AN EVALUATION OF BASE LAYER COMPRESSION GARMENTS FOR SPORTSWEAR

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Dedication

I dedicate this thesis to my friends and family. Particularly to my parents, Madeline and David Allsop, who have supported me not only during this MSc but also on any task I set out to complete, and to Benjamin Dalby for his constant support and motivation over the past year.

Abstract

Consumption of functional sportswear to enhance performance on and off the field of elite athletes has increased in the recent past in the UK. Compression sportswear in particular, based on evidence on compression therapy which was widely used for treating venous disorders, is now apparent in the ready to wear market.

The completion of a literature review documented the history of compression garments, highlighted benefits of wearing compression sportswear and different pressure measurement systems currently used. To further analyse ready to wear compression sportswear, five brands of commercially available compression garments were examined with reference to size and seam types. Additionally, fabric analysis of the samples highlighted variations between brands.

The lack of research currently available regarding variations of pressure distribution, of the same specified size, inhibits informed consumer choices within the market.

Using the Tekscan system the pressures exerted by the five medium samples were also analysed. Differences were found between the pressure values recorded, thus highlighting the differences amongst ready to wear garments of the same size.

Next, using a 3D avatar in V-Stitcher two of the garments were simulated. FAST testing was also completed and results put into the software to give a true to life representation of the fabrics tested. The simulation of the experimental work was then assessed via the pressure maps on the system to observe whether the values given in the CAD model matched the experimental work.

The expanding compression market needs to take in to account contributing factors, such as fabric composition, garment dimensions and placements of seams, when developing garments. The development of a simulation model that can map experimental work with regards to pressure distribution may allow the product development of compression base layers to be better assessed and help enable informed consumer choices.

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List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
CAD	Computer Aided Design
C.F	Centre Front
CSIRO	Commonwealth Scientific and Industrial Research Organisation
FAST	Fabric Assurance by Simple Testing
KES-F	Kawabata Evaluation System for Fabrics
MECS	Medical Elastic Compression Stockings
NASA	National Aeronautics and Space Administration
UK	United Kingdom

List of Measurement Abbreviations

ºC	Degrees Celsius
µN	Micro Newton
cm	Centimetre
g	Gram
hPa	Hectopascal
in	Inch
m	Metre
mm	Millimetre
mm Hg	Millimetres of Mercury
N	Newton

1.0 Introduction

1.1 Introduction

In recent years, participation in sport in the UK has risen to over 50% of the adult population (Mintel, 2009) and it is predicted that the approaching 2012 Olympic Games, in London, will account for a further increase of this figure (Mintel, 2011). Due to its increasing popularity a wide range of fashion sportswear and performance clothing has been developed and can be seen in sportswear retailers and high-street stores across the UK (Mintel, 2009). In particular, sportswear innovation to enhance performance and prevent injury continues to be in demand and further developed (Shishoo, 2005). Now, an increasing number of compression garments are available to purchase which are said to *"enhance athletic performance through increased blood flow and oxygenation"* (Cole, 2008, p.58).

Since the 19th Century, compression bandaging and garments have been successfully used for the treatment and prevention of medical ailments such as hypertrophic scarring, deep vein thrombosis and oedema in pregnancy (Thomas, 1998 and Ramelet, 2002). A plethora of research has highlighted the positive effects of pressure therapy including improved recovery rates of post-surgery patients and as a result, compression therapy is a norm in the medical profession (Miyamoto *et al*, 2011; and Miller, 2011). With the expansion into sportswear, further research regarding compression garments is also evident in the literature, with a focus on improved performance and recovery rates of athletes (Doan *et* al, 2003; Pain *et al*, 2008; Higgins *et al*, 2009; and Ali *et al*, 2011).

Little research is evident on the effect of body size and shape on pressure distribution. Although Fan and Chan (2005) used different size girdles in their research, few conclusions regarding size were drawn from this. A possible explanation for this is that research has focused more on the use of custom-made products. As incorrect fit of compression garments hinders their functionality (Miller, 2011) the advantage of custom-made garments is that the pressure delivery has been determined to be most beneficial for the specific wearer and use. However, as everyday consumers are continually demanding performance sportswear; more affordable, ready to wear garments are increasingly available on the market. A lack of research focused on the sizing of ready to wear compression garments is currently available. This deficiency is inhibiting informed consumer choices when purchasing compression sportswear. Therefore, there is a need for research in the area.

In order to analyse the influence of garment shape, fabric type and body shape on compression base layers, the pressures exerted need to be determined. It is thought that clothing technologists would benefit from a standardised system to measure the areas of compression. Ferguson-Pell *et al* (2000) explains how a wide range of pressure measurement systems currently exist to determine the pressure values exhibited through compression garments. However, there is often disagreement in the literature over the most accurate and appropriate method to use.

This research aims to analyse compression variations between commercially available garments. Different brands will be of particular interest to consider the effect of fabric type and garment shape on the distribution of compression. Moreover, the use of a CAD model, that will allow the mapping of experimental work with compression against a virtual system, will be investigated to observe how beneficial such systems may be for the future product development of sporting apparel. The hypothesis of the project is that many variations will be encountered between the distributions of pressure on same size garments. Development in the product development of such garments may allow for variances to be highlighted and greater understood.

1.2 Aims

1. To analyse current base layer products in sportswear, with particular reference to dimensions, materials and construction.
2. To measure the compression exerted by medium sized upper base layer garments, on a mannequin, with particular reference to the influence of material properties, garment construction and body shapes.
3. To create a CAD model that allows the mapping of experimental work with compression against a virtual system.

1.3 Chapter Summary

The next section, Chapter 2.0, is an analysis of the published research in the area, with particular focus on the increasing popularity of base layer compression garments for sportswear, the benefits claimed for wearing such compression garments and the different pressure measurement systems previously and currently used.

Chapter 3.0, Methodology, details the primary and secondary research methods used within this research to meet the aims of the project.

Chapter 4.0, Database of Garments, is an analysis of some of the current base layer products commercially available in the market. This section particularly references similarities and variations of dimensions, materials and construction of garments between different brands.

Chapter 5.0, Compression Measurement Analysis, focuses on the results gathered through the experimental work of measuring pressure distribution in five brands of compression base layer garments.

Chapter 6.0, Simulation Model, shows the results from the 3D CAD simulation of the experimental work.

The final section, Chapter 7.0, Conclusions and Recommendations looks at the overall results emerging from the research project and offers suggestions for future research in the area.

Competitive sports produce athletes who seem determined to achieve personal bests, including breaking world records at each competitive event. Some athletes are even willing to go to extreme lengths, such as Tiger Woods who has allegedly had surgery to correct his vision and therefore improve his game (Mayes, 2010). Although not as extreme, it is becoming the norm for performance sportswear, which aims to aid performance, to be worn to help achieve these high standards.

Compression has been used since the 19th Century to treat medical ailments (Thomas, 1998 and Ramelet, 2002) and has featured increasingly since the 1980's, when the use of Lycra gained popularity in sportswear (Walzer, 2004). A new wave of compression garments is now emerging.

2.1 Medical Compression

Although compression therapy has been widely used since the 19th Century (Thomas, 1998 and Ramelet, 2002), the use of bandages to help treat venous disease has in fact been dated as far back as 450-350BC (Van Geest *et al*, 2003). However, Van Geest *et al* (2003) explain how the introduction of elasticated stockings came after the discovery of the elastomeric fibre in the mid 1880's. Medical practice has found the use of graduated compression favourable particularly as it works with the muscles to encourage blood flow toward the heart (Moffatt *et al*, 2007). Other notable benefits of compression therapy are thought to be:

- The absorption of exudate (fluid) from the wound (Thomas *et al*, 2007).
- Reduction of scar size and improvement of scar appearance (Wienert, 2003).
- *"Relieves the symptoms associated with venous disease"* (Moffatt *et al*, 2007, pp339)

Compression can be achieved through two methods, either traditional bandaging techniques, or by specially manufactured garments, such as medical elastic compression stockings (MECS) (Ramelet, 2002; Van Geest *et al*, 2003 and URGO

Medical, 2010). However, Van Geest *et al* (2003) explains how these categories can be divided again as both may be either elastic or inelastic. Although inelastic bandages may be worn for 24 hours due to a low resting pressure, elastic compression requires to be removed during a 24 hour period to avoid high resting pressure accumulating from the constant compression.

Inelastic bandages, also known as short-stretch, only apply light pressure for a short period of time due to their inability to adapt with the leg, with a high percentage of the pressure provided being lost in a matter of hours (Ramelet, 2002 and Moffatt *et al*, 2007). Elastic bandages, or long-stretch, sustain the pressure provided for a longer period of time due to the flexibility of the structure (Moffatt *et al*, 2007) however are more likely to cause discomfort to the wearer (Ramelet, 2002).

Medical elastic compression stockings are available in a variety of lengths dependant on the wearers needs. MECS's are divided into classification for prescription with the pressure delivered to the ankle varying from 10 mm Hg to ≥ 49 mm Hg depending on the treatment necessary (Van Geest *et al*, 2003). The classifications and the compression at the ankle for each can be seen in Table 2.1. Current classifications of bandages do not solely incorporate those for compression. Patients that have very specific needs in terms of fit may be given made to measure MECS's to ensure the support given (Ramelet, 2002). Additionally, ready to wear versions are available in a range of classifications. Ramelet (2002) explains how some patients find MECS's hard to put on, particularly the higher classification garments however devices are available to help this and are generally well tolerated whilst on.

Table 2.1 Classification of MECS
(Van Geest *et al*, 2003, pp101)

Compression Class	Compression at ankle	
	hPa	mm Hg
Ccl A light	13-19	10-14
Ccl I mild	20-28	15-21
Ccl II moderate	31-43	23-32
Ccl III strong	45-61	34-46
Ccl IV very strong	≥65	≥49
1 mm Hg = 1.333 hPa		

Although bandages and MECS's are the most commonly used forms of compression therapy in medicine, the use of other compression clothing is often associated with the treatment of burns and hypertrophic scarring since its successful use was investigated in the early 1970’s (Wiernert, 2003). Wiernert (2003) explains how compression clothing is available in many forms including all in one body suits, and gloves and is habitually worn 24 hours a day.

Some debate of the effectiveness of compression therapy for medical ailments is apparent (Weller *et* al, 2010; Feist *et al*, 2011; and Miller, 2011). However, the variations between success and failure with reference to compression therapy are typically dependant on such key factors as:

- **Size**

Watkins (2010) highlights the importance of ensuring each patient is wearing the correct size compression garment. In a study by Miller (2011) a need for a standardised method for measuring limbs was called for to ensure patients are fitted correctly. Incorrect fit not only is a cause of discomfort for the wearer but can also result in the incorrect amount of pressure being given resulting in ineffective compression treatment. Watkins (2010) also explains how patients should be sized for post-operative compression garments prior to surgery unless a significant change in body shape or size is predicted.

- **Patient Adherence**

Feist *et al* (2011) and Miller (2011) both determine a key factor to the success of compression therapy is patient adherence. Although both state discomfort as one of the main reasons why patients fail to comply with the treatment, Miller (2011) also explains that poor patient education is a key contributor to lack of adherence to the regime.

- **Duration**

Understanding compression therapy with regards to how long patients must wear bandages or garments and possible problems resulting from removing them prior to the completion of this period were not highlighted in the majority of cases observed. Furthermore, 100% of the cases observed did not receive any written information about the importance of compliance.

However, the continued success of compression therapy is perhaps a main reason as to why sportswear retailers began to incorporate the same theories into sporting apparel. The expansion of compression garments in the sportswear market is apparent and growing.

2.2 Expansion into Sportswear

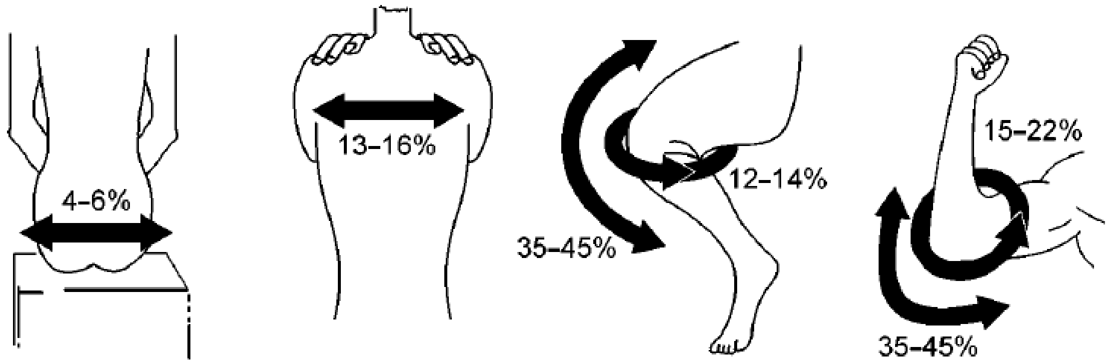


Figure 2.1 Key Areas of Stretch (Voyce *et al*, 2005, pp204)

Stretch fabrics have become a staple in sportswear apparel due to the increased comfort and fit the highly extensible fibres offer (Voyce *et al,* 2005). In day-to-day activities, Voyce *et al* (2005) explain how a person's skin stretches considerably with some key areas of stretch including 35% to 45% at knees and elbows (see Figure 2.1) and with sporting activities increasing such numbers, stretch of sportswear apparel is key for comfort. Although elastomeric fabrics are continuously used to improve comfort, sportswear specifically designed to compress muscles is becoming produced more frequently. Compression is believed to be an effective tool for athletes due to the increase in blood flow when worn. Increased blood flow speeds up the removal of lactic acid, which builds up when a person partakes in physical activity. In addition, the compression is believed to reduce muscle oscillation (reduce energy loss), and help improve aerodynamics thus reducing wind resistance.

In the summer of 2000, public attention was firmly on the Olympic Games in Sydney, especially on the Fastskin swimsuits which were both praised and criticised during the games. The skin tight compression body suits by Speedo, which aimed to reduce drag whilst allowing full body movement, were worn by almost 85% of the gold medal winners in swimming during the games (Swim-Faster.com, 2012). Although similar suits had been developed and worn at the

1992 and 1996 Olympic Games, the replication of a shark's skin for the Fastskin swimsuit was even more effective than previous incarnations (Voyce *et* al, 2005). Craik (2011) explains that the controversy surrounding the suits, including the wearers increased ability to break world records, led to the banning in 2010. However, this ban was not enforced until after much development of the suits and the introduction of other models including the Fastskin FSII, Fastskin FS-PRO and most notably the "world's fastest" suit the LZR Racer Suit (McKeegan, 2008). McKeegan (2008) and Mayes (2010) explain that the LZR Racer Suit, which is made using an innovative fabric without any seams, has been tested by the National Aeronautics and Space Administration (NASA) and found to be more aerodynamic than any other of its kind.

Compression garments not only sparked media attention in swimming at this time but also in other sports including track and field. The all in one head to toe Nike Swift Suit, aims to aid athletes in the same way as the swimsuits by reducing drag and increasing aerodynamics (Bondy, 2000). American athlete Marion Jones famously wore the Nike suit to reduce resistance during running (Mayes, 2010); however, the trend for head to toe suits for running events does not seem to have the prolonged success as with swimming. Similarly, Nike Swift Suits were used in other disciplines, including speed skating and cycling, in following years with positive effects (Voyce *et al*, 2005). Both sports continue to feature athletes in similar compression garments.

In 2003, the introduction of compression t-shirts was welcomed in Rugby (Voyce *et al*, 2005). The much tighter fit of the shirts, compared to the traditional rugby jersey, means that not only are the players benefited by the increased blood flow and muscle support, but also other players cannot easily grip the tops during play.

McCurry (2004); Shishoo (2005); Cole (2008); and Mintel (2009) all state that the public demand for performance sportswear has increased in recent years, and noted a rise in compression garments being sold on the market from this time. It is thought that the increasing media attention on the Speedo Fastskin suits acted as a catalyst for this despite compression garments being available prior to this. Walzer (2004) highlights how compression garments have advanced since the 1990s to include a wider variation of products and colours for all genders, which highlights the greater demand for the product. Also, replicas of professional products, such as the LZR Racer Suit, have also been released to the consumer market (McKeegan, 2008).

More recently, surfing brand Quiksilver entered the compression market (Cortad, 2011). Cortad (2011) explains that although the new garment has the conventional appearance of boardshorts, there is a hidden compressive short underneath with taping precisely positioned to support muscles. The shorts which utilise the technology usually seen in other sports are proving successful thus far also, with a surfing champion wearing them. (Watson, cited in Cortad, 2011). It is thought that this success in a different field may see the compression sportswear market expand even more.

Furthermore, compression sportswear garments are also entering new markets. Proskins (2012) have created a range of compression clothing with ingredients such as caffeine and vitamin E incorporated into the fabric to help reduce cellulite. This clothing is not only marketed as sportswear but is also suggested for day to day use, thus expanding the compression market further.

Loenneke *et al* (2012) also explain how an extreme form of compression, where blood flow is restricted to a working muscle during exercise, is becoming popular with rehabilitating athletes. Blood flow restriction training is being used during low intensity exercise to reduce the amount of exercise needed to be completed before muscular fatigue.

As the compression market continues to grow popular in both the professional and consumer markets the benefits often cited in marketing for doing so are being continually questioned.

2.3 Perceived Benefits when using Compression

Although there is an increasing trend to wear compression sportswear, there is much debate over the effectiveness of wearing such garments for sporting activities. Many compression sportswear companies claim that the garments will, to name just a few:

- Improve circulation;
- Improve performance; and

Table 2.2 Taxonomy of Claims and Results						
Author	**Test Method**	**Performance**			**Recovery**	
		Noticeable Benefits	**Small Benefits**	**No Benefits**	**Improvement**	**No Improvement**
Ali et al	Measured jump height after running trials	X		X		
Chatard et al	Subjects monitored with/without compression after cycling				X	
Dascombe et al	Monitored performance levels of flat water kayakers			X		
Davies et al	Performance monitored before and after wearing compression			X	X	
Doan et al	Measured sprint times, muscle oscillation and jump heights.	X	X	X	X	
Duffield and Portus	Distance and accuracy throwing tests analysed, along with sprint times.			X		
Higgins et al	Measured sprint times and jump height after netball style circuits		X			
Jakeman et al	Jump heights recorded before and after wearing compression				X	
Miyamoto et al	Torque monitored before and after calf raise exercises.	X		X		
Montgomery et al	Compression compared to cold water bathing and carbohydrate consumption					X
Sperlich et al	Recorded lactate concentration and oxygen uptake during running			X		

- Reduce recovery times.

(2XU Pty Ltd, 2009; and Skins™, 2012).

These claims have led to the completion of a plethora of research in the area. However, there is yet to be an holistic agreement on the benefits of performance and recovery due to conflicting results of many of the investigations completed (Doan *et al*, 2003; Chatard *et al*, 2004; Duffield and Portus, 2007; Montgomery *et al*, 2008; Davies *et al*, 2009; Higgins *et al*, 2009; Jakeman *et al*, 2010; Sperlich *et al*, 2010; Ali *et al*, 2011; and Miyamoto *et al*, 2011). A taxonomy of the literature analysed can be seen in Table 2.2 which highlights the results of the research.

2.3.1 Noticeable Benefits to Performance

An investigation by Doan *et al* (2003) reported that twenty track athletes completed a series of tests to measure sprint times, muscle oscillation and jump power in both loose gym shorts and compression shorts. The jump heights recorded in the research were increased by 2.4 cm when wearing the compression garment. Doan *et al* (2003) believed the greater support given by the garment, compared to the control gym shorts, allowed a greater squat before the jump thus increasing the upward drive of the jump and subsequently the overall height. Although this somewhat explains the differences between conditions due to the tight nature of compression garments compared to the control shorts, the participants may have performed to a greater standard due to the perceived difference between the garments. Particularly so as the subjects were aware as to which garment was being scrutinised in each test.

Ali *et al* (2011) were interested in the effect of varying levels of compression stockings on performance. Three levels (low, medium and high) were used during a series of countermovement jumps before and after running trials. It was found that the changes in jump height from before to after exercise were much bigger when wearing the low and medium stockings compared to when wearing a control garment. Perhaps essential to the study was that the subjects were also asked to rate the comfort of each stocking along with the amount of energy for each condition they believed to exert. The ratings for exertion showed no significant differences between all conditions thus helping to rule out the possible placebo effect.

Miyamoto *et al* (2011) focused on the effect of compression on torque of the triceps. Triplet torque was monitored both before and after calf raise exercises and there was a smaller reduction of power after exercise when wearing the compression stocking with 30 mm Hg at the ankle. However, this was not found with the 18 mm Hg ankle stockings.

2.3.2 Small Benefits to Performance

The research by Doan *et al* (2003) also highlighted some possible effect to stride frequency of sprint athletes. Elasticity tests on a mannequin highlighted a reduction in hip range when wearing compression garments. However, the 60 metres sprint times for the athletes were no different between the two conditions, thus suggesting an increase in stride frequency to account for the loss of range. It was noted, however, that it would be beneficial to test this theory further; in particular with longer sprint distances in order to fully understand the effect of this.

More recently, Higgins *et al* (2009) highlighted some benefits of wearing compression garments. Nine netball players either wore a compression garment, placebo elastomeric garment without compression or condition garment for circuit exercises including sprints and jumps. After four, fifteen minute, sessions of exercise were completed, it was concluded that the athletes wearing a compression garment increased sprint times, flight times and jump height during the exercises. However, these were only highlighted when using the Scheffe method for analysis, with no differences being highlighted if using a traditional statistical method. Maxwell and Delaney (2004) explained that the Scheffe method is favourable when examining multiple comparisons. Using a standard analysis to compare the data no significant differences were found for sprint times, flight times and jump heights. The benefits determined through this research are questionable as the significance is unapparent without more detailed statistical analysis or the reason behind the improved performance.

2.3.3 No Benefits to Performance

Although Doan *et al* (2003) highlighted effects to stride frequency during sprinting in compression garments, no difference in sprint times were found whilst wearing pressure garments.

Duffield and Portus (2007) monitored the effects of full body compression garments. Participants in the study completed a series of distance and accuracy throwing tests along with sprints in either a control garment or one of three brands of full body compression garments. However, there were no significant differences between the control condition and the three brands of compression garment.

Davies *et al* (2009), although concerned primarily with recovery benefits, also noted that there were no significant differences during performance tests consisting of sprints and jumps, among female athletes.

In 2010, Sperlich *et al,* observed the differences to performance benefits of compression socks, compression tights, whole body compression garments and control running clothing. All fifteen participants completed running tests on a treadmill in each type of clothing and performance was measured by monitoring lactate concentration and oxygen uptake. These measurements were used to observe whether compression effectively increased blood flow to speed up lactic acid removal from the body, thus aiding the athlete during performance.

Furthermore, although Ali *et al* (2011) found countermovement jumps were improved with the use of compression stockings, the running times monitored were not affected by the garments.

The research by Dascombe *et al* (2011) was focused on the use of upper body compression garments. The performance levels of seven flat water kayakers were observed with and without upper body compression garments; however, no significant improvements were noted. It should be noted that there has been very little research focused solely on upper body compression garments and as a result, the work by Dascombe *et al* (2011) is particularly interesting. In regards to this, future research on upper body compression would be beneficial to ensure conclusive results.

It must be taken in to account that the participants in these investigations by Doan *et al* (2003); Duffield and Portus (2007); Davies *et* al (2009); Sperlich *et* al (2010);

Ali *et al* (2011); and Dascombe *et al* (2011) were trained athletes accustomed to the exercise being monitored. As a result, any improvements regarding benefits of wearing such garments may not have prevailed. It may be that the athletes who take part have already reached full potential due to years of training and competitions and that compression garments will do little to alter the performances. It would be of interest to investigate the same tests with non-athletes as subjects to see if there are any significant differences.

Despite the recent study in 2011 by Miyamoto *et al* demonstrating some performance benefits to triplet torque, there was found to be no improvement to the maximal voluntary contraction torque with 30 mm Hg or 18 mm Hg stockings. Miyamoto *et al* (2011) claims this indicates fatigue, thus leading to no benefit to the performance of the participant.

2.3.4 Benefits to Recovery

Whilst many of the researchers in the area were concerned with improved performance benefits of athletes, some research also examined the effects of compression garments on the recovery of athletes. For example, in the investigation by Doan *et al* (2003) a noticeable reduction in muscle oscillation during jump landings was observed. It is stated that a reduction like this is likely to reduce injury (Rogers, 2012) and, therefore, improve the recovery time.

Chatard *et al* (2004) researched this concerning elderly male cyclists. Two five-minute cycling exercises were completed separated by 80 minutes. During the resting interval, subjects sat with the legs elevated either with or without the compression garment depending on the condition monitored. When comparing the five minute cycling exercises, there was a smaller drop of power sustained for the second five minutes when wearing the compression garments. However, although the results seem to show an improvement of recovery time for the athletes, 83% of the participants also noted that they believed wearing a compression garment might have influenced the subsequent five-minute performance.

Davies *et al* (2009) focused on the use of compression tights to reduce muscle soreness. Seven female and four male participants took part in the investigation whereby subjects had to complete performance tests including sprints and counter movement jumps 48 hours after a series of jump tests. All subjects wore compression tights after one of the jump tests for 48 hours with no sporting garment being worn for the control condition. From this, Davies *et al* (2009) found that sprint times during the performance tests were significantly better for the condition with compression garments, thus implying a greater recovery has taken place. On the other hand, this result was highlighted when grouping the male and female results together; whereas, female results alone showed no significant differences in this area.

In 2010, Jakeman *et al* also investigated the effects of compression garments on recovery. Seventeen female volunteers completed a series of 'drop jumps' and squat jumps with half of the participants wearing compression tights for a 12 hour recovery period. It was established that jump heights during recovery were better maintained in the condition wearing compression garments. Similarly, Doan *et al* (2003) found squat jump height was improved during performance and both may be due to a greater support given to the participant during squat when wearing compression garments.

2.3.5 No Benefits to Recovery

Despite some research highlighting the benefits of compression garments on recovery, Montgomery *et al* (2008) argued that other techniques still appear to be favourable. In the research compression garments were used as a recovery tool for a three-day exercise procedure. Similarly, the use of cold water bathing and carbohydrate consumption along with post exercise stretching were two other conditions for the investigation. In this circumstance, cold water bathing was deemed to be more beneficial to recovery than the use of compression garments or carbohydrate consumption and post exercise stretching. This was particularly the case in maintaining line drill performance and acceleration.

2.4 Psychology of Compression Garments

Although there is disagreement in literature about how effective compression for sportswear may be, there still remains an increased consumer demand for the garments. Lobby (2010) highlights how psychological effects of wearing compression may aid athletes. It is becoming increasingly popular, therefore, for research regarding compression garments to include perceptual measures by the participants. It is thought that monitoring factors such as perceived exertion may help to highlight if the placebo effect has occurred rather than a true change in performance.

Although Chatard *et al* (2004) reported some performance benefits, it should be noted that 83% of the participants believed that wearing the compression garment during exercise may have influenced how well they performed. On the other hand, no correlation between those who thought the garment would improve their performance and the results gathered could be found.

In 2010, Duffield *et al* completed an investigation whereby eleven participants completed ten sets of sprints and jumps, once with a compression garment and once without during the exercise as well as for a 24 hour period afterwards. Although results highlighted no improved performance or recovery rates, the participant's ratings of muscle soreness were reduced when wearing the compression garments. Therefore, while the results examined show no improvement, a placebo effect may be in place in this situation in terms of perceived recovery.

In the research by Ali *et al* (2010) participants noted that low grade compression garments were more comfortable than the high grade compression garments. Furthermore, some participants even experienced discomfort due to unnecessary compression when wearing high grade garments. Similarly in the 2011 research by Ali *et al* the low grade and control garments were rated as being more comfortable than the high and medium grade compression garments. Nevertheless, the rating of exertion for each condition did not alter in this case, despite noted discomfort.

Although some of the research studied highlights that participants often believe the compression garments are having a positive effect on their performance, there is little evidence to confirm this. However, researchers are still intrigued with the concept of the placebo effect on athletes. Laymon, cited in Lobby (2010) states that, *"…It may be that with compression, if you think it works, it truly does work for you".* Wallace *et al* (2008) states that although the use of compression has not been proven to improve performance there have also been no negative effects on performance highlighted. Therefore, wearing the garments purely for psychological impact can do no harm.

2.5 Pressure Measurement Systems

A plethora of research has been completed in order to evaluate existing pressure measurement systems. Ferguson-Pell *et al* (2000) explained how a wide range of pressure measurement systems currently exist to determine the pressure values exhibited through compression garments however, there is often disagreement in literature over the most accurate and appropriate method to use.

In 1997, Giele *et al* examined the use of direct measurement to monitor pressures between the skin and a compression garment being used to aid the treatment of hypertrophic scarring. Measuring pressure between garment and skin had previously been found to meet problems with garment wrinkling and the measurement devices not lying closely to the skin. Therefore, the research by Giele *et al* (1997) measured the sub-dermal pressures in an attempt to overcome these issues. Pressure was measured using a needle connected to a pressure transducer, with and without the compression garment being worn. Thus enabling comparisons, between the resting pressure and the pressures produced by the garment, to be made. It was concluded within the study that the sub-dermal method reliably allows pressure to be measured and highlights the need to monitor sub-dermal as well as interface pressures from compression garments. However, as Giele *et* al (1997) states, the research is based on an assumption that the pressures reflect those transmitted through the skin. However, due to the intrusive nature of measuring sub-dermally, only one subject participated in the study and studies with more participants would be beneficial to greater understand the pressures monitored.

Teng *et al* (2007) highlighted another example of direct measurement of pressures. Similarly, to Giele *et al* (1997), the research focused on the pressure therapy of hypertrophic scarring looking at the pressures between the garment and scar. One male subject took part in the research where an air-pack sensor was placed between the skin and the garment on the leg and arm. In all, four positions on the limbs were monitored with five readings at each site being taken to allow for averages to be taken. In this instance, the accuracy of the new system was directly compared to the results obtained by an existing pressure device used for clinical testing. Teng *et al* (2007) concluded that pressure readings gathered through the new device and the comparable measurements from the existing system were in very close agreement, hence confirming the rationale for using both systems. Although the research showed good correlation with less than 5 mm Hg between the new measuring system and the commercially available system at each measurement, some issues have been raised concerning direct measurement of pressure on live participants. It is thought that the characteristically small sample size of participants in direct measurement studies means that even research that is intended to measure comparable outcomes can conflict due to this lack of reliability (Feist *et al*, 2011). Therefore, the small sample size for this investigation raises concern. Furthermore, as previously mentioned, Giele *et al* (1997) were concerned with the distortion of the garment and this problem can be exaggerated by the subject simply moving, making it hard to eliminate the problem all together.

The problem with movement distorting results associated with direct measurement on humans stated above, coupled with time consumption, reproducibility and accuracy, led Fan and Chan (2005) to investigate how predictions of clothing pressure could be made on a conventional mannequin. After taking pressure measurements directly on six female subjects in ten positions, the measurements were recorded again on a standard dress maker's mannequin. From the information gathered a simple statistical model was created to predict the pressure from a mannequin which was concerned with differences in girth, weight and constants for body positions. Although the simple statistical model achieved satisfactory results for some areas, such as the waist; body curvature and body fat were not taken into account thus restricted the success of the simple system. Further statistical modelling which assumed that curvature is related to body mass index was shown to improve almost all results, however, success was still limited due to assumptions. The research concluded that a mannequin with 'skin' more representative of a human's skin and body fat would improve the prediction model. Furthermore, while the research examined three brands and three sizes of girdle, few conclusions regarding sizing were drawn from this as the research focused on creating the prediction model rather than focusing on the pressures observed.

Another indirect method investigated the use of a spherical pressure system to monitor the distribution of pressure amongst a series of compression fabrics (Wang *et al*, 2010). Within the investigation, the spherical pressure monitor was utilised with five high precision sensors. As fabrics were fixed in place beneath the system, the monitor was driven to the fabric and a computer system recorded the details of when the fabrics deformed under the pressure. The exploration was also supported by completing fabric analysis of the samples prior to testing. Material characteristics were measured using the Kawabata Evaluation System for Fabrics (KES-F). KES-F is an objective measurement system looking at the deformation and recovery of fabrics (Shishoo, 1995). Carr and Latham (2008) explain how the system focuses on four areas:

- Tensile and Shear
- Bending
- Compression
- Surface Tester

The testing system then creates control charts in the form of graphs for each fabric. By examining these areas, characteristics of the fabric which could impact on the behaviour of the samples during testing could be highlighted and help to greater understand the overall results from the research. It was to be expected that the four fabrics examined in this study would reach the sensors at the same time due to the predetermined speed set on the system. However, the differences in knit structure affected this which also resulted in variations of pressure. The research highlighted the importance of determining the differences in fabric characteristics when working with a number of samples in order to understand the effect of the fabric on the pressure tests.

Similarly, Yildiz (2007) emphasises the importance of fabric assessment prior to measuring pressure in order to highlight any characteristics that may aid or inhibit the pressure distribution. Thickness, area density and fibre composition were all taken into account in the research. Furthermore, thermo-physiological characteristics were examined to provide insight into how comfortable the garment would feel when worn. Although Yildiz (2007) is focused on thermo-physiological properties concerned with abrasion against a developing scar, tests such as air permeability and water absorption would also benefit research for the comfort of athletes in sports research.

Sawada (1993) investigated how bony prominences and areas of body fat may affect the compression achieved from a pressure garment. Using seven different conditions to test under (see Table 2.3) bony prominences and body fat were simulated using plastic plates and sponges. The pressure values were monitored using a control-inflator with a range to 88 millimetres of mercury (mm Hg) at the forearm, upper arm, thigh and leg.

Table 2.3 Testing Conditions (Sawada, 1993)	
Test	**Conditions**
1	Garment only
2	Garment with a thin sponge
3	Garment with a thin sponge and a thin plastic plate
4	Garment with a thin sponge and a thick plastic plate
5	Garment with a thick sponge
6	Garment with a thick sponge and a thin plastic plate
7	Garment with a thick sponge and a thick plastic plate

The testing concluded that the pressure increased when applying a sponge, of either size, or a plastic plate thus concerning the effect of prominences and fat when wearing medical compression garments. The research not only highlighted these differences but also focused on a pressure measurement system which was inexpensive to produce, thus desirable. However, it would be beneficial to compare the results found through this with a commercially used system like the research by Teng *et al* (2007) to validate the accuracy of the system. The relationship between body fat and bony prominences on compression is especially interesting with regards to ready to wear compression garments. As each wearer will be different in terms of body size and shape (eg: weight; muscle; and fat) it is impossible to predict how a garment's compression will be affected. Future research, such as that completed by Sawada (1993), concerned with ready to wear compression sportswear would be beneficial to investigate this.

A reoccurring theme in research regarding pressure measurement is the use of the Laplace Law (Ramelet, 2002; Maklewska *et al,* 2007; Moffatt, 2008; Lin *et al*, 2010). Maklewska *et al* (2007, pp 217) explain how the

"Laplace Law has been widely used to calculate the pressure delivered to a cylinder of known radius by a fabric under known Tension".

Maklewska *et al's* (2007) approach in the research concerning pressure under compression garments utilised Laplace's Law to quantify the pressures exerted. The 'Textilpress' system was used to measure the pressure of a compression garment placed over a rigid cylinder. The system contained a matrix of eighteen gauges, which combined, measure the curvature radius of the testing area and the tension exhibited. Using the radius and tension measurements, the pressure is then determined, as per the following Laplace equation (Maklewska *et al*, 2007).

$$\text{Pressure} = \frac{\text{Tension}}{\text{Radius}}$$

Averages of the pressure measured were then taken in order to ensure accuracy. The use of cylinders to represent a body part may be beneficial in future research to characterise many parts of the anatomy for indirect measurements. Similarly, the research by Lin *et al* (2010) utilised the Laplace Law. Using the Laplace equation, theoretical pressures for fabrics were determined and then compared to experimental data using a cylinder method. Both Lin *et al* (2010) and Ferguson-Pell *et al* (2000) used the same Flexiforce system by Tekscan in the research studied. Tekscan Inc (2007a) stated that the system is an "*ultra-thin (0.008 in.), flexible printed circuit that senses contact force"*. The slenderness and suppleness of such a system is something which Ferguson-Pell *et al* (2000) noted to be of high importance when working with pressure measurement systems to ensure accuracy and, therefore, deemed FlexiForce to be suitable for use. The results from the experimental work and the theoretical hypotheses by Lin *et al* (2010) were found to be sufficiently comparable and therefore highlighted the success of the FlexiForce sensors.

Unlike Lin *et* al (2010) Ferguson-Pell *et al* (2000) highlighted the concern with the drift of measurements when testing. Likewise, Macintyre (2011) also highlighted this concern when working with Tekscan equipment. When investigated, it was established that pressure readings reached a constant level after five to ten minutes and the repeatability of the results were adequate. The drift of measurements which has been detected when using Tekscan systems could, however, be of great interest with reference to the way compression garments act when worn. It is unlikely that a garment with a high degree of elasticity being worn during high intensity sport would maintain a constant level of pressure and therefore, the drift of measurements may be seen as a positive attribute of the systems to help better understand the garments characteristics.

2.6 Sizing

A large percentage of consumers are often thought to be unhappy with clothing sizes due to big variations between sizes of different brands or in different shops (Le Pechoux and Ghosh, 2002; and Otieno, 2008). Loker (2007) explains how a company's desire to produce a small range of sizes to cater for a large population of consumers means that ready to wear garments often fit only a select group. For companies focused on a mass market, Loker (2007) states that large studies of body shape and size for the desired population are examined and sizes created to fit the majority. Such anthropometric studies have benefitted from 3D body scanners in recent years to reduce the time taken to collate body measurements; however, are still costly and time consuming to conduct (Le Pechoux and Ghosh, 2002; Yu, 2004; Loker, 2007; and Otieno, 2008). Le Pechoux and Ghosh (2002) explain that variations between gender, race and generations are apparent through studies on body shape. Although custom made garments produced to specific measurements can ensure a perfect fit, the time and cost to produce such garments is so much that this is not viable for mass markets (Loker, 2007).

2.6.1 Body Shapes

It is popular in current literature to divide male body shapes in to three categories which can be labelled as: endomorph; mesomorph; and ectomorph. The following Figure 2.2 shows these shapes. As the pictures illustrate, ectomorph shapes are

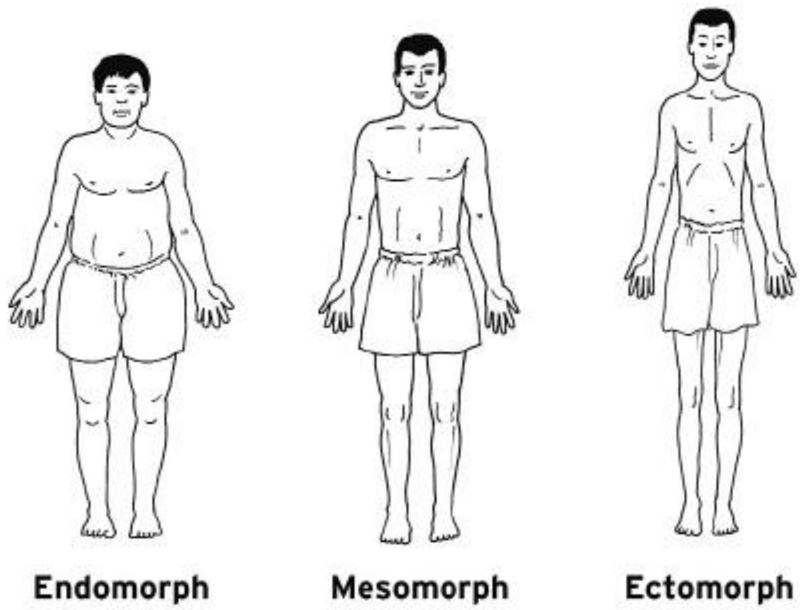


Figure 2.2 Male Body Shapes (Shepherd, Date Unknown, online)

characterised by being tall, lean builds with little excess body fat. Mesomorph's are a medium build and have a more athletic frame with broad shoulders and a narrow waist. Whilst endomorph shapes have a wider frame and generally more fat.

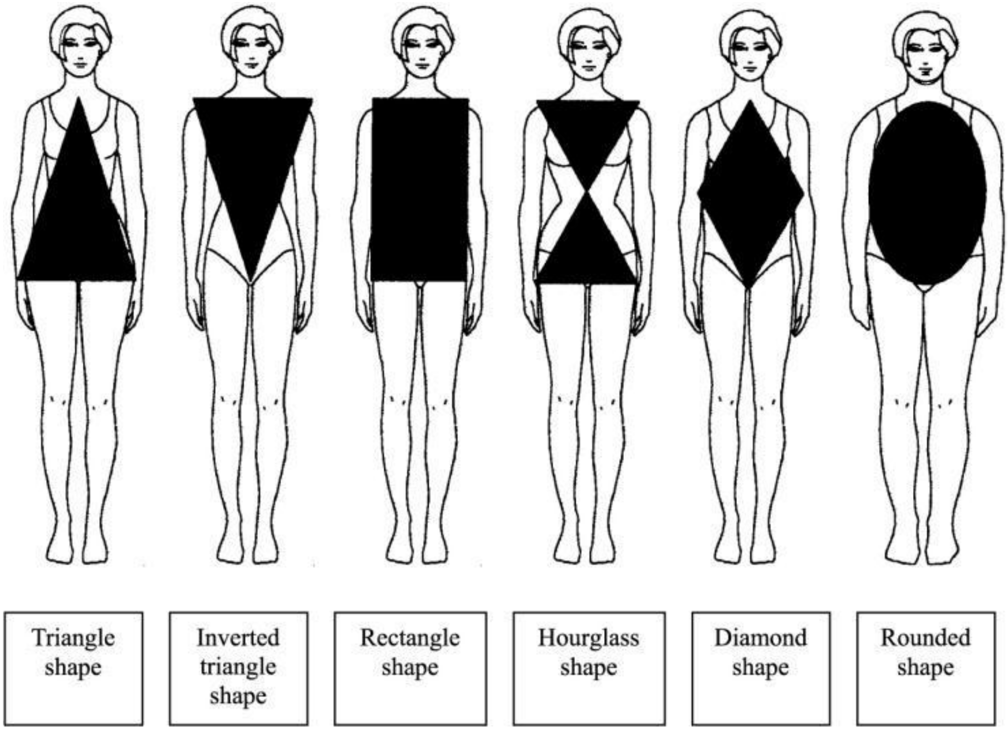


Figure 2.3 Female Body Shapes (The Style Aficionado, 2009, online)

Similarly, female body shapes are also often divided in to categories. For women there are six main categories: triangle; inverted triangle; rectangle; hourglass; diamond; and rounded (Figure 2.3). Female body shapes are primarily concerned with the location of body fat and because of such the size of the individual's shoulders, bust, waist and hips. For example, a female with similar measurements for these areas may be classed as a rectangle shape; whereas, a woman with similar measurements for bust and hip with a defined waist would be classified as an hourglass figure. As it can be seen in the Figure 2.3, body fat percentage may significantly differ between women. As previously mentioned, the work by Sawada (1993) highlighted that body fat affects the pressure exhibited by compression garments. As such, sizing for ready to wear compression sportswear is thought to be difficult.

Table 2.4 Body Fat Percentage Categories (BMI Calculator, Date Unknown)

Classification	Women (% fat)	Men (% fat)
Essential Fat	10-12	2-4
Athletes	14-20	6-13
Fitness	21-24	14-17
Acceptable	25-31	18-25
Obese	32+	25+

Furthermore, body fat percentages between men and women also differ significantly. Table 2.4 highlights the levels of body fat currently highlighted in research for men and women of the same fitness level. As it can be seen for all categories, women should exhibit much higher levels of body fat which would directly affect the pressure exhibited from compression garments. These values, coupled with the large variation in location of body fat between women, lead to difficulties in sizing.

As such, standardised sizing for men's ready to wear compression sportswear is thought to be catered for more of the general population due to the lower values of body fat and fewer variations in body shape. However, as previously noted, the most common body shapes in a population are further affected by many factors including race, gender and life style (Le Pechoux and Ghosh, 2002). Furthermore, although these specific body types are highlighted, many can be a variation of different types. These factors mean that sizing garments for ready to wear garments can be extremely difficult for both men and women thus often resulting in consumer dissatisfaction.

2.6.2 Sizing for Stretch Garments

Sizing for stretch garments, such as compression base layers, varies even more due to the characteristics of the fabric. Branson and Nam (2007) explain that garments made with stretch fabrics can be particularly difficult to size due to the extensibility of the materials being used. It is common place therefore to make patterns for such garments smaller than body size to achieve a better fit. However, Branson and Nam (2007) also explain that due to the high elasticity of such garments, different body shapes may fit in to one size top, unlike a similar size top in a non-stretch fabric. Hardaker and Fozzard (1997) also highlight the importance of correct fabric selection as a mistake in this may set production back to early stages.

Hunter and Fan (2004) explain how fabric characteristics, which may affect the fit and sizing of garments, can be assessed using the Kawabata Evaluation System for Fabrics (KES-F) or similarly the Fabric Assurance by Simple Testing (FAST) method. Thus enabling manufacturers to predict problems before they result in high costs to adjust. To help assess results from KES-F and FAST tests, which can be often difficult to interpret, McLoughlin and Hayes (2011) have produced a computer system which analyses the test results. The Fabric Sewability system not only produces fingerprints of the fabrics but also written analysis of the fabrics tested. The creation of such a system could further aid the use of objective tests to measure fabric handle, reducing the time needed to assess the results without the requirement of an experienced technician.

2.7 3D Simulation

The use of Computer Aided Design (CAD) in industry is under continual development. The introduction of 3D body scanners for example, has helped to streamline the method of recording body measurements and instantly creates a virtual record for analysis (Le Pechoux and Ghosh, 2002). Such anthropometric data can then be used in conjunction with many CAD systems. Williams *et al* (2004) used CAD to produce models of a hand to assess fit of military combat gloves. The research emphasised the importance of using anthropometric data to ensure accuracy of a CAD model. Williams *et al* (2004) also explained how such methods of design and manufacture are particularly of use when dealing with products that require a precise fit. Virtual systems used in the product development process also boast benefits such as reduction in lead times and increased precision (Davies, 1994). Software which allows users to recreate 2D patterns and simulate them in 3D on virtual avatars is available from many of the big suppliers of CAD packages (King, 2009). V-Stitcher by Browzwear, Modaris by Lectra and 3D Runway Designer by OptiTex are leaders in the market which enable 3D simulation (OptiTex International Ltd, 2011; Browzwear, 2012; and Lectra, 2012). All also include the capability for pressure maps to display pressure values of the pressures exhibited by garments whilst on the body. This function is improved by the realistic simulation of fabrics. Choi and Ko (2005) explain how fabric can now be realistically recreated in a virtual system thus largely improving the accuracy of the simulation process. Similarly to how fabric characteristics can be assessed before manufacture via KES-F and FAST (Hunter and Fan, 2004), the same results can be put in to many of the virtual systems. Thus, accurately recreating fabric characteristics in a virtual system. V-Stitcher, Modaris and 3D Runway Suite systems all allow users to alter fabric properties in such a way (OptiTex International Ltd, 2011; Browzwear, 2012; and Lectra, 2012). King (2009) explains how streamlining the product development process by sampling garments virtually can also make the industry more sustainable. Concern regarding the reduction of waste is growing across countless industries and this technology is thought to help tackle the issue.

It is believed that 3D simulation of pressure garments during the product development process would be a particularly useful tool due to the speed in which garments can be assessed and adapted if necessary. The pressure maps which can be used in the systems could also allow for assessment of pressures exhibited without creation of samples and timely experimental testing. The development of such tools would therefore be beneficial in the compression sportswear market.

2.8 Summary

It is clear from the literature reviewed that the compression market, although present for many years, is still expanding. Whilst much research has focused on improved performance characteristics and recovery times of athletes there is still yet to be a clear understanding of whether compression garments worn during sporting activities are always beneficial. A plethora of pressure measurement systems have been researched with regards to both medical and sporting industries with varying results. Thin, flexible sensors have been found to be beneficial when measuring pressure and as such should be considered for this research project (Ferguson-Pell *et al*, 2000; Lin *et al*, 2010; and Macintyre, 2011).

Furthermore, the studies by Yildiz (2007) and Wang *et al* (2010) have highlighted the importance of determining fabric characteristics to observe the role such factors contribute to pressure distributed. The understanding of fabric characteristics has also been highlighted by Hunter and Fan (2004) as being particularly vital when dealing with stretch garments. In view of this, experimental work regarding pressure measurement must be coupled with fabric analysis.

The work by Ferguson-Pell *et al* (2000) and Macintyre (2011) will be of particular interest in this research as both are concerned with the drift of measurements associated with pressure measurement systems. The drift of measurements is believed to be resulting from the fabrics stretching and relaxing on the body and therefore pressures continually changing during wear. Therefore any drift recorded through pressure measurement will be of interest, coupled with fabric characteristic information, in the hope of better understanding the pressures given by compression garments.

Sizing ready to wear garments has been highlighted as causing difficulties due to a wide variation of body shapes and sizes in the general population (Loker, 2007). The effect of body fat on pressure measurements further complicates the sizing of ready to wear compression base layers. However, the on-going development of 3D simulation tools, by key providers of CAD software, may enable simulation of compression garments which could potentially identify variations before production. The work of Hardaker and Fozzard (1997) and Hunter and Fan (2004) explained how carefully selecting fabrics, and determining the properties of such, prior to production can help streamline the sizing process. Furthermore, objective measurement systems such as KES-F and FAST have been identified as useful tools for successfully assessing fabric properties and can be used in conjunction with 3D simulation models.

This research analyses variations between compression sportswear brands and aims to create a CAD model which can map empirical work on compression measurement. The next chapter 3.0, Methodology, focuses on the primary and secondary research methods used to conduct the research project. Sampling methods and limitations encountered will also be detailed.

3.0 Methodology

This chapter specifies the methodologies that were used to accomplish both the primary and secondary research for the project. The selected methodologies were critically evaluated in order to ensure that the research data collated was consistent.

First and foremost, it needs to be decided upon whether a qualitative, quantitative or mixed method approach is to be used. Creswell (2009) explains how qualitative and quantitative research is often differentiated by the use of words (qualitative) or numbers (quantitative). Neuman (2011) and Bryman (2012) explain how quantitative research focuses on hypotheses where methods make use of experimental variables and accurate tests. As a consequence, quantitative data is concerned with the measurement of variables (Creswell, 2009). Conversely, qualitative research is more concerned with collecting data in a natural or social environment rather than in a controlled one, and the data of interest is typically subjective opinion (Neuman, 2011; and Bryman, 2012). In this case, a quantitative research methodology is considered appropriate. Although consumer opinion may be an interesting aspect to future research, quantitative research methods are considered suitable to fulfil the aims proposed in this research (see Chapter 1.0).

Although research design is concerned with which approach (qualitative or quantitative) is to be used, it is also essential to consider the type of theory used in the research process. In the case of this research project, the concept of empiricism will be used and both inductive and deductive methods will be followed.

3.1 Deduction and Induction

The main difference between inductive and deductive approaches is the time in which a theory is developed: prior to or after data collection (Bryman, 2012). Inductive theory is primarily concerned with the researcher making observations and identifying patterns during testing and from this creating a theory. On the other hand, deduction is a research technique which first focuses on creating a hypothesis from a theory and subsequently using scientific methods to test the hypothesis (Saunders *et al*, 2007; Neuman, 2011; and Bryman, 2012). In this research, a process of induction shall be adopted to complete aim one whereby similarities and differences between base layers will be observed and patterns identified. From this, theories will be formulated. Furthermore, an inductive approach will also be adopted to achieve aim two as after measuring compression the data will be analysed for patterns and again theories developed. For aim three, a process of deduction shall be implemented. The hypothesis that the experimental work with compression measurement can be mapped on a CAD system will be tested and either confirmed or rejected. Figure 3.1 highlights the step by step process associated with deduction theory and this will be applied to achieve aim three.

Figure 3.1 The Process of Deduction (Bryman, 2012, pp24)

Sections 3.2 to 3.4 highlight more specifically the methods for both the inductive and deductive portions of the research project.

Samples for testing in the research need to be selected using a sampling method. Sampling methods are mainly divided in two categories; probability, which is where samples are selected at random, and non-probability, where samples have not been randomly selected. The sampling procedures to be undertaken in the research are discussed in sections 3.2 to 3.4.

3.2 Aim One

To begin the inductive portions of the research and to accomplish aim one, a review of literature was first conducted. Such secondary research was completed to better understand and analyse the current compression sportswear trend. The research considered the origins of compression bandaging, how compression therapy has moved into the sportswear market, perceived benefits of using compression for sports and the wide range of pressure measurement systems available. Information was gathered from books, journals and magazine articles. Online resources were also used with caution to ensure the information gathered is authentic.

To further achieve aim one, a physical examination of compression base layers available to the mass market was also conducted in order to develop a database of typical fabric choice and construction techniques for compression base layers. A selection of base layer products needed to be selected to be assessed. As the research is focused on commercially available garments, the samples obtained needed to be those which are available to the mass market. The sports clothing and footwear retail report by Mintel (2011) (see Table 3.1) which highlights the most popular stores for sportswear was utilized to determine where samples would be purchased. As Table 3.1 shows, Sports Direct

Table 3.1 Results from Sports Clothing and Footwear Report (Mintel. 2011)

Retailer	% of Shoppers
Sports Direct	39
JJB	32
Internet	25
JD Sports	21
Supermarket	19
Value Retailer	19
Next	12
Outdoor Clothing Store	11
Footwear Shop	10
Mail Order	10
Marks and Spencer	9
Independent Retailer	9
Department Store	8
Other sports specialist	6
Mid-Market fashion shop	6
Other	13

was noted as the top sportswear retailer with almost four out of ten consumers (39%) buying garments, followed by JJB with 32% and Internet stores with 25%. To decide which samples to purchase and from which stores a sampling method had to be determined. A type of probability sampling is preferred in academic research as it is assumed to be more representative and is less likely to avoid sampling error (Neuman, 2011 and Bryman, 2012). Although a totally random sampling method was considered favourable to be representative of the market it would have been difficult to gather all possible options together to choose from, as well as being costly with regards to time and money. Therefore, cluster sampling was thought to be a more practical sampling method. In cluster sampling a group, or cluster, rather than a whole sampling population is taken to sample from (Neuman, 2011 and Bryman, 2012). This method assists with time and funding issues. In this case the top three retailers from the Mintel report were selected as the sampling group and therefore a selection of base layer compression garments purchased from them. To further help with funding an additional group was determined whereby only samples between set prices were sampled. As a small, medium and large sample of each brand need to be purchased for grading to be investigated only garments with all of three sizes available were put in the sampling cluster. Five different brands of base layer were purchased in order to establish key similarities and differences between some of the main competitors of the market. From the cluster determined three samples were bought from Sports Direct with one further sample from JJB and one from an Internet store (Amazon).

To create the database after purchase of the garments, the key details of each sample, including garment dimensions were collated to enable an inductive process. Although garments can sometimes be measured whilst on the stand, this was considered unsuitable for the garments in this research due to the high elastane content. If placed on a stand to measure, the garment would be stretched and therefore any recorded measurement unrepresentative of the sample. To avoid this issue, detailed measurements of all samples purchased were manually recorded on the half, whilst the garment was laid flat. Although the similarities and differences of the medium sized samples are of particular interest, measurements of the small, medium and large samples were recorded in order to evaluate overall differences in size alongside the differences in grading between brands. The sizing charts for each garment were also retrieved from each store website. These sizing charts will enable comparisons between the ideal body sizes the manufacturer suggests the garment is suitable in relation to the sizes of the samples recorded.

Furthermore, assessment of the five brands of compression base layers, both individually and comparatively, included fabric testing. All testing took place in a controlled laboratory with relative humidity of 65% ± 4% and temperature of 20°C ± 2°C, conditions in line with the relevant British Standard (BS 139, 2005) to maintain reliability of results. Fibre composition was recorded from the care label on each sample and therefore not determined independently. The following parameters were also tested:

- **Thickness:** A portable thickness gauge was used in order to determine the fabric thickness. The thickness was measured at five different points of each fabric, thus allowing an average reading to be made.
- **Area Density**
- **Bulk Density**
- **Courses and Wales**
- **Fabric Structure:** The fabric structure of each fabric was established using a piece glass.
- **Stretch and Recovery:** Stretch and recovery of the five fabrics were tested as per the British Standard (BS 4294, 1968). Three wale and three course samples were tested, allowing averages to be determined. The test looks at the amount the fabric will extend without breaking and, subsequently, the degree to which the fabric relaxes back to its original size. The results of this test will therefore be of particular interest as compression garments rely on the stretch properties of the fabric to create compression. Poor recovery will be detrimental to frequent use of the base layer.

Although breaking strength tests would record at which point the fabrics may stretch to it would not be possible to monitor the recovery of the sample also. The stretch and recovery tests are therefore favoured in order to relate the test results with the wearing of the garments.

Finally, the constructions of the bought samples were established to highlight variations between brands. The positioning of seams coupled with the stitch types used to construct garments was also assessed. This data was recorded to also monitor any correlation between the construction of the sample and the pressure distribution found.

3.3 Aim Two

Similarly, an inductive process was used to achieve aim two. An experimental approach was used to assess the compression provided by the medium sized base layers. In order to do this, a system for measuring compression was required. From the research gathered through the literature review (Chapter 2.0) it was concluded that the Tekscan systems were favourable. Tekscan is of particular interest due to the thin sensors of the system which Ferguson-Pell *et al* (2000) highlighted to be of particular interest when measuring compression of garments. Therefore the High Speed I-Scan pressure measurement system (Tekscan, 2007b) was selected. Each of the medium sized samples was fitted on a male Alvaform and the I-Scan sensor used to measure the compressive forces between the mannequin and the garment. It must be noted that limitations are encountered using this method of measuring pressure concerning simulation of the skin. A mannequin's surface is unlike skin and does not include soft areas of body fat. Therefore, the true relationship between the compressive forces measured and a wearer's body fat cannot be assessed. Mannequins that better resemble body fat with the use of foam within its structure are available, such as the Alvaform Soft series (Alvanon, 2009). Although testing on such mannequins may be of interest in future research these were unavailable for this research project.

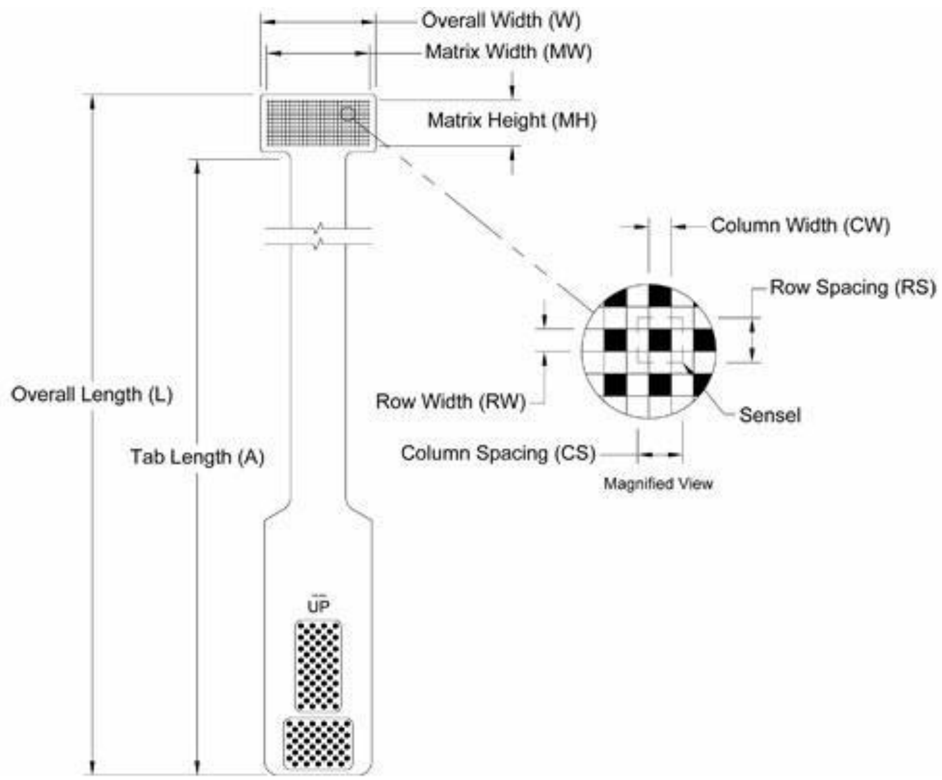


Figure 3.2 4201 Sensor (Tekscan, 2007c)

There are many different sensors available with the Tekscan system. However, the 4201 sensor, which contains 264 sensels in just a 4.57 cm by 2.11 cm matrix, was selected to be used as its small size allows for greater flexibility around the contours of the mannequin (Tekscan, 2007c) (see Figure 3.2).

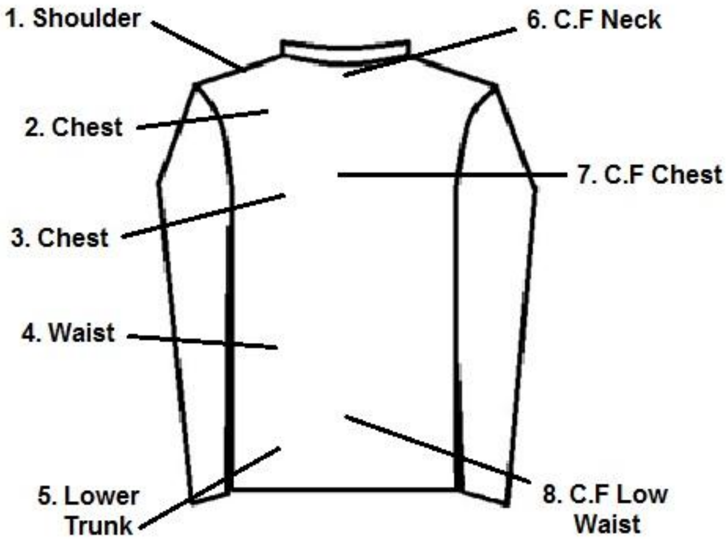


Figure 3.3 Areas to be measured using Tekscan

Small areas of pressure were pinpointed around the garments to produce a depiction of the pressures distributed in all of the samples. After assessing the task, it was concluded that a comprehensive picture could be obtained by defining eight areas on the garments. These were examined using the 4201 sensor and included the shoulder seam, chest and waist, all of which are highlighted in the Figure 3.3. As the system is temperature-sensitive, all experimental work took place in a controlled laboratory with humidity of 65% ± 4% and temperature of 20°C ± 2°C, conditions in line with the relevant British Standard (BS 139, 2005). The sensor was carefully inserted between the garment and mannequin in order to record the pressure. The tight fit of the garment allowed the sensor to be sufficiently held in place without the need of any adhesives which would have interfered with the pressure readings obtained. As ‘drift’ of measurements has previously been detected by the system in the work by Macintyre (2011) each measurement was monitored for around thirty seconds and the fluctuation of measurements recorded. It is anticipated that this will highlight the effect of relaxation on the compression values and draw attention to the initial compression a wearer may receive along with the likely compression after this. From each position that the sensor was placed, the Tekscan equipment will create a pressure map compiled of many squares with different shades of colour. The colour of the squares represents the amount of pressure experienced in that specific location. The values recorded from these tests are to be analysed alongside the garment database results to assess the effect of garment dimensions, fibre composition and fabric properties on pressure distribution.

3.4 Aim Three

Completion of aim three was by a method of deduction. The hypothesis that the experimental work with compression measurement can be mapped on a CAD system was tested to be either confirmed or rejected. In order to test this hypothesis the compression measurement tests completed in the laboratory were virtually simulated within a computer aided design (CAD) programme. From the simulation systems discussed in the literature review, V-Stitcher was selected to be used to create the CAD model. V-Stitcher allows the user to see digital patterns on detailed 3D avatars, thus allowing flaws to be highlighted (Browzwear, 2012).

The results from the garment database and compression measurement analysis were assessed to select samples for simulation. Two samples were selected for simulation as they had contrasting fabric properties and pressure measurements. Dissimilar samples were selected to determine the accuracy of the CAD model to simulate a variation of properties.

To recreate the garments virtually and begin the simulation, patterns for the randomly chosen garments were reconstructed. Although the detailed measurements taken of each sample for the database could have been used to create such patterns, it was believed that the deconstruction of the samples would help the patterns to be more precise. Particularly when recreating the curves of the garments. The paper patterns were then digitised so that they were able to be viewed and manipulated within the V-Stitcher software. The patterns next had to be virtually 'sewn' together. To do this each seam needed to be manually assigned to its right position. These instructions then enable the system to virtually construct the garment. An avatar was then modified to the dimensions of the male mannequin used during the experimental procedure for the simulation. Once the patterns were displayed digitally on the avatar, pressure maps could be viewed within the system. The hypothesis will then be validated if the readings from these maps correlate with the pressures found through experimental testing.

3.4.1 Fabric Assurance by Simple Testing (FAST)

In order to simulate the pressure tests on the body form and to further support aim three, fabric properties were put into the V-Stitcher programme that are representative of the fabrics used in the commercial garments. Browzwear (2012) states that the *"Unique texture mapping capabilities provide photo-like representation of fabric"* thus ensuring the simulation is as true to life as possible. Fabric Assurance by Simple Testing (FAST) is a collection of tests, created by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to determine the deformation of fabrics by low loads (CSIRO, 2004). Although subjective measurement is used widely throughout industry for determining fabric handle, the FAST system was created in order to eliminate bias from the qualitative methods previously used (Hunter and Fan, 2004). Prior to the creation of FAST, Kawabata and associates created the Kawabata Evaluation System for Fabrics (KES-F) in order to examine the deformation and recovery of fabrics. However, KES-F is often cited as being expensive and difficult to use, points which the FAST system was designed to overcome. Ly *et al* (1991) and Fan and Ng (2001) claim that it achieves this objective. Furthermore, FAST is more beneficial in this circumstance as the results from which could be put directly in to the V-Stitcher system, unlike the results derived using the KES-F equipment. By doing this the relevant patterns were better simulated in the CAD system with more true to life garment characteristics. FAST is comprised of four tests, each of which is detailed below (Minazio, 1995):

- **Compression -** The FAST 1 test initially measures the fabrics thickness. Although this is a measurement used to better understand the characteristics of a fabric, the thickness alone does not indicate much regarding the fabric performance during construction and use. To further understand this, FAST 1 measures the thickness of each fabric under two loads, so that it is possible to calculate the stability of the fabrics thickness when under pressure. Durability of the fabric can also be calculated by repeating the thickness test after steaming the fabric, thus indicating the effect of such low loads.
- **Bending -** FAST 2 focuses on the rigidity of each fabric. The system measures how easily the fabric begins to bend and therefore how well it is likely to drape. The test determines two parameters: bending length; and bending rigidity
- **Extensibility -** The FAST 3 extension meter measures how far a fabric will stretch in all the warp, weft and bias directions. The extension of each will be measured using three weights, 5 g, 20 g and 100 g. From the results gathered by FAST 3 the shear rigidity can also be calculated. The FAST

system was produced for tailoring fabrics and as such the parameters of the test are for woven fabrics (McLoughlin *et al*, 2010). Therefore, the fabrics are likely to reach the limit of the machine at 100 g.

- **Dimensional Stability -** FAST 4 is used to determine the dimensional stability and hygral expansion of the fabric. In order to calculate this, the fabrics need to be dried, soaked in water and then re-dried, being measured at each point for differences in size to be calculated.

After the completion of the FAST tests, the formability of each fabric will also be determined through a simple calculation using previous results.

The research methods outlined in this chapter include a combination of inductive and deductive processes which were completed in order to achieve the three aims of the research. Secondary research was gathered in the form of a literature review to assess the use of compression in medicine and the increased availability in sportswear. Primary research collection began with the selection of base layer garments through cluster sampling. The chosen samples were then analysed with reference to fabric properties, garment measurements and seams to create a garment database of commercially available base layers to satisfy the first aim of the research.

Next, compression measurement using the Tekscan system was completed and assessed against the results from the garment database to accomplish aim two. The Tekscan system was selected as thin flexible sensors have been favoured in literature regarding pressure measurements and it is believed that the drift of measurements associated with the system will highlight the relaxation of the samples.

Finally, two samples were randomly selected to be recreated in a 3D simulation model. The CAD model was created to test the hypothesis that the experimental data can be mapped in a virtual system. FAST testing of the fabrics also allowed for fabric properties to be put in the system for a more true to life simulation of the garments to be created.

The next chapter focuses on the garment database detailed in this chapter focusing on the construction, fabric types and measurements of compression base layers on the current market.

4.0 Database of Garments

This database was compiled to observe the variations present between brands of compression base layers for sport. Five different brands of compression base layer were randomly chosen for this (see Chapter 3.0 Methodology). It is hoped that the research gathered will highlight some of the main differences between mass market brands which consumers consider upon purchase. Furthermore, the information collected for this database with reference to dimensions, materials and construction, shall be used to better analyse effects on the pressures measured from each sample. It is believed that the database information coupled with the compression measurement results will highlight some of the main effects of sizing, construction and fabric differences between brands.

4.1 Garment Overview

As the compression sportswear market has expanded, a wide range of garments are available for the everyday consumer to purchase. All samples purchased were long sleeved base layer t-shirts. Short sleeved shirts, as well as leggings, socks and shorts are also available.

The price of the samples purchased range from £15.99 to £19.99. Although more expensive garments are available these were not on offer by the three top retailers as detailed in the sports and clothing retail report by Mintel (2011).

From the five brands of base layer purchased (refer to Appendix A for photos) the fabric compositions, measurements and construction were compared to produce this database.

4.2 Fabric

The following Table 4.1 shows the fibre composition of the five different styles of base layers purchased. All fibre compositions were taken directly from the care label and not determined independently. From the fabric compositions displayed in Table 4.1 it is interesting to point that garments were made of eight and eighteen

Table 4.1 Fibre Compositions of Samples Purchased	
Sample	**Fibre Composition**
A	63% Nylon, 23% Polyester, 14% Elastane
B	65% Nylon, 25% Polyester, 10% Elastane
C	92% Nylon, 8% Elastane
D	84% Polyester, 16% Elastane
E	82% Nylon, 18% Elastane

per cent elastomeric material. Miller (1989, p.53) noted that elastane fibres may *"stretch 500% to 600% before breaking"* and *"have a high rate of recovery from stretch up to 200%"*. Taylor (1990) however stated that elastane can stretch up to 700% its original size whilst still maintaining high recovery rates.

Both samples A and B contain a combination of nylon and polyester whilst samples C, D and E are made of either polyester or nylon. Nylon is a strong fibre capable of high recovery after stretch (Taylor, 1990). These properties bode well for compression sportswear garments due to the frequent strain on the fabric during use (wearing and washing). Polyester, on the other hand, is characterised by maintaining the stability of its structure, it does not easily extend (Taylor, 1990). Miller (1989) however stated that in the case of garments which require stretch whilst maintaining stability, polyester is favoured over nylon. Furthermore, the large amounts of elastane in the garments should compensate for any lack of extension.

The effect of the fibre compositions of all five samples is of particular interest when examining both the fabrics ability to recover with reference to the stretch and recovery tests and the pressure values obtained using the Tekscan equipment.

4.2.1 Fabric Analysis

As noted in Chapter 3.0 Methodology, area density, thickness, and bulk density of the five samples were all determined to create a fabric analysis for the database of

Table 4.2 Knitted Fabric Analysis Results					
Sample	**A**	**B**	**C**	**D**	**E**
Area Density (g/m^2)	213	250	223	174	237
Thickness (mm)	0.86	0.74	0.37	0.49	0.62
Bulk Density (g/cm^3)	0.25	0.34	0.61	0.36	0.38
Courses (per cm)	26	30	-	-	34
Wales (per cm)	20	22	-	-	25

compression base layers. These results, along with the courses and wales per cm of each fabric can be found in the Table 4.2. All calculations completed to get these results can be found in Appendix B.

As highlighted, sample B was found to be the heaviest fabric with an area density of 250 g/m^2. In contrast sample D has the lightest recorded weight of just 174 g/m^2. The thickness of the fabrics varies considerably from 0.86 mm to 0.37 mm (see Table 4.2). Taylor (1990) states how the thickness of the fabric can improve the warmth of the garment and this may be the reasoning for the variation between the garments assessed. Although the thickness of a fabric is dependent on the bulk density of the yarns other factors such as construction of the fabric and chemical treatments can also affect the thickness (Taylor, 1990). Other factors such as these may account for the difference in thickness between sample D of 0.49 mm and sample E of 0.62 mm as both were found to have similar bulk densities. Similarly, although samples D and E were found to be thinner than sample B at 0.74 mm, the bulk density of B is again smaller at 0.34 g/cm^3. This contradicts the notion that a higher value for bulk density will equate to thicker fabric.

Due to the complex nature of the knitted fabric structures, only two of the fabric structures were analysed. Both samples A and B were noted as tricot warp knit structures. Tricot warp knit is considered as having good elongation and soft fabric handle (Taylor, 1990) which are favourable qualities for sportswear such as compression base layers. The knit structure of the other three samples was unable to be determined due to the tightness of the knit. This made it difficult to remove yarns and subsequently examine the knit structure even with the use of a piece glass. The companies which make the garments would not disclose the structure of the knit and therefore cannot be determined at this time.

It should also be noted that sample B also contains small mesh panels. However, this fabric was not analysed due to an insufficient amount of available to test.

4.2.2 Stretch and Recovery

Further to the basic fabric analysis of the samples, stretch and recovery of the samples was tested. The ability of the fabrics to stretch and recover was of interest in order to simulate repeated wear of the garments. As the fit of compression

Table 4.3 Stretch and Recovery Results in %						
	A	**B**	**C**	**D**	**E**	**Range**
Stretch Courses	95	107	192	101	116	21
Recovery Courses	96	95	89	96	96	7
Stretch Wales	94	79	214	161	161	135
Recovery Wales	95	95	85	94	89	10

garments is crucial for the functionality of the garment it was imperative to understand how the commercially bought samples perform under such tests. Table 4.3 shows the stretch and recovery results for both the courses and wales for all five samples. Calculations completed to determine these results may be found in Appendix C.

From these results it can be seen that, although sample C contains the least amount of elastane, it exhibited the most stretch reaching 192% for the courses and 214% for the wales. However, sample C was also found to recover poorly only returning 89% in the course direction and 85% in the wale direction. Although this poor recovery may be expected when coupled with the high levels of stretch exhibited, this may highlight an insufficiency with this fabric as a compression garment for the everyday consumer as compression is unlikely to be maintained after use. On the other hand, although sample B did not reach the same high levels of stretch as sample C, it did exhibit good values of recovery in both the course and wale direction. Additionally, sample A, which is a very similar fibre composition as sample B performed similarly in this test. It shall be of interest to see whether both samples A and B also have comparable pressure measurements.

Sample E is of immediate interest when looking at these results due to the high values of stretch for both the courses and wales. Although this sample exhibits extremely high stretch, the recovery value for the courses is also one of the best across the board. However, the recovery of sample E in the wales direction is only 89%, thus suggesting probable shrinkage in this direction after wear and washing.

The values for both stretch and recovery for sample D were both found to be in the middle of the group. However, sample D stretched significantly more in the wale direction but it is unclear how this will affect the pressure distribution of the sample. Samples D and E have comparable elastane values but contain polyester and nylon respectively. For this test, sample D and sample E exhibited very similar results which suggested that nylon and polyester are alike with reference to recovery after wear.

4.3 Garment Measurements

One way to initially observe the variations between brands was to measure each of the samples to highlight differences in garment size and shape.

Figure 4.1 displays the points at which the samples were measured. Table 4.4 details the manual measurements taken for the five medium samples. The measurements listed show variations among ready to wear samples of the same size.

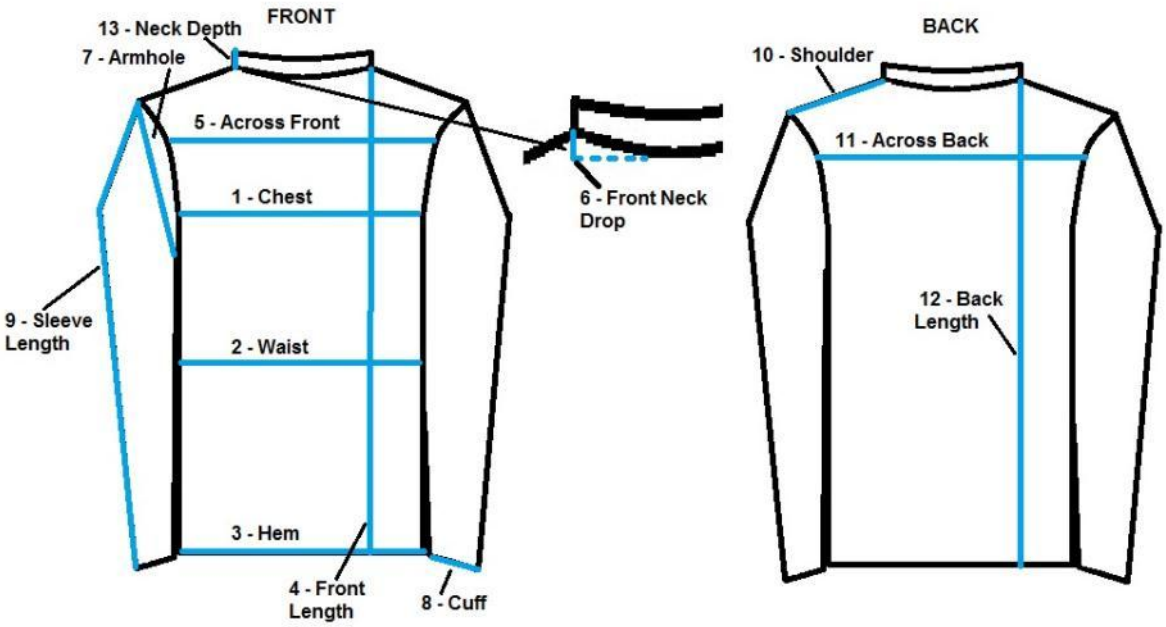


Figure 4.1 Measurement Points in a Typical Base Layer

The width measurements are of particular interest as these in particular will affect the garment fit, hence the compression. The sizing charts provided by each retailer for the recommended fit were taken from the relevant websites (Sports Direct, 2011; JJB Sports, 2011; Amazon.com, 2011) (see Appendix D). These were then observed to further assess the significance of the measurements recorded. These charts stated the recommended size of the wearer at the chest for a small, medium and large sample. Sports Direct have one sizing chart for all

Table 4.4 Measurements of Medium Sized Samples							
	Measurement Point	**A**	**B**	**C**	**D**	**E**	**CV %**
1	Chest (measured across width at 2.5 cm down from underarm)	42.3	36.4	33.8	40.4	37.4	7.9%
2	Waist (measured across width at 40 cm down from side neck point)	37.4	35.1	32.3	38.1	33.8	6.1%
3	Hem – Straight	36.2	35	31.5	36.5	36.4	5.4%
4	Front Length – side neck point to hem	66.5	66.4	64.7	65.7	63	2.0%
5	Across Front (measured across chest at 13 cm from side neck point)	32.8	36.3	27.2	36	34.1	9.9%
6	Front Neck Drop (side neck point to neck seam)	4.3	6.3	10	9	7.6	27.0%
7	Armhole Straight	28.1	19.6	23.9	18.5	17.2	18.7%
8	Cuff Straight	8	7.4	9.6	9	8.1	9.3%
9	Sleeve Length	70.5	55	68.8	54.9	52.2	12.8%
10	Shoulder Length (from side neck point)	24.4	13.9	7.1	13.5	10.9	41.2%
11	Across Back (measured across at 13 cm from side neck point)	33.3	36.1	27.6	37.4	33.8	10.0%
12	Back Length – side neck point to hem	69.9	66.1	64.8	66.4	63.8	3.1%
13	Neck Rib Depth	5.2	5.2	2.1	1.6	1.7	53.0%

garments and therefore the three samples from this store are to be compared to the one set of suggested sizes.

Sample C was found to have the smallest width measurements for points 2 - (waist), 3 - (hem), 5 - (across front) and 11 – (across back). However, sample C also contains the least amount of elastane of any of the samples. The use of 92% Nylon in sample C may account for more stretch and therefore the smaller sizing may have seen fit to accommodate this.

Sample E was measured around the middle for all width measurements. The sizing chart for sample E stated a suggested chest size of 48 cm to 50.5 cm for a medium sized sample. Point 1 – (chest) measurement for sample E was measured at 37.4 cm and therefore significantly below both the lower and upper limits of recommended body size. Although it may be assumed that due to the high elastane content of sample E (18%) it will stretch the most this may not be the case. The fineness and the quality of the elastomeric fibres used will also influence the garments ability to stretch.

Although samples D (16%) and E (18%) both contain similar values of elastane content, sample D, which contains polyester, is bigger at measurement points 1 – (chest), 2 – (waist), 5 – (across front) and 11 – (across back), as opposed to sample E which contains nylon. Again, the quality of elastane fibres will influence the garments stretch characteristics. As previously noted, Miller (1989) and Taylor (1990) both state that polyester is characterised by having good stability and therefore is less likely to stretch than Nylon. Therefore the variations in size between D and E may be in order to accommodate this. Samples A and B also have similar fibre compositions and are therefore of particular interest when observing if measurements are comparable. Although sample A was found to be have broader width measurements at points 1 – (chest), 2 – (waist) and 3 – (hem), sample B is wider at points 5 – (across front) and 11 – (across back). The sizing chart for sample B states a recommended chest size of 47 cm to 49.5 cm. Sample B was measured as 36.4 cm at point 1 – (chest) and therefore is much smaller than the suggested chest size of the wearer.

Medium sized garments A, C and D, from Sports Direct, were all recommended for a chest size between 48.5 cm to 51 cm. However, the point 1 - (chest) measurements recorded for these three samples vary significantly from 33.8 cm for sample C to 42.3 cm for sample A. This means sample C is made to be much smaller than the lower limit of the recommended chest size. Although the chest measurements recorded for sample D and sample A were found to be over 6 cm and 8 cm (respectively) bigger than sample C, the measurements are still below the lower limit of the recommended chest size. This wide variation between the size of different brands, which have the same recommended chest size, is thought to effect the pressure distributed by the garments when worn by different sized individuals. In particular if the wearer of the garments is towards the upper limit of the recommended sizes. Although it has been previously noted that the measurements for sample C may need to be slightly bigger due to the stability of polyester, it may be the case that this sample will not provide as much pressure as desired. Again, especially if the person wearing said garment is toward the higher limit of the recommended size.

All the samples examined were significantly below the lower limit of recommended chest sizes specified by the retailers. However, there was a wide variation of proximities to said limits. Whilst sample A measured 6.2 cm below the limit, sample C measured 14.7 cm below. The wide variation in differences between these samples highlights the need for more detailed sizing recommendations for consumers to ensure correct fit and therefore adequate compression. It also must be taken into account that only one medium sized sample has been measured per brand. Although this helps to highlight the differences between garments when consumers purchase them, the exact size of a medium sample is not able to be determined. Some of the measurements taken may be unrepresentative as a whole and a result of mistakes in production.

The relationship between the size of the garments and the fibre content will again be of particular interest when looking at the pressure distribution of the samples. Where the samples have the same recommended torso size but exhibit varying chest measurements the effect of this on the compression will also be greatly interesting.

While not the main focus of the research, the small and large sample garment measurements were also examined. Each of the small and large samples was measured at the same points as detailed in Figure 4.1. All measurements can be found in Appendix E. As with the medium sizes, many variations between brands are evident. In particular many of the width measurements, which will affect the garment fit and compression, vary significantly between brands. For example, the measurements recorded for point 1 – (chest) on the small samples vary more than 5 cm between brands (sample C 32.3 cm and sample A 37.9 cm). Similarly, point 3 – (hem) has a variation of around 4cm between brands. The measurements of the large samples were found to differ even more. Point 1 – (chest) was found to vary almost 10 cm between brands (sample C 36 cm and sample A 45.8 cm). In addition, point 2 - (waist) fluctuated around 7 cm and point 3 – (hem) more than 6 cm between brands.

The differences between the three sizes of the same brand were also examined to consider variations in grading. Again there were many differences between brands. The measurements for sample A had the biggest difference between each size with around 4 cm between each of the small, medium and large sizes for points 1 – (chest), 2 – (waist) and 3 – (hem). Conversely, sample C only varies around 1 – 2 cm between each size at points 1 – (chest), 2 – (waist), 3 – (hem) and 5 – (across front). It is believed that these variations in grading will affect the pressure distributed across sizes. It should again be noted that although big differences with grading have been highlighted from these measurements only one sample in each size has been examined. Therefore, some of the measurements taken may be unrepresentative as a whole and a result of mistakes in production. Therefore, research that further investigates these differences in grading on a much larger number of samples may be beneficial.

4.4 Stitches

Table 4.5 Stitches Used in Samples Purchased.	
Sample	**Stitches**
A	607 Wide Cover Stitch, 406 Bottom Cover Stitch and 504 Over edge.
B	605 Cover Stitch and 504 Over edge.
C	607 Wide Cover Stitch and 514 Four Thread Over edge
D	607 Wide Cover Stitch, 406 Bottom Cover Stitch and 401 Double Locked Stitch
E	605 Cover Stitch and 607 Wide Cover Stitch

The Table 4.5 lists the stitches used in the compression samples analysed. Combinations of the following six different stitch types have been identified in the samples:

- **401 Double Locked Stitch:** The 401 Double Locked Stitch is used to join fabric such as the neck seam on sample D. Cooklin (2006) explains how the 401 stitch, although similar to the common 301 allows a greater extension and is therefore more suitable for stretch fabrics.

- **406: Bottom Cover Stitch:** On both samples A and D the 406 bottom cover stitch is used for the hems of the garments. This stitch allows the hem to be neatened whilst being sewn and its high elasticity means it is suitable for use on fabrics with high stretch (Carr and Latham, 2008).

- **504: Over edge:** To join the neck seam on sample A and both the side seams and sleeve seams on sample B, the 504 over edge stitch has been used. The three thread stitch exhibits both good stretch and recovery and therefore is suitable for stretch fabrics (Carr and Latham, 2008).

- **514: Four Thread Over edge:** The 514 stitch both neatens and joins using, as the name suggests, four threads. This stitch increases the strength of the seam without compromising on the bulkiness of it (Cooklin, 2006). Carr and Latham (2008) explain how the 514 stitch is less vulnerable to rupture due to its increased width compared to the similar 504. The 514 stitch was identified on the neck attachment of sample C.

- **605: Cover Stitch:** The majority of seams for both samples B and E are the 605 cover stitch. This stitch type has excellent stretch properties and is usually used to *"eliminate some overlocking operations"* (Cooklin, 2006, pp110).
- **607: Wide Cover Stitch:** Similar to the 605 cover stitch, the 607 stitch boasts high elongation and therefore suitability for garments such as those being analysed. Unlike the 605, the 607 has a wider bight and is made using six threads rather than five. On samples A, C and D the majority of seams are constructed using the 607 wide cover stitch.

All six stitches identified within the samples are considered to display adequate levels of elasticity for use in stretch garments and are therefore unlikely to affect the garment. The 607 wide cover stitch is noted as having a wider bight than the similar 605 cover stitch, as does the 514 four thread over edge compared to the 504 over edge. The wider bight in these stitches should create a stronger seam. The increased durability from this may ensure the garment is fit for purpose for a longer period. Although, it is thought that this will have no bearing on the compression measurement during this research.

4.4.1 Positioning of Seams

Although the construction of the seams is noteworthy to highlight similarities and differences between the samples, it may be argued that the position of the seams is of greater importance on the impact of the pressure distribution. The following Figures 4.2 to 4.6 are working drawings to show the positioning of the seams and panels of each sample. As it can be seen from these images, no two samples were alike with reference to seam positioning. Whilst sample E is a 'basic' style long sleeve t-shirt, sample B incorporates many panels on both the back and the front of the garment. It will be of particular interest when recording the pressure vales of the garments whether these panels appear to effect the distribution and values of pressure.

Figure 4.2 to 4.6 Positioning of Seams

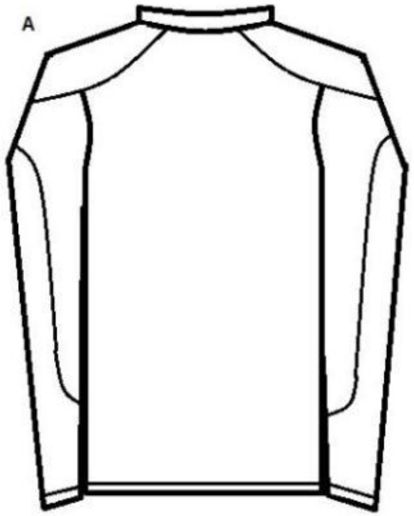


Figure 4.2

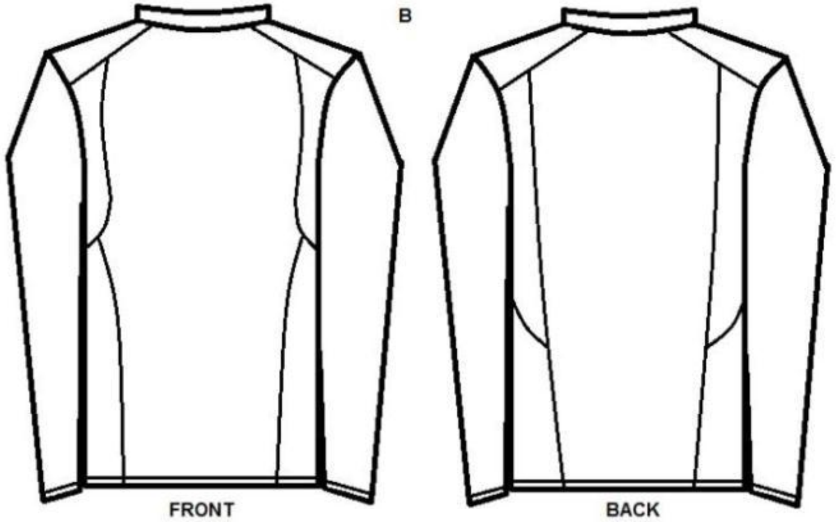


Figure 4.3

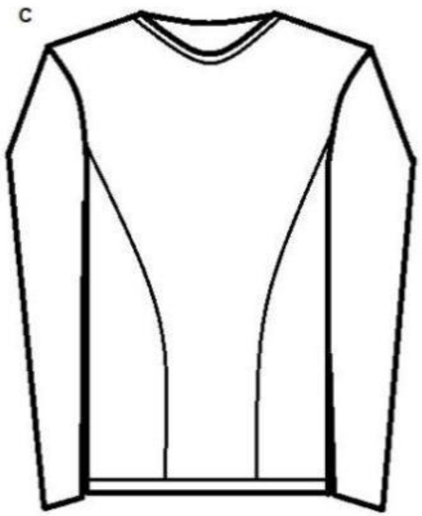


Figure 4.4

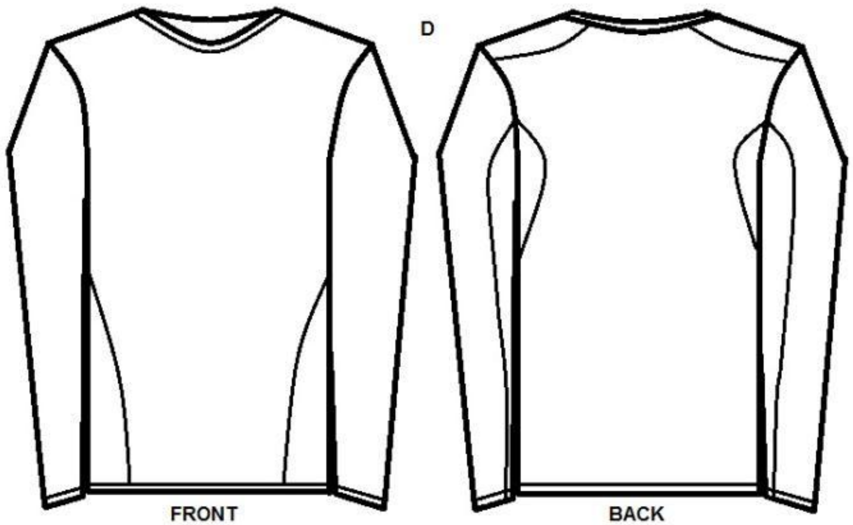


Figure 4.5

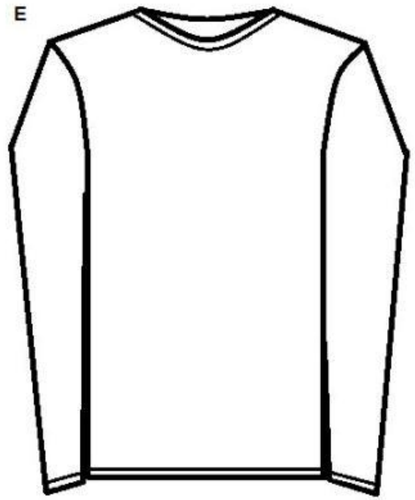


Figure 4.6

4.5 Summary

All in all there have been both variations and similarities highlighted through the collation of the garment database. Nylon, polyester or a combination of the two fibres have been used in all the fabrics examined. It is likely that these fibres have been utilised for high values of stretch and recovery and the good stability associated with the fibres. However, after testing the stretch and recovery of garments some poor recovery rates were highlighted. Although high levels of elastomeric fibres have been used in all garments the insufficiency of recovery found may be a result from poor elastomeric fibre quality. No matter what the reason for the poor recovery, this will directly affect the compression exhibited in the garments when worn multiple times. Thus meaning that the support the garments will provide to the wearer will reduce after each wear due to their inability to return to their original state.

From the manual measurements taken, the samples vary considerably between garments of the same specified size. This is a particular concern with regards to the three samples purchased from one retailer as the size chart for all is the same. By having the same size chart but different brands which are inevitably of different fits compression consumers will get from each garment will vary considerable. However, unless purchasing all and comparing, consumers may be unaware of this. The size charts from all three retailers are also very basic with only a few guideline measurements given. It is thought that garments such as these require much more accurate size charts and more detailed help for fitting in order for consumers to make informed choices when buying.

Combinations of six stitch types were identified in the five samples. All are thought to be appropriate for stretch garments and whilst some boast bigger bights resulting in increased strength this is not thought to be an issue with regards the compression measurement analysis. The position of seams and panels varies widely between all samples analysed. It is yet to be determined what effect, if any, this will have on the distribution and values of pressure. It could be the case that these panels were designed merely for aesthetic purposes but the impact of this could be significant if seams are found to have effected compression. Again, there is no information at point of purchase about the effect of seams and panels. Although these may be thought to be ergonomically placed, there is no further explanation as to what this means and their effect on the body. Further detail on such factors would also aid consumer choices.

Overall, it is clear that there is a huge variation between brands with regards to ready to wear compression base layers. More detailed sizing information for consumers will perhaps help overcome these differences as sizing charts provided currently are only vague. The differences highlighted here shall help to analyse variations and similarities between the pressures measured

The next Chapter, 5.0 Compression Measurement Analysis, highlights the key findings from the pressure measurements taken of the five samples in the database. From the analysis in Chapter 5.0, it may be possible to allow a better understanding of the behaviour of the fabrics with reference to compression values and distribution.

Pressure testing using the Tekscan system was utilised with the aim of exploring the differences between the pressure distributions of the consumer samples purchased, as noted in Chapter 3.0 Methodology. The pressure was determined at eight different points on each of the five medium sized samples and the results are presented in raw data form in the below Table 5.1. Although the Tekscan system was calibrated after the pressure measurement analysis to be able to convert the results from raw data, such calibrations are not reproducible within the system. Therefore, with the calibrated equipment, it is unlikely to be able to adequately reproduce the results collected. Raw data, on the other hand, is much more reproducible and as a result more consistent for this research than the calibrated form. As a result of such, the measurements discussed within this chapter are all expressed as raw data. When measuring the compression with Tekscan, real time relaxation of the garments was monitored through a fluctuation of pressure. The raw data in Table 5.1 gives the range of values that varied randomly during the compression measurements using Tekscan. A drift of measurements is something which others have previously associated with Tekscan systems (Ferguson-Pell *et al*, 2000; and Macintyre, 2011) and is thought to capture the wide variation in pressure when a garment relaxes.

Table 5.1 Pressure Measurement (Raw Data)

	Measurement Point							
Sample	**1** Shoulder	**2** Chest	**3** Chest	**4** Waist	**5** Lower Trunk	**6** C.F Neck	**7** C.F Chest	**8** C.F Low Waist
A	920-950	40	520-580	540-580	225	40-60	40-60	150-180
B	1050-1150	10-20	340-370	700-750	140-200	10-30	0-10	240-300
C	950-1080	0	740-780	60-70	100-130	0	5-15	120-160
D	780-830	10-15	820-890	240-280	50-90	20-35	0-15	160-180
E	700-770	0	760-850	440-530	260-320	60-100	0-20	110-130

Although the real time relaxation of compression is of interest in this research, the tendency for the pressure measurement to vary in such a way does have implications for testing. To measure pressure values it would be beneficial to have a more stable position to capture however, the drift of measurements would still need to be understood. Figure 5.1 also displays the raw data in the form of a graph. Where a fluctuation of measurements was recorded at one point the median value for that area has been taken and plotted on the graph. Immediately from the results, shown in both Table 5.1 and Figure 5.1, clear similarities and differences between samples A to E can be observed. Very little compression is thought to be required down the centre front of the body due to the close proximity to the heart. Therefore, the low values of pressure which are shown on Figure 5.1 at points six (Centre Front (C.F) neck) and seven (C.F chest) are to be expected. Although on the centre front of the body, point eight (C.F low waist) exhibited slightly more pressure than the other centre front measurements. However, compression here is likely to facilitate the return of deoxygenated blood toward the heart. Very little compression was also measured on all samples at point three (chest). Again, this area is a close immediacy to the heart and, therefore, little pressure is expected here. The areas of most pressure have been found to be at point one (shoulder) and point three (chest). However, Figure 5.1 clearly highlights how sample B differs from other garments at measurement points three (chest) and four (waist) with the higher value at point four (waist). Similarly, sample A also exhibits higher pressure values for point four (waist) than point three (chest) although with a much smaller difference between the two. These anomalies will be of interest when further analysing the compression measurement.

Pressure maps collected via the Tekscan system also help to highlight the vast differences in the way the pressures are distributed. Figure 5.2 is the colour legend to which the pressure maps relate to. The results from the five samples need to be analysed collectively and in relation to fabric properties, garment measurements and garment seams and construction for the effect of variances between compression garments of the same stated size to be identified.

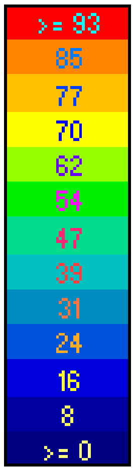
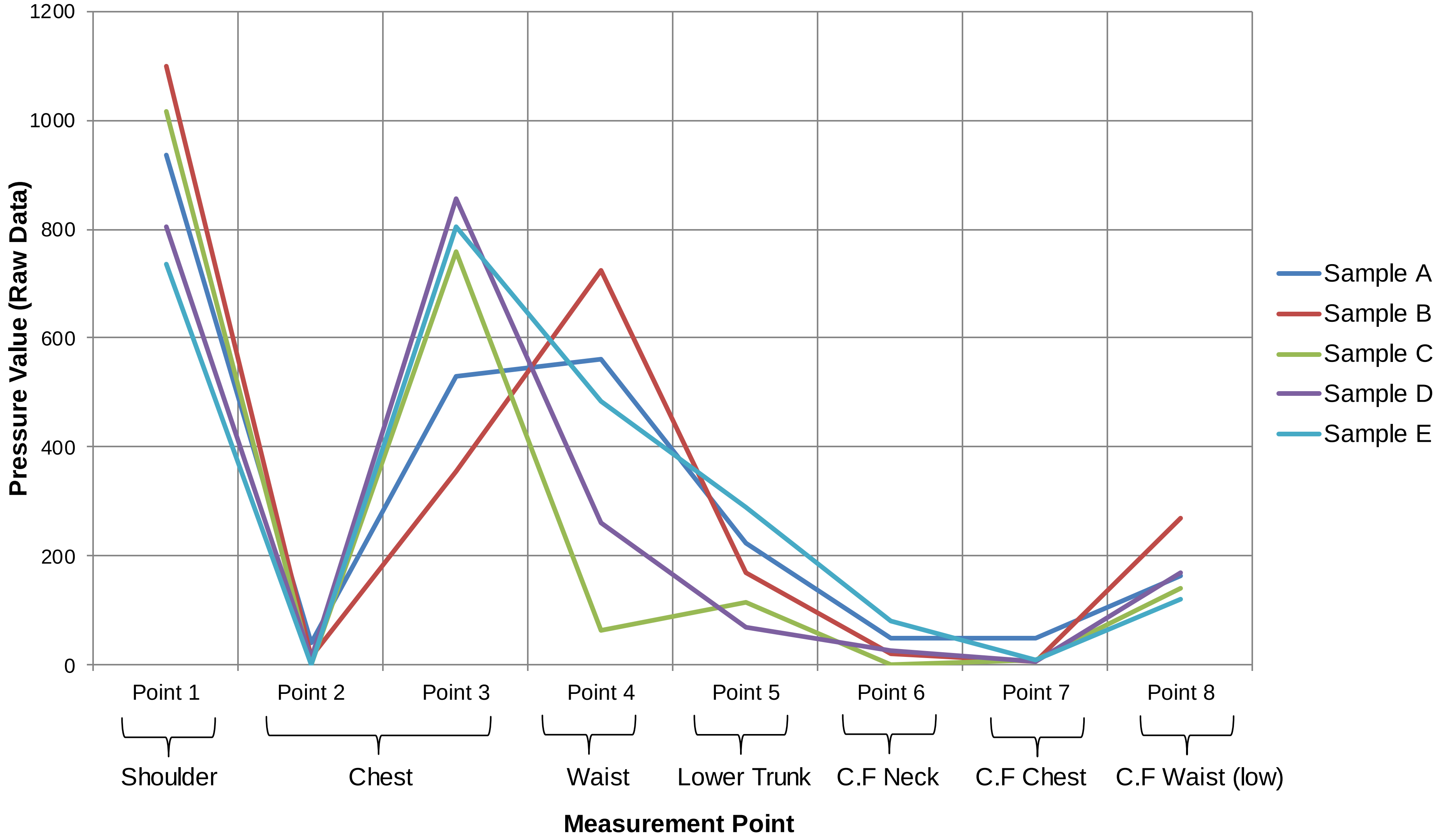


Figure 5.1 Colour Legend for Tekscan

5.1 Pressure Measurement Analysis

To begin the pressure measurement analysis patterns of pressure distribution across all five sizes were identified. Immediately it can be seen that all five

Figure 5.2 Distribution of Pressure



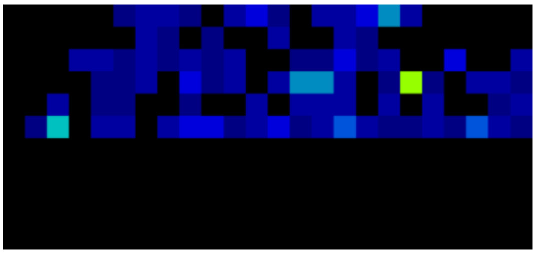


Figure 5.3 Sample A Point 1 (shoulder)

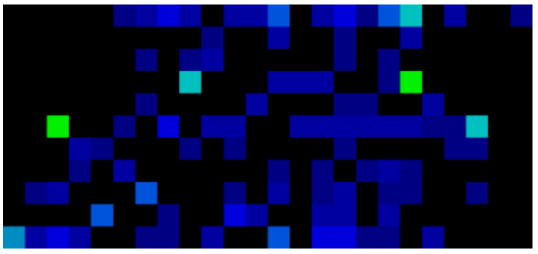


Figure 5.4 Sample B Point 1 (shoulder)

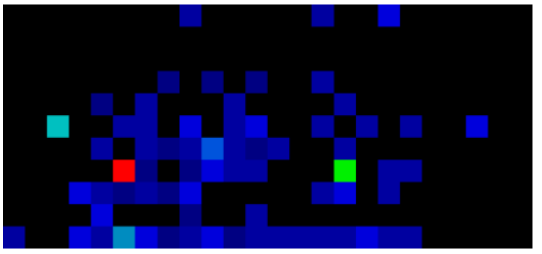


Figure 5.5 Sample C Point 1 (shoulder)

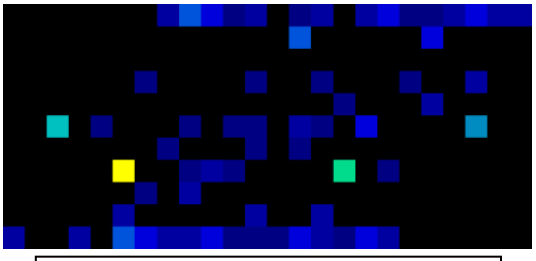


Figure 5.6 Sample D Point 1 (shoulder)

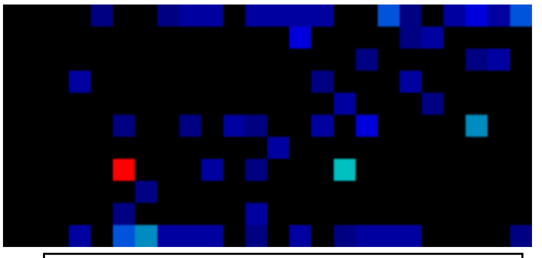


Figure 5.7 Sample E Point 1 (shoulder)

garments tested exhibited the greatest amount of pressure at point one (shoulder). The pressure maps collected through the Tekscan system for point one (shoulder) can be seen in the Figures 5.3 - 5.7. In addition, all five fabrics show a dramatic decrease of pressure from point one (shoulder) to point two (chest) with either very little or no pressure exhibited at this point.

The relationship between points three (chest) and four (waist), are of particular interest when looking at the different brands as the samples exhibited different patterns of pressure distribution at these points. Sample A is essentially the same for the two points but is the only sample to remain so. Conversely, sample B shows a significant increase at point four (waist) and the pressure exhibited is double that at the previous point. In contrast, the pressure of sample C significantly decreased by a value of around 700 from point three (chest) to four (waist). This decline in pressure is also apparent in the measurements for samples D and E; however, the extent of this is smaller for these other two samples. Due to the variations in pattern distribution at these points, this area will be vital in identifying patterns between the effects of fabric properties, garment measurements and construction.

All samples, except C, show a significant decrease from the point four (waist) to point five (lower trunk). This may suggest a smaller need for pressure to be present at this point as all samples exhibit similar values. Although sample C shows an increase from point four (waist) to five (lower trunk), unlike the other garments, the pressure value at this point is still comparable to the other samples. (Please see Figures 5.8 – 5.12).

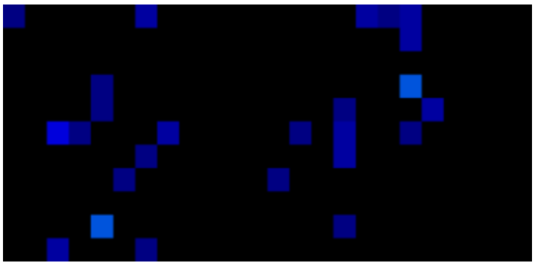


Figure 5.8 Sample A Point 5 (hem)

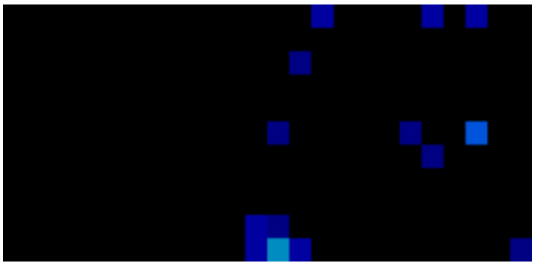


Figure 5.9 Sample B Point 5 (hem)

Figure 5.10 Sample C Point 5 (hem)

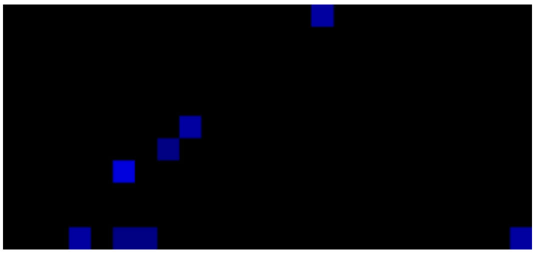


Figure 5.11 Sample D Point 5 (hem)

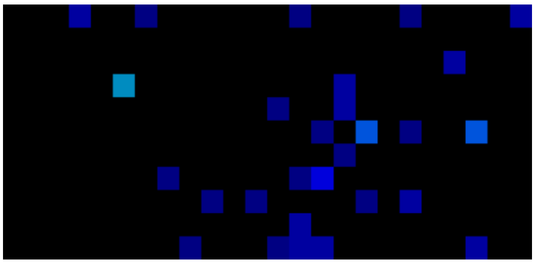


Figure 5.12 Sample E Point 5 (hem)

The centre front pressure measurements, in particular points six (C.F. neck) and seven (C.F. chest) for the neck and chest positions, exhibit very little pressure in all samples examined. Similarly, all samples show a return of pressure at point eight (C.F. low waist). Once more, sample B shows the greatest pressure at point eight (C.F. low waist) of all the samples, of 240-300.

5.1.1 Fabric Properties

The effect of the samples fibre composition on the distribution of pressure was highlighted in Chapter 4.0 to be of interest. From the recorded data in the garment database it was highlighted that samples A and B have very similar fibre compositions, containing nylon, polyester and elastane. In addition, both had comparable results for the stretch and recovery tests. However, there is a noticeable variation between some of the pressure measurements collected. In particular, points three (chest), four (waist) and eight (C.F. low waist). Although sample B has slightly lower elastomeric fibre content than sample A (10% as opposed to 14%) and this may reflect the variations in values, other factors such as garment size and seams are likely to be affecting the pressure values. Additionally, samples C and E have similar fibre compositions, with a nylon and elastane blend, however showed big variations between points one (shoulder), four (waist) and five (lower trunk). Although sample C has 10% less elastane than sample E, there is no apparent pattern between the difference in elastane content and the pressure values recorded. Neither sample was monitored as exhibiting higher values than the other across the board. Furthermore, samples D and E have comparable fibre compositions though sample D contains polyester opposed to sample E which contains nylon. The biggest variations of pressure recorded on these two samples are at points four (waist), five (lower trunk) and six (C.F. neck). Similarity between the pressures recorded at the other points may suggest that pattern or size have more impact on the compression rather than the fibre composition. With reference to the fabric analysis results from the garment database, the two fabrics, A and B, whose construction are known to be a tricot warp knit, have some comparable values for pressure. Certain points, such as three (chest), four (waist) and eight (C.F low waist) show some variation however, as previously mentioned, may be influenced by garment design and shape. Furthermore, as the knit type of the remaining three samples was undetermined these similarities in pressure cannot be completely accounted for by the fabric construction. No patterns of pressure with fabric thickness or area density were recognized in this investigation.

5.1.2 Garment Measurements

In Chapter 4.0 it was highlighted that manual width measurements recorded, in particular measurement points 1 – (chest), 2 – (waist) and 3 – (hem), were of particular interest in relation to pressure values exhibited. These measurements will specifically correlate to the pressure recorded at points: two (chest); three (chest); four (waist); five (lower trunk); and seven (C.F. chest). From the information gathered for the garment database, sample C was found to have the smallest width measurements for points 1 – (chest), 2 – (waist), 3 – (hem), 5 – (across front) and 11 – (across back). Sample E measured around the middle for all width measurements and the largest measurements as a whole were recorded for sample D. However, the compression values recorded using the Tekscan equipment showed no correlation between width in size and values of pressure.

At point one (shoulder), samples C and D both have no shoulder seam, yet sample C was measured to have much more pressure in this area. One explanation for this may be the short length from the side neck point to the armhole on this garment. The measurement at this position was almost half of the same measurement on sample D. This difference may have, therefore, impacted the pressure distributed here; especially due to the similarities of these two garments otherwise.

All in all, no relationship between variation of garment size and pressure values were identified in this case. Although the five samples examined did vary with regard to garment measurements; the size of this variation may in fact be too small to truly affect the pressure. Furthermore, it would be interesting to observe the effect body fat and muscle would have on this relationship.

5.1.3 Seams and Construction

The five bought samples varied significantly on the positioning of seams with no two samples the same. It was believed that these differences will help identify patterns with pressure distribution.

Samples A and B both have similar panels over the shoulder and because of such pressures measured at point one (shoulder) are expected to be similar for both samples. The high pressures measured at point one (shoulder) for both A and B is comparable which indicates that the panels inserted have influenced the pressures exerted. Samples C and D both have no shoulder seam at the position measured, however sample C was measured to have much more pressure at this point one (shoulder). Sample E shows the smallest amount of pressure at point one (shoulder) and is the only sample to be constructed with a 'normal' shoulder seam at this position with no other panels to influence the compression thus further indicating the influence of panel insertion on pressure.

The sudden decrease of pressure from point one (shoulder) to point two (chest), noted previously, also shows some correlation with the panels at the shoulder. Sample A and B, which both have shoulder panels show some pressure at point two but only minimal values. An explanation as to why sample A exhibits the most pressure could be that the shoulder panel of this garment comes down the body further than that on sample B, thus extending the area of greater pressure. The zero pressure measurement for sample C in this area may be another resulting factor from having no shoulder panel. Similarly, sample E also has no shoulder panel and shows no recorded pressure at point two (chest). However, if this is the case, sample D is an anomaly as a small amount of pressure was noted at point two (chest). On the other hand, the minimal values may be thought to be insignificant here.

The variances in pressure at points three (chest) and four (waist) can also be analysed with reference to seams. Sample B has some panels down the sides of the torso, which may account for the difference at these points between A and B that were previously exhibiting similar values around the point one (shoulder) area. Similarly to sample A, C, D and E also have no panels at the side of the torso, which may explain why the pressure did not increase as with sample B. However, there is still an obvious difference between the brands studied at these points and therefore seams alone do not appear solely accountable for this.

From point four (waist) to point five (lower trunk), although all samples exhibited a decrease in pressure, once again, sample B shows the most significant difference between the two points with a decrease of around 500. Again, it is thought that the side panels in the garment may account for this.

In reference to points six (C.F. neck) and seven (C.F. chest), samples A and E show the greatest pressures here (Figures 5.13 to 5.16 show the pressure maps at these points). Both samples A and E have mock polo necks and therefore much higher collars than the other samples. This may have added more pressure to these areas compared to garments with a lower neck line.

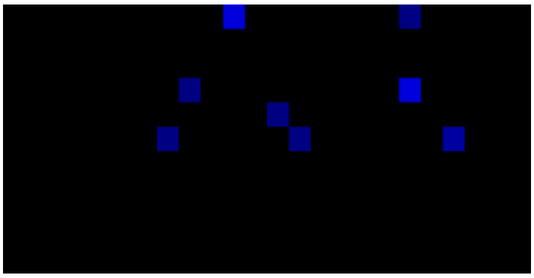


Figure 5.13 Sample A Point 6 (C.F neck)

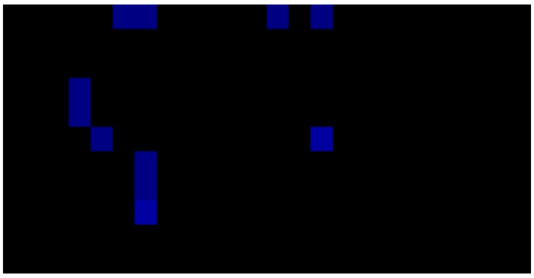


Figure 5.14 Sample E Point 6 (C.F neck)

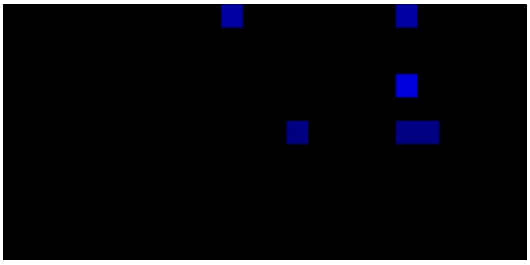


Figure 5.15 Sample A Point 7 (C.F chest)

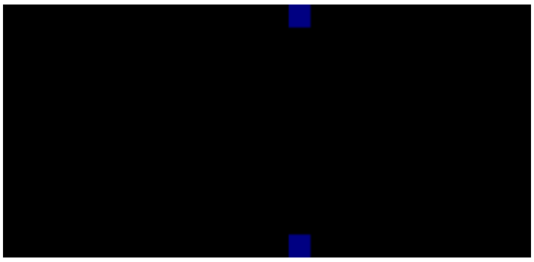


Figure 5.16 Sample E Point 7 (C.F chest)

Overall, the insertion of panels in the garments studied appears to result in a clear effect on pressure. The inclusion of panels not only seems to be for aesthetics but also to increase pressure at areas on the body. The variations in pressure are much more apparent when studying garments with more seams and panels as opposed to sample E which is a more basic style.

5.2 Summary

From the analysis of the database information and the pressure values recorded at eight points on the five randomly chosen samples difference between brands have been highlighted.

No clear pattern between percentage of elastomeric fibres in the fabrics and the values of pressure recorded was determined. Although some variations in pressure were found between sample D containing polyester and sample E containing nylon it has not yet been determined whether this alone has caused this difference.

Whilst garment measurements did not appear to affect the pressure values in this case, it is thought that body muscle and fat of a wearer would alter these results. Sawada (1993) highlighted that bony prominences and body fat do increase compression by using sponges and plastic plates to simulate them. Although the testing in this case did not simulate body fat or bony prominences, the investigation by Sawada *et al* (1993) would suggest that the build of the wearer would certainly effect the compression exhibited. Further investigation in to this would be useful to help understand the true relationship between measurements and pressure values. Furthermore, future research to evaluate the effect of differences in grading on pressure distribution would help to analyse the influence of garment measurements on compression.

It was clear that the positioning of seams in the garments have clearly affected the distribution of pressure. Many of the sudden increases and decreases in pressure in the garments are situated around seams, thus highlighting the influence of them to pressure. Some of the most clear increases and decreases in compression between measurement points were recorded for samples A and B, both of which have many seams, compared to the other samples.

The spread of data, which has been highlighted as the relaxation of the garment, is apparent from the compression measurement. Although this relaxation has been noted to be beneficial in understanding the pressure exhibited in compression garments it is questionable about how such issues effect the testing of compression garments. In order to achieve truly fully reproducible values through pressure testing a ‘stable’ position needs to be captured. However, such a stable position also still needs to capture the true pressure exhibited in garments. An effective way of testing which considers fluctuation of results yet is able to take a stable reading is needed for the industry.

The next chapter, 6.0 Simulation Model, discusses the testing of the hypothesis that experimental work regarding compression measurement can be simulated using a CAD model. Test results from the FAST system will also be analysed.

The empirical work on compression analysis using Tekscan highlighted the pressure values at eight different points (shoulder, chest at two positions, waist, lower trunk, centre front (C.F) neck, C.F chest, C.F low waist). The garment measurements did not affect the pressure values for the samples explored; however the positioning of seams clearly affected the distribution of pressure (frequent variations). A CAD simulation model was explored to evaluate whether a virtual system can be used to re-create the compression measurements obtained using Tekscan. This chapter presents the simulation model. The model was created using the V-Stitcher software, by Browzwear, and FAST data was used to represent fabric properties. If the simulation model is successful, then there is potential for it to be used as a tool in the product development process of compression garments. It will facilitate understanding of the effect of fabric, garment measurements and construction on compression without the expense and time of creating the garments. Furthermore, a simulation model could be used as a research tool for consumers so that they may make more informed choices before purchase.

6.1 Fabric Assurance by Simple Testing (FAST) Results

Table 6.1 FAST Results

	A	B	C	D	E
Weight (g)	2.13	2.50	2.23	1.74	2.37
Thickness at 2 g (mm)	1.11	0.88	1.17	0.60	0.63
Thickness at 100 g (mm)	0.84	0.74	0.86	0.49	0.59
Surface Thickness (mm)	0.26	0.14	0.30	0.11	0.04
Bending Rigidity Wale (μNm)	5.33	7.22	8.41	3.07	2.44
Bending Rigidity Course (μNm)	6.82	8.00	6.67	3.07	3.85
Formability Wale (mm^2)	3.66	5.75	9.56	2.40	2.14
Formability Course (mm^2)	7.44	4.43	7.15	1.65	2.30
Extension Wale %	>20.3	>20.3	>20,3	>20.3	>20.3
Extension Course %	>20.3	>20.3	>20.3	>20.3	>20.3
Shear Rigidity N/m	40.33	67.10	91.11	18.59	62.02

Testing of the fabric properties of the five different samples was conducted using FAST to enable simulation of the fabrics in the virtual system. Results for all five fabrics are in the Table 6.1. The results from the tests will enable a further understanding of the fabric properties. Although not all of the samples were simulated in the CAD model all fabrics were tested using FAST to further contribute to the analysis of the garments. From the data generated from the FAST tests a series of calculations have been completed to obtain each fabric's performance. Results such as formability and bending rigidity were not measured directly by the system but have been calculated using the relevant equations. For the full set of original data and calculations for samples A to E refer to Appendix F. Further to this, FAST control charts have been created for each of the five fabrics using these results, which are in Appendix G. FAST charts give the finger print of the fabrics and highlight the potential problem areas during garment manufacturing should the plots fall into shaded areas of the chart. Falling beyond these limits highlight possible problems with production issues such as seam pucker, difficulties whilst cutting, sleeve insertion and laying up. Although it would be desirable for the fabrics tested to fall within these predetermined limits, it must be remembered that the system was created for worsted suiting fabrics. Therefore, the shaded limits on the control charts may not be entirely suitable for determining the handle and performance during manufacture of the warp knitted fabrics tested in this case. However, in this case the FAST data was used primarily to input the fabric behaviour/performance in the CAD simulation software.

As shown in Table 6.1, all results of extension at 100 g for wale and course directions for the five fabrics were found to be >20.3%. However, this is constrained by the limit to which the FAST extension apparatus can measure and therefore not a true representation of the fabrics extension. The stretch and recovery tests completed for the garment database (Chapter 4.0) highlight each fabric's ability to extend. Shear rigidity is unaffected by the limit of the FAST extension apparatus as the result is calculated from the bias extension results, which are only tested at 5 g.

The FAST 4 test, which determines dimensional stability and hygral expansion, has not been completed on this occasion as it is not required to simulate the garments on the virtual system. In addition, there was a limited amount of fabric available for testing and as such the template for the FAST 4 test was too large to include.

Although the results from FAST identify CSIRO's concerns for each fabric during garment production and for the fabrics hand, it must be noted that all fabrics tested are part of ready-made garments. This means that any production problems encountered must have been overcome during make-up.

6.1.1 Compression

The values for thickness as discussed in the garment database are comparable to the FAST results for thickness at 100 g and therefore do not highlight any significant points.

From the results of thickness at 2 g and 100 g surface thickness was calculated. The surface thickness is concerned with the stability of the fabric and higher values for surface thickness equate to a greater stability. Looking at the surface thickness results it can be seen that sample C was found to have the highest value and sample E the lowest.

The released surface thickness was not measured at this time as it was not required for the simulation of fabrics.

6.1.2 Bending Rigidity

Bending rigidity relates to the stiffness of a fabric and the ability of fabric to drape (freely fall or hang over a three-dimensional form). A high value for bending rigidity signifies that a fabric is stiff, while a low value indicates a fabric is very pliable. CSIRO claim a low value, below the pre-determined limits of the FAST chart, may suggest problems during garment construction whilst cutting. It is also believed that bending rigidity, as it is concerned with drape, will highlight how well a fabric will conform to the body. In this circumstance the ability of a fabric to conform to the body is vital for compression and therefore bending rigidity values within the pre-set limits would be beneficial. Nonetheless, all the samples tested at this time have high elastomeric values and as such their conformity to the body is almost certain.

Sample D exhibits very low bending rigidity values with both wale and course direction at 3.07 µNm which CSIRO claim to highlight problems during manufacture (please see Table 6.1) due to being very pliable. Conversely, sample B was found to have the highest bending rigidity values with 8.00 µNm in the course direction and 7.22 µNm in the wale direction. Nonetheless, these values are both within the predetermined limits. The bending rigidity value for sample E was found to be only 2.44 µNm in the wale direction which is the lowest of all samples. This could highlight possible problems during manufacture for garments made with fabric E due to the suppleness of the fabric.

Both sample B and C displayed similar results for bending rigidity and are both within the FAST limits as on the control chart. Although lower than the values for sample B and C, the results of bending rigidity for sample A are also within the limits. All three samples are therefore predicted to conform to the body sufficiently. The low bending rigidity value for sample E in the wale direction could also suggest problems with drape. However, as the course value for the same sample is within the limits set by FAST, and the garment has a high degree of elasticity no problems with conforming to the body are expected.

6.1.3 Extensibility

The extension values noted in Table 6.1 are those tested at 100 g. As it can be seen, all samples displayed extensibility values of >20.3% in both the wale and course directions which exceeds the limit the FAST extension apparatus can measure. The restriction of the FAST apparatus to measure the true value of extension is a limitation to the use of FAST results in a virtual system. However, it continues to be used within industry in various CAD simulation packages.

As the extension values at 100 g are therefore not a true representation of each fabric's stretch, the values for extension at 5 g and 20 g are also to be analysed. Although this data is not directly used to create the FAST control charts these values have been highlighted to further assess the differences noted between fabrics. These values were both obtained during testing and the averages for each sample are noted in Table 6.2.

The recorded averages for extension at 5 g and 20 g are also of importance as they are required for the simulation of the fabrics in V-Stitcher. The values for extension at 5 g for sample B (0.9 and 0.8) and sample C (0.6 and 0.8) are comparable. However, sample C exhibited much more stretch at 20 g (17.3 and 16.5) than sample B (12.6 and 8.9). Samples A exhibited some similar results for extension as sample C at 20 g however show much greater extension at 5 g.

Table 6.2 Extension Results at 5 g and 20 g (%)				
Sample	**Extension at 5 g**		**Extension at 20 g**	
	Wale	**Course**	**Wale**	**Course**
A	2.1	3.3	12.2	19.4
B	0.9	0.8	12.6	8.9
C	0.6	0.8	17.3	16.5
D	2.4	4.5	13.8	12.4
E	3.3	1.1	16.2	9.9

6.1.4 Shear Rigidity

Shear rigidity is a measure of the ease with which a fabric can be distorted and is calculated from bias extension. Low values indicate that the fabric can be distorted easily (while marking, laying, cutting etc). High values mean the fabric is difficult to form in to 3D shapes, causing problems in sleeve insertion.

Samples A, B and E were measured to have shear rigidity values which are within the pre-determined limits by CSIRO on the FAST control chart. Therefore, CSIRO claim that there should be no problems regarding sleeve insertion during manufacture. On the other hand, sample C was higher than the top FAST limit for shear rigidity at 91.11 N/m and therefore CSIRO suggest that moulding problems are likely. Differing from this, sample D was lower than the limit at 18.59 N/m which highlights possible problems with laying up of fabric.

6.1.5 Formability

Formability is the ability of a fabric to absorb compression without buckling and is an indicator of seam pucker during/after sewing. Although many factors such as thread size, needle size and thread tension may contribute to this its main result is seam pucker. Sample C’s results for bending rigidity were found to be the highest at 9.56 mm^2 and 7.15 mm^2 for the wale and course respectively. The lowest formability value was the course result for sample D of 1.65 mm^2 however this is still within the pre-determined limits of the FAST control chart and therefore CSIRO would not expect pucker to be likely for this fabric.

Once FAST testing was completed, the simulation of the empirical work could then take place. The following section 6.2 highlights the procedure to create the model and explains in more detail how the FAST data was used within the CAD system.

6.2 3D Simulation Model

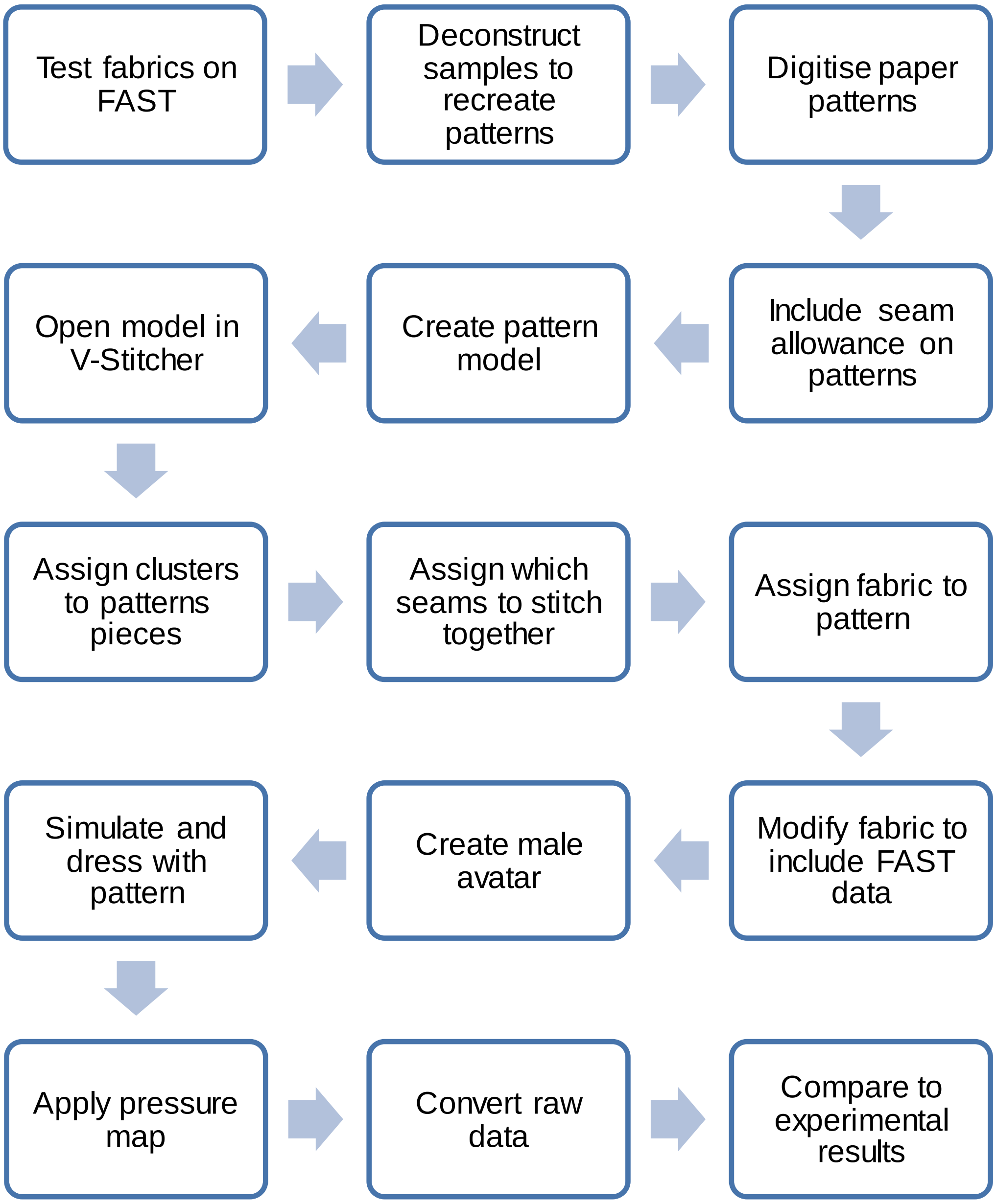


Figure 6.1 Process Flow Diagram for the Simulation Model

After testing the fabrics on FAST, the simulation model was created. The flow chart (Figure 6.1) highlights the step by step process to create the CAD simulation model. In order to assess whether the model was successful at simulating the compression measurements found through the experimental procedure, two of the samples were selected to be simulated. Samples A and E (see Figures 6.2 and 6.3) varied significantly with regards to seams and the influence of these differences were highlighted in the garment database. Furthermore, samples A and E varied considerably with regards to fabric analysis results including those for stretch and recovery. These samples were chosen to therefore see if the CAD system also detects these variations in pressure, as shown by the work with

Figure 6.2 Sample A

Figure 6.3 Sample E

Tekscan. Once chosen, patterns were recreated to the style and size of the medium size garment. These 2D patterns were then digitised using Gerber and opened in Pattern Design Studio and seam allowances added to enable virtual construction. The single pattern pieces then had to be saved collectively as a pattern model to be imported in to the V-Stitcher software. Once opened in V-Stitcher, seams were assigned to the pattern pieces in order to instruct the virtual system how to 'sew' the garment together. In addition fabrics were assigned to each pattern piece, the colours of which were altered to look like the real garment. It is at this point when the fabric properties gathered from FAST were put in to the system. To do this, the results derived from the FAST tests had to be put in a FAST converter system which produces the relevant data necessary for V-Stitcher. This was then transferred to the fabric properties of the relevant fabric. Subsequently a male avatar was created to the measurements of the mannequin used for the experimental research. The measurements of the mannequin were taken from the supplier website to ensure accuracy. The sizing chart for which can be found in Appendix H. Although measurements for the modified avatar were all put in the system, the across shoulder measurement of the avatar is not the same measurement as found on the mannequin. This is due to the V-Stitcher system linking some measurement points. In this circumstance, to modify the chest measurement of the avatar to the correct size, the across shoulder measurement was automatically adjusted and as such could not be the correct size. Furthermore, although the mannequin used within the research does have an option of adding arms, these were not used for the pressure measurement work as the garment would not correctly fit on the mannequin. The simulation of the mannequin varies as the arms cannot be removed in this system. Unfortunately this may affect the pressure values found on the CAD system. After creation of the personalised avatar the pattern could then be simulated in order for the accuracy of the CAD system to be assessed.

It should be highlighted that difficulties with simulation arose from the attachment of sleeves and the neck. It is important to ensure notches are added at these points to ensure correct assembly. Furthermore, once simulated anchor points on the patterns had to be manually adjusted to ensure the garment fitted correctly on the avatar. For example, when first simulated the neck line came over the top of the neck of the avatar. After modifying the position of the anchor points on the neck pattern piece and front pattern piece, the neck line then fitted in the correct position. This adjustment of anchor points contained much trial and error when first simulating, where by the anchor was altered and then the pattern simulated to see the effect. Subsequently, if still not correct the process was repeated until amended.

Once simulation was complete, pressure values of the experimental work needed to be compared to the pressure values on the CAD model. In order to do this the raw data from the pressure measurement analysis needed to be converted to g/cm^2 (see Table 6.3). The pressure maps in V-Stitcher are displayed in colours over the garment. The Figure 6.4 shows the scale the V-Stitcher pressure maps show and the colours which correspond to this.

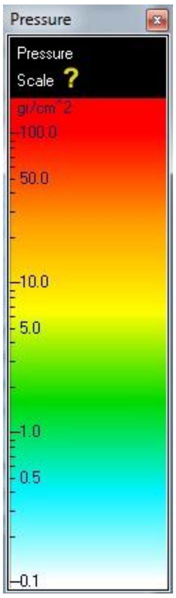


Figure 6.4 Pressure Scale in V-Stitcher

Although the values of pressure were converted from raw data to an equivalent value in grams, it has proved difficult to pin point the specific areas measured by Tekscan in the CAD model. Therefore, it has not been possible to compare the exact values of pressure between the two systems. Due to this, the analysis of the system is focused more on whether the distribution of pressure has been successfully mapped.

Table 6.3 Pressure Measurement Values (g/cm^2)								
	Measurement Point							
Sample	**1** Shoulder	**2** Chest	**3** Chest	**4** Waist	**5** Lower Trunk	**6** C.F Neck	**7** C.F Chest	**8** C.F Low Waist
A	288 – 297	13	163 – 181	169 – 181	70	13 – 19	13 – 19	47 – 56
E	219 – 241	0	238 – 266	138 – 166	81 – 100	19 – 31	0 – 6	34 – 41

6.2.1 Simulation of Sample A

There were some issues encountered during the simulation process of sample A. The more complex style and pattern pieces of sample A, compared to sample E, proved difficult to correctly simulate. The trial and error process of moving anchor points to adjust the position of pattern pieces was a much longer procedure than with sample E. After doing this, the simulated sample A, although draped on the mannequin was still exhibiting some wrinkles around the sleeve pattern pieces. Limited time meant that the simulation had to take place whilst some wrinkling was still evident on the sample. Therefore, this may have affected the pressure of the simulated garment.

Figure 6.5 Simulation of Sample A

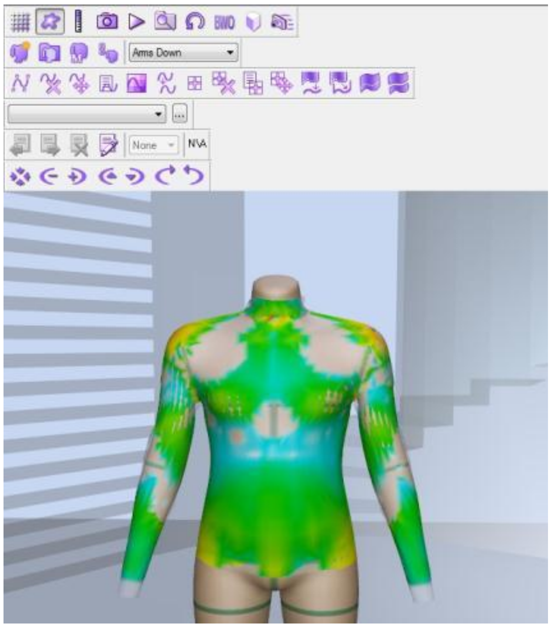


Figure 6.6 Pressure Map of Sample A

Figure 6.5 shows the simulated version of sample A and Figure 6.6 shows the simulated sample A with the pressure map applied. From the compression values recorded using Tekscan, the area of most pressure was found to be at Point 1 – Shoulder for sample A. The highest areas of pressure on the simulation model have also been found to be at the shoulder. Although this has been found, the area of highest pressure is not in the specific location highlighted through experimental testing and is instead at the sleeve head point. Further testing with Tekscan could highlight if this area does in fact have more pressure exhibited than at measurement Point 1 – Shoulder.

The pressure map of Sample A also clearly highlights areas with no recorded pressure. Point 2 – Chest is one such area on the simulation which exhibits no pressure. Although the experimental compression measurement did detect pressure at the same point (13 g/cm^2) this was only found to be of a small value.

This difference is not thought to highlight a big flaw in the system. Similarly, the area of Point 7 – C.F Chest on the simulation model shows no pressure, however, was found to exhibit a small amount through Tekscan measurement (13-19 g/cm^2).

On the one hand, no pressure highlighted at Point 7 –C.F Chest is not thought to highlight problems with the CAD system. However on the other hand, Point 6 – C.F Neck was also found to exhibit the same amount of pressure than Point 7 – C.F Chest during experimental testing. Yet, the simulation model shows much higher pressure values at Point 6- C.F Neck than at Point 7 – C.F Chest. This inaccuracy with the CAD model compared to the experimental compression measurement could however be a result from the wrinkling of the garment in the virtual system.

Point 3 – Chest and Point 4 – Waist both were found to have very similar values of pressure during measurement with the Tekscan. This is comparable to the pressure displayed in these two areas during the simulation. Furthermore, less pressure is displayed on the simulation model at Point 5 – Lower Trunk that at these two areas, which is also comparable to the lower pressure value found through the experimental procedure.

6.2.2 Simulation of Sample E

The following Figures 6.7 and 6.8 show the simulated garment and the simulated garment with the added pressure map on. Similarly to sample A, highlighting the specific areas of compression is difficult due to not being able to pin point certain areas. However, the distribution of pressure can again be analysed in relation to the experimental data.

Immediately, when looking at Figure 6.8, it can be seen that no pressure was displayed at the centre front portion of the chest and the higher portions of the chest on both the left and the right of the torso. This is comparable to the compression values found in these areas with Tekscan at point 2 – Chest (0 g/cm^2) and point 7 – C.F Chest (0-6 g/cm^2).

The areas of highest pressure which can be seen on the simulation model are on both shoulders and reach around 100 g/cm^2. Similarly, one of the highest areas of pressure for sample E measured using the Tekscan was at Point 1 – Shoulder.

Figure 6.7 Simulation of Sample E

Figure 6.8 Pressure Map of Sample E

The experimental procedure also highlighted Point 3 – Chest to exhibit similar pressures. However, although the simulation model did exhibit pressure at this point, it does not appear to be of the same values as the yellow area represents between 5 g/cm^2 and 10 g/cm^2. Point 5 – Lower Trunk and point 6 - C.F Neck are also comparable to the simulation with more pressure found at the lower trunk.

6.3 Summary

FAST testing was completed in order to further assess fabric characteristics of the samples and also to better simulate fabric properties in the virtual system. Formability values were found to be within the pre-determined limits of FAST and therefore problems of pucker are thought to be unlikely during construction with the fabrics. Values of extension at 100 g were all measured as being 20.3% due to this being the limit of the FAST extension apparatus. All fabrics are thought to have higher extension values than 20.3% at 100 g and therefore this result does not correctly display the fabrics capabilities. The stretch and recovery tests completed in the garment database (Chapter 4.0) highlighted the degree to which each fabric can stretch. Results for bending rigidity were found to be low for samples D and E which CSIRO claims to indicate possible problems during cutting. Samples A, B and C, however, were calculated as having bending rigidity values within the limits set by FAST.

Two samples were selected to be recreated due to many variations with regards to seams, fabric analysis results and pressure measurements. The simulation of sample E has showed the capability of the V-Stitcher system to highlight the distribution of pressure across base layers. Areas of pressure simulated on this sample are relatively comparable to those highlighted during the experimental procedure. The simulation of sample A, although highlighted the correct distribution of pressure in some areas, did show some discrepancies between the pressure distributed in the experimental work and the CAD model. Difficulties in simulation, with sample A, due to the complexity of pattern pieces could be the reason for this. Further experimentation with the CAD system and different patterns may help to overcome these simulation problems. Conversely, it could be that the issues with the simulation of pressures are unconnected to the difficulties encountered. Thus meaning that rectifying them may not amend the discrepancies found in simulation.

Although areas of highest and lowest compression values where displayed in the simulation model, it was difficult to determine the exact compression values in specific areas. Therefore, it may be the case that although the system may be used to highlight distributions of pressure, it alone cannot be used to accurately measure compression in specific areas. Again it would be beneficial for future research to include further experimentation with V-Stitcher. In addition, it would also be of interest to recreate the CAD model using different software packages in order to assess the capabilities of each and therefore determine if there is a more suitable CAD system for this simulation.

The next chapter, 7.0 Conclusions and Recommendations, highlights the main conclusions emerging from this research and also recommendations for future research which are believed to be beneficial for this area.

7.0 Conclusions and Recommendations

This chapter highlights the conclusions that emerged through the research process, with reference to the aims highlighted in Chapter 1.0. Recommendations for further research in the field, which have materialised whilst completing the research, are also discussed.

7.1 Conclusions

To recognise the use of compression sportswear and its increased availability in the market a literature review was completed (Chapter 2.0). The analytical approach to the literature review first began with understanding the use of compression therapy in medicine (section 2.1). The use of compression garments in professional sports was then investigated and found to be a catalyst for an increased demand for such garments in the ready to wear market (section 2.2). Although much research has been completed, and continues to be undertaken, with regards to how beneficial compression is to the wearer, there is still disagreement about its effectiveness (section 2.3). It was also noted that very little research has been conducted with reference to ready to wear compression garments and the differences between brands. This justifying the need for research in the area of ready to wear garments. Pressure measurement systems were also studied, which were found to vary significantly, however thin, flexible sensors were noted as being preferable (section 2.5). The research also focused on the problems encountered with sizing for mass market (section 2.6) and considered the growing tendency for CAD systems to be used as a product development tool (section 2.7).

In addition, long sleeved compression base layer products available to the mass market were analysed in order to achieve aim one (Chapter 4.0). Five different brands were selected for analysis through cluster sampling. The creation of a garment database which examined the variations in materials, garment dimensions and construction between the brands was then completed. All samples were noted as having high elastane content, although some exhibited poor recovery rates after stretch. Results also emphasised a significant variation in the positioning of seams with no two samples looking the same in this respect.

Variations in measurements between the same specified sizes also raised concern, particularly with reference to three samples purchased from the same retailer. Sizing charts from the retailers which are to help consumers to buy the appropriate size garment were also very sparse with only a few basic measurements. It is thought that more detailed sizing charts, tailored for each specific brand, would aid consumers whilst purchasing such garments to ensure correct fit.

After completion of the garment database, the compression exerted by the medium sized upper base layer garments was measured using the High Speed I-Scan system by Tekscan to accomplish aim two (Chapter 5.0). The Tekscan system was selected due to its thin flexible sensors which were outlined in the literature review as being beneficial for pressure measurement. On a male mannequin, the pressure was recorded at eight areas around the body to provide an insight in to the pressure values exhibited and the distribution of pressure. The readings from this experimental work were then analysed with particular reference to the influence of material properties, garment measurements and construction. Patterns were recognised between dramatic compression gradients and proximity to seams. This highlighted the importance of the positioning of panels for influencing compression values and distribution. Garment measurements, although varied between the brands, did not appear to effect the pressure values. However, it is believed that these measurements coupled with variations in body muscle and fat of individuals would affect the overall compression exerted by the garment. The temporal drift of measurements detected by the Tekscan system was also of interest during testing and highlighted the natural relaxation of the garment when worn whilst motionless.

Finally, the hypothesis that a CAD model could map the experimental work with compression on a virtual system was tested to realise aim three (Chapter 6.0). Two of the five samples were selected to be simulated within the V-Stitcher system. Limitations with the CAD software were encountered when the across shoulder measurement of the avatar was linked to the chest measurement and as a result the shoulder width could not be exactly amended to the size of the male mannequin. Furthermore, the simulated mannequin had arms, whereas the mannequin's arms could not be used during the experimental procedure in the laboratory. Nonetheless, the simulation of sample E highlighted the models capability to map the distribution of pressure found through compression measurement with Tekscan. Although simulation of sample A proved more difficult, due to an increased complexity in component patterns, the distribution of pressure in the virtual system was still largely comparable to that in the experimental work. More specific pressure values were found to be difficult to pin point in the virtual system and as a result the CAD model needs further development to precisely identify pressures at key areas on the body.

Overall, compression sportswear continues to be demanded by everyday consumers and its increased availability for the mass market is apparent. Since reported research has been inconclusive, further work is needed to determine the effectiveness of such garments in use. A greater understanding of ready to wear base layers is required to aid consumers during purchase. The five brands analysed in the research have highlighted many variations between seemingly similar products. Compression measurement with the Tekscan further emphasised differences and the effects of them on pressure values and distribution. With further development, the use of a simulation model could be used to not only facilitate the product design and development for manufacturers but also to allow consumers to have a greater understanding of the compression garments they are purchasing.

7.2 Recommendations

During the process of completing this research, further research in some areas has been mentioned. The following recommendations for future academic research have been suggested:

Firstly, measuring pressures around a cylinder may further quantify the pressures determined by the Tekscan system. Laplace's Law could be utilised to do so and therefore further justify the use of Tekscan to measure compression exerted by compression sportswear.

Secondly, as the exploration of small and large sizes was only a small portion of this research it is suggested that further research is conducted to explore grading issues of ready to wear compression base layers. The effect of any grading differences on compression values and distribution would also be beneficial using the Tekscan, thus building on the garment database created in the current research.

Thirdly, to expand this research to involve ready to wear compression base layers for women would help to highlight the effect of body fat on pressure values and distribution. A similar garment database could be used to highlight variations between brands. Measurement of the compression values and distribution of samples would also distinguish difference between compression base layers for males and females.

An investigation in to how effective other CAD systems could be at simulating the compression measurement work would be advantageous to determine if the V-Stitcher software is the most appropriate for this work due to the limitations faced. Simulating the same pattern in a number of systems and comparing to experimental pressure data would highlight the effectiveness.

Finally, to develop the research so that, after participants body measurements are determined through a 3D body scanner, individuals could then be simulated in the CAD system. This could help to further understand the effect of body shape and size on compression. If such a model is proven successful this research tool could be used by consumers as a way of determining the pressure of ready to wear samples before purchase.

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A. Photos of Samples

Sample A Front and Back

Sample B Front and Back

Sample C Front and Back

Sample D Front and Back

Sample E Front and Back

B. Fabric Analysis Calculations

Sample A

Area Density = Weight x 100
= 2.13 x 100
= 213 g/m^2

Thickness $= \frac{0.9 + 0.83 + 0.85 + 0.87 + 0.83}{5}$
$= \frac{4.28}{5}$
= 0.856
= 0.86 mm

Bulk Density $= \frac{\text{Area Density} \div \text{Thickness}}{1000}$
$= \frac{213 \div 0.856}{1000}$
$= \frac{248.8317757}{1000}$
= 0.248831775
= 0.25 g/m^3

Sample B

Area Density = Weight x 100
= 2.50 x 100
= 250 g/m^2

Thickness $= \frac{0.73 + 0.74 + 0.73 + 0.75 + 0.73}{5}$
$= \frac{3.68}{5}$
= 0.736
= 0.74 mm

Bulk Density $= \frac{\text{Area Density} \div \text{Thickness}}{1000}$
$= \frac{250 \div 0.736}{1000}$
$= \frac{339.673913}{1000}$
= 0.339673913
= 0.34 g/m^3

Sample C

Area Density = Weight x 100
= 2.23x 100
= 223 g/m^2

$$\text{Thickness} = \frac{0.38 + 0.37 + 0.36 + 0.36 + 0.37}{5}$$
$$= \frac{1.84}{5}$$
$$= 0.368$$
$$= 0.37 \text{ mm}$$

$$\text{Bulk Density} = \frac{\text{Area Density} \div \text{Thickness}}{1000}$$
$$= \frac{223 \div 0.368}{1000}$$
$$= \frac{605.9782609}{1000}$$
$$= 0.60597826$$
$$= 0.61 \text{ g/m}^3$$

Sample D

Area Density = Weight x 100
= 1.74 x 100
= 174 g/m^2

$$\text{Thickness} = \frac{0.50 + 0.49 + 0.49 + 0.49 + 0.50}{5}$$
$$= \frac{2.47}{5}$$
$$= 0.494$$
$$= 0.49 \text{ mm}$$

$$\text{Bulk Density} = \frac{\text{Area Density} \div \text{Thickness}}{1000}$$
$$= \frac{174 \div 0.49}{1000}$$
$$= \frac{355.102041}{1000}$$
$$= 0.35510204$$
$$= 0.36 \text{ g/m}^3$$

Sample E

Area Density = Weight x 100
= 2.37 x 100
= 237 g/m^2

$$\text{Thickness} = \frac{0.62 + 0.62 + 0.61 + 0.62 + 0.61}{5}$$
$$= \frac{3.08}{5}$$
$$= 0.616$$
$$= 0.62 \text{ mm}$$

$$\text{Bulk Density} = \frac{\text{Area Density} \div \text{Thickness}}{1000}$$
$$= \frac{237 \div 0.616}{1000}$$
$$= \frac{384.74026}{1000}$$
$$= 0.384740259$$
$$= 0.38\ g/m^3$$

C. Stretch and Recovery Calculations

<u>Sample A</u>

Stretch and Recovery Courses =

L1 = 7.6 7.6 7.6

L2 = 15.0 14.7 14.8

L3 = 8 7.9 7.9

L1 Average = 7.6

L2 Average = 14.833333333

L3 Average = 7.933333333

$$\text{Stretch} = \frac{L2 - L1}{L1} \times 100$$
$$= \frac{14.83333333 - 7.6}{7.6} \times 100$$
$$= \frac{7.233333333}{7.6} \times 100$$
$$= 0.951754386 \times 100$$
$$= 95.1754386$$
$$= 95.18\%$$

$$\text{Recovery} = \frac{L3 - L1}{L1} \times 100$$
$$= \frac{7.933333333 - 7.6}{7.6} \times 100$$
$$= \frac{0.333333333}{7.6} \times 100$$
$$= 0.043859649 \times 100$$
$$= 4.385964912$$
$$\text{Recovery} = 100 - 4.385964912$$
$$= 95.61403509$$
$$= 95.61\%$$

Stretch and Recovery Wales =

L1 = 7.6 7.6 7.6

L2 = 14.6 14.7 15

L3 = 7.9 8 8

L1 Average = 7.6

L2 Average = 14.76666667

L3 Average = 7.966666667

$$\text{Stretch} = \frac{L2 - L1}{L1} \times 100$$
$$= \frac{14.76666667 - 7.6}{7.6} \times 100$$
$$= \frac{7.166666667}{7.6} \times 100$$
$$= 0.942982456 \times 100$$
$$= 94.29824561$$
$$= 94.30\%$$

$$\text{Recovery} = \frac{L3 - L1}{L1} \times 100$$
$$= \frac{7.966666667 - 7.6}{7.6} \times 100$$
$$= \frac{0.366666666}{7.6} \times 100$$
$$= 0.048245614 \times 100$$
$$= 4.824561403$$
$$\text{Recovery} = 100 - 4.824561403$$
$$= 95.1754386$$
$$= 95.18\%$$

Sample B

Stretch and Recovery Courses =

L1 = 7.6 7.6 7.6

L2 = 15.8 15.6 15.9

L3 = 8.1 7.9 7.9

L1 Average = 7.6

L2 Average = 15.76666667

L3 Average = 7.966666667

$$\text{Stretch} = \frac{L2 - L1}{L1} \times 100$$
$$= \frac{15.76666667 - 7.6}{7.6} \times 100$$
$$= \frac{8.166666667}{7.6} \times 100$$
$$= 1.074561404 \times 100$$
$$= 107.4561404$$
$$= 107.46\%$$

$$\text{Recovery} = \frac{L3 - L1}{L1} \times 100$$
$$= \frac{7.966666667 - 7.6}{7.6} \times 100$$
$$= \frac{0.366666666}{7.6} \times 100$$
$$= 0.048245614 \times 100$$
$$= 4.824561403$$
$$\text{Recovery} = 100 - 4.824561403$$
$$= 95.1754386$$
$$= 95.18\%$$

Stretch and Recovery Wales =

L1 = 7.6 7.6 7.6

L2 = 13.6 13.7 13.6

L3 = 8 8 7.9

L1 Average = 7.6

L2 Average = 13.63333333

L3 Average = 7.966666667

$$\text{Stretch} = \frac{L2 - L1}{L1} \times 100$$
$$= \frac{13.63333333 - 7.6}{7.6} \times 100$$
$$= \frac{6.033333333}{7.6} \times 100$$
$$= 0.793859649 \times 100$$
$$= 79.38596491$$
$$= 79.39\%$$

$$\text{Recovery} = \frac{L3 - L1}{L1} \times 100$$
$$= \frac{7.966666667 - 7.6}{7.6} \times 100$$
$$= \frac{0.366666666}{7.6} \times 100$$
$$= 0.048245614 \times 100$$
$$= 4.824561403$$
$$\text{Recovery} = 100 - 4.824561403$$
$$= 95.1754386$$
$$= 95.18\%$$

Sample C

Stretch and Recovery Courses

L1 = 7.6 7.6 7.6

L2 = 22.8 22.8 20.9

L3 = 8.5 8.5 8.4

L1 Average = 7.6

L2 Average = 22.16666667

L3 Average = 8.466666667

$$\text{Stretch} = \frac{L2 - L1}{L1} \times 100$$
$$= \frac{22.16666667 - 7.6}{7.6} \times 100$$
$$= \frac{14.56666667}{7.6} \times 100$$
$$= 1.916666667 \times 100$$
$$= 191.6666667$$
$$= 191.67\%$$

$$\text{Recovery} = \frac{L3 - L1}{L1} \times 100$$
$$= \frac{8.466666667 - 7.6}{7.6} \times 100$$
$$= \frac{0.866666666}{7.6} \times 100$$
$$= 0.114035087 \times 100$$
$$= 11.40350877$$
$$\text{Recovery} = 100 - 11.40350877$$

= 88.59649123
= 88.60%

Stretch and Recovery Wales

L1 = 7.6 7.6 7.6
L2 = 24.5 22.8 24.3
L3 = 8.6 8.8 8.8

L1 Average = 7.6
L2 Average = 23.86666667
L3 Average = 8.733333333

Stretch = $\frac{L2 – L1}{L1}$ x 100
= $\frac{23.86666667 – 7.6}{7.6}$ x 100
= $\frac{16.26666667}{7.6}$ x 100
= 2.140350877 x 100
= 214.0350877
= 214.04%

Recovery = $\frac{L3 – L1}{L1}$ x 100
= $\frac{8.733333333 – 7.6}{7.6}$ x 100
= $\frac{1.133333333}{7.6}$ x 100
= 0.149122807 x 100
= 14.9122807
Recovery = 100 – 14.9122807
= 85.0877193
= 85.09%

Sample D

Stretch and Recovery Courses

L1 = 7.6 7.6 7.6
L2 = 15.4 15.3 15.2
L3 = 7.9 7.9 7.8

L1 Average = 7.6
L2 Average = 15.3
L3 Average = 7.866666667

Stretch = $\frac{L2 – L1}{L1}$ x 100
= $\frac{15.3 - 7.6}{7.6}$ x 100
= $\frac{7.7}{7.6}$ x 100
= 1.013157895 x 100
= 101.3157895
= 101.32%

Recovery = $\frac{L3 – L1}{L1}$ x 100
= $\frac{7.866666667 - 7.6}{7.6}$ x 100
= $\frac{0.266666666}{7.6}$ x 100
= 0.035087719 x 100
= 3.50877193
Recovery = 100 – 3.50877193
= 96.49122807
= 96.50%

Stretch and Recovery Wales

L1 = 7.6 7.6 7.6
L2 = 19.8 19.9 19.7
L3 = 8 8.1 8

L1 Average = 7.6
L2 Average = 19.8
L3 Average = 8.033333333

Stretch = $\frac{L2 – L1}{L1}$ x 100
= $\frac{19.8 – 7.6}{7.6}$ x 100
= $\frac{12.2}{7.6}$ x 100
= 1.605263158 x 100
= 160.5263158

Recovery = $\frac{L3 – L1}{L1}$ x 100
= $\frac{8.033333333 – 7.6}{7.6}$ x 100
= $\frac{0.433333333}{7.6}$ x 100
= 0.057017543 x 100
= 5.701754386

$= 160.53\%$

$\text{Recovery} = 100 - 5.701754386$
$= 94.29824562$
$= 94.30\%$

Sample E

Stretch and Recovery Courses

L1 = 7.6 7.6 7.6
L2 = 16.5 16.3 16.5
L3 = 7.9 7.9 8.0

L1 Average = 7.6
L2 Average = 16.43333333
L3 Average = 7.933333333

$$\text{Stretch} = \frac{L2 - L1}{L1} \times 100$$
$$= \frac{16.43333333 - 7.6}{7.6} \times 100$$
$$= \frac{8.833333333}{7.6} \times 100$$
$$= 1.162280702 \times 100$$
$$= 116.2280702$$
$$= 116.23\%$$

$$\text{Recovery} = \frac{L3 - L1}{L1} \times 100$$
$$= \frac{7.933333333 - 7.6}{7.6} \times 100$$
$$= \frac{0.333333333}{7.6} \times 100$$
$$= 0.043859649 \times 100$$
$$= 4.385964912$$
$$\text{Recovery} = 100 - 4.385964912$$
$$= 95.61403509$$
$$= 95.61\%$$

Stretch and Recovery Wales

L1 = 7.6 7.6 7.6
L2 = 20 19.7 19.8
L3 = 8.5 8.4 8.5

L1 Average = 7.6
L2 Average = 19.83333333
L3 Average = 8.466666667

$$\text{Stretch} = \frac{L2 - L1}{L1} \times 100$$
$$= \frac{19.83333333 - 7.6}{7.6} \times 100$$
$$= \frac{12.23333333}{7.6} \times 100$$
$$= 1.609649123 \times 100$$
$$= 160.9649123$$
$$= 160.96\%$$

$$\text{Recovery} = \frac{L3 - L1}{L1} \times 100$$
$$= \frac{8.466666667 - 7.6}{7.6} \times 100$$
$$= \frac{0.866666666}{7.6} \times 100$$
$$= 0.114035087 \times 100$$
$$= 11.40350877$$
$$\text{Recovery} = 100 - 11.40350877$$
$$= 88.59649123$$
$$= 88.60\%$$

D. Size Chart from Retailers

Sports Direct Sizing Chart (to nearest 0.5 cm)				
		Small	**Medium**	**Large**
Chest	Circular Measurement	91.5	96.5 - 101.5	106.5 -112
	Half Measurement	45.5	48.5 - 51	53.5 – 56

JJB Sports Sizing Chart (to nearest 0.5 cm)				
		Small	**Medium**	**Large**
Chest	Circular Measurement	86.5 – 91.5	94 - 99	101.5 - 106.5
	Half Measurement	43-45.5	47-49.5	50.5 - 53

Amazon Sizing Chart (to nearest 0.5cm)				
		Small	**Medium**	**Large**
Neck	Circular Measurement	35.5 - 37	38 - 39.5	40.5 - 42
	Half Measurement	18 - 18.5	19 - 20	20 - 21
Chest	Circular Measurement	86 - 91	96 - 101	107 - 111
	Half Measurement	43 - 45.5	48 - 50.5	53.5 - 55.5
Sleeve Length	Circular Meas.	80 - 81	82.5 - 84	85 - 86.5
	Half Measurement	40 - 40.5	41 - 42	42.5 - 43

E. Small and Large Garment Measurements

Small Garment Measurements (cm)						
	Measurement Point	**A**	**B**	**C**	**D**	**E**
1	Chest (measured across chest at 2.5 cm down from underarm)	37.9	34	32.3	37.7	35.2
2	Waist (measured across width at 40 cm down from side neck point)	33.5	33.5	31.5	35.5	31.7
3	Hem – Straight	32	32.9	30.9	34.5	34.3
4	Front Length – side neck point to hem	64	64.7	64.3	64	58.5
5	Across Front (measured across chest at 13 cm from side neck point	30.4	34.2	26.5	33.4	32.2
6	Front Neck Drop (side neck point to neck seam)	4	6.6	10.3	9	6.8
7	Armhole Straight	25.9	19.8	23.7	18.4	16.7
8	Cuff Straight	7.4	7.5	9.6	8.5	7.6
9	Sleeve Length	68.5	54	69	54.2	48.5
10	Shoulder Length (from side neck point)	24.2	12.4	6.5	13	10.7
11	Across Back (measured across at 13 cm from side neck point)	30.5	34	26.1	35.6	32.1
12	Back Length – side neck point to hem	64.8	64.2	65.3	64.5	59.1
13	Neck Rib Depth	5.2	5.3	2.1	1.6	2

Large Garment Measurements (cm)						
	Measurement Point	**A**	**B**	**C**	**D**	**E**
1	Chest (measured across chest at 2.5 cm down from underarm)	45.8	37.9	36	42.8	39.8
2	Waist (measured across width at 40 cm down from side neck point)	41.5	37.2	34.4	40	36.3
3	Hem – Straight	40.3	36.5	33.8	39.4	38.4
4	Front Length – side neck point to hem	68.2	68.6	64.5	69	66.4
5	Across Front (measured across chest at 13 cm from side neck point	36.2	37.6	28.2	38.6	35.6
6	Front Neck Drop (side neck point to neck seam)	5	6.9	10.3	9	7.1
7	Armhole Straight	29.5	19.5	24	19.5	17.8
8	Cuff Straight	8.2	7.5	9.9	9.5	8.6
9	Sleeve Length	71.6	56.8	68.6	55.2	53.5
10	Shoulder Length (from side neck point)	24.3	13.7	7	14.5	11.8
11	Across Back (measured across at 13 cm from side neck point)	36	37.9	28	39.8	35.6
12	Back Length – side neck point to hem	69.3	68.4	64.9	68	66.8
13	Neck Rib Depth	5.3	5.1	2.1	1.7	1.6

F. FAST Data and Calculations

FAST Data Sample A						
Sample A: COMPRESSION						
Sample	**20 g**			**100 g**		
1	1.112		1.109	0.844		0.840
2	1.108		1.111	0.846		0.849
3	1.102		1.094	0.845		0.841
Average	**1.1**			**0.8**		
Sample A: BENDING						
Sample	**Wale (mm)**			**Course (mm)**		
1	13.0			14.0		
2	14.5			14.0		
3	13.5			16.5		
Average	**13.7**			**14.8**		
Sample A: EXTENSION						
Sample	**Wale (%)**			**Course (%)**		
	5 g	**20 g**	**100 g**	**5 g**	**20 g**	**100 g**
1	2.6	12.2	20.3	2.8	19.7	20.3
2	2.1	11.8	20.3	4.2	19.4	20.3
3	1.6	12.6	20.3	3.0	19.0	20.3
Average	**2.1**	**12.2**	**>20.3**	**3.3**	**19.4**	**>20.3**
Sample A: BIAS EXTENSION						
1 and 2	3.8			2.7		
3 and 4	3.5			2.2		
5 and 6	3.5			2.6		
Average	**3.1**					

Surface Thickness = $T_2 - T_{100}$
= 1.106 – 0.844166666
= 0.261833334
= 0.26 mm

Thickness at 2g = 1.11 mm

Thickness at 100g = 0.84 mm

Bending Rigidity = $W(BL)^3 \times 9.81 \times 10^{-6}$
= $213\ (13.6666667)^3 \times 9.81 \times 10^{-6}$
= $543710.1151 \times 9.81 \times 10^{-6}$
= $5333796.229 \times 10^{-6}$
= 5.333796229
Wale = 5.33 µNm

$= 213\ (14.83333333)^3 \times 9.81 \times 10^{-6}$
$= 695177.7634 \times 9.81 \times 10^{-6}$
$= 6819693.859 \times 10^{-6}$
$= 6.819693859$

Course = 6.82 µNm

Formability $= \frac{(E20 - E5)\ B}{14.7}$

$= \frac{(12.2 - 2.1)\ 5.333796229}{14.7}$

$= \frac{10.1 \times 5.333796229}{14.7}$

$= \frac{53.87134191}{14.7}$

$= 3.664717137$

Wale = 3.66 mm^2

$= \frac{(19.36666667 - 3.333333333)\ 6.819693859}{14.7}$

$= \frac{16.03333334 \times 6.819693859}{14.7}$

$= \frac{109.3424249}{14.7}$

$= 7.438260197$

Course = 7.44 mm^2

Extensibility Wale = 20.3% Course = 20.3%

Shear Rigidity $= \frac{123}{EB5}$

$= \frac{123}{3.05}$

$= 40.32786885$

$= 40.33$ N/m

FAST Data Sample B						
Sample B:	**COMPRESSION**					
Sample	**20 g**			**100 g**		
1	0.867		0.864	0.736		0.726
2	0.871		0.885	0.733		0.744
3	0.888		0.882	0.743		0.746
Average	**0.9**			**0.7**		
Sample B:	**BENDING**					
Sample	**Wale (mm)**			**Course (mm)**		
1	15.5			14.5		
2	13.5			15.0		
3	14.0			15.0		
Average	**14.3**			**14.8**		
Sample B:	**EXTENSION**					
Sample	**Wale (%)**			**Course (%)**		
	5 g	**20 g**	**100 g**	**5 g**	**20 g**	**100 g**
1	1.3	12.8	20.3	1.4	9.3	20.3
2	0.8	12.6	20.3	0.5	8.8	20.3
3	0.7	12.5	20.3	0.4	8.6	20.3
Average	**0.9**	**12.6**	**>20.3**	**0.8**	**8.9**	**>20.3**
Sample B:	**BIAS EXTENSION**					
1 and 2	2.8			1.9		
3 and 4	0.7			1.8		
5 and 6	1.6			2.2		
Average	**1.8**					

Surface Thickness = $T_2 - T_{100}$
= 0.876166666 – 0.738
= 0.138166666
= 0.14 mm

Thickness at 2g = 0.88 mm

Thickness at 100g = 0.74 mm

Bending Rigidity = $W(BL)^3 \times 9.81 \times 10^{-6}$
= $250\ (14.33333333)^3 \times 9.81 \times 10^{-6}$
= $736175.9254 \times 9.81 \times 10^{-6}$
= $7221885.828 \times 10^{-6}$
= 7.221885828
Wale = 7.22 µNm

$= 250 (14.83333333)^3 \times 9.81 \times 10^{-6}$
$= 815936.342 \times 9.81 \times 10^{-6}$
$= 8004335.515 \times 10^{-6}$
$= 8.004335515$
Course = 8.00 µNm

Formability $= \frac{(E20 - E5)\ B}{14.7}$

$= \frac{(12.63333333 - 0.93333333)\ 7.221885828}{14.7}$

$= \frac{11.7 \times 7.221885828}{14.7}$

$= \frac{84.49606417}{14.7}$

$= 5.748031576$

Wale = 5.75 mm^2

$= \frac{(8.9 - 0.766666666)\ 8.004335515}{14.7}$

$= \frac{8.133333334 \times 8.004335515}{14.7}$

$= \frac{65.10192886}{14.7}$

$= 4.428702644$

Course = 4.43 mm^2

Extensibility Wale = 20.3% Course = 20.3%

Shear Rigidity $= \frac{123}{EB5}$

$= \frac{123}{1.833333333}$

$= 67.0909091$

= 67.10 N/m

FAST Data Sample C						
Sample C: COMPRESSION						
Sample	**20 g**			**100 g**		
1	1.114		1.116	0.851		0.855
2	1.295		1.129	0.912		0.848
3	1.257		1.094	0.878		0.840
Average	**1.2**			**0.9**		
Sample C: BENDING						
Sample	**Wale (mm)**			**Course (mm)**		
1	14.5			14.5		
2	15.0			13.5		
3	17.5			15.5		
Average	**15.7**			**14.5**		
Sample C: EXTENSION						
Sample	**Wale (%)**			**Course (%)**		
	5 g	**20 g**	**100 g**	**5 g**	**20 g**	**100 g**
1	0.8	16.5	20.3	0.9	12.6	20.3
2	0.6	16.8	20.3	0.4	17.8	20.3
3	0.4	18.6	20.3	1.0	19.2	20.3
Average	**0.6**	**17.3**	**>20.3**	**0.8**	**16.5**	**>20.3**
Sample C: BIAS EXTENSION						
1 and 2	0.8			1.8		
3 and 4	1.2			1.9		
5 and 6	0.7			1.7		
Average	**1.4**					

Surface Thickness = $T_2 - T_{100}$
= 1.1675 – 0.864
= 0.3035
= 0.30 mm

Thickness at 2g = 1.17 mm

Thickness at 100g = 0.86 mm

Bending Rigidity = $W(BL)^3 \times 9.81 \times 10^{-6}$
= $223\ (15.66666667)^3 \times 9.81 \times 10^{-6}$
= $857501.0746 \times 9.81 \times 10^{-6}$
= $8412085.542 \times 10^{-6}$
= 8.412085542
Wale = 8.41 µNm

$= 223\ (14.5)^3 \times 9.81 \times 10^{-6}$
$= 679843.375 \times 9.81 \times 10^{-6}$
$= 6669263.509 \times 10^{-6}$
$= 6.669263509$

Course = 6.67 µNm

Formability $= \frac{(E20 - E5)\ B}{14.7}$

$= \frac{(17.3 - 0.6)\ 8.412085542}{14.7}$

$= \frac{16.7 \times 8.412085542}{14.7}$

$= \frac{140.4818286}{14.7}$

$= 9.556586976$

Wale = 9.56 mm^2

$= \frac{(16.53333333 - 0.766666666)\ 6.669263509}{14.7}$

$= \frac{15.76666666 \times 6.669263509}{14.7}$

$= \frac{105.1520546}{14.7}$

$= 7.153200996$

Course = 7.15 mm^2

Extensibility Wale = 20.3% Course = 20.3%

Shear Rigidity $= \frac{123}{EB5}$

$= \frac{123}{1.35}$

$= 91.11111111$

= 91.11 N/m

FAST Data Sample D				
Sample D: COMPRESSION				
Sample	**20 g**		**100 g**	
1	0.603	0.595	0.487	0.488
2	0.598	0.596	0.485	0.487
3	0.592	0.598	0.484	0.484
Average	**0.6**		**0.5**	

Sample D: BENDING		
Sample	**Wale (mm)**	**Course (mm)**
1	12.5	15.0
2	12.0	11.0
3	12.0	10.5
Average	**12.2**	**12.2**

Sample D: EXTENSION						
Sample	**Wale (%)**			**Course (%)**		
	5 g	**20 g**	**100 g**	**5 g**	**20 g**	**100 g**
1	3.2	15.1	20.3	4.6	12.6	20.3
2	1.9	14.2	20.3	4.0	12.3	20.3
3	2.0	12.2	20.3	4.9	12.3	20.3
Average	**2.4**	**13.8**	**>20.3**	**4.5**	**12.4**	**>20.3**

Sample D: BIAS EXTENSION		
1 and 2	5.5	5.8
3 and 4	7.3	7.1
5 and 6	7.3	6.7
Average	**6.7**	

Surface Thickness = $T_2 - T_{100}$
= 0.597 – 0.485833333
= 0.111166667
= 0.11 mm

Thickness at 2g = 0.60 mm

Thickness at 100g = 0.49 mm

Bending Rigidity = $W(BL)^3 \times 9.81 \times 10^{-6}$
= $174\ (12.16666667)^3 \times 9.81 \times 10^{-6}$
= $313374.8058 \times 9.81 \times 10^{-6}$
= $3074206.845 \times 10^{-6}$
= 3.074206845
Wale = 3.07 µNm

$= 174 (12.16666667)^3 \times 9.81 \times 10^{-6}$
$= 313374.8058 \times 9.81 \times 10^{-6}$
$= 3074206.845 \times 10^{-6}$
$= 3.074206845$
Course = 3.07 µNm

Formability $= \frac{(E20 - E5)\, B}{14.7}$

$= \frac{(13.83333333 - 2.366666667)\, 3.074206845}{14.7}$

$= \frac{11.46666666 \times 3.074206845}{14.7}$

$= \frac{35.25090514}{14.7}$

$= 2.398020758$

Wale = 2.40 mm^2

$= \frac{(12.4 - 4.5)\, 3.074206845}{14.7}$

$= \frac{7.9 \times 3.074206845}{14.7}$

$= \frac{24.28623408}{14.7}$

$= 1.652124767$

Course = 1.65 mm^2

Extensibility Wale = 20.3% Course = 20.3%

Shear Rigidity $= \frac{123}{EB5}$

$= \frac{123}{6.616666667}$

$= 18.58942065$

= 18.59 N/m

FAST Data Sample E						
Sample E: COMPRESSION						
Sample	**20 g**			**100 g**		
1	0.627		0.633	0.584		0.591
2	0.630		0.640	0.587		0.593
3	0.630		0.628	0.586		0.588
Average	**0.6**			**0.6**		
Sample E: BENDING						
Sample	**Wale (mm)**			**Course (mm)**		
1	10.5			10.5		
2	9.0			14.0		
3	11.0			11.0		
Average	**10.2**			**11.8**		
Sample E: EXTENSION						
Sample	**Wale (%)**			**Course (%)**		
	5 g	**20 g**	**100 g**	**5 g**	**20 g**	**100 g**
1	3.5	18.5	20.3	1.2	10.3	20.3
2	2.9	12.7	20.3	0.6	9.2	20.3
3	3.5	17.4	20.3	1.6	10.2	20.3
Average	**3.3**	**16.2**	**>20.3**	**1.1**	**9.9**	**>20.3**
Sample E: BIAS EXTENSION						
1 and 2	1.5			2.3		
3 and 4	2.0			1.5		
5 and 6	1.5			3.1		
Average	**2.0**					

Surface Thickness = $T_2 - T_{100}$
= 0.631333333 – 0.588166666
= 0.043166667
= 0.04 mm

Thickness at 2g = 0.63 mm

Thickness at 100g = 0.59 mm

Bending Rigidity = $W(BL)^3 \times 9.81 \times 10^{-6}$
= $237\ (10.16666667)^3 \times 9.81 \times 10^{-6}$
= $249048.5975 \times 9.81 \times 10^{-6}$
= $2443166.741 \times 10^{-6}$
= 2.443166741
Wale = 2.44 µNm

$= 237\ (11.83333333)^3 \times 9.81 \times 10^{-6}$
$= 392707.9024 \times 9.81 \times 10^{-6}$
$= 3852464.523 \times 10^{-6}$
$= 3.852464523$
Course = 3.85 µNm

Formability $= \frac{(E20 - E5)\ B}{14.7}$

$= \frac{(16.2 - 3.3)\ 2.443166741}{14.7}$

$= \frac{12.9 \times 2.443166741}{14.7}$

$= \frac{31.51685096}{14.7}$

$= 2.144003467$

Wale = 2.14 mm^2

$= \frac{(9.9 - 1.133333333)\ 3.852464523}{14.7}$

$= \frac{8.766666667 \times 3.852464523}{14.7}$

$= \frac{33.77327232}{14.7}$

$= 2.297501518$

Course = 2.30 mm^2

Extensibility Wale = 20.3% Course = 20.3%

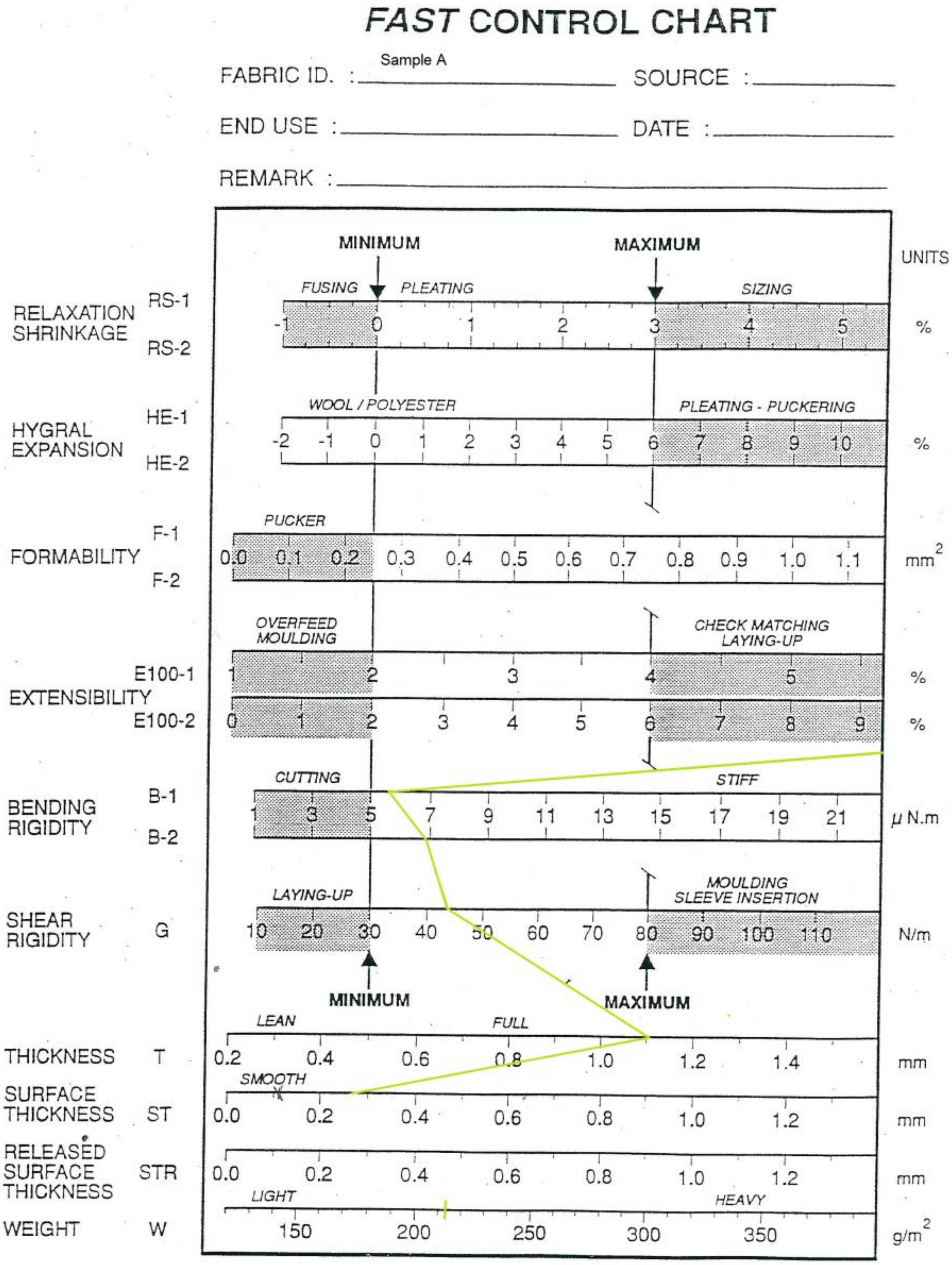
Shear Rigidity $= \frac{123}{EB5}$

$= \frac{123}{1.983333333}$

$= 62.01680673$

= 62.02 N/m

G. FAST Fingerprints

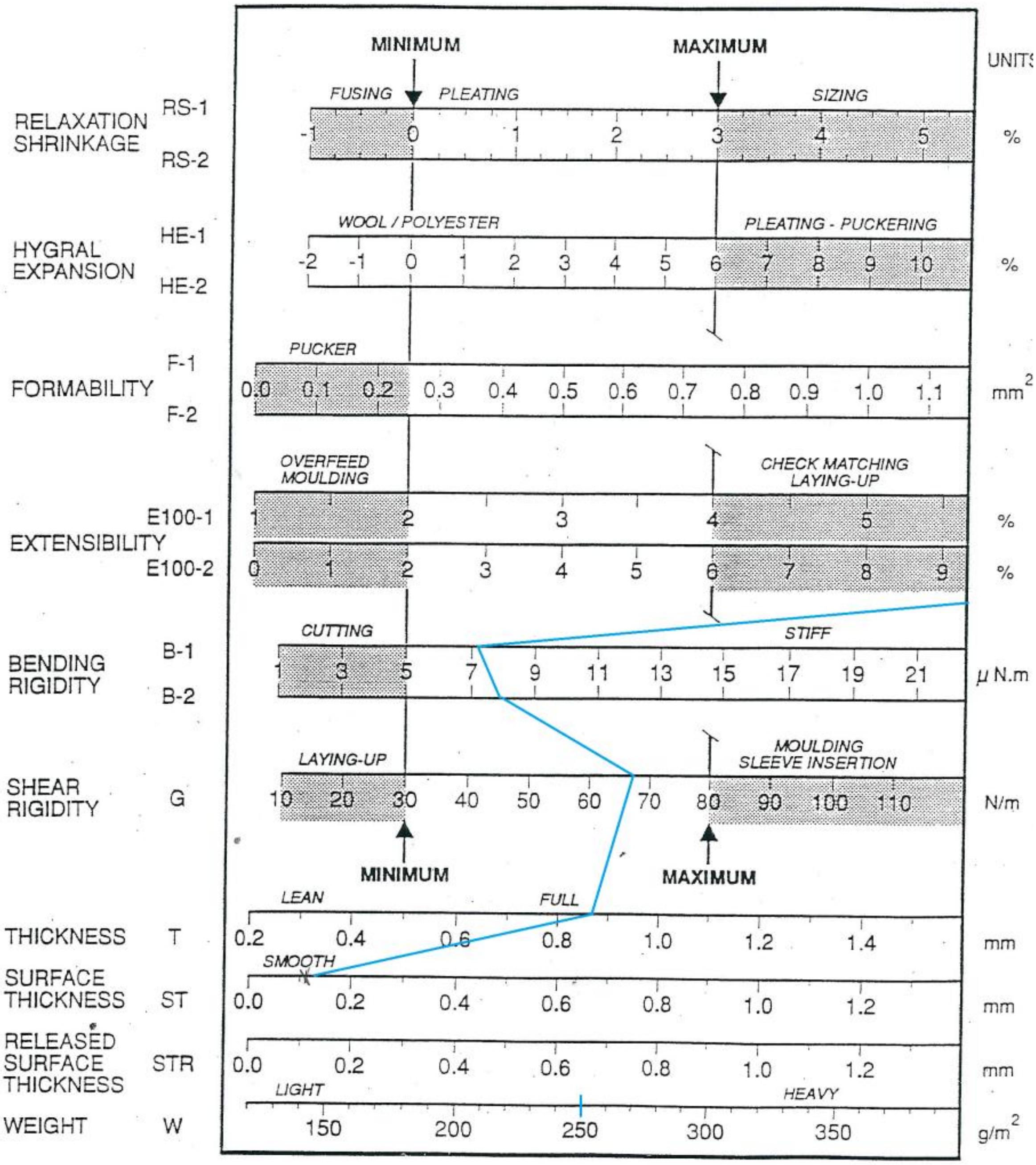


FAST CONTROL CHART

FABRIC ID. : Sample B SOURCE : ______

END USE : ______ DATE : ______

REMARK : ______

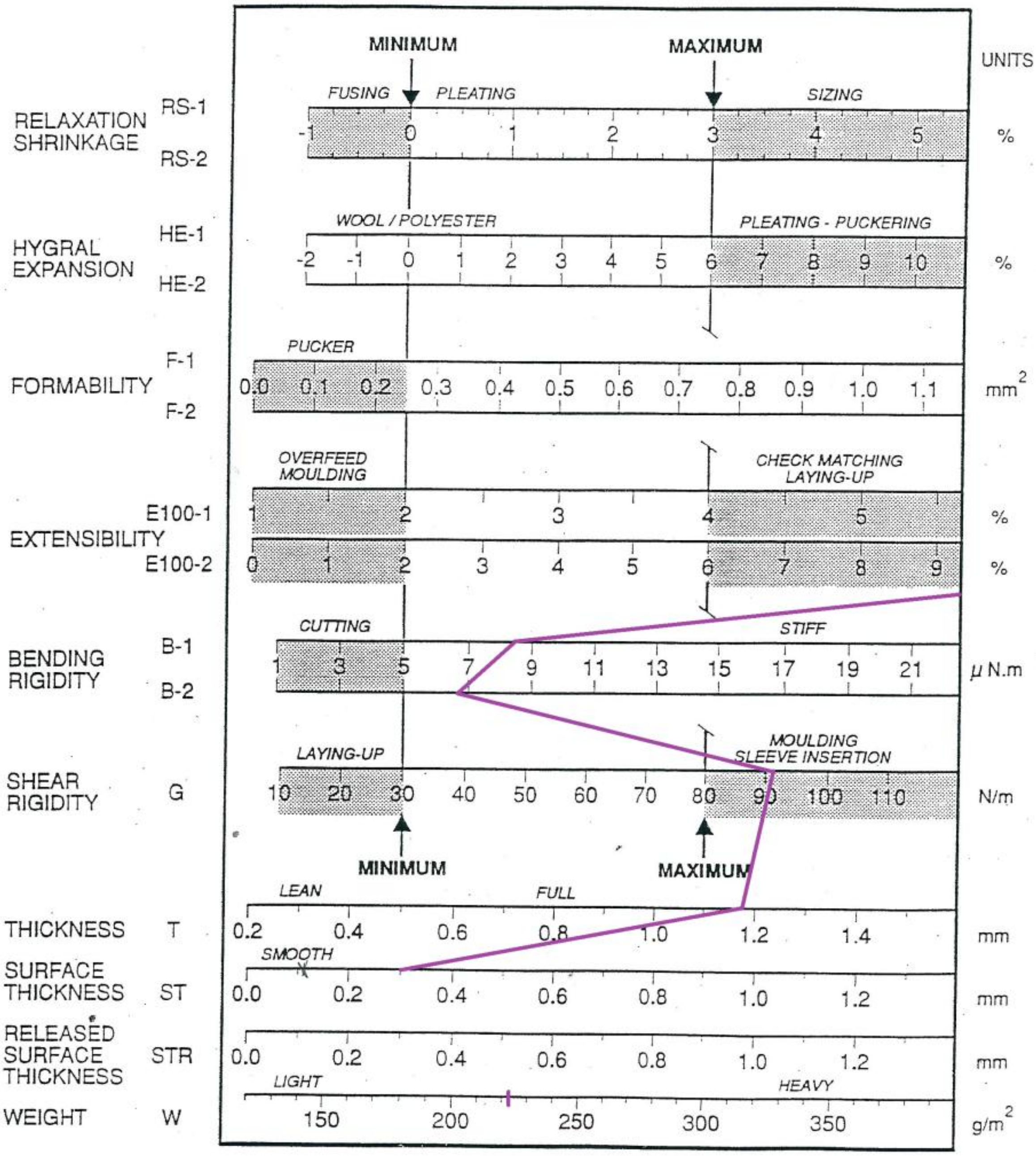


FAST CONTROL CHART

FABRIC ID. : Sample C SOURCE :

END USE : DATE :

REMARK :

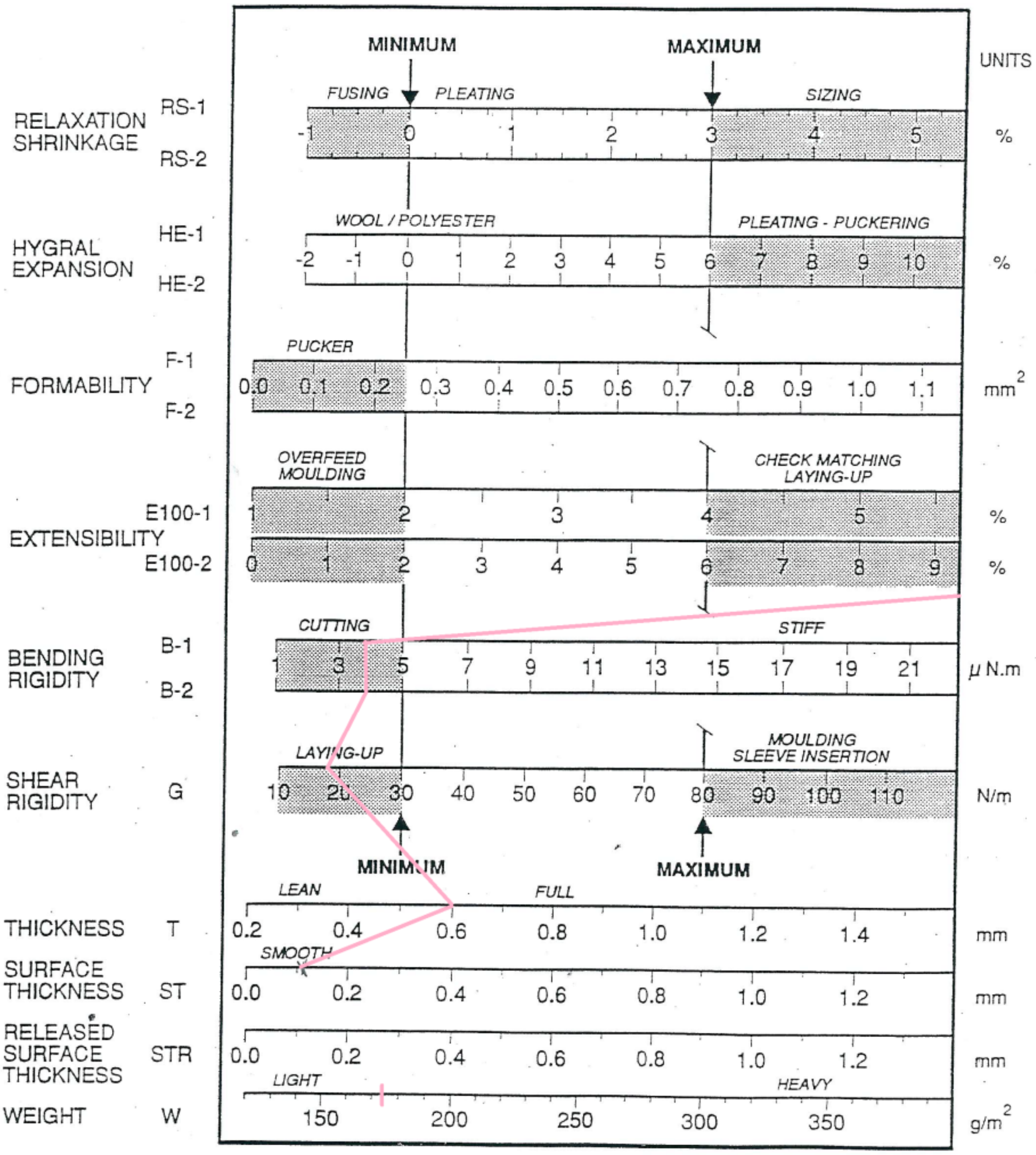


FAST CONTROL CHART

FABRIC ID. : Sample D SOURCE :

END USE : DATE :

REMARK :

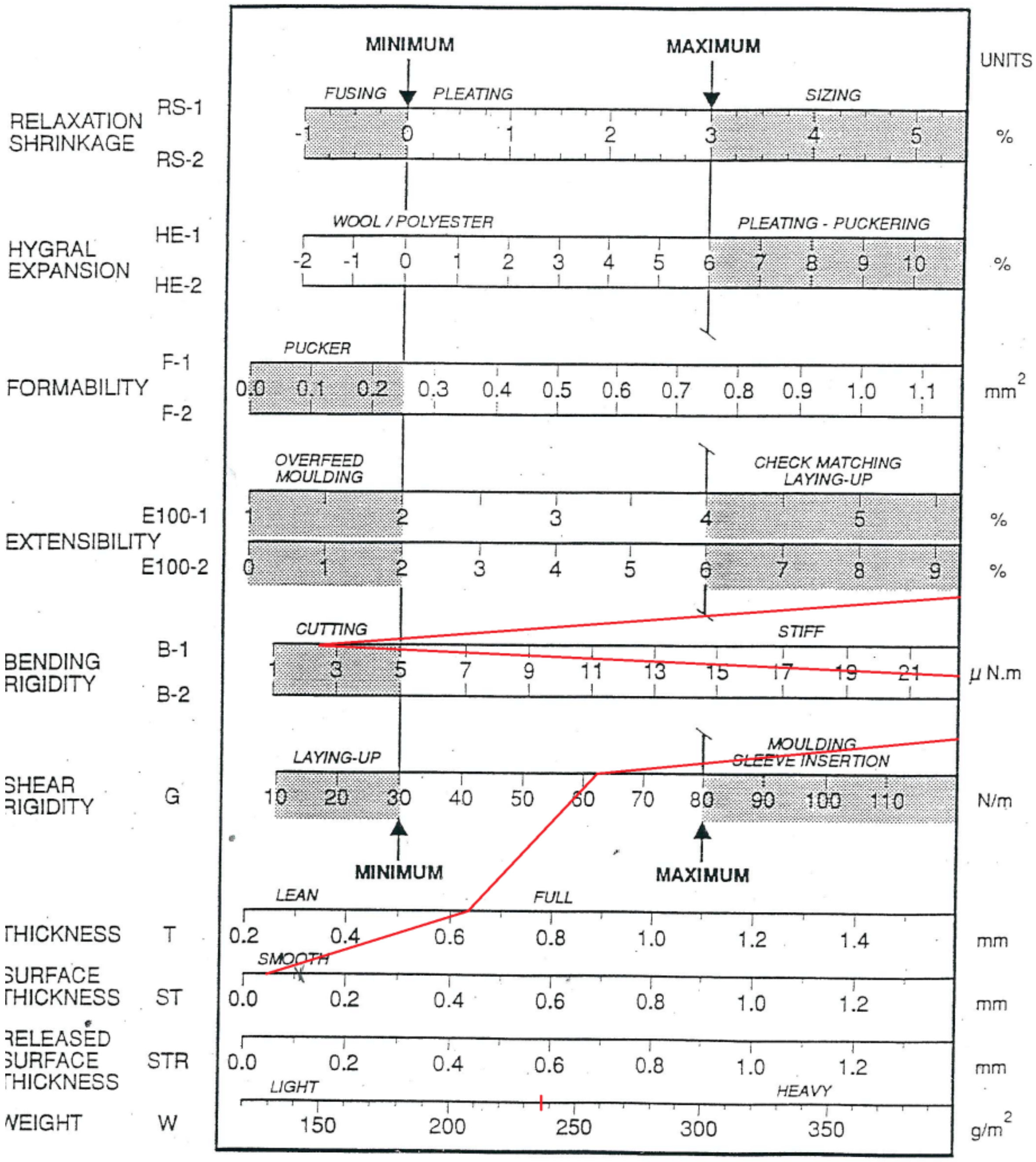


FAST CONTROL CHART

FABRIC ID. : Sample E ______________________ SOURCE : ______________

END USE : ______________________ DATE : ______________

REMARK : ____



H. Size Chart for Mannequin

ALVANON STANDARD ADULT

Size Type	Men		Men		Men		Men		Men		Men		Men Large		Men Large	
Size Number	34		36		38		40		42		44		46		48	
Chest	34	86.5	36	91.5	38	96.5	40	101.5	42	106.5	44	112	46	117	48	122
Waist	28	71	30	76	32	81.5	34	86.5	36	91.5	38 1/4	97	40 1/2	103	43	109
Hip	34	86.5	36	91.5	38	96.5	40	101.5	42	106.5	44 1/8	112	46	117	48	122
Thigh	20 3/4	52.5	22	56	23 1/4	59	24 1/2	62	25 3/4	65.5	27	68.5	28 1/4	72	29 1/2	75
Front Waist Length	15	38	15 1/4	38.5	15 1/2	39.5	15 3/4	40	16	40.5	16 1/8	41	16 1/2	42	16 7/8	43
Back Waist Length	17 1/8	43.5	17 1/2	44.5	17 7/8	45.5	18 1/4	46.5	18 1/2	47	18 3/8	46.5	19	48.5	19 1/4	49
Neck Base	14	35.5	14 1/2	37	15	38	15 1/2	39.5	16	40.5	16 5/8	42	17	43	17 1/2	44.5
Across Shoulder	16 1/2	42	16 3/4	42.5	17	43	17 1/2	44.5	18	45.5	18 3/4	47.5	19 1/4	49	20	51
Across Back	15	38	15 3/8	39	15 5/8	39.5	16 1/4	41.5	16 3/4	42.5	17 3/8	44	18	45.5	18 3/4	47.5
Inseam	32 1/4	82	32 1/4	82	32 3/8	82	32 1/2	82.5	32 1/2	82.5	32 1/2	82.5	32 1/2	82.5	32 1/8	81.5
Total Rise	24 1/2	62	25 3/4	65.5	27	68.5	28	71	29	73.5	30 1/4	77	31	78.5	32	81.5
Full Sleeve Length	32 1/2	82.5	33	84	33 5/8	85.5	34 1/4	87	34 3/4	88.5	34 1/2	87.5	35 3/4	91	36	91.5
Bicep	11 1/2	29	12	30.5	12 3/4	32.5	13 1/4	33.5	13 1/2	34.5	14	35.5	14 1/2	37	15	38