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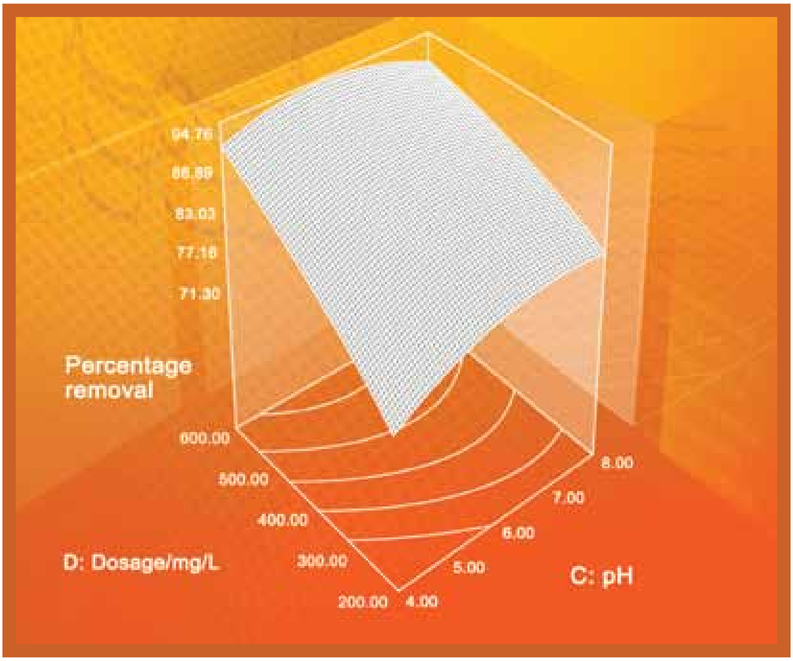

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Seam Quality: Experimental and Modelling Works using the Structural Equation Methodology

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ABSTRACT

Seam quality in terms of appearance and strength were investigated for very light weight fabrics (weight less than 80 g m^{-2}). Seams were constructed with different sewing parameters, which included types of thread, stitch densities and needle size. Before constructing the seam for appearance and strength evaluation the mechanical properties of all fabrics were determined. The mechanical properties of 48 fabrics were determined using the Kawabata Evaluation System (KES-F), the Fabric Assurance Simple Test (FAST) and an Instron Tensile Tester. Evaluation of seam quality was performed with respect to all the sewing parameters and the seams were ranked accordingly. The same evaluation ranking for seam appearance and strength was used for further analysis using Structural Equation Modelling (SEM) under AMOS. SEM was used to establish the relationship between seam quality with respect to appearance and strength, and fabric mechanical properties. SEM was adopted to perform confirmative analysis to identify the fabrics mechanical properties that influence seam quality. From the experimental work, it was established that seams constructed with 100 % spun polyester thread with a ticket number of 75 gave the best ranking in terms of seam strength. This thread performed at optimum values when used with 6.5 stitches per centimetre (spcm) with a Metric needle size (Nm) of 90. For seam appearance, 100 % spun polyester with a ticket number of 120 and Metric needle size of 80 gave the best ranking.

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SEM established that extensibility and shear were the main fabric mechanical properties that determine seam quality of very light weight fabrics.

Keywords: *Seam quality, seam appearance, seam strength, confirmative analysis, Structural Equation Modelling*

Introduction

A seam is a joint between two pieces of fabric and can be defined as 'the application of a series of stitches or stitch types to one or several thicknesses of material' [1]. Evidently based upon this definition, there are two major components of a seam, namely the stitches and the materials in the form of fabrics. Besides stitches, other factors such as needle size and thread properties, which can be categorized as sewing parameters, also influence seam quality. Therefore it can be hypothesized that seam quality is affected by two main factors, which are the fabric mechanical properties and the sewing parameters.

Seam quality applies to two areas; appearance and strength. Seam appearance concerns the situation known as seam pucker. Seam pucker is an unacceptable waviness in appearance along the seam length that occurs immediately after seam construction or may develop after several washing and drying processes [2]. The Oxford English Dictionary [3] defines seam pucker as "a ridge, wrinkle or corrugation of the material or a number of small wrinkles running across and into one another, which appear in sewing together two pieces of cloth".

One of the most common seam puckers is known as a displacement pucker. Displacement pucker is due to the compactness of the warp and weft yarn in the fabric known as structural jamming. The yarns position in the fabric is disrupted during sewing by the insertion of the needle and thread. Structural jamming occurs when yarns in the fabric are displaced from their original position as the needle and thread penetrate the fabric. The warp and weft yarns in the fabric have to make space for the thread through extension along the line of the seam, but on the other side of the seam no extension occurs and this causes the fabric to buckle and produces a seam pucker [4, 5].

Seam strength is evaluated by applying a load across a seam, known as transverse loading. In the case of transverse loading, seam strength can be increased by providing more seam allowance, using stronger sewing thread and a higher number of stitches cm^{-1}. Conversely longitudinal loading refers to a load that is applied parallel to the direction of the sewing and hence it is closely related to the extensibility of the seam [6, 7]. Seam strength can be affected by changes in the type of seam and stitch, because it affects the interlacing of the sewing thread with the yarns in the fabric [8]. Elongation in the seam can be defined as the degree to which a seam can be stretched without breaking, hence suitable stitch type, seam type, thread tension, stitch density, sewing thread and fabric properties are essential to enable the seam to elongate to teh same degree as the fabric [9]. A failed seam makes apparel unwearable even though the fabric may still be in good condition, which is why it is very important to identify a relationship and correlation between sewing parameters and fabric properties.

SEM under AMOS [10] was used to determine the relationship between seam quality, with respect to different sewing parameters, and the fabric mechanical properties. "Structural Equation Modelling (SEM) is a statistical methodology that takes a confirmatory approach to the analysis of a structural theory bearing on some phenomenon" [11].

SEM is suitable to be used as an analysis tool, because it enables elucidation of the interactions, nonlinearities and correlations between various independent (48 fabric mechanical properties) and dependent (seam quality sewn with different sewing parameters) variables involved during seam construction. SEM provides a graphical modelling interface, which enables clearer evaluation and understanding of the relationships that exist between the variables.

There are many commercialised types of SEM software on the market, such as LISREL, CALIS, EQS and SEPATH, however for the purposes of this research Analysis of MOment Structures (AMOS) has been chosen. The toolset provided by AMOS Graphic is very flexible and makes it possible for the user to draw and modify the graphical diagrams to be modelled with ease. AMOS software is very user-friendly and is designed to prevent mistakes during user-defined model specification.

Methodology

Sewing Parameters

In order to establish the effect of different sewing parameters on seam quality, five different threads were chosen to be used for the seam constructions. The chosen threads are commonly used in apparel

Table 1: Thread Selection

Thread	Types	Ticket Number	Needle size
1	100 % spun polyester	120	80
2	100 % spun polyester	75	90
3	100 % polyester core-spun	120	80
4	100 % polyester core-spun	75	90
5	Poly/Cotton core-spun	75	90

manufacture and vary in terms of sizes, fibre composition and construction, Table 1. The ticket number indicates the size of the thread; the higher the value, the finer the thread.

A superimposed seam with a seam allowance of 25.4 mm and a British Standard (BSST) 301 lockstitch were selected to be employed in sewing all the fabrics. The seam and stitch types were selected for this study, because they are the most common seam type used by clothing manufacturers. The stitch densities were; 5.5 (a), 6.5 (b) and 7.5 (c) spcm. For the purpose of ease of identification during the experimental and modelling works the sewn fabrics were identifiable with respect to the thread and stitch densities. For example, S1a indicates a fabric sewn with Thread 1 with a stitch density of 5.5 spcm.

Fabrics were sewn in the warp direction, because usually the number of yarns in the warp direction is greater than in the weft direction and hence the effect of inserting a thread during sewing in the warp direction should a more pronounced effect on the seam performance. Furthermore, apparel manufacturers usually cut and sew their products in the warp direction due to the motif and design of the fabric.

The seam appearance was evaluated with respect to the two settings chosen to sew the fabric, namely manual and automatic. The manual setting means the sewing machine is operated manually with the sewing operator pressing the foot pedal in order to operate the machine. This results in speed variation with time, depending on the quantity of pressure applied by the sewing operator's foot to the pedal. During the duration of the sewing process the operator also needs to hold the fabric and inherently the operator tends to pull the fabric during sewing, which will affect the quality of the seam.

The automatic setting uses a fixed speed throughout the whole sewing process. The length of the stitches to be sewn into the fabric was also set so that the sewing machine stops at the end of the fabric length and automatically cuts the sewing thread. The operator in this instance just needs to place the fabric under the presser foot and depress the foot pedal once in order to initiate operation of the sewing machine and release his/her foot once the machine is operating. This alleviates the influence of the sewing operator on the speed and movement of the fabric during seam construction. Upon completion the sewn fabric is removed from the machine and the process is repeated on a new fabric set until all samples are processed.

The sewn fabric was evaluated visually using photographic comparative ratings for single needle seams, where a rating of 5 represents no pucker at all and 1 represents the poorest seam pucker rating. The evaluations of seam appearance under the manual and automatic settings were compared in order to establish whether a manual or automatic setting was the most suitable to evaluate the sewing parameters. The results for all fabrics in the same category using the same sewing parameters were averaged out and ranked according to seam appearance with respect to the different sewing parameters and whether the fabric was sewn manually or automatically.

The seam strength was evaluated with respect to breaking load minimum force required to rupture the seam. The fabrics were prepared according to the British Standard: Textiles – Seam tensile properties of fabrics and made-up textile articles – Part 1: Determination of maximum force to seam rupture using the strip method [12].

The average minimum force required for each seam to rupture was determined and used to rank the seams with respect to the different sewing parameters. Upon establishing the rankings for seam strength and seam appearance for both manually and automatically sewn seams the sewing parameters with the same rankings were grouped together and correlated with the fabric properties through modelling.

Fabrics

Nine fabrics with different fibre types and weave structures were selected for this study. All fabrics have a weight below 80 g m^{-2} and are categorized as very light weight. All nine fabrics and their corresponding thicknesses and weights are presented in Table 2.

Table 2: Fabrics Basic Properties

Fabric I.D.	Thickness	Weight (g m^{-2})	Fibre types	Weave Structures
1	0.251	65.2	Silk	Jacquard
2	0.113	36.2	Silk	Plain
3	0.220	68.8	Silk	Satin
4	0.251	71.3	Silk	Plain
9	0.116	68.3	Poly	Satin
15	0.189	74.9	Poly	Plain
17	0.363	56.1	Poly	Plain
22	0.191	54.8	Poly	Plain
25	0.374	75.1	Poly	Plain

Fabric Mechanical Properties

All fabrics were tested using KES-F, FAST and the Instron tensile tester. KES-F consists of four instruments, which includes FB 1: Tensile and shearing, FB 2: Bending, FB 3: Compression and FB 4: Surface friction and thickness. FAST consists of three instruments, which includes FAST 1: Compression meter, FAST 2: Bending meter and FAST 3: Extensibility meter. The Instron tensile tester was used to test all fabrics for their warp and weft tensile strengths according to the British Standard: Textiles-Tensile properties of fabrics-Part 1: Determination of maximum force and elongation at maximum force using the strip method [14]. From all these tests, 48 fabric mechanical properties were collected, Table 3.

Structural Equation Modelling

Structural Equation Modelling (SEM) is a multiple regression technique used to identify relationships between different factors [11]. SEM under AMOS was used in this study to ascertain whether relationships existed between the fabric properties (KES -F, FAST, and Instron) and the results from seam quality evaluation (appearance and strength).

There are five steps in SEM:

1. Model specification – Identify the variables to be used in as input in the analysis and to draw a Confirmatory Factor Analysis (CFA) path diagram. The path diagram enables visualization of the relationships between the variables considered in the study;

Table 3: List of Fabric Mechanical Properties

No.	Properties	Definition	Equipment
1.	F1	Warp formability	FAST
2.	F2	Weft formability	FAST
3.	E5 warp	Warp extensibility at 5 g	FAST
4.	E5 weft	Weft extensibility at 5 g	FAST
5.	E20 warp	Warp extensibility at 20 g	FAST
6.	E20 weft	Weft extensibility at 20 g	FAST
7.	E100 warp	Warp extensibility at 100 g	FAST
8.	E100 weft	Weft extensibility at 100 g	FAST
9.	EB5	Bias extensibility at 5 g	FAST
10.	C1	Warp bending length	FAST
11.	C2	Weft bending length	FAST
12.	B_f1	Warp bending rigidity	FAST
13.	B_f2	Weft bending rigidity	FAST
14.	G_f	Shear rigidity	FAST
15.	T2	Thickness pressure of 2 Gf	FAST
16.	T100	Thickness pressure of 100 Gf	FAST
17.	ST	Surface thickness (T2 – T100)	FAST
18.	EM1	Warp extensibility	KES
19.	EM2	Weft extensibility	KES
20.	LT1	Warp linearity of extension	KES
21.	LT2	Weft linearity of extension	KES
22.	WT1	Warp tensile energy	KES
23.	WT2	Weft tensile energy	KES
24.	RT1	Warp tensile resiliency	KES
25.	RT2	Weft tensile resiliency	KES
26.	B1	Warp bending stiffness	KES
27.	B2	Weft bending stiffness	KES
28.	HB1	Warp bending hysteresis	KES
29.	HB2	Weft bending hysteresis	KES
30.	G1	Warp shear rigidity	KES
31.	G2	Weft shear rigidity	KES
32.	HG1	Warp shear hysteresis	KES
33.	HG2	Weft shear hysteresis	KES
34.	HG5 warp	Warp shear hysteresis at 5 °	KES
35.	HG5 weft	Weft shear hysteresis at 5 °	KES

(*continued*)

Table 3 (*continued*)

No.	Properties	Definition	Equipment
36.	MIU warp	Warp mean frictional coefficient	KES
37.	MIU weft	Weft mean frictional coefficient	KES
38.	MMD warp	Warp surface frictional roughness	KES
39.	MMD weft	Weft surface frictional roughness	KES
40.	SMD warp	Warp surface geometrical roughness	KES
41.	SMD weft	Weft surface geometrical roughness	KES
42.	LC	Linearity of compression	KES
43.	WC	Compression energy	KES
44.	RC	Compression resiliency	KES
45.	T	Thickness	KES
46.	W	Weight (mg cm^{-2})	KES
47.	Suwarp	Force (N) to break fabric in warp direction	INSTRON
48.	Suweft	Force (N) to break fabric in weft direction	INSTRON

2. Identification – Estimate whether the quantity of data provided is sufficient for analysis with respect to the degrees of freedom (df). There are three categories of (df): 'under-identified', 'just-identified' and 'over-identified'. The preferred (df) value is over-identified, which has a positive degree of freedom value;
3. Estimation – Establish the regression weight between the variables. A few estimation methods are available such as Maximum Likelihood, Generalized least squares and Neighed least squares. The most commonly employed estimation method is Maximum Likelihood which was used for the study;
4. Testing fit – Determine whether the model describes the sample data adequately. Examples of commonly used model fit criteria are *chi-s*quare, goodness-of-fit index (GFI), adjusted goodness-of-fit index (AGFI), and root-mean-square residual (RMR). In this study, the Goodness of Fit Index (GFI) was used. Interpretation of GFI value is easier where the closer the GFI value to one (1), the better the model describes the provided data;

5. Re-specification – Required when the model fails to adequately describe the data and the GFI value is near to zero. In this instance, the regression weight values and the relevant parameters need to be reassessed and re-identified. It may also constitute modification of the model. Analysis is performed again until a satisfactory GFI value is obtained. It is common to perform four to five analyses before the final selection of fabric properties, which yield a satisfactory GFI value, is attained.

Results and Analysis

Seam Appearance Analysis

The raw data for seam appearance sewn manually and automatically for all fabrics were collected and average values were calculated to enable ranking of the seam appearance based on thread and stitch density. This enabled the best sewing parameters to be identified and comparison of seam appearance between manually and automatically sewn seams to be performed. A seam evaluation of 5 indicates the best appearance with no pucker and an evaluation of 1 indicates a poor appearance with very severe pucker.

For threads 1 and 3, the seam appearance for automatically sewn seams have better evaluations than those sewn manually. Threads 1 and 3 have a ticket number of 120, which means that they are suitable to be used on light weight category fabrics. The speed of the automatic setting

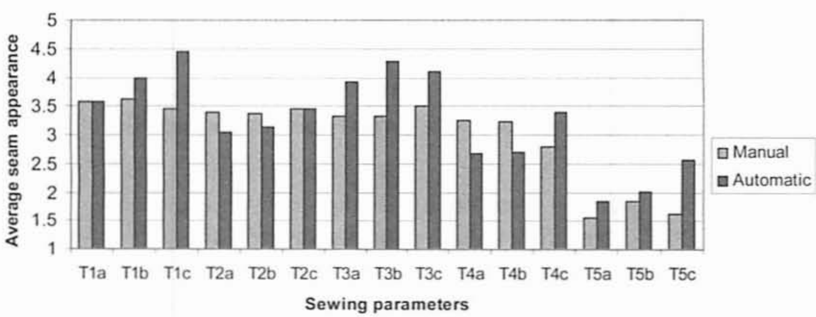

Figure 1: Seam Appearance Ranking

* T1 – T5 : Thread 1 - 5

* a = 5.5 spcm, b = 6.5 spcm, c = 7.5 spcm

does not have a significant impact on the quality of the seams. With the right combination of thread size and sewing speed, an increase in production with a good quality seam appearance is achievable. For example, thread 1 can be sewn automatically at 7.5 spcm, and still obtain a very good seam evaluation; an average of 4.5. This is also true for thread 3 sewn automatically at 6.5 spcm, which has an average evaluation between 4 and 4.5.

Threads 2 and 4 when sewn manually receive better average evaluations than when sewn automatically. Threads 2 and 4 are coarser with a ticket number of 75, which will influence the seam appearance. Manually sewing these threads enables greater control, especially in terms of speed during sewing, and results in better seam quality. It is possible that when sewing automatically the speed might be too fast and since this is a light weight fabric, the combination of too high a speed and too coarse a thread leads to severe seam puckering. Coarser thread can cause pucker due to structural jamming and occurs when yarns in the fabric are displaced from their original position during seam construction [15].

Even though thread 5 has the same ticket number as threads 2 and 4, sewing it automatically is better than doing so manually, since it is a Poly/Cotton core-spun thread, which breaks easily every time the sewing machine stops. This can be attributed to the different extension rates between polyester and cotton and thus leads to thread breakage. When sewn automatically the fabric is sewn throughout the length of the seam non-stop and produces a better seam than sewing it manually. However, overall thread 5 has the lowest seam appearance ranking. It has been reported that staple fibres such as the wrapper can slip from the core yarn, which is known as 'strip-back', and can lead to incomplete coverage of the core yarn [16]. When this occurs, there will be a lot of breakage during further processing due to increased friction between the thread and machine parts; in this case the thread and sewing needle.

Table 4: Pearson Correlation (r) of the Seam Appearance for Manually and Automatically Sewn Seams

Thread	T1	T2	T3	T4	T5
5.5 manual – 5.5 automatic	0.661	0.882	0.179	0.381	0.605
6.5 manual – 6.5 automatic	0.682	0.719	0.659	0.765	0.579
7.5 manual – 7.5 automatic	0.410	0.780	0.737	0.738	0.544

Pearson correlation gives regression (r) values that indicate that there is a relationship between the seam appearances for manually and automatically sewn seams. Thread 2 has a higher r value for all stitch densities, which means that manually or automatically sewn seams using thread 2 are of almost equal quality. Threads 3 and 4 sewn with high density of 6.5 and 7.5 spcm also yield significant results for both settings, but not at 5.5 spcm. Based on Figure 1, manual sewing at 5.5 spcm yields better quality seams for thread 4, but the converse is true for thread 3, which when sewn at a higher and constant speed yields better results. This is due to the ticket number; thread 3 is finer and hence the possibility of seam pucker is reduced even when sewn at much higher speeds. For threads 1 and 5, the r values for the manually and automatically sewn seams indicate only moderate differences in their perceived quality, but based upon the results presented in Figure 1 the automatically sewn seams are deemed to be better for both threads 1 and 5.

The best manual sewing parameter with respect to seam appearance is for thread 1 at 6.5 spcm and the worst sewing parameter is for thread 5 at 5.5 spcm. By comparison the best automatic sewing parameter with respect to seam appearance is thread 1 at 7.5 spcm and the worst seam appearance is for thread 5 at 5.5 spcm. Evidently 100 % spun polyester thread would appear to be the best selection in terms of reducing seam pucker.

Seam Strength Analysis

Seam strength data for all fabrics was collected and average values were calculated thus enabling ranking of the seam strengths. Further to this, correlation between the seam strength and the fabric tensile value for warp and weft were calculated to identify the effect of sewing in a selected direction.

Thread 2, which is 100 % spun polyester, sewn at 6.5 spcm has the highest seam strength ranking, followed by thread 4, which is a poly core-spun, sewn at 7.5 spcm. Both threads 2 and 4 have a ticket number of 75, which is coarser than threads 1 and 3. Thread 4 has the highest tensile strength, but when sewn, thread 2, which has the second highest tensile strength, gives better seam strength results. Thread 1 sewn at 5.5 and 7.5 spcm is ranked fifth and seventh whereas thread 3 at 6.5, 5.5 and 7.5 spcm is ranked tenth, thirteenth and fourteenth, respectively. Based on the thread tensile strength values, thread 3 has the greatest strength,

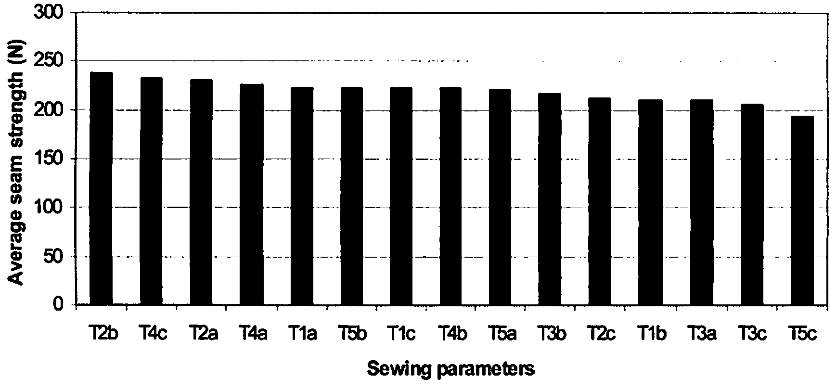

Figure 2: Seam Strength Ranking

but upon seam strength evaluation thread 1 yields the greatest strength. It can be summarized that thread structure plays an important role in determining the seam strength value. The 100 % spun polyester of thread 2 and 1 yields better seam strength compared to poly core-spun threads (threads 3 and 4) and that thread 5, a poly/cotton core-spun at 7.5 spcm has the lowest seam strength.

On average, fabrics sewn with stitch densities of 7.5 spcm, give the lowest seam strength values with respect to the results for threads 2, 3 and 5. Higher stitch densities produce more holes during sewing, due to the increased number of needle penetrations, and this reduces the strength performance of the seam. Fabrics sewn at 6.5 spcm for threads 2, 3 and 5 have the best seam strength values. This is a moderate stitch density and provides good grip between the yarns in the fabric and the thread without damaging the fabric.

Figure 3 indicates that there is a strong relationship ($R^2 = 0.702$) between the seam strength and the fabric tensile strength in the weft direction. The seams prepared for the strength and appearance evaluations were sewn in the warp direction. By sewing in the warp direction, stretch and shrinkage can be minimized [17], because the number of ends cm^{-1} is usually higher compared to the picks cm^{-1} and this factor contributes to the strength of the seam. In the apparel industry, fabrics are usually sewn in the warp direction due to motifs and designs and hence it is more appropriate to sew in a lengthwise direction.

The seam strength evaluation using the Instron tensile tester stretches seam fabrics in the weft direction [12]. Both ends of the fabric in the weft direction are clamped so that the seam in the warp direction is in the middle of the clamped area. The force is applied perpendicularly to the direction of the seam and hence the tensile strength in the weft direction has a more prominent effect on the seam strength compared to the tensile strength in the warp direction, Figure 4.

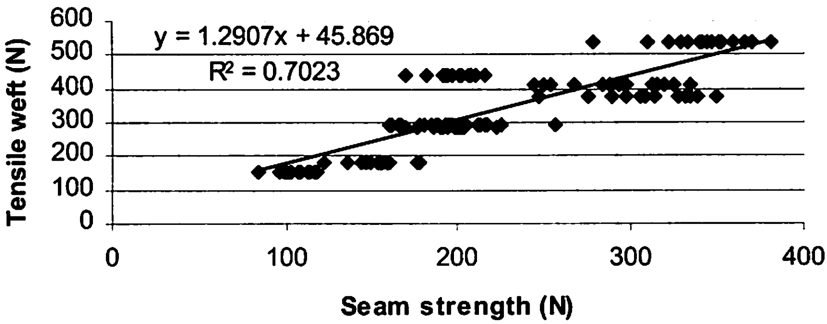

Figure 3: Relationship Between Seam Strength and Tensile in Weft Direction

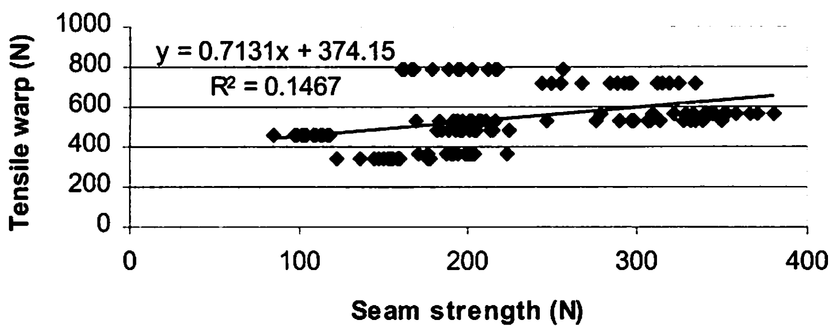

Figure 4: Relationship Between Seam Strength and Tensile in Warp Direction

Modelling Results and Analysis

Based on the experimental results, the best seam strength was for thread 2 at 6.5 spcm (T2b) and the best manually sewn seam appearance was for thread 1 at 5.5 spcm (T1bm) and the best automatically sewn appearance was for thread 1 at 7.5 spcm (T1ca). All 48 fabric mechanical properties were modelled with respect to the selected sewing parameters as shown in the following path diagram, Figure 5.

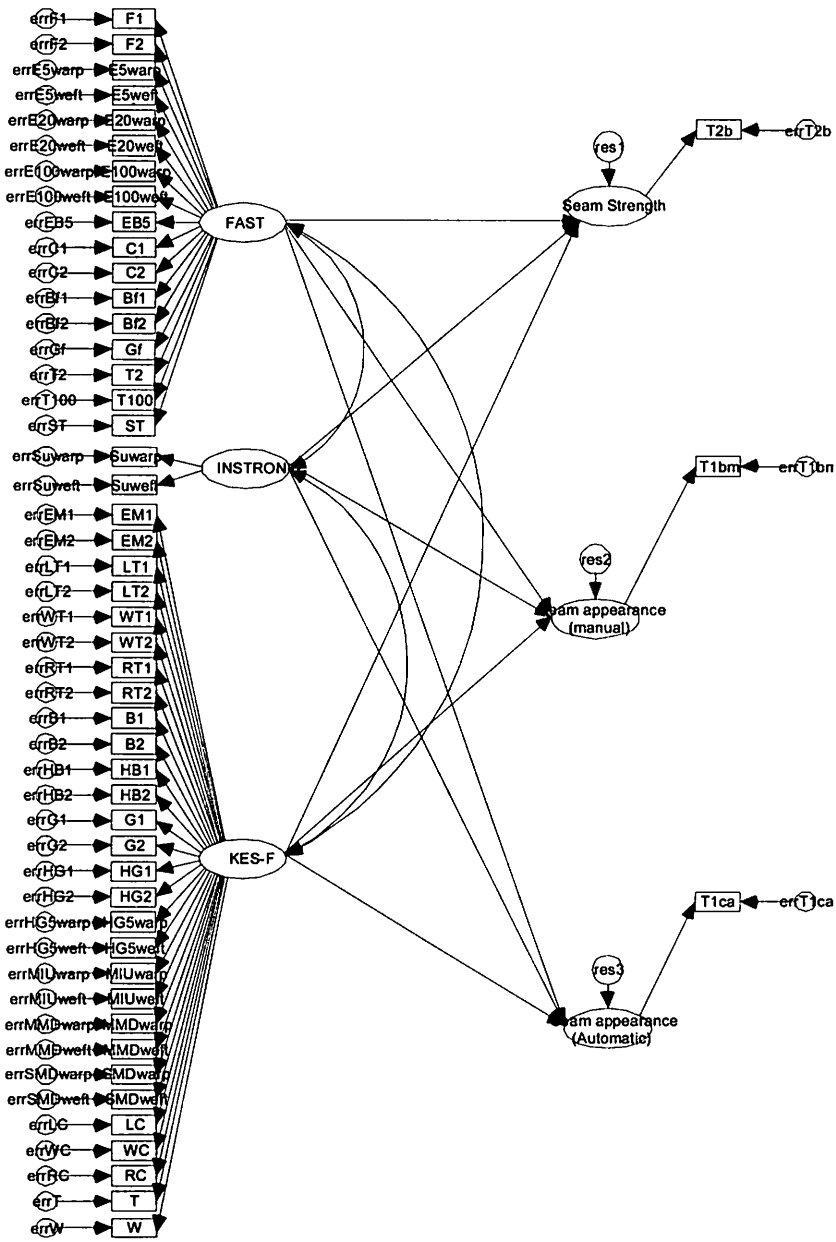

Figure 5: Confirmatory Factor Analysis (First Ranking)

The first SEM analysis performed using the above path diagram yielded a GFI value of 0.123, which is too low and indicates that there is only a very weak correlation between the fabric properties and the selected sewing parameters for seam appearance and strength evaluation. In order to improve the GFI value some fabric properties are eliminated with respect to standardized regression weights from the first analysis of the path diagram. Only fabric properties with a correlation greater than 0.9 with the seam evaluation values are selected. Table 6 presents the selected fabric properties, regression weights and GFI values for all the analyses performed until the best GFI value was achieved.

Table 6: Goodness of Fit Index (First Ranking)

Analysis	Fabric properties	Regression weight	Goodness of Fit Index
First	All 48 fabric properties	Values more than 0.9 were selected for second analysis	0.123
Second			
1	E100weft	0.970	
2	E20weft	1.019	
3	E5weft	0.948	
4	HG5weft	1.025	0.394
5	HG5warp	0.936	
6	HG2	0.930	
7	G2	0.908	
8	HB1	0.643	
Third			
1	E100weft	0.960	
2	E20weft	1.024	
3	E5weft	0.945	0.444
4	HG5weft	1.070	
5	HG5warp	0.736	
6	HG2	0.911	
Fourth			
1	E100weft	0.987	
2	E20weft	1.008	0.854
3	E5weft	0.977	
4	HG5weft	0.249	
Fifth			
1	E100weft	0.988	
2	E20weft	1.008	0.687
3	E5weft	0.978	

From the second analysis, eight fabric properties were selected and yielded a GFI value of 0.394. This was improved upon by eliminating two more fabric properties and the GFI value increased to 0.444. A major improvement was made during the fourth analysis whereby four fabric properties, which included all the extensibility value from FAST and also the HG5 weft from the KES-F, were correlated and yielded a GFI value of 0.854. This result indicates that these fabric properties considerably affect seam quality. Eliminating HG5 weft for the fifth analysis caused a decrease in GFI value to 0.687. This signifies that a better fit can be achieved with four fabric properties rather than three fabric properties. The fourth analysis is considered to best describe the correlation between fabric properties and the seam quality, Figure 6.

The previously presented analysis was based upon the parameters, which provided the best seam appearance and strength. Similar analysis

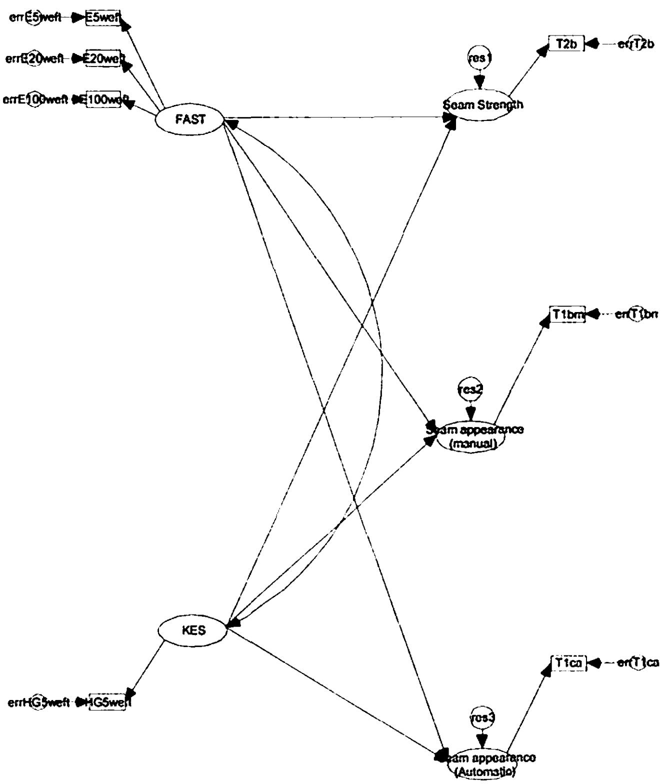

Figure 6: Final Confirmatory Factor Analysis (First ranking)

was performed on the parameters for the second best seam, which corresponds to sewing thread 4 at 7.5 spcm (T4c) for seam strength, sewing thread 1 at 5.5 spcm (T1am) for seam appearance (manual) and sewing thread 3 at 6.5 spcm (T3ba) for seam appearance (automatic). The results of the GFI analysis are presented in Table 7. For the second best seam only three fabric properties were identified, which were the

Table 7: Goodness of Fit Index (Second ranking)

Analysis	Fabric properties	Regression weight	Goodness of Fit Index
First	All 48 fabric properties	Values more than 0.9 were selected for second analysis	0.127
Second			
1	E100weft	0.992	
2	E20weft	1.004	
3	E5weft	0.985	
4	$S_u$weft	1.099	
5	HG5weft	1.002	0.392
6	HG5warp	0.995	
7	HG2	0.996	
8	G2	0.991	
9	HB1	0.981	
Third			
1	E100weft	0.994	
2	E20weft	1.003	
3	$S_u$weft	0.835	
4	HG5weft	1.046	0.462
5	HG5warp	0.886	
6	HG2	0.908	
7	G2	0.878	
Fourth			
1	E100weft	0.985	
2	E20weft	1.010	0.798
3	HG5weft	1.518	
4	HG2	0.632	
Fifth			
1	E100weft	0.980	
2	E20weft	1.016	0.876
3	HG5weft	0.288	
Sixth			
1	E100weft	0.988	
2	E20weft	1.007	0.770

same as those identified in the best seam analysis minus the extensibility at 5 gram.

In order to justify the selection of fabric properties for all the fabrics considered in this study, all seam quality values for all the seams were analysed one by one by in an identical manner to the first two best seams. From the SEM analysis it has been possible to identify the most important fabric properties that influence seam quality, Table 8.

Table 8: Selected Fabric Properties for All Seams

Ranking	Fabric properties	Goodness of Fit Index
1	E100weft	
	E20weft	0.854
	E5weft	
	HG5weft	
2	E100weft	
	E20weft	0.876
	HG5weft	
3	E100weft	
	E20weft	0.833
	E5weft	
	HG5weft	
4	E100weft	
	E20weft	0.796
	E5weft	
	HG2	
5	E100weft	
	E20weft	0.696
	E5weft	
	HG5weft	
6	E100weft	
	E20weft	
	E5weft	0.753
	Suweft	
	HG5weft	
7	E20weft	
	E5weft	0.826
	HG5weft	

(continued)

Table 8 (*continued*)

8	G2	0.748
9	E100weft	
	E20weft	
	E5weft	0.738
	Suweft	
	HG5weft	
10	E100weft	
	E20weft	0.873
	G2	
11	E100weft	
	E20weft	0.808
	HG5weft	
12	E100weft	
	E20weft	0.658
	E5weft	
	HG5weft	
13	E100weft	
	E20weft	0.756
	E5weft	
	HG2	
14	E100weft	
	E20weft	
	E5weft	0.731
	HG5weft	
15	E100weft	
	E20weft	
	E5weft	0.808
	HG5weft	

The extensibility properties, which determine the ability of the fabric to be stretched during apparel production [18], obtained from FAST (E100weft, E20weft and E5weft) have been identified in all cases as critical seam quality properties. Fabrics have high resistance to be moulded during sewing and extensibility values below 2 % for the warp and weft can cause seam pucker [19]. Extensibility values greater than 4 % for the warp and 6 % for the weft direction mean that the fabric stretches easily and the fabric needs special attention during laying, cutting and sewing.

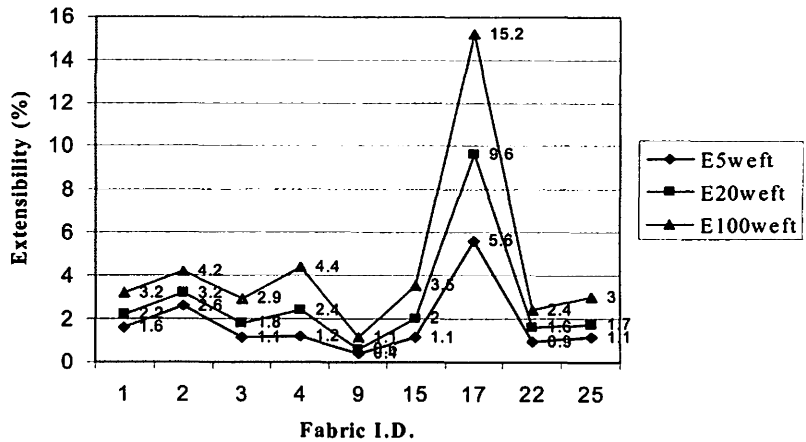

Figure 7: Weft Extensibility Values for FAST

From Figure 7, it can be seen that when extension is 5 gram (E5weft), the extensibility values are below 2 % for all fabrics except for Fabric I.D. 17 (5.6 %). The extensibility percentage increases as the weight increases to 20 and 100 gram. Fabrics I.D. 17 and I.D.9 have the highest and lowest extensibility percentages in all cases, respectively.

The other fabric property considered in this study was shear, which includes weft shear hysteresis (HG2 and HG5weft) and weft shear rigidity (G2) and the tensile strength in the weft direction (Suweft). It is recommended that fabrics have a shear hysteresis value in the range of 0.5-5.0 gf cm^{-1} [20]. If the value is below 0.5 gf cm^{-1} it will be difficult to press the fabric, since the fabric is easily distorted. If Suweft is greater than 5.0 gf cm^{-1} the fabric can damage the sewing needle and the cutting blade, since the fabric will be difficult to shape and mould during cutting and sewing [21]. From Figure 8, all fabrics have shear hysteresis (HG2) values below 0.5 gf cm^{-1}, except Fabrics I.D. 9 and 17.

The seam quality for the first, middle and last ranked seams from the experimental work have been analyzed in order to relate the fabric properties and sewing parameters to the seam quality,. From the extensibility and shear values, Fabric I.D. 9 and 17 give extreme results compared to other fabrics. From Table 9, most of the results for seam appearance and strength are according to the seam quality ranking, but Fabrics I.D. 9 and 17 the result of seam strength does not follow the ranking. Since the shear values for Fabrics I.D. 22 and 25 are higher than those for Fabrics I.D. 1, 2, 3, 4 and 15, the seam strength evaluation

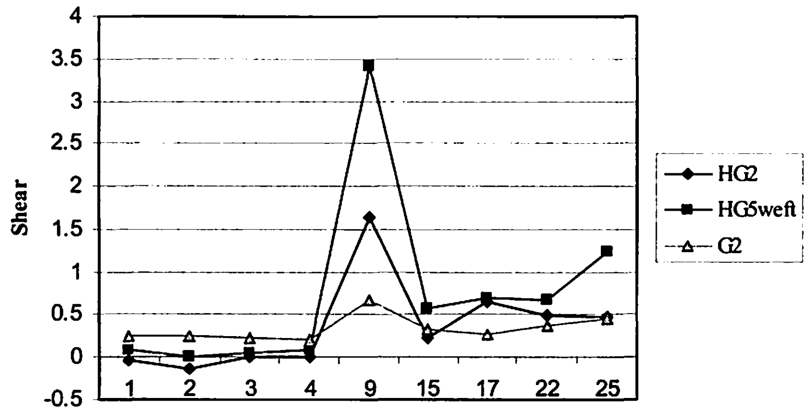

Figure 8: Weft Shear Values for FAST

contains some ranking variation. It can be summarized that these fabric properties influence the seam quality especially in terms of strength. Selected sewing parameters based on the ranking can be very useful in ensuring quality seams when the fabric has moderate extensibility and shear properties. If the fabric has extreme mechanical properties, extra care should be taken in selecting the sewing parameters to ensure better seam quality.

Table 9: Ranking of Seam Quality

Seam Quality	Seam appearance (Manual)			Seam appearance (Automatic)			Seam strength (N)		
Fabric I.D.	First T1b	Middle T3b	Last T5a	First T1c	Middle T4c	Last T5a	First T2b	Middle T4b	Last T5c
1	4	3.8	2.2	4.5	3.6	2.2	325.6	288.3	296
2	2.2	1.5	1	4	1.3	1	201.7	201	198.4
3	3.3	4	1	4.8	4.8	3	257.2	195.1	178.5
4	4.5	4.2	2.6	4.8	4.8	3.5	349.8	308.7	314.3
9	4	3	2.6	4	3.6	2.2	*329.3*	*358.9*	*351*
15	2.6	3	1.6	4	3	1.2	177.9	147.2	160
17	3.8	4	1	4.5	2.6	1.3	*96.81*	*112.9*	*113.6*
22	4.3	3.5	1	4.6	3.3	1	194.3	192.6	216.3
25	4	3	1	4.8	3.6	1.3	214.2	195.7	204.9

Conclusion

Two important objectives have been achieved through this study, firstly ranking of seam quality in terms of appearance and strength has been experimentally achieved. Through establishing this ranking, the best sewing parameters to produce good seam quality have been identified. The identified sewing parameters correspond to types of thread, stitch density and needle size. The second objective was to use Structural Equation Modelling to identify the most important fabric mechanical properties that influence seam quality for very light weight fabrics. Based on the SEM analysis it is apparent that extensibility and shear properties are the two most important properties in ensuring a quality seam as corroborated by previous works in this field [19, 22]. Through a modelling approach it has been possible to correlate sewing parameters and fabric mechanical properties thus enabling identification of the best combinations to achieve quality seams. It is recommended that future studies investigate the other sewing parameters and fabric end usage.

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