)

Determination of sample size of subjective evaluation of flat appearance and crease retention in air:

Testing conditions:

Air temperature = 60 °C
Relative humidity = 65% R.H.
Recovery: in the Conditioning Chamber
Drying: in the Conditioning Chamber

Pilot study:

(i) Flat sample

Preliminary sample of size: (observations)	90 observations
No. of observers for each sample	3
Sample Mean ($\bar{x}$)	3.1
Standard Deviation	0.143
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.015
Upper Confidence Limit (UCL)	0.030
Lower Confidence Limit (LCL)	0.030
Coefficient of variation (CV)	4.648
% Error: (E/ $\bar{x}$) *100	0.960
Required sample size (n)	3 (as 8 observations)

(ii) Creased sample

Preliminary sample of size: (observations)	90 observations
No. of observers for each sample	3
Sample Mean ($\bar{x}$)	3.2
Standard Deviation	0.149
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.016
Upper Confidence Limit (UCL)	0.031
Lower Confidence Limit (LCL)	0.031
Coefficient of variation (CV)	4.737
% Error: (E/ $\bar{x}$) *100	0.979
Required sample size (n)	3 (as 9 observations)

Determination of sample size of objective evaluation of flat Appearance and crease retention in water

Testing conditions:

Water temperature = 60 °C
Recovery: water immersion
Drying: hold on the flame

Pilot study:

(i) Flat sample (long dimension parallel to the warp direction)

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	168.4
Standard Deviation	1.973
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.334
Upper Confidence Limit (UCL)	0.654
Lower Confidence Limit (LCL)	0.654
Coefficient of variation (CV)	1.172
% Error: (E/ $\bar{x}$) *100	0.388
Required sample size (n)	3.74 = 4.0 (rounded up)

(ii) Flat sample (long dimension parallel to the weft direction)

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	171.3
Standard Deviation	2.037
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.344
Upper Confidence Limit (UCL)	0.675
Lower Confidence Limit (LCL)	0.675
Coefficient of variation (CV)	1.190
% Error: (E/ $\bar{x}$) *100	0.394
Required sample size (n)	3.99 = 4.0 (rounded up)

(iii) Creased sample

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	38.5
Standard Deviation	1.884
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.319
Upper Confidence Limit (UCL)	0.624
Lower Confidence Limit (LCL)	0.624
Coefficient of variation (CV)	4.897
% Error: (E/ $\bar{x}$) *100	1.622
Required sample size (n)	3.41 = 4.0 (rounded up)

Determination of sample size of objective evaluation of flat Appearance and crease retention in air

Testing conditions:

Air temperature = 60 °C
Relative humidity = 65% R.H.
Recovery: in the Conditioning Chamber
Drying: in the Conditioning Chamber

Pilot study:

(i) Flat sample (long dimension parallel to the warp direction)

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	153.2
Standard Deviation	1.891
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.320
Upper Confidence Limit (UCL)	0.627
Lower Confidence Limit (LCL)	0.627
Coefficient of variation (CV)	1.234
% Error: (E/ $\bar{x}$) *100	0.409
Required sample size (n)	3.43 = 4 (rounded up)

(ii) Flat sample (long dimension parallel to the weft direction)

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	168.8
Standard Deviation	2.386
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.403
Upper Confidence Limit (UCL)	0.791
Lower Confidence Limit (LCL)	0.791
Coefficient of variation (CV)	1.414
% Error: (E/ $\bar{x}$) *100	0.468
Required sample size (n)	5.47 = 6 (rounded up)

(iii) Creased sample

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	67.8
Standard Deviation	2.030
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.343
Upper Confidence Limit (UCL)	0.673
Lower Confidence Limit (LCL)	0.673
Coefficient of variation (CV)	2.996
% Error: (E/ $\bar{x}$) *100	0.993
Required sample size (n)	3.96 = 4 (rounded up)

Determination of sample size of objective evaluation of bagging recovery effect:

Testing conditions:

Water temperature = 60 °C
Recovery: water immersion
Drying: line dry

Pilot study:

(i) Sample - Recovered warp length (Rp)

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	45.7
Standard Deviation	0.382
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.065
Upper Confidence Limit (UCL)	0.127
Lower Confidence Limit (LCL)	0.127
Coefficient of variation (CV)	0.837
% Error: (E/ $\bar{x}$) *100	0.277
Required sample size (n)	6.24 = 7 (rounded up)

(ii) Sample - Recovered weft length (Rt)

Preliminary sample of size: (observations)	35
Sample Mean ($\bar{x}$)	45.5
Standard Deviation	0.343
Critical value ($Z_{\alpha/2}$)	1.96
Standard Error (S.E.)	0.058
Upper Confidence Limit (UCL)	0.114
Lower Confidence Limit (LCL)	0.114
Coefficient of variation (CV)	0.754
% Error: (E/ $\bar{x}$) *100	0.250
Required sample size (n)	5.02 = 6 (rounded up)

Appendix B (1-4)

[Appendix B1]

Fabric Shape Memory Effect of Different Types of Fabrics

➢ SA Rating: flat appearance in water (recovery temperature: 50°C)

Sample code	Cotton Cu	Cotton C1	Cotton C2	Silk Su	Silk S1	Silk S2	Ramie Ru	Ramie R1	Ramie R2
Mean	2.5	2.8	2.8	4.5	4.5	4.5	1.5	1.5	1.5
Standard Deviation	0.07	0.14	0.13	0.12	0.00	0.06	0.08	0.07	0.07
Critical value ($t_{\alpha/2}$)	2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110
Standard Error (S.E.)	0.02	0.03	0.03	0.03	0.00	0.02	0.02	0.02	0.02
Upper Confidence Limit (UCL)	0.035	0.072	0.066	0.059	0.000	0.032	0.041	0.033	0.033
Lower Confidence Limit (LCL)	0.035	0.072	0.066	0.059	0.000	0.032	0.041	0.033	0.033
Coefficient of variation (CV)	2.84	5.12	4.69	2.64	0.00	1.44	5.61	4.38	4.38
% Error: (E/ Mean) *100	1.41	2.55	2.33	1.31	0.00	0.72	2.79	2.18	2.18
Range	0.2	0.4	0.4	0.5	0.0	0.2	0.3	0.2	0.2
Minimum	2.3	2.6	2.6	4.0	4.5	4.3	1.3	1.5	1.5
Maximum	2.5	3.0	3.0	4.5	4.5	4.5	1.6	1.7	1.7

➢ CR Rating: crease retention in water (recovery temperature: 50°C)

Sample code	Cotton Cu	Cotton C1	Cotton C2	Silk Su	Silk S1	Silk S2	Ramie Ru	Ramie R1	Ramie R2
Mean	1.0	3.5	3.0	1.0	1.5	1.5	1.0	1.5	2.0
Standard Deviation	0.00	0.18	0.09	0.00	0.06	0.08	0.00	0.03	0.08
Critical value ($t_{\alpha/2}$)	2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110
Standard Error (S.E.)	0.00	0.04	0.02	0.00	0.01	0.02	0.00	0.01	0.02
Upper Confidence Limit (UCL)	0.000	0.089	0.046	0.000	0.029	0.039	0.000	0.017	0.038
Lower Confidence Limit (LCL)	0.000	0.089	0.046	0.000	0.029	0.039	0.000	0.017	0.038
Coefficient of variation (CV)	0.00	5.14	3.02	0.00	3.90	5.32	0.00	2.29	3.90
% Error: (E/ Mean) *100	0.00	2.56	1.50	0.00	1.94	2.65	0.00	1.14	1.94
Range	0.0	0.7	0.3	0.0	0.2	0.2	0.0	0.2	0.2
Minimum	1.0	3.0	3.0	1.0	1.3	1.3	1.0	1.4	1.8
Maximum	1.0	3.7	3.3	1.0	1.5	1.5	1.0	1.6	2.0

[Appendix B2]

Effect of Temperature (Water Immersion, C1 Fabric)

- SA Rating: flat appearance (recovery temperature: 15, 25, 40, 60 °C)

Recovery temperature: 15 °C

Sample code	0	1	2	3	4	5	6	7	8
Mean	2.5	1.5	1.5	1.0	2.0	1.0	1.0	1.0	1.3
Standard Deviation	0.00	0.00	0.09	0.00	0.11	0.00	0.00	0.00	0.08
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.00	0.03	0.00	0.04	0.00	0.00	0.00	0.03
Upper Confidence Limit (UCL)	0.000	0.000	0.068	0.000	0.086	0.000	0.000	0.000	0.060
Lower Confidence Limit (LCL)	0.000	0.000	0.068	0.000	0.086	0.000	0.000	0.000	0.060
Coefficient of variation (CV)	0.00	0.00	5.71	0.00	5.59	0.00	0.00	0.00	6.07
% Error: (E/ mean) *100	0.00	0.00	4.39	0.00	4.30	0.00	0.00	0.00	4.66
Range	0.0	0.0	0.2	0.0	1.0	0.0	0.0	0.0	0.4
Minimum	2.5	1.5	1.5	1.0	1.8	1.0	1.0	1.0	1.2
Maximum	2.5	1.5	1.7	1.0	2.2	1.0	1.0	1.0	1.4

Recovery temperature: 25 °C

Sample code	0	1	2	3	4	5	6	7	8
Mean	2.5	2.0	2.0	1.8	2.0	1.0	1.0	1.3	1.5
Standard Deviation	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.08	0.00
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.00
Upper Confidence Limit (UCL)	0.000	0.000	0.000	0.123	0.000	0.000	0.000	0.060	0.000
Lower Confidence Limit (LCL)	0.000	0.000	0.000	0.123	0.000	0.000	0.000	0.060	0.000
Coefficient of variation (CV)	0.00	0.00	0.00	9.16	0.00	0.00	0.00	6.45	0.00
% Error: (E/ mean) *100	0.00	0.00	0.00	7.04	0.00	0.00	0.00	4.96	0.00
Range	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0
Minimum	2.5	2.0	2.0	1.5	2.0	1.0	1.0	1.1	1.5
Maximum	2.5	2.0	2.0	2.0	2.0	1.0	1.0	1.3	1.5

Recovery temperature: 40 °C

Sample code	0	1	2	3	4	5	6	7	8
Mean	2.5	3.0	2.5	2.5	2.5	1.5	1.5	1.5	1.8
Standard Deviation	0.00	0.10	0.00	0.25	0.00	0.05	0.00	0.11	0.20
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.03	0.00	0.08	0.00	0.02	0.00	0.04	0.07
Upper Confidence Limit (UCL)	0.000	0.077	0.000	0.192	0.000	0.038	0.000	0.084	0.154
Lower Confidence Limit (LCL)	0.000	0.077	0.000	0.192	0.000	0.038	0.000	0.084	0.154
Coefficient of variation (CV)	0.00	3.30	0.00	10.00	0.00	3.33	0.00	7.18	11.11
% Error: (E/ mean) *100	0.00	2.53	0.00	7.69	0.00	2.56	0.00	5.52	8.54
Range	0.0	0.3	0.0	1.0	0.0	1.0	0.0	1.0	0.5
Minimum	2.5	3.0	2.5	2.0	2.5	1.4	1.5	1.0	1.5
Maximum	2.5	3.3	2.5	3.0	2.5	1.6	1.5	2.0	2.0

Recovery temperature: 60 °C

Sample code	0	1	2	3	4	5	6	7	8
Mean	2.5	3.3	3.0	3.3	3.0	1.5	1.5	2.0	2.3
Standard Deviation	0.00	0.25	0.00	0.25	0.00	0.00	0.00	0.25	0.26
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.08	0.09
Upper Confidence Limit (UCL)	0.000	0.192	0.000	0.192	0.000	0.000	0.000	0.192	0.203
Lower Confidence Limit (LCL)	0.000	0.192	0.000	0.192	0.000	0.000	0.000	0.192	0.203
Coefficient of variation (CV)	0.00	7.50	0.00	7.50	0.00	0.00	0.00	12.50	11.57
% Error: (E/ mean) *100	0.00	5.77	0.00	5.77	0.00	0.00	0.00	9.61	8.89
Range	0.0	0.5	0.0	0.5	0.0	0.0	0.0	1.0	0.5
Minimum	2.5	3.0	3.0	3.0	3.0	1.5	1.5	1.5	2.0
Maximum	2.5	3.5	3.0	3.5	3.0	1.5	1.5	2.5	2.5

- CR Rating: crease retention (recovery temperature: 15, 25, 40, 60 °C)

Recovery temperature: 15 °C

Sample code	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean	1.0	2.8	2.8	2.8	3.0	3.3	2.8	2.5	2.0
Standard Deviation	0.00	0.25	0.25	0.25	0.00	0.25	0.25	0.00	0.00
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.08	0.08	0.08	0.00	0.08	0.08	0.00	0.00
Upper Confidence Limit (UCL)	0.000	0.192	0.192	0.192	0.000	0.192	0.192	0.000	0.000
Lower Confidence Limit (LCL)	0.000	0.192	0.192	0.192	0.000	0.192	0.192	0.000	0.000
Coefficient of variation (CV)	0.00	8.82	8.82	8.82	0.00	7.50	8.82	0.00	0.00
% Error: (E/ mean) *100	0.00	6.78	6.78	6.78	0.00	5.77	6.78	0.00	0.00
Range	0.0	0.5	0.5	0.5	0.0	0.5	0.5	0.0	0.0
Minimum	1.0	2.5	2.5	2.5	3.0	3.0	2.5	2.5	2.0
Maximum	1.0	3.0	3.0	3.0	3.0	3.5	3.0	2.5	2.0

Recovery temperature: 25 °C

Sample code	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean	1.0	2.8	2.8	2.8	2.5	2.5	2.3	2.0	1.8
Standard Deviation	0.00	0.25	0.24	0.24	0.00	0.29	0.25	0.00	0.21
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.08	0.08	0.08	0.00	0.10	0.08	0.00	0.07
Upper Confidence Limit (UCL)	0.000	0.192	0.187	0.187	0.000	0.221	0.192	0.000	0.164
Lower Confidence Limit (LCL)	0.000	0.192	0.187	0.187	0.000	0.221	0.192	0.000	0.164
Coefficient of variation (CV)	0.00	8.82	8.58	8.58	0.00	11.72	10.71	0.00	11.54
% Error: (E/ mean) *100	0.00	6.78	6.60	6.60	0.00	9.01	8.24	0.00	8.87
Range	0.0	0.5	0.5	0.5	0.0	0.8	0.5	0.0	0.5
Minimum	1.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0	1.5
Maximum	1.0	3.0	3.0	3.0	2.5	2.8	2.5	2.0	2.0

Recovery temperature: 40 °C

Sample code	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean	1.0	1.8	2.5	2.3	1.5	1.8	1.8	1.5	1.3
Standard Deviation	0.00	0.21	0.00	0.25	0.00	0.21	0.14	0.00	0.12
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.07	0.00	0.08	0.00	0.07	0.05	0.00	0.04
Upper Confidence Limit (UCL)	0.000	0.164	0.000	0.192	0.000	0.164	0.109	0.000	0.095
Lower Confidence Limit (LCL)	0.000	0.164	0.000	0.192	0.000	0.164	0.109	0.000	0.095
Coefficient of variation (CV)	0.00	11.54	0.00	10.71	0.00	11.54	7.72	0.00	9.19
% Error: (E/ mean) *100	0.00	8.87	0.00	8.24	0.00	8.87	5.93	0.00	7.07
Range	0.0	0.5	0.0	0.5	0.0	0.5	0.5	0.0	0.5
Minimum	1.0	1.5	2.5	2.0	1.5	1.5	1.6	1.5	1.0
Maximum	1.0	2.0	2.5	2.5	1.5	2.0	2.0	1.5	1.2

Recovery temperature: 60 °C

Sample code	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Standard Deviation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Upper Confidence Limit (UCL)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Confidence Limit (LCL)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coefficient of variation (CV)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% Error: (E/ mean) *100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Range	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minimum	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Maximum	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[Appendix B3]

Effect of Temperature (Water Immersion, C3 Fabric)

- SA Rating: flat appearance (recovery temperature: 25 and 60 °C)

Temperature: 25 °C / Line dry

Sample code	**U**	**SM4**	**SM11**	**SM17**	**SM22**
Mean	1.0	2.2	2.3	2.3	2.4
Standard Deviation	0.00	0.14	0.13	0.13	0.10
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.05	0.04	0.04	0.03
Upper Confidence Limit (UCL)	0.000	0.109	0.102	0.100	0.080
Lower Confidence Limit (LCL)	0.000	0.109	0.102	0.100	0.080
Coefficient of variation (CV)	0.00	6.61	5.84	5.71	4.27
% Error: (E/ mean) *100	0.00	5.08	4.49	4.39	3.28
Range	0.0	0.4	0.3	0.3	0.2
Minimum	1.0	2.0	2.1	2.2	2.3
Maximum	1.0	2.4	2.4	2.5	2.5

Temperature: 60 °C / Line dry

U	**SM4**	**SM11**	**SM17**	**SM22**
1.0	2.6	2.7	2.6	2.8
0.00	0.09	0.22	0.15	0.10
2.306	2.306	2.306	2.306	2.306
0.00	0.03	0.07	0.05	0.03
0.000	0.067	0.168	0.115	0.077
0.000	0.067	0.168	0.115	0.077
0.00	3.33	7.97	5.77	3.61
0.00	2.56	6.13	4.43	2.78
0.0	0.2	0.5	0.3	0.2
1.0	2.5	2.5	2.5	2.7
1.0	2.7	3.0	2.8	2.9

- CR Rating: crease retention (recovery temperature: 25 and 60 °C)

Temperature: 25 °C / Line dry

Sample code	**U**	**SM4**	**SM11**	**SM17**	**SM22**
Mean	1.0	2.1	2.1	2.4	2.6
Standard Deviation	0.00	0.10	0.10	0.10	0.10
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.03	0.03	0.03	0.03
Upper Confidence Limit (UCL)	0.000	0.077	0.077	0.077	0.077
Lower Confidence Limit (LCL)	0.000	0.077	0.077	0.077	0.077
Coefficient of variation (CV)	0.00	4.84	4.84	4.11	3.90
% Error: (E/ mean) *100	0.00	3.72	3.72	3.16	2.99
Range	0.0	0.2	0.2	0.2	0.2
Minimum	1.0	2.0	2.0	2.3	2.5
Maximum	1.0	2.2	2.2	2.5	2.7

Temperature: 60 °C / Line dry

U	**SM4**	**SM11**	**SM17**	**SM22**
1.0	2.2	2.4	2.8	2.9
0.00	0.05	0.10	0.14	0.10
2.306	2.306	2.306	2.306	2.306
0.00	0.02	0.03	0.05	0.03
0.000	0.038	0.077	0.107	0.077
0.000	0.038	0.077	0.107	0.077
0.00	2.24	4.11	4.94	3.41
0.00	1.72	3.16	3.80	2.62
0.0	0.1	0.2	0.3	0.2
1.0	2.2	2.3	2.7	2.8
1.0	2.3	2.5	3.0	3.0

ANOVA Test **(at the 0.05 level of significance)**

Effect among temperatures on fabric shape memory effects

A response variable	Factor	Sample	Drying Method	F	P-Value	Significant difference (D) / Not significant difference (ND)
Fabric shape memory effect of flat appearance (SA Rating)	Temperature	U	Line dry	-	-	ND
		SM4		64.000	0.0000	D
		SM11		30.154	0.0000	D
		SM17		23.690	0.0002	D
		SM22		46.704	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Temperature	U	Line dry	-	-	ND
		SM4		20.000	0.0004	D
		SM11		60.500	0.0000	D
		SM17		46.226	0.0000	D
		SM22		60.500	0.0000	D

[Appendix B4]

Effect of Temperature, Washing and Drying

➢ SA Rating: flat appearance (recovery temperature: 25 and 60 °C)

Temperature: 25 °C / Line dry — Temperature: 60 °C / Line dry

Sample code	U	SM4	SM11	SM17	SM22	U	SM4	SM11	SM17	SM22
Mean	1.0	2.7	2.9	2.9	3.0	1.0	2.9	3.0	2.9	3.0
Standard Deviation	0.00	0.15	0.09	0.10	0.05	0.00	0.10	0.05	0.10	0.05
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.05	0.03	0.03	0.02	0.00	0.03	0.02	0.03	0.02
Upper Confidence Limit (UCL)	0.000	0.115	0.067	0.077	0.038	0.000	0.077	0.038	0.075	0.038
Lower Confidence Limit (LCL)	0.000	0.115	0.067	0.077	0.038	0.000	0.077	0.038	0.075	0.038
Coefficient of variation (CV)	0.00	5.56	2.99	3.41	1.69	0.00	3.41	1.69	3.33	1.65
% Error: (E/ mean) *100	0.00	4.27	2.30	2.62	1.30	0.00	2.62	1.30	2.56	1.27
Range	0.0	0.3	0.2	0.2	0.1	0.0	0.2	0.1	0.2	0.1
Minimum	1.0	2.5	2.8	2.8	2.9	1.0	2.8	2.9	2.8	3.0
Maximum	1.0	2.8	3.0	3.0	3.0	1.0	3.0	3.0	3.0	3.1

Temperature: 25 °C / Tumble dry — Temperature: 60 °C / Tumble dry

Sample code	U	SM4	SM11	SM17	SM22	U	SM4	SM11	SM17	SM22
Mean	1.0	3.5	3.5	3.7	3.9	1.0	3.7	3.7	3.8	4.4
Standard Deviation	0.00	0.05	0.05	0.10	0.13	0.00	0.05	0.09	0.15	0.15
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.02	0.02	0.03	0.04	0.00	0.02	0.03	0.05	0.05
Upper Confidence Limit (UCL)	0.000	0.038	0.038	0.077	0.102	0.000	0.038	0.067	0.115	0.118
Lower Confidence Limit (LCL)	0.000	0.038	0.038	0.077	0.102	0.000	0.038	0.067	0.115	0.118
Coefficient of variation (CV)	0.00	1.44	1.42	2.68	3.42	0.00	1.34	2.34	3.95	3.49
% Error: (E/ mean) *100	0.00	1.11	1.09	2.06	2.63	0.00	1.03	1.80	3.03	2.69
Range	0.0	0.0	0.0	0.2	0.3	0.0	0.1	0.2	0.3	0.3
Minimum	1.0	3.4	3.5	3.6	3.7	1.0	3.7	3.6	3.7	4.2
Maximum	1.0	3.5	3.6	3.8	4.0	1.0	3.8	3.8	4.0	4.5

➢ Crease retention (recovery temperature: 25 and 60 °C)

Temperature: 25 °C / Line dry — Temperature: 60 °C / Line dry

Sample code	U	SM4	SM11	SM17	SM22	U	SM4	SM11	SM17	SM22
Mean	1.0	2.5	2.3	2.8	3.0	1.0	2.5	2.6	3.0	3.1
Standard Deviation	0.00	0.05	0.21	0.25	0.05	0.00	0.00	0.10	0.00	0.15
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.02	0.07	0.08	0.02	0.00	0.00	0.03	0.00	0.05
Upper Confidence Limit (UCL)	0.000	0.038	0.165	0.192	0.038	0.000	0.000	0.077	0.000	0.115
Lower Confidence Limit (LCL)	0.000	0.038	0.165	0.192	0.038	0.000	0.000	0.077	0.000	0.115
Coefficient of variation (CV)	0.00	1.97	9.38	8.82	1.65	0.00	0.00	3.90	0.00	4.84
% Error: (E/ mean) *100	0.00	1.52	7.21	6.78	1.27	0.00	0.00	2.99	0.00	3.72
Range	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.2	0.0	0.3
Minimum	1.0	2.5	2.0	2.5	3.0	1.0	2.5	2.5	3.0	3.0
Maximum	1.0	2.6	2.5	3.0	3.1	1.0	2.5	2.7	3.0	3.3

Temperature: 25 °C / Tumble dry — Temperature: 60 °C / Tumble dry

Sample code	U	SM4	SM11	SM17	SM22	U	SM4	SM11	SM17	SM22
Mean	1.0	3.5	3.6	3.8	4.0	1.0	4.0	4.0	4.0	4.0
Standard Deviation	0.00	0.05	0.09	0.18	0.00	0.00	0.05	0.00	0.05	0.0\5
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.02	0.03	0.06	0.00	0.00	0.02	0.00	0.02	0.02
Upper Confidence Limit (UCL)	0.000	0.038	0.072	0.139	0.000	0.000	0.038	0.000	0.038	0.038
Lower Confidence Limit (LCL)	0.000	0.038	0.072	0.139	0.000	0.000	0.038	0.000	0.038	0.038
Coefficient of variation (CV)	0.00	1.42	2.58	4.79	0.00	0.00	1.24	0.00	1.24	1.24
% Error: (E/ mean) *100	0.00	1.09	1.99	3.68	0.00	0.00	0.95	0.00	0.95	0.95
Range	0.0	0.1	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Minimum	1.0	3.5	3.5	3.6	4.0	1.0	4.0	4.0	4.0	4.0
Maximum	1.0	3.6	3.7	4.0	4.0	1.0	4.1	4.0	4.1	4.1

ANOVA Test **(at the 0.05 level of significance)**

Effect among temperatures on fabric shape memory effects

A response variable	Factor	Sample	Drying Method	F	P-Value	Significant difference (D) / Not significant difference (ND)
Fabric shape memory effect of flat appearance (SA Rating)	Temperature	U	Line dry	-	-	ND
		SM4		15.077	0.0013	D
		SM11		4.000	0.0628	ND
		SM17		0.057	0.8141	ND
		SM22		8.000	0.0121	D
Fabric shape memory effect of crease retention (CR Rating)	Temperature	U	Line dry	-	-	ND
		SM4		4.000	0.0628	ND
		SM11		12.376	0.0029	D
		SM17		4.000	0.0628	ND
		SM22		1.600	0.2240	ND
Fabric shape memory effect of flat appearance (SA Rating)	Temperature	U	Tumble dry	-	-	ND
		SM4		128.000	0.0000	D
		SM11		25.000	0.0001	D
		SM17		1.231	0.2837	ND
		SM22		63.210	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Temperature	U	Tumble dry	-	-	ND
		SM4		450.000	0.0000	D
		SM11		162.274	0.0000	D
		SM17		18.286	0.0006	D
		SM22		4.000	0.0628	ND

Effect among drying methods on fabric shape memory effects

A response variable	Factor	Sample	Washing temperature (°C)	F	P-Value	Significant difference (D) / Not significant difference (ND)
Fabric shape memory effect of flat appearance (SA Rating)	Drying method	U	25	-	-	ND
		SM4		211.600	0.0000	D
		SM11		361.000	0.0000	D
		SM17		288.000	0.0000	D
		SM22		364.500	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Drying method	U	25	-	-	ND
		SM4		1800.000	0.0000	D
		SM11		284.294	0.0000	D
		SM17		82.526	0.0000	D
		SM22		3364.000	0.0000	D
Fabric shape memory effect of flat appearance (SA Rating)	Drying method	U	60	-	-	ND
		SM4		460.800	0.0000	D
		SM11		484.000	0.0000	D
		SM17		217.078	0.0000	D
		SM22		646.331	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Drying method	U	60	-	-	ND
		SM4		8464.000	0.0000	D
		SM11		1849.000	0.0000	D
		SM17		3844.000	0.0000	D
		SM22		313.600	0.0000	D

Effect among recovery methods on fabric shape memory effects

A response variable	Factor	Sample	Washing temperature (°C)	F	P-Value	Significant difference (D) / Not significant difference (ND)
Fabric shape memory effect of flat appearance (SA Rating)	Recovery method	U	25	-	-	ND
		SM4		62.364	0.0000	D
		SM11		144.400	0.0000	D
		SM17		143.546	0.0000	D
		SM22		188.656	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Recovery method	U	25	-	-	ND
		SM4		156.800	0.0000	D
		SM11		7.921	0.0125	D
		SM17		19.862	0.0004	D
		SM22		156.800	0.0000	D
Fabric shape memory effect of flat appearance (SA Rating)	Recovery method	U	60	-	-	ND
		SM4		57.143	0.0000	D
		SM11		9.800	0.0065	D
		SM17		29.252	0.0001	D
		SM22		51.200	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Recovery method	U	60	-	-	ND
		SM4		256.000	0.0000	D
		SM11		8.000	0.0121	D
		SM17		14.629	0.0015	D
		SM22		7.692	0.0136	D

Appendix C (1-3)

[Appendix C1]

Evaluation using Shape Memory Coefficient

Wrinkle recovery angle (WRA) of flat samples

Warp direction

Smaple Number	Mean (Warp)	Standard Deviation (Warp)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	92	2.23	2.571	0.91	2.339	2.339	2.42	2.54
9	85	7.03	2.571	2.87	7.381	7.381	8.31	8.72
11	86	1.63	2.571	0.67	1.714	1.714	1.89	1.99
35	100	2.94	2.571	1.20	3.089	3.089	2.95	3.10
36	113	1.72	2.571	0.70	1.808	1.808	1.53	1.60
37	81	2.93	2.571	1.19	3.072	3.072	3.61	3.78
38	86	2.40	2.571	0.98	2.520	2.520	2.80	2.94
39	83	1.21	2.571	0.49	1.271	1.271	1.46	1.54
40	72	3.44	2.571	1.41	3.615	3.615	4.76	5.00
41	74	1.47	2.571	0.60	1.545	1.545	1.98	2.08
42	86	2.04	2.571	0.83	2.142	2.142	2.37	2.49
43	96	1.60	2.571	0.65	1.681	1.681	1.67	1.75
44	99	1.05	2.571	0.43	1.101	1.101	1.06	1.12
45	82	2.40	2.571	0.98	2.520	2.520	2.92	3.07
46	85	1.72	2.571	0.70	1.808	1.808	2.02	2.12
47	78	1.05	2.571	0.43	1.101	1.101	1.35	1.42
48	70	2.56	2.571	1.05	2.689	2.689	3.65	3.83
49-50	77	1.97	2.571	0.80	2.064	2.064	2.56	2.69
50	97	1.47	2.571	0.60	1.545	1.545	1.51	1.59
51	77	3.72	2.571	1.52	3.908	3.908	4.86	5.10
52	85	1.47	2.571	0.60	1.545	1.545	1.73	1.81
53	96	4.04	2.571	1.65	4.237	4.237	4.23	4.44
54	76	2.73	2.571	1.12	2.868	2.868	3.58	3.76
56	88	3.37	2.571	1.38	3.538	3.538	3.82	4.01
58	73	3.25	2.571	1.33	3.411	3.411	4.44	4.66

Weft direction

Smaple Number	Mean (Weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	96	0.98	2.571	0.40	1.032	1.032	1.03	1.08
9	90	2.07	2.571	0.84	2.168	2.168	2.29	2.40
11	97	1.83	2.571	0.75	1.926	1.926	1.89	1.98
35	107	2.32	2.571	0.95	2.431	2.431	2.17	2.28
36	116	1.94	2.571	0.79	2.037	2.037	1.67	1.75
37	86	2.66	2.571	1.09	2.790	2.790	3.08	3.23
38	93	1.47	2.571	0.60	1.545	1.545	1.58	1.66
39	86	2.99	2.571	1.22	3.142	3.142	3.49	3.66
40	71	1.37	2.571	0.56	1.434	1.434	1.93	2.03
41	80	2.32	2.571	0.95	2.431	2.431	2.90	3.05
42	93	1.94	2.571	0.79	2.037	2.037	2.09	2.19
43	101	2.99	2.571	1.22	3.142	3.142	2.96	3.11
44	103	3.39	2.571	1.38	3.559	3.559	3.31	3.47
45	92	3.14	2.571	1.28	3.296	3.296	3.40	3.57
46	97	2.71	2.571	1.11	2.848	2.848	2.80	2.94
47	88	2.43	2.571	0.99	2.549	2.549	2.78	2.91
48	82	2.56	2.571	1.05	2.689	2.689	3.13	3.29
49-50	89	2.73	2.571	1.12	2.868	2.868	3.06	3.21
50	110	3.60	2.571	1.47	3.779	3.779	3.28	3.44
51	80	2.40	2.571	0.98	2.520	2.520	3.01	3.16
52	89	1.94	2.571	0.79	2.037	2.037	2.18	2.29
53	100	1.64	2.571	0.67	1.724	1.724	1.65	1.73
54	92	2.94	2.571	1.20	3.089	3.089	3.21	3.37
56	101	2.86	2.571	1.17	2.999	2.999	2.83	2.97
58	77	3.19	2.571	1.30	3.346	3.346	4.15	4.36

Wrinkle recovery angle (WRA) of flat samples (Average value of warp and weft)

Sample Number	Mean (warp & weft)
U	94
9	88
11	92
35	103
36	115
37	84
38	90
39	84
40	72
41	77
42	90
43	99
44	101
45	87
46	91
47	83
48	76
49-50	83
50	104
51	78
52	87
53	98
54	84
56	95
58	75

Flat sample: Original Angle (Of)

Warp direction

Smaple Number	Mean (Warp)	Standard Deviation (Warp)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
9	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
11	180	0.41	2.571	0.17	0.428	0.428	0.23	0.24
35	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
36	178	0.52	2.571	0.21	0.542	0.542	0.29	0.30
37	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
38	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
39	179	0.52	2.571	0.21	0.542	0.542	0.29	0.30
40	178	0.82	2.571	0.33	0.857	0.857	0.46	0.48
41	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
42	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
43	179	0.82	2.571	0.33	0.857	0.857	0.46	0.48
44	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
45	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
46	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
47	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
48	179	0.75	2.571	0.31	0.790	0.790	0.42	0.44
49-50	178	0.82	2.571	0.33	0.857	0.857	0.46	0.48
50	179	0.98	2.571	0.40	1.032	1.032	0.55	0.58
51	178	0.82	2.571	0.33	0.857	0.857	0.46	0.48
52	178	0.82	2.571	0.33	0.857	0.857	0.46	0.48
53	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
54	178	0.82	2.571	0.33	0.857	0.857	0.46	0.48
56	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
58	178	0.41	2.571	0.17	0.428	0.428	0.23	0.24

Weft direction

Smaple Number	Mean (Weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
9	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
11	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
35	178	0.82	2.571	0.33	0.857	0.857	0.46	0.48
36	176	1.86	2.571	0.76	1.954	1.954	1.06	1.11
37	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
38	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
39	177	1.37	2.571	0.56	1.434	1.434	0.77	0.81
40	176	0.41	2.571	0.17	0.428	0.428	0.23	0.24
41	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
42	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
43	179	0.75	2.571	0.31	0.790	0.790	0.42	0.44
44	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
45	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
46	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
47	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
48	179	0.52	2.571	0.21	0.542	0.542	0.29	0.30
49-50	178	0.82	2.571	0.33	0.857	0.857	0.46	0.48
50	179	0.52	2.571	0.21	0.542	0.542	0.29	0.30
51	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
52	178	0.98	2.571	0.40	1.032	1.032	0.55	0.58
53	180	0.00	2.571	0.00	0.000	0.000	0.00	0.00
54	178	0.98	2.571	0.40	1.032	1.032	0.55	0.58
56	178	0.98	2.571	0.40	1.032	1.032	0.55	0.58
58	180	0.41	2.571	0.17	0.428	0.428	0.23	0.24

Mean of warp and weft (Of)

Sample Number	**Mean (warp & weft)**
U	180
9	180
11	180
35	179
36	177
37	180
38	180
39	178
40	177
41	180
42	180
43	179
44	180
45	180
46	180
47	180
48	179
49-50	178
50	179
51	179
52	178
53	180
54	178
56	179
58	179

Flat sample: Shape Memory Angle (Mf)

Warp direction

Smaple Number	Mean (Warp)	Standard Deviation (Warp)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	156	1.52	2.571	0.62	1.592	1.592	0.98	1.02
9	170	0.89	2.571	0.37	0.939	0.939	0.53	0.55
11	163	1.21	2.571	0.49	1.271	1.271	0.74	0.78
35	170	2.71	2.571	1.11	2.848	2.848	1.60	1.68
36	155	2.17	2.571	0.89	2.275	2.275	1.40	1.47
37	164	2.17	2.571	0.89	2.275	2.275	1.33	1.39
38	166	2.34	2.571	0.95	2.454	2.454	1.41	1.48
39	175	3.08	2.571	1.26	3.229	3.229	1.75	1.84
40	161	2.17	2.571	0.89	2.275	2.275	1.35	1.42
41	169	2.10	2.571	0.86	2.201	2.201	1.24	1.30
42	171	2.19	2.571	0.89	2.299	2.299	1.28	1.34
43	167	1.94	2.571	0.79	2.037	2.037	1.16	1.22
44	178	0.52	2.571	0.21	0.542	0.542	0.29	0.30
45	161	2.74	2.571	1.12	2.874	2.874	1.71	1.79
46	163	2.10	2.571	0.86	2.201	2.201	1.29	1.35
47	147	2.34	2.571	0.95	2.454	2.454	1.59	1.67
48	170	0.63	2.571	0.26	0.664	0.664	0.37	0.39
49-50	175	1.75	2.571	0.71	1.838	1.838	1.00	1.05
50	152	2.86	2.571	1.17	2.999	2.999	1.88	1.97
51	150	1.47	2.571	0.60	1.545	1.545	0.98	1.03
52	155	2.42	2.571	0.99	2.542	2.542	1.57	1.64
53	158	3.14	2.571	1.28	3.296	3.296	1.98	2.08
54	155	1.75	2.571	0.71	1.838	1.838	1.13	1.19
56	157	1.86	2.571	0.76	1.954	1.954	1.19	1.25
58	163	2.16	2.571	0.88	2.267	2.267	1.32	1.39

Weft direction

Smaple Number	Mean (Weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	148	1.60	2.571	0.65	1.681	1.681	1.08	1.13
9	162	2.86	2.571	1.17	2.999	2.999	1.76	1.85
11	153	2.17	2.571	0.89	2.275	2.275	1.42	1.49
35	166	2.25	2.571	0.92	2.362	2.362	1.35	1.42
36	143	2.17	2.571	0.89	2.275	2.275	1.52	1.60
37	154	1.63	2.571	0.67	1.714	1.714	1.06	1.12
38	154	1.75	2.571	0.71	1.838	1.838	1.14	1.20
39	169	0.89	2.571	0.37	0.939	0.939	0.53	0.56
40	155	2.99	2.571	1.22	3.142	3.142	1.93	2.03
41	157	1.51	2.571	0.61	1.580	1.580	0.96	1.00
42	165	2.43	2.571	0.99	2.549	2.549	1.48	1.55
43	173	1.60	2.571	0.65	1.681	1.681	0.93	0.97
44	177	0.84	2.571	0.34	0.878	0.878	0.47	0.50
45	151	3.78	2.571	1.54	3.968	3.968	2.51	2.64
46	161	2.42	2.571	0.99	2.542	2.542	1.51	1.58
47	153	2.07	2.571	0.85	2.176	2.176	1.36	1.43
48	170	2.40	2.571	0.98	2.520	2.520	1.41	1.48
49-50	173	2.50	2.571	1.02	2.627	2.627	1.45	1.52
50	162	3.76	2.571	1.54	3.950	3.950	2.33	2.44
51	144	2.26	2.571	0.92	2.370	2.370	1.57	1.65
52	145	3.03	2.571	1.24	3.183	3.183	2.09	2.20
53	150	3.14	2.571	1.28	3.296	3.296	2.10	2.20
54	149	3.33	2.571	1.36	3.491	3.491	2.23	2.34
56	163	2.16	2.571	0.88	2.267	2.267	1.33	1.39
58	153	1.67	2.571	0.68	1.756	1.756	1.09	1.15

Mean of warp and weft (Mf)

Sample Number	Mean (warp & weft)
U	152
9	166
11	158
35	168
36	149
37	159
38	160
39	172
40	158
41	163
42	168
43	170
44	178
45	156
46	162
47	150
48	170
49-50	174
50	157
51	147
52	150
53	154
54	152
56	160
58	158

Creased sample: Original Angle (Oc)

Smaple Number	Mean (Weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	33	1.80	2.201	0.52	1.144	1.144	5.43	3.45
9	33	1.72	2.201	0.50	1.095	1.095	5.28	3.35
11	35	2.14	2.201	0.62	1.358	1.358	6.06	3.85
35	30	1.08	2.201	0.31	0.689	0.689	3.60	2.29
36	30	2.96	2.201	0.86	1.884	1.884	9.77	6.21
37	33	1.93	2.201	0.56	1.225	1.225	5.86	3.72
38	33	2.48	2.201	0.72	1.576	1.576	7.48	4.75
39	36	2.50	2.201	0.72	1.587	1.587	7.01	4.45
40	41	2.59	2.201	0.75	1.644	1.644	6.34	4.03
41	45	3.89	2.201	1.12	2.470	2.470	8.69	5.52
42	37	3.65	2.201	1.05	2.322	2.322	9.90	6.29
43	36	2.15	2.201	0.62	1.367	1.367	5.99	3.81
44	46	2.93	2.201	0.84	1.860	1.860	6.33	4.02
45	41	2.31	2.201	0.67	1.470	1.470	5.63	3.58
46	30	2.53	2.201	0.73	1.606	1.606	8.49	5.40
47	38	2.72	2.201	0.79	1.731	1.731	7.14	4.54
48	34	2.00	2.201	0.58	1.271	1.271	5.88	3.74
49-50	33	2.86	2.201	0.83	1.817	1.817	8.67	5.51
50	33	2.91	2.201	0.84	1.847	1.847	8.83	5.61
51	33	2.45	2.201	0.71	1.556	1.556	7.42	4.72
52	37	2.87	2.201	0.83	1.827	1.827	7.86	4.99
53	32	2.10	2.201	0.61	1.336	1.336	6.51	4.13
54	46	2.52	2.201	0.73	1.603	1.603	5.48	3.48
56	50	4.05	2.201	1.17	2.570	2.570	8.09	5.14
58	40	3.26	2.201	0.94	2.071	2.071	8.17	5.19

Creased sample: Shape Memory Angle (Mc)

Smaple Number	Mean (Weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	92	2.56	2.201	0.74	1.628	1.628	2.78	1.77
9	104	2.78	2.201	0.80	1.765	1.765	2.68	1.70
11	98	3.66	2.201	1.06	2.323	2.323	3.75	2.38
35	36	2.22	2.201	0.64	1.408	1.408	6.15	3.91
36	114	4.71	2.201	1.36	2.992	2.992	4.13	2.62
37	118	3.96	2.201	1.14	2.519	2.519	3.36	2.13
38	110	4.24	2.201	1.22	2.696	2.696	3.86	2.45
39	108	3.55	2.201	1.03	2.258	2.258	3.28	2.08
40	117	3.34	2.201	0.96	2.124	2.124	2.86	1.82
41	95	2.72	2.201	0.79	1.731	1.731	2.86	1.82
42	92	1.71	2.201	0.49	1.088	1.088	1.86	1.18
43	83	5.79	2.201	1.67	3.678	3.678	7.00	4.45
44	104	4.98	2.201	1.44	3.165	3.165	4.81	3.06
45	88	6.52	2.201	1.88	4.140	4.140	7.41	4.71
46	70	3.66	2.201	1.06	2.328	2.328	5.25	3.33
47	77	3.50	2.201	1.01	2.225	2.225	4.54	2.89
48	90	3.77	2.201	1.09	2.398	2.398	4.21	2.67
49-50	67	4.74	2.201	1.37	3.009	3.009	7.10	4.51
50	66	2.64	2.201	0.76	1.677	1.677	4.02	2.55
51	64	1.71	2.201	0.49	1.084	1.084	2.67	1.69
52	59	5.48	2.201	1.58	3.485	3.485	9.36	5.95
53	76	3.59	2.201	1.04	2.283	2.283	4.73	3.00
54	108	3.38	2.201	0.98	2.148	2.148	3.13	1.99
56	92	3.59	2.201	1.04	2.283	2.283	3.91	2.48
58	97	5.47	2.201	1.58	3.474	3.474	5.67	3.60

Calculated results of Shape Memory Coefficients of flat samples (Sf%) and Shape Memory Coefficients of creased samples (Sc%)

$$Sf\% = [1 - (\frac{|Of - Mf|}{180})]*100 \qquad Sc\% = [1 - (\frac{|Oc - Mc|}{180})]*100$$

Subjective results of SA Rating and CR Rating

	Flat sample	**Creased sample**
Sample Number	**Shape memory coefficient (Sf%)**	**Shape memory coefficient (Sc%)**
U	84.44	67.22
9	92.22	60.56
11	87.78	65.00
35	93.89	96.67
36	84.44	53.33
37	88.33	52.78
38	88.89	57.22
39	96.67	60.00
40	89.44	57.78
41	90.56	72.22
42	93.33	69.44
43	95.00	73.89
44	98.89	67.78
45	86.67	73.89
46	90.00	77.78
47	83.33	78.33
48	95.00	68.89
49-50	97.78	81.11
50	87.78	81.67
51	82.22	82.78
52	84.44	87.78
53	85.56	75.56
54	85.56	65.56
56	89.44	76.67
58	88.33	68.33

	SA Rating (flat appearance)		**CR Rating (crease retention)**	
Sample Number	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
U	2.5	0.00	1.0	0.00
9	3.2	0.21	1.0	0.00
11	3.0	0.10	1.0	0.00
35	3.5	0.09	3.7	0.25
36	2.3	0.26	1.0	0.00
37	3.3	0.25	1.0	0.00
38	3.2	0.26	1.0	0.00
39	3.7	0.11	1.0	0.00
40	3.0	0.00	1.0	0.00
41	3.3	0.26	1.0	0.00
42	3.3	0.25	1.0	0.00
43	3.3	0.25	1.0	0.00
44	3.7	0.25	1.0	0.00
45	3.0	0.00	1.0	0.00
46	3.3	0.25	2.4	0.10
47	2.5	0.00	2.3	0.26
48	3.5	0.10	1.0	0.00
49-50	3.5	0.00	2.7	0.25
50	3.0	0.09	2.9	0.10
51	2.5	0.05	3.0	0.00
52	2.5	0.09	3.2	0.26
53	2.5	0.00	2.1	0.10
54	2.5	0.00	1.0	0.00
56	3.0	0.00	2.0	0.00
58	3.0	0.00	1.0	0.00

Regression

Comparison between wrinkle recovery angles (WRA) and Shape Memory Angle of flat samples (Mf)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.013180014
R Square	0.000173713
Adjusted R Square	-0.043297
Standard Error	10.46461407
Observations	25

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.437604	0.437604	0.003996088	0.950142
Residual	23	2518.687	109.5081		
Total	24	2519.125			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	86.44693778	40.44141	2.137585	0.04340547	2.787514	170.1064	2.787514	170.1064
X Variable 1	0.015912878	0.251728	0.063215	0.950141784	-0.50483	0.536652	-0.50483	0.536652

[Appendix C2]

Relationship between Shape Memory Angle and Subjective Rating

Regression

Flat sample (Mf and SA Rating)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9330501
R Square	0.8705824
Adjusted R Square	0.8649556
Standard Error	0.1563139
Observations	25

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.780417082	3.7804171	154.71928	1.08E-11
Residual	23	0.561982918	0.024434		
Total	24	4.3424			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-4.4519605	0.604088651	-7.3697138	1.70E-07	-5.701613	-3.2023079	-5.701613	-3.2023079
X Variable 1	0.0467711	0.003760154	12.438621	1.076E-11	0.0389927	0.0545496	0.0389927	0.0545496

Creased sample (Mc and CR Rating)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.894425
R Square	0.799997
Adjusted R Square	0.791301
Standard Error	0.407823
Observations	25

ANOVA

	df	SS	MS	F	Significance F
Regression	1	15.30105528	15.30106	91.99805	1.67E-09
Residual	23	3.825344719	0.166319		
Total	24	19.1264			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	5.070963	0.369734577	13.71515	1.47E-12	4.306109	5.835818	4.306109	5.835818
X Variable 1	-0.03886	0.004051974	-9.59156	1.67E-09	-0.04725	-0.03048	-0.04725	-0.03048

Relationship between Shape Memory Angle and Shape Memory Coefficient

Regression

Flat sample (Mf and Sf%)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.993219
R Square	0.986483
Adjusted R Square	0.985895
Standard Error	0.556446
Observations	25

ANOVA

	df	SS	MS	F	Significance F
Regression	1	519.7426576	519.7427	1678.58092	5.3E-23
Residual	23	7.121539958	0.309632		
Total	24	526.8641975			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.613739	2.150433798	0.750425	0.46060741	-2.83477	6.062251	-2.83477	6.062251
X Variable 1	0.548406	0.013385391	40.97049	5.2983E-23	0.520716	0.576096	0.520716	0.576096

Creased sample (Mc and Sc%)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.963312
R Square	0.92797
Adjusted R Square	0.924838
Standard Error	2.965981
Observations	25

ANOVA

	df	SS	MS	F	Significance F
Regression	1	2606.655035	2606.655	296.3103	1.24E-14
Residual	23	202.332061	8.797046		
Total	24	2808.987096			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	116.0364	2.688977271	43.15262	1.63E-23	110.4738	121.599	110.4738	121.599
X Variable 1	-0.50727	0.029468886	-17.2137	1.24E-14	-0.56823	-0.44631	-0.56823	-0.44631

Relationship between Shape Memory Coefficient and Subjective Rating

Regression

Flat sample (Sf% and SA Rating)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.917991
R Square	0.842707
Adjusted R Square	0.835868
Standard Error	0.172328
Observations	25

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.659369022	3.659369	123.223529	1.03E-10
Residual	23	0.683030978	0.029697		
Total	24	4.3424			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-4.41527	0.673572318	-6.555	1.0917E-06	-5.80866	-3.02188	-5.80866	-3.02188
X Variable 1	0.08334	0.0075077	11.10061	1.0292E-10	0.067809	0.098871	0.067809	0.098871

Creased sample (Sc% and CR Rating)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.856965
R Square	0.734389
Adjusted R Square	0.722841
Standard Error	0.469976
Observations	25

ANOVA

	df	SS	MS	F	Significance F
Regression	1	14.04621433	14.04621	63.5927406	4.53E-08
Residual	23	5.08018567	0.220878		
Total	24	19.1264			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-3.40114	0.635633814	-5.35078	1.9623E-05	-4.71605	-2.08623	-4.71605	-2.08623
X Variable 1	0.070718	0.008868041	7.974506	4.5304E-08	0.052373	0.089063	0.052373	0.089063

[Appendix C3]

Evaluation using improved equations

Calculated values of FRec% and CRec%

$$\text{Flat Recovery \% (FRec\%)} = \frac{\text{Mf}}{\text{Of}} \text{ X } 100\% \qquad \text{Crease Recovery \% (CRec\%)} = \frac{(180 - \text{Mc})}{(180 - \text{Oc})} \text{ X } 100\ \%$$

Sample Number	Flat Recovery % (FRec%)	Crease Recovery % (CRec%)
U	84.44	59.86
9	92.22	51.70
11	87.78	56.55
35	93.85	96.00
36	84.18	44.00
37	88.33	42.18
38	88.89	47.62
39	96.63	50.00
40	89.27	45.32
41	90.56	62.96
42	93.33	61.54
43	94.97	67.36
44	98.89	56.72
45	86.67	66.19
46	90.00	73.33
47	83.33	72.54
48	94.97	61.64
49-50	97.75	76.87
50	87.71	77.55
51	82.12	78.91
52	84.27	84.62
53	85.56	70.27
54	85.39	53.73
56	89.39	67.69
58	88.27	59.29

Regression

Relationship	R	Intercept	X Variable 1	P-value (X)
Flat Recovery % and SA Rating	0.920823	-4.38945	0.083096	6.97E-11
Crease Recovery % and CR Rating	0.879119	-2.08395	0.058316	7.33E-09

Appendix D (1-3)

[Appendix D1]

Subjective Evaluation (in air)

Results of subjective rating

SA Rating: flat appearance

Temp. (25°C)/ 35% RH

Sample	Mean	Standard Deviation	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	1.5	0.05	2.306	0.02	0.038	0.038	3.41	2.62
A13	1.6	0.09	2.306	0.03	0.067	0.067	5.41	4.16
A20	1.6	0.05	2.306	0.02	0.038	0.038	3.19	2.45

Temp. (60°C)/ 35% RH

Sample	Mean	Standard Deviation	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.000	0.000	0.000	0.00	0.00
A10	2.0	0.05	2.306	0.017	0.017	0.038	2.46	1.89
A13	2.1	0.16	2.306	0.053	0.122	0.122	7.73	5.95
A20	2.0	0.05	2.306	0.017	0.017	0.038	2.46	1.89

Temp. (25°C)/ 65% RH

Sample	Mean	Standard Deviation	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	2.8	0.25	2.306	0.08	0.192	0.192	8.82	6.78
A13	2.9	0.10	2.306	0.03	0.077	0.077	3.41	2.62
A20	2.8	0.25	2.306	0.08	0.192	0.192	8.82	6.78

Temp. (60°C)/ 65% RH

Sample	Mean	Standard Deviation	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	3.2	0.25	2.306	0.08	0.192	0.192	7.89	6.07
A13	3.1	0.10	2.306	0.03	0.077	0.077	3.19	2.45
A20	3.0	0.05	2.306	0.02	0.038	0.038	1.65	1.27

Temp. (25°C)/ 90% RH

Sample	Mean	Standard Deviation	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.2	0.09	2.306	0.03	0.068	0.068	7.63	5.87
A10	3.1	0.10	2.306	0.03	0.077	0.077	3.26	2.51
A13	3.0	0.05	2.306	0.02	0.038	0.038	1.65	1.27
A20	3.0	0.05	2.306	0.02	0.038	0.038	1.65	1.27

Temp. (60°C)/ 90% RH

Sample	Mean	Standard Deviation	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.2	0.05	2.306	0.02	0.038	0.038	4.05	3.12
A10	3.5	0.05	2.306	0.02	0.038	0.038	1.42	1.09
A13	3.6	0.15	2.306	0.05	0.115	0.115	4.17	3.20
A20	3.6	0.15	2.306	0.05	0.115	0.115	4.17	3.20

CR Rating: crease retention

Temp. (25°C)/ 35% RH

Sample	Mean	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	2.9	0.10	2.306	0.03	0.077	0.077	3.41	2.62
A13	3.0	0.13	2.306	0.04	0.102	0.102	4.36	3.35
A20	2.9	0.05	2.306	0.02	0.038	0.038	1.70	1.31

Temp. (60°C)/ 35% RH

Sample	Mean	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	3.5	0.05	2.306	0.02	0.038	0.038	1.42	1.09
A13	3.6	0.15	2.306	0.05	0.115	0.115	4.17	3.20
A20	3.5	0.05	2.306	0.02	0.038	0.038	1.42	1.09

Temp. (25°C)/ 65% RH

Sample	Mean	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	2.8	0.13	2.306	0.04	0.102	0.102	4.67	3.59
A13	2.7	0.13	2.306	0.04	0.102	0.102	4.96	3.81
A20	2.8	0.15	2.306	0.05	0.115	0.115	5.36	4.12

Temp. (60°C)/ 65% RH

Sample	Mean	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	3.2	0.13	2.306	0.04	0.102	0.102	4.18	3.21
A13	3.2	0.23	2.306	0.08	0.176	0.176	7.16	5.50
A20	3.1	0.15	2.306	0.05	0.115	0.115	4.84	3.72

Temp. (25°C)/ 90% RH

Sample	Mean	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	1.5	0.05	2.306	0.02	0.038	0.038	3.41	2.62
A13	1.3	0.10	2.306	0.03	0.077	0.077	7.89	6.07
A20	1.3	0.13	2.306	0.04	0.102	0.102	9.92	7.63

Temp. (60°C)/ 90% RH

Sample	Mean	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
U	1.0	0.00	2.306	0.00	0.000	0.000	0.00	0.00
A10	1.6	0.15	2.306	0.05	0.115	0.115	9.37	7.21
A13	1.5	0.00	2.306	0.02	0.038	0.038	3.41	2.62
A20	1.5	0.05	2.306	0.02	0.038	0.038	3.41	2.62

ANOVA Test (at the 0.05 level of significance)

Effect among temperatures on fabric shape memory effects

A response variable	Factor	Sample	Relative humidity (%RH)	F	P-Value	Significant difference (D) / Not significant difference (ND) (at the 0.05 level of significance)
Fabric shape memory effect of flat appearance (SA Rating)	Temperature	U	35	-	-	ND
		A10		578.000	0.0000	D
		A13		35.636	0.0000	D
		A20		392.000	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Temperature	U	35	-	-	ND
		A10		259.200	0.0000	D
		A13		72.250	0.0000	D
		A20		648.000	0.0000	D
Fabric shape memory effect of flat appearance (SA Rating)	Temperature	U	65	-	-	ND
		A10		8.000	0.0121	D
		A13		18.000	0.0006	D
		A20		5.538	0.0317	D
Fabric shape memory effect of crease retention (CR Rating)	Temperature	U	65	-	-	ND
		A10		28.571	0.0001	D
		A13		36.571	0.0000	D
		A20		18.000	0.0006	D
Fabric shape memory effect of flat appearance (SA Rating)	Temperature	U	90	2.000	0.1765	ND
		A10		156.800	0.0000	D
		A13		115.600	0.0000	D
		A20		115.600	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Temperature	U	90	-	-	ND
		A10		6.400	0.0223	D
		A13		28.800	0.0001	D
		A20		8.000	0.0121	D

Effect among relative humidities on fabric shape memory effects

A response variable	Factor	Sample	Air Temperature (°C)	F	P-Value	Significant difference (D) / Not significant difference (ND) (at the 0.05 level of significance)
Fabric shape memory effect of flat appearance (SA Rating)	Relative humidity	U	25	14.286	0.0001	D
		A10		268.933	0.0000	D
		A13		864.500	0.0000	D
		A20		253.037	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Relative humidity	U	25	-	-	ND
		A10		604.333	0.0000	D
		A13		521.556	0.0000	D
		A20		500.706	0.0000	D
Fabric shape memory effect of flat appearance (SA Rating)	Relative humidity	U	60	196.000	0.0000	D
		A10		244.593	0.0000	D
		A13		208.500	0.0000	D
		A20		617.818	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Relative humidity	U	60	-	-	ND
		A10		669.882	0.0000	D
		A13		448.000	0.0000	D
		A20		1166.182	0.0000	D

[Appendix D2]

Objective Evaluation (in air)

Original Angle (Of and Oc): assumed 180 (mean of warp & weft)

Measured values of Shape Memory Angle (Mf and Mc)

Air temperature: 25°C (Flat sample)
Flat sample: Shape Memory Angle (Mf)

Warp direction

Conditions	Sample Number	Average value of warp	Standard Deviation (Warp)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
25°C/35%	U	106	2.35	2.571	0.96	2.461	2.461	2.22	2.33
	A10	112	2.32	2.571	0.95	2.431	2.431	2.07	2.17
	A13	129	2.45	2.571	1.00	2.571	2.571	1.90	1.99
	A20	131	1.97	2.571	0.80	2.064	2.064	1.50	1.57
25°C/65%	U	125	1.79	2.571	0.73	1.877	1.877	1.43	1.50
	A10	142	3.74	2.571	1.53	3.927	3.927	2.63	2.77
	A13	154	2.35	2.571	0.96	2.461	2.461	1.53	1.60
	A20	150	1.97	2.571	0.80	2.064	2.064	1.31	1.37
25°C/90%	U	132	3.60	2.571	1.47	3.779	3.779	2.73	2.87
	A10	142	2.10	2.571	0.86	2.201	2.201	1.48	1.55
	A13	152	1.72	2.571	0.70	1.808	1.808	1.13	1.19
	A20	162	2.25	2.571	0.92	2.362	2.362	1.39	1.46

Weft direction

Conditions	Sample Number	Average value of weft	Standard Deviation (Weft)	Critical value ($t_{\alpha}/2$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
25°C/35%	U	114	2.93	2.571	1.19	3.072	3.072	2.56	2.69
	A10	142	1.63	2.571	0.67	1.714	1.714	1.15	1.21
	A13	142	3.19	2.571	1.30	3.346	3.346	2.25	2.36
	A20	156	1.94	2.571	0.79	2.037	2.037	1.25	1.31
25°C/65%	U	145	2.93	2.571	1.19	3.072	3.072	2.02	2.12
	A10	100	3.02	2.571	1.23	3.166	3.166	3.01	3.16
	A13	103	3.39	2.571	1.38	3.554	3.554	3.30	3.47
	A20	103	1.63	2.571	0.67	1.714	1.714	1.58	1.66
25°C/90%	U	160	2.07	2.571	0.84	2.168	2.168	1.29	1.36
	A10	168	3.56	2.571	1.45	3.740	3.740	2.13	2.23
	A13	163	3.92	2.571	1.60	4.114	4.114	2.40	2.52
	A20	171	2.16	2.571	0.88	2.267	2.267	1.26	1.32

Mean of warp and weft (Mf)

Sample Number	**Mean (warp & weft)**
U	110
A10	127
A13	135
A20	144
U	135
A10	153
A13	157
A20	159
U	146
A10	155
A13	158
A20	167

Air temperature: 60°C (Flat sample)
Flat sample: Shape Memory Angle (Mf)

Conditions	Sample Number	Average value of warp	Standard Deviation (Warp)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
60°C/35%	U	101	1.97	2.571	0.80	2.064	2.064	1.94	2.04
	A10	125	2.19	2.571	0.89	2.299	2.299	1.75	1.84
	A13	125	3.13	2.571	1.28	3.280	3.280	2.50	2.63
	A20	127	2.64	2.571	1.08	2.770	2.770	2.08	2.18
60°C/65%	U	129	2.48	2.571	1.01	2.606	2.606	1.93	2.02
	A10	144	2.79	2.571	1.14	2.925	2.925	1.93	2.03
	A13	157	3.94	2.571	1.61	4.132	4.132	2.52	2.64
	A20	161	1.47	2.571	0.60	1.545	1.545	0.91	0.96
60°C/90%	U	141	2.23	2.571	0.91	2.339	2.339	1.58	1.66
	A10	164	1.47	2.571	0.60	1.545	1.545	0.90	0.94
	A13	174	2.32	2.571	0.95	2.431	2.431	1.33	1.40
	A20	165	2.43	2.571	0.99	2.549	2.549	1.48	1.55

Conditions	Sample Number	Average value of weft	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
60°C/35%	U	114	3.03	2.571	1.24	3.183	3.183	2.66	2.79
	A10	136	4.59	2.571	1.88	4.821	4.821	3.39	3.56
	A13	151	2.35	2.571	0.96	2.461	2.461	1.56	1.64
	A20	152	2.28	2.571	0.93	2.393	2.393	1.50	1.57
60°C/65%	U	146	2.07	2.571	0.84	2.168	2.168	1.42	1.49
	A10	169	3.02	2.571	1.23	3.166	3.166	1.79	1.88
	A13	169	3.56	2.571	1.45	3.735	3.735	2.10	2.21
	A20	168	3.03	2.571	1.24	3.183	3.183	1.81	1.89
60°C/90%	U	160	3.25	2.571	1.33	3.411	3.411	2.03	2.13
	A10	179	0.75	2.571	0.31	0.790	0.790	0.42	0.44
	A13	179	0.75	2.571	0.31	0.790	0.790	0.42	0.44
	A20	178	2.07	2.571	0.84	2.168	2.168	1.16	1.22

Mean of warp and wft (Mf)

Sample Number	**Mean (warp & weft)**
U	108
A10	130
A13	138
A20	139
U	137
A10	156
A13	163
A20	165
U	151
A10	172
A13	177
A20	171

Air temperature: 25°C (Creased sample)

Creased sample: Original Angle (Oc)

Conditions	Sample Number	Mean (weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
25°C/35%	U	137	1.96	2.201	0.57	1.245	1.245	1.43	0.91
	A10	40	2.90	2.201	0.84	1.840	1.840	7.19	4.57
	A13	37	3.03	2.201	0.87	1.922	1.922	8.25	5.24
	A20	43	2.62	2.201	0.76	1.666	1.666	6.12	3.89
25°C/65%	U	138	2.04	2.201	0.59	1.299	1.299	1.48	0.94
	A10	41	2.77	2.201	0.80	1.758	1.758	6.71	4.26
	A13	35	1.98	2.201	0.57	1.255	1.255	5.63	3.58
	A20	40	1.71	2.201	0.49	1.088	1.088	4.31	2.74
25°C/90%	U	137	1.35	2.201	0.39	0.857	0.857	0.98	0.63
	A10	42	2.11	2.201	0.61	1.340	1.340	5.07	3.22
	A13	35	1.56	2.201	0.45	0.994	0.994	4.42	2.81
	A20	42	1.93	2.201	0.56	1.225	1.225	4.58	2.91

Creased sample: Shape Memory Angle (Mc)

Conditions	Sample Number	Mean (weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
25°C/35%	U	150	2.70	2.201	0.78	1.713	1.713	1.80	1.14
	A10	47	2.15	2.201	0.62	1.364	1.364	4.53	2.88
	A13	56	2.30	2.201	0.66	1.459	1.459	4.10	2.61
	A20	60	2.59	2.201	0.75	1.648	1.648	4.32	2.75
25°C/65%	U	152	1.78	2.201	0.51	1.132	1.132	1.17	0.75
	A10	69	3.29	2.201	0.95	2.089	2.089	4.74	3.01
	A13	58	3.36	2.201	0.97	2.135	2.135	5.77	3.67
	A20	69	2.56	2.201	0.74	1.628	1.628	3.73	2.37
25°C/90%	U	165	2.71	2.201	0.78	1.723	1.723	1.64	1.04
	A10	81	2.31	2.201	0.67	1.470	1.470	2.85	1.81
	A13	80	2.91	2.201	0.84	1.847	1.847	3.64	2.31
	A20	86	2.05	2.201	0.59	1.303	1.303	2.39	1.52

Air temperature: 60°C (Creased sample)

Creased sample: Original Angle (Oc)

Conditions	Sample Number	Mean (weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
60°C/35%	U	136	2.10	2.201	0.61	1.336	1.336	1.55	0.99
	A10	44	1.83	2.201	0.53	1.164	1.164	4.17	2.65
	A13	36	2.44	2.201	0.71	1.552	1.552	6.81	4.32
	A20	41	2.12	2.201	0.61	1.345	1.345	5.13	3.26
60°C/65%	U	137	2.04	2.201	0.59	1.295	1.295	1.49	0.94
	A10	42	2.23	2.201	0.64	1.416	1.416	5.27	3.35
	A13	36	2.35	2.201	0.68	1.492	1.492	6.46	4.11
	A20	39	2.11	2.201	0.61	1.341	1.341	5.48	3.48
60°C/90%	U	138	2.53	2.201	0.73	1.610	1.610	1.83	1.16
	A10	43	2.56	2.201	0.74	1.628	1.628	5.93	3.76
	A13	37	1.93	2.201	0.56	1.225	1.225	5.27	3.35
	A20	43	2.47	2.201	0.71	1.567	1.567	5.68	3.61

Creased sample: Shape Memory Angle (Mc)

Conditions	Sample Number	Mean (weft)	Standard Deviation (Weft)	Critical value ($t_{\alpha/2}$)	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
60°C/35%	U	150	2.15	2.201	0.62	1.367	1.367	1.44	0.91
	A10	45	2.09	2.201	0.60	1.331	1.331	4.63	2.94
	A13	50	2.97	2.201	0.86	1.887	1.887	6.00	3.81
	A20	51	2.19	2.201	0.63	1.390	1.390	4.26	2.71
60°C/65%	U	154	2.42	2.201	0.70	1.541	1.541	1.57	1.00
	A10	60	2.25	2.201	0.65	1.429	1.429	3.74	2.38
	A13	56	2.60	2.201	0.75	1.651	1.651	4.66	2.96
	A20	57	2.27	2.201	0.66	1.445	1.445	4.02	2.55
60°C/90%	U	166	3.26	2.201	0.94	2.069	2.069	1.96	1.24
	A10	92	3.81	2.201	1.10	2.421	2.421	4.13	2.63
	A13	93	1.95	2.201	0.56	1.237	1.237	2.10	1.33
	A20	95	1.97	2.201	0.57	1.251	1.251	2.08	1.32

Calculated values of Flat Recovery % (FRec%) and Crease Recovery % (CRec%)

$$\text{Flat Recovery \% (FRec\%)} = \frac{Mf}{Of} \times 100\%$$

$$\text{Crease Recovery \% (CRec\%)} = \frac{(180 - Mc)}{(180 - Oc)} \times 100\%$$

Flat sample

Sample	%RH	Air temperature: 25°C	Air temperature: 60°C
		FRec%	FRec%
U	35%	61.11	60.00
A10		70.28	72.22
A13		75.19	76.67
A20		80.00	77.22
U	65%	75.00	76.11
A10		85.14	86.67
A13		87.22	90.37
A20		88.33	91.67
U	90%	81.11	83.61
A10		86.11	95.56
A13		87.78	98.15
A20		92.59	95.19

Creased sample

Sample	%RH	Air temperature: 25°C	Air temperature: 60°C
		CRec%	CRec%
U	35%	70.31	68.18
A10		95.00	99.51
A13		86.71	90.07
A20		87.59	92.58
U	65%	66.67	60.47
A10		80.05	86.75
A13		84.14	86.11
A20		79.29	87.44
U	90%	34.88	33.33
A10		71.74	64.23
A13		69.12	60.84
A20		68.12	61.89

[Appendix D3]

Regression

Correlation between FRec% and SA Rating at various air conditions

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.85308327
R Square	0.72775107
Adjusted R Square	0.71537612
Standard Error	0.50063362
Observations	24

ANOVA

	df	SS	MS	F	Significance F
Regression	1	14.7393849	14.7393849	58.808	1E-07
Residual	22	5.51394839	0.25063402		
Total	23	20.2533333			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-4.1811522	0.84914582	-4.9239507	6E-05	-5.9422	-2.4201316	-5.9421728	-2.4201
X Variable 1	0.07862397	0.01025263	7.66866335	1E-07	0.0574	0.09988662	0.05736131	0.0999

Correlation between CRec% and CR Rating at various air conditions

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.84853147
R Square	0.72000565
Adjusted R Square	0.70727864
Standard Error	0.54189914
Observations	24

ANOVA

	df	SS	MS	F	Significance F
Regression	1	16.6129305	16.6129305	56.573	2E-07
Residual	22	6.46040288	0.29365468		
Total	23	23.0733333			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-1.5529438	0.50675014	-3.0645158	0.0057	-2.6039	-0.5020083	-2.6038793	-0.502
X Variable 1	0.05001086	0.00664905	7.52150351	2E-07	0.0362	0.06380015	0.03622157	0.0638

Appendix E

Results of SA Rating and CR Rating in Water and Air

SA Rating: Temperature 60°C (Air and water)

Temp./ %RH	Hot Air: 60°C/65% (no dry)		Hot Air: 60°C/65% (line dry)		Hot Air: 60°C/65% (tumble dry)		Wash Temp (60ºC)/ line dry		Wash Temp (60ºC)/ tumble dry	
Sample No.	U	SM3	U	SM3	U	SM3	U	SM3	U	SM3
Mean	1.0	2.8	1.0	2.9	1.0	3.1	1.0	3.1	1.0	3.6
Standard Deviation	0.00	0.13	0.00	0.10	0.00	0.13	0.00	0.13	0.00	0.15
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.04	0.00	0.03	0.00	0.04	0.00	0.04	0.00	0.05
Upper Confidence Limit	0.000	0.102	0.000	0.077	0.000	0.102	0.000	0.102	0.000	0.115
Lower Confidence Limit	0.000	0.102	0.000	0.077	0.000	0.102	0.000	0.102	0.000	0.115
Coefficient of variation	0.00	4.67	0.00	3.41	0.00	4.22	0.00	4.24	0.00	4.17
% Error: (E/ mean) *100	0.00	3.59	0.00	2.62	0.00	3.25	0.00	3.26	0.00	3.20

CR Rating: Temperature 60°C (Air and water)

Temp./ %RH	Hot Air: 60°C/65% (no dry)		Hot Air: 60°C/65% (line dry)		Hot Air: 60°C/65% (tumble dry)		Wash Temp (60ºC)/ line dry		Wash Temp (60ºC)/ tumble dry	
Sample No.	U	SM3	U	SM3	U	SM3	U	SM3	U	SM3
Mean	1.0	2.7	1.0	2.8	1.0	3.2	1.0	3.1	1.0	3.6
Standard Deviation	0.00	0.13	0.00	0.05	0.00	0.18	0.00	0.13	0.00	0.15
Critical value ($t_{\alpha/2}$)	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306	2.306
Standard Error (S.E.)	0.00	0.04	0.00	0.02	0.00	0.06	0.00	0.04	0.00	0.05
Upper Confidence Limit	0.000	0.102	0.000	0.038	0.000	0.139	0.000	0.102	0.000	0.115
Lower Confidence Limit	0.000	0.102	0.000	0.038	0.000	0.139	0.000	0.102	0.000	0.115
Coefficient of variation	0.00	4.96	0.00	1.81	0.00	5.69	0.00	4.31	0.00	4.17
% Error: (E/ mean) *100	0.00	3.81	0.00	1.39	0.00	4.38	0.00	3.32	0.00	3.20

ANOVA Test (at the 0.05 level of significance)

Comparison between the effect in water (tumble dry) and air (no dry); the effect in water and air with line dry; the effect in water and air with tumble dry

Effect among conditions (air and water) on fabric shape memory effects

A response variable	Factor	Sample	Drying Method	F	P-Value	Significant difference (D) / Not significant difference (ND)
Fabric shape memory effect of flat appearance (SA Rating)	Conditions	U	Tumble dry (water) and line dry (air)	-	-	ND
		SM3		132.250	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Conditions	U	Tumble dry (water) and line dry (air)	-	-	ND
		SM3		196.000	0.0000	D
Fabric shape memory effect of flat appearance (SA Rating)	Conditions	U	Line dry	-	-	ND
		SM3		14.440	0.0016	D
Fabric shape memory effect of crease retention (CR Rating)	Conditions	U	Line dry	-	-	ND
		SM3		40.500	0.0000	D
Fabric shape memory effect of flat appearance (SA Rating)	Conditions	U	Tumble dry	-	-	ND
		SM3		49.000	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Conditions	U	Tumble dry	-	-	ND
		SM3		30.727	0.0000	D

Effect of Drying Method on Samples in Air and Water

Effect among conditions (air and water) on fabric shape memory effects

A response variable	Factor	Sample	Recovery conditions	F	P-Value	Significant difference (D) / Not significant difference (ND)
Fabric shape memory effect of flat appearance (SA Rating)	Drying method	U	Air	-	-	ND
		SM3		14.000	0.0001	D
Fabric shape memory effect of crease retention (CR Rating)	Drying method	U	Air	-	-	ND
		SM3		36.000	0.0000	D
Fabric shape memory effect of flat appearance (SA Rating)	Drying method	U	Water	-	-	ND
		SM3		46.372	0.0000	D
Fabric shape memory effect of crease retention (CR Rating)	Drying method	U	Water	-	-	ND
		SM3		64.000	0.0000	D

Appendix F

Measured value of Original Length (Op and Ot)

Op and Ot: 45 mm for all samples

Measured value of Deformed Length (Dp and Dt)

Temperature: 25°C

Sample Number	Dp (mean)	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	52	0.2108	2.262	0.07	0.151	0.151	0.40	0.29
K1-1	52	0.2234	2.262	0.07	0.160	0.160	0.43	0.31
K1-2	52	0.1581	2.262	0.05	0.113	0.113	0.30	0.22
C3-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C3-1	48	0.2108	2.262	0.07	0.151	0.151	0.44	0.31
C3-2	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C7-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C7-1	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24

Sample Number	Dt (mean)	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	51	0	2.262	0.00	0.000	0.000	0.00	0.00
K1-1	51	0	2.262	0.00	0.000	0.000	0.00	0.00
K1-2	51	0.3536	2.262	0.11	0.253	0.253	0.69	0.49
C3-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C3-1	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C3-2	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C7-U	46	1.4376	2.262	0.45	1.028	1.028	3.11	2.23
C7-1	48	0.2108	2.262	0.07	0.151	0.151	0.44	0.31

Temperature: 60°C

Sample Number	Dp (mean)	Standard Deviation	Critical value $t(\alpha/2)$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	52	0.1581	2.262	0.05	0.113	0.113	0.30	0.22
K1-1	52	0.1581	2.262	0.05	0.113	0.113	0.30	0.22
K1-2	52	0	2.262	0.00	0.000	0.000	0.00	0.00
C3-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C3-1	48	0.2582	2.262	0.08	0.185	0.185	0.54	0.39
C3-2	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C7-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C7-1	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24

Sample Number	Dt (mean)	Standard Deviation	Critical value $t(\alpha/2)$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	51	0	2.262	0.00	0.000	0.000	0.00	0.00
K1-1	51	0.1581	2.262	0.05	0.113	0.113	0.31	0.22
K1-2	51	0.1581	2.262	0.05	0.113	0.113	0.31	0.22
C3-U	48	0	2.262	0.00	0.000	0.000	0.00	0.00
C3-1	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C3-2	48	0.283	2.262	0.09	0.202	0.202	0.59	0.42
C7-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C7-1	48	0.2108	2.262	0.07	0.151	0.151	0.44	0.31

Measured value of Recovered Length (Rp and Rt)

Temperature: 25°C

Sample Number	Rp (mean)	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	52	0.2108	2.262	0.07	0.151	0.151	0.41	0.29
K1-1	50	0.2357	2.262	0.07	0.169	0.169	0.47	0.34
K1-2	51	0	2.262	0.00	0.000	0.000	0.00	0.00
C3-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C3-1	47	0	2.262	0.00	0.000	0.000	0.00	0.00
C3-2	47	0.1581	2.262	0.05	0.113	0.113	0.34	0.24
C7-U	48	0	2.262	0.00	0.000	0.000	0.00	0.00
C7-1	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24

Sample Number	Rt (mean)	Standard Deviation	Critical value $t_{(\alpha/2)}$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	50	0	2.262	0.00	0.000	0.000	0.00	0.00
K1-1	51	1.4376	2.262	0.45	1.028	1.028	2.83	2.02
K1-2	49	0.1581	2.262	0.05	0.113	0.113	0.32	0.23
C3-U	48	0	2.262	0.00	0.000	0.000	0.00	0.00
C3-1	47	0.1581	2.262	0.05	0.113	0.113	0.34	0.24
C3-2	47	0.1581	2.262	0.05	0.113	0.113	0.34	0.24
C7-U	48	0	2.262	0.00	0.000	0.000	0.00	0.00
C7-1	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24

Temperature: 60°C

Sample Number	Rp (mean)	Standard Deviation	Critical value $t(\alpha/2)$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	51	0.158	2.262	0.05	0.113	0.113	0.31	0.22
K1-1	46	0.211	2.262	0.07	0.151	0.151	0.46	0.33
K1-2	47	0.158	2.262	0.05	0.113	0.113	0.34	0.24
C3-U	48	0.236	2.262	0.07	0.169	0.169	0.49	0.35
C3-1	46	0.158	2.262	0.05	0.113	0.113	0.34	0.25
C3-2	47	0.158	2.262	0.05	0.113	0.113	0.34	0.24
C7-U	48	0	2.262	0.00	0.000	0.000	0.00	0.00
C7-1	47	0.158	2.262	0.05	0.113	0.113	0.34	0.24

Sample Number	Rt (mean)	Standard Deviation	Critical value $t(\alpha/2)$	Standard Error (S.E.)	Upper Confidence Limit (UCL)	Lower Confidence Limit (LCL)	Coefficient of variation (CV)	% Error: (E/ mean) *100
K1-U	50	0	2.262	0.00	0.000	0.000	0.00	0.00
K1-1	45	0.1581	2.262	0.05	0.113	0.113	0.35	0.25
K1-2	45	0.2108	2.262	0.07	0.151	0.151	0.46	0.33
C3-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C3-1	46	0.1581	2.262	0.05	0.113	0.113	0.34	0.25
C3-2	46	0.1581	2.262	0.05	0.113	0.113	0.34	0.25
C7-U	48	0.1581	2.262	0.05	0.113	0.113	0.33	0.24
C7-1	47	0.1581	2.262	0.05	0.113	0.113	0.34	0.24

Calculated value of BPR%, BTR% and BRR

$$\text{Bagging Warp Recovery \%} \quad (\text{BPR\%}) = \frac{(Dp - Rp)}{(Dp - Op)} \times 100\,\% \qquad \text{Bagging Weft Recovery \%} \quad (\text{BTR\%}) = \frac{(Dt - Rt)}{(Dt - Ot)} \times 100\,\%$$

Temperature: 25°C

Sample Number	BPR% (25°C)	BTR% (25°C)	BRR (25°C)	Grade (a)	Grade (b)
K1-U	0.0	16.7	1.5	1	2
K1-1	28.6	33.3	3.5	3	4
K1-2	14.3	33.3	3.0	2	4
C3-U	0.0	0.0	1.0	1	1
C3-1	33.3	33.3	4.0	4	4
C3-2	33.3	33.3	4.0	4	4
C7-U	0.0	0.0	1.0	1	1
C7-1	0.0	0.0	1.0	1	1

Temperature: 60°C

Sample Number	BPR% (60°C)	BTR% (60°C)	BRR (60°C)	Grade (a)	Grade (b)
K1-U	14.3	16.7	2.0	2	2
K1-1	85.7	100.0	9.5	9	10
K1-2	71.4	100.0	9.0	8	10
C3-U	0.0	0.0	1.0	1	1
C3-1	66.7	66.7	7.0	7	7
C3-2	33.3	66.7	5.5	4	7
C7-U	0.0	0.0	1.0	1	1
C7-1	33.3	33.3	4.0	4	4

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