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Performance Analysis of the Mechanical Behaviour of Seams with Various Sewing Parameters for Cotton Canopy Fabrics

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Abstract
This study aims to develop a tool to predict the behaviour under a load of textile seams, to enable the selection of materials for specified end uses in the parachute industry. The strength of an assembly is directly dependent on the strengths of the various joints and seams required to make the structure. This study seeks to understand the performance of seams woven into cotton fabrics. A combination of five parameters has been studied here. Two properties, the seam strength and seam efficiency (% ratio of seam strength to fabric strength), are used as performance estimators. Both were found to vary significantly not only with the primary parameters but also with the interactions of primary parameters as well. That is, they change with each of the primary parameters but vary in a different manner when other parameters also change. Multiple regression has been used to construct preliminary predictor equations.

Key words: *parachute, canopy, lapped seams, fabrics, strength, efficiency.*

Introduction

Textile fabrics are anisotropic in nature, which influences the mechanical properties of un-seamed and seamed fabrics with s change in the specimen's test direction. Therefore the tensile properties of fabrics along various directions besides warp and weft are very important in many technical textiles like in parachutes, military garments, airbags etc., where the joining of parts is not only along the principle direction but also at a different bias angle [1-3].

The parachute canopy is a fabric construction whose purpose is to provide deceleration by means of air drag to a load hanging from it. The role of suspension lines and risers which connect the load to the canopy is to help balance the aerodynamic forces – provide a smooth descent for the load [4]. In the structure of a parachute, textile materials are the largest component. The parachute design is the joining of a number of panels and gores with stitches and seams [5, 6]. In this study, one of our purposes is to enlighten the parachute industry about the significance of how variations in textile materials affects their suitability for use in parachutes. As an extension we also wish to provide an objective method to estimate from basic properties a proper method for the selection of textile materials.

The wide variety of uses to which parachutes are now applied has stimulated the development of numerous new designs. For these new designs a number of fabrics have been especially developed and novel fabricating techniques have been employed. However, structural details of heavy load parachutes are still based on the stitched circular canopy. The practical significance of this is, in all but a few exceptional instances, that the strength and durability of the parachute is the prime consideration, and this, in turn, is directly dependent on the strength of the multitude of joints and seams of the structure. Thus seam efficiency in the final analysis ranks high among the governing considerations in the design calculations of most parachutes. The designer has a variety of choices to make among parameters like the strength of thread, the number of stitches per inch, the number of rows of stitches, the reinforcement, stitch type, seam type, etc. Without prior knowledge of these in various fabrics, a designer will have little chance of selecting an optimum combination for a given requirement.

Coplan and Bloch [7] studied the seam efficiency of lapped seam parachute fabric in orthogonal and 45° bias direction and concluded that the 45 bias angle gives highest seam efficiency.

Akt et al [8] studied the impact of the sewing thread and stitch type on the seam strength and efficiency of the superimposed seam for cotton apparel. This study has also covers the behaviour of seams with different stitches and threads in cotton fabrics.

Sular et al. [9] compared the seam performance of 12 woven fabrics in terms of the seam strength, seam efficiency, seam pucker and seam slippage properties of cotton and polyester woven fabrics.

Namiranianet et al. [10] studied the effect of fabric extensibility and stitch density on the seam slippage and strength behaviour of elastic woven fabrics. They reveal that an increase in stitch density results in a higher seam slippage load and strength value.

Barbulov et al. [11] studied the influence of the stitch density and type of sewing thread on the seam strength. They defined the optimal value of seam strength that maximises the compliance to sewed seam parameters.

Maaroul [12] studied the effect of seam efficiency and puckering on denim sewability and found that the higher the seam pucker, the less the sewability is.

Mukhopadhay et al. [13, 14] studied the influence of the bias angle of stitching on the tensile characteristics of lapped seam parachute canopy fabric and postulated an optimised dimension of test specimens for evaluation of the tensile characteristics of parallel/opposite stitched specimens. This can be used for comparative analysis of the breaking strength and elongation of un-seamed and seamed fabric at different bias angles.

The objective of this study was to determine the effect of sewing parameters on the seam strength and seam performance for cotton canopy fabrics.

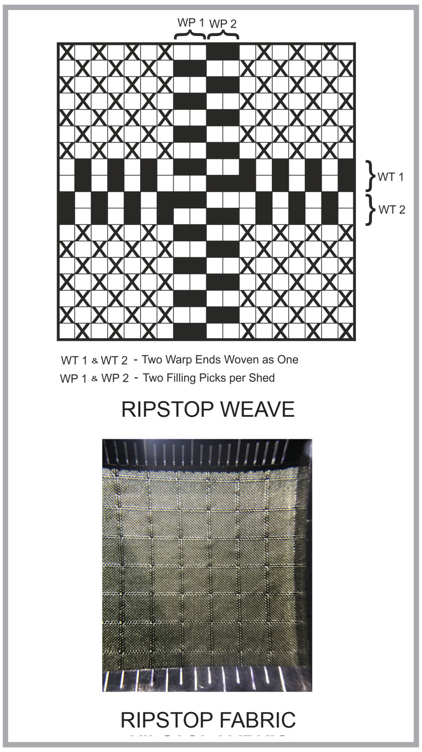

Figure 1. *Ripstop weave.*

Materials and methods

Sample preparation

A number of cotton woven fabrics with plain, twill (2/1) and rip-stop weave (***Figure 1***) were used for this study. Details of the fabrics and sewing threads used are given in ***Tables 1*** and ***2***.

Structure of the model

Five factors were studied: the types of weaves, the direction of the seam, stitch types, a lapped seam with 2 rows and 4 rows of stitches, and the stitch density. Details of each parameter are given in ***Table 3***.

Experimental methods

Fabric tensile strength

A 'Universal Tensile Machine' (Instron R-3369, USA) was used for fabric tensile testing. The tensile properties of fabrics were tested according to the ASTM D5034 standard (grab test). The rate of extension is 300 mm/min, and five specimens for each fabric in the warp, weft and bias (45°) directions were tested. Tests in the bias direction were carried out to check the isotropy of the material – an important consideration in the case of multi-axis loading. Tests were carried out on the samples after conditioning for 24 hours at standard temperature and R.H.

Seam strength testing

ASTM D5034 (grab test) was employed as the test mode for the seam strength. ***Figure 2*** shows the experimental setup of the specimen. Five test specimens were tested and two factors measured, the seam strength and seam efficiency (in the warp, weft and bias directions) for the various permutation of the model. As in strength testing, the samples were conditioned for 24 hours.

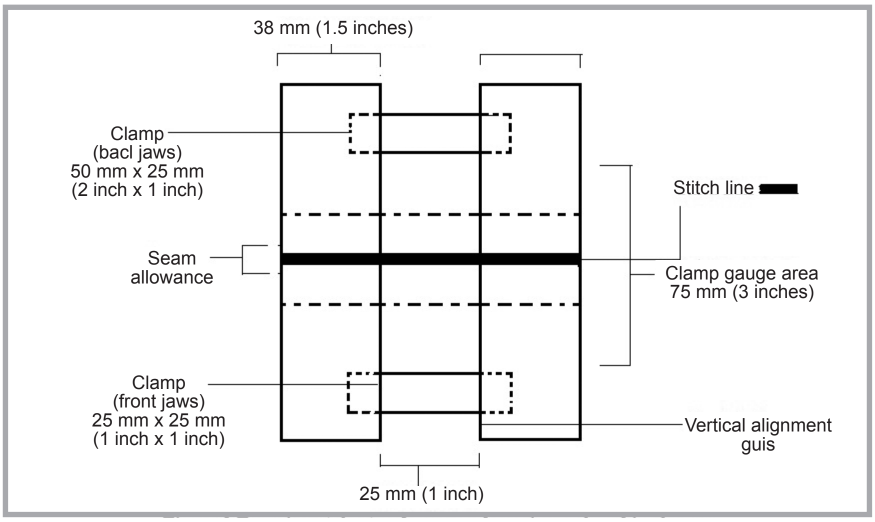

Figure 2. *Experimental setup for seamed specimen placed in clamps.*

Table 1. *Material details.*

S1. No.	Test parameters	Plain weave		Rip-stop weave		Twill weave (2/1)	
		Warp	Weft	Warp	Weft	Warp	Weft
1	Yarn linear density, tex	66	66	49	66	59	74
2	Ends per cm	24		28		24	
3	Picks per cm	22		26		22	
4	Fabric weight, GSM	327		334		329	
5	Thickness, mm	0.52		0.50		0.52	
6	Cloth cover factor	25.23		26.23		25.24	

Table 2. *Properties of sewing thread used.*

S. No	Sewing thread	Linear density, dtex	Ticket number	Breaking strength, cN/dtex	Extension, %
1	Cotton	800	38	2.6	21

Rows of stitches

Among the variety of seams, lapped ones, shown in ***Figure 3***, are considered the best for joining the panels and gores of parachute canopies [15]. Seam types LSc 2 and LSc 4 were studied here.

Estimation of damage (theoretical) to the fabric from sewing

Fabric damage at the seam was estimated using the yarn liner density of both the warp and weft and the construction parameters. The damage was calculated using an assumption that the yarns are arranged parallel to each other and evenly spread as a yarn sheet with no yarns overlapping. The other parameters considered were the needle blade diameter (0.14 mm), the rows of stitches (2 and 4) and stitch density [16].

Results and discussion

ANOVA was used on the results of the fabric seam strength and efficiency tests. The method of multiple regression was used to create predictor equations for both properties. These are given below.

Fabric tensile strength

Figure 4 shows values of the fabric breaking strength and elongation in the warp, bias and weft directions of the three weaves. It is clear that the effect of weave and the direction of testing significantly influenced the breaking strength. It is clear that there is an increase in strength and elongation in the weft direction compared to the warp and bias in plain and rip-stop weaves. However, in twill weave a different trend was observed, where the maximum tensile strength is in the bias direction, followed by the weft, and the least in the warp direction.

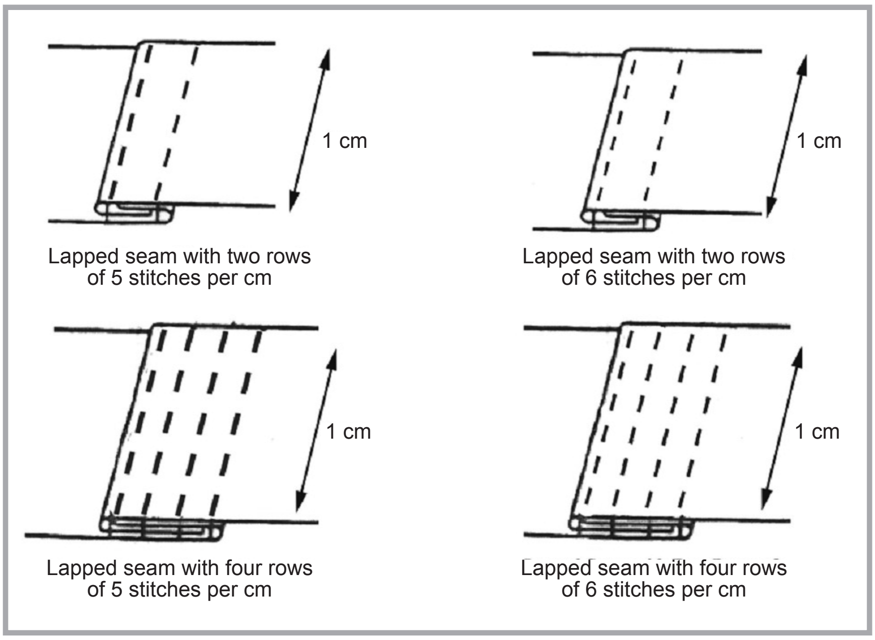

Figure 3. *Lapped seam with 2 and 4 rows of stitches.*

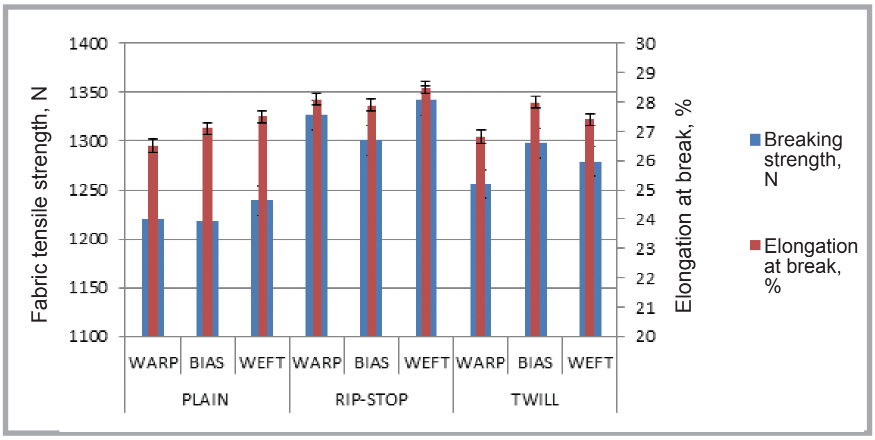

Figure 4. *Effect of weave type on fabric tensile strength and elongation.*

Fabric seam strength

Figure 5 shows values of the seam strength. In all three fabrics, the material is strongest when the seam is perpendicular to the warp direction, and weakest when the seam is perpendicular to the weft direction, with the bias samples having values in-between. This implies that the seam fails via fabric rupture rather than by sewing thread failure.

Fabric seam efficiency

Figure 6 shows values of seam efficiency. The chain stitch provides the highest efficiency due to the fact that stitches are more elastic because the percentage of sewing thread accommodated per stitch is higher when compared to the other two stitches, with the zig-zag being the second and lock stitch the lowest for all three fabrics.

Predictor equations for seam strength and seam efficiency

Based on the ANOVA results an empirical equation to estimate the seam strength and seam efficiency was calculated using the multiple regression method. ***Table 4*** shows coefficients of the regression equation which are obtained for the seam strength and seam efficiency from different variables. The correlation of seam efficiency with respect to the direction therefore shows quite an opposite trend to that for the seam strength.

The coefficient for the cut angle is positive, indicting that the efficiency of stitching perpendicular to the wefts is greater than stitching perpendicular to the bias direction, which, in turn, is more efficient.

A scatter graph of the seam strength and seam efficiency measured and calculated is shown in ***Figure 7***. A linear trend line was fitted to the points, which has a slope of about 45°. Then a 2nd order polynomial trend curve was also fitted to the points. The curve coming from a second order polynomial fit to the scatter data is included to show that it does not vary significantly from the linear equation. The variation in the polynomial from the linear trend line is sufficiently small to allow us to conclude that the linear model is accurate enough as a predictor and that in the case of seam efficiency the polynomial deviation was slight and judged to be not significantly better at describing the variation; hence the linear equation has been retained.

Estimation of theoretical damage due to needle blade

Attempts were made to calculate the seam efficiency and strength using the cover factors of the fabrics measured and the calculated estimate of the damage done to the fabric by the sewing machine

Table 3. *Experimental parameters.*

Raw materials	Weave	Direction	Stitch type	Seam type	Stitch, cm
Cotton	Plain	Warp	Lock, chain and zig-zag	Lapped seam with 2 rows (LSc 2) of stitches and with 4 rows of stitches (LSc 4)	5:1 Stitches/cm 6:1 Stitches/cm
		Bias (45°)			
		Weft			
	Rip-stop	Warp			
		Bias (45°)			
		Weft			
	Twill (2/1)	Warp			
		Bias (45°)			
		Weft			

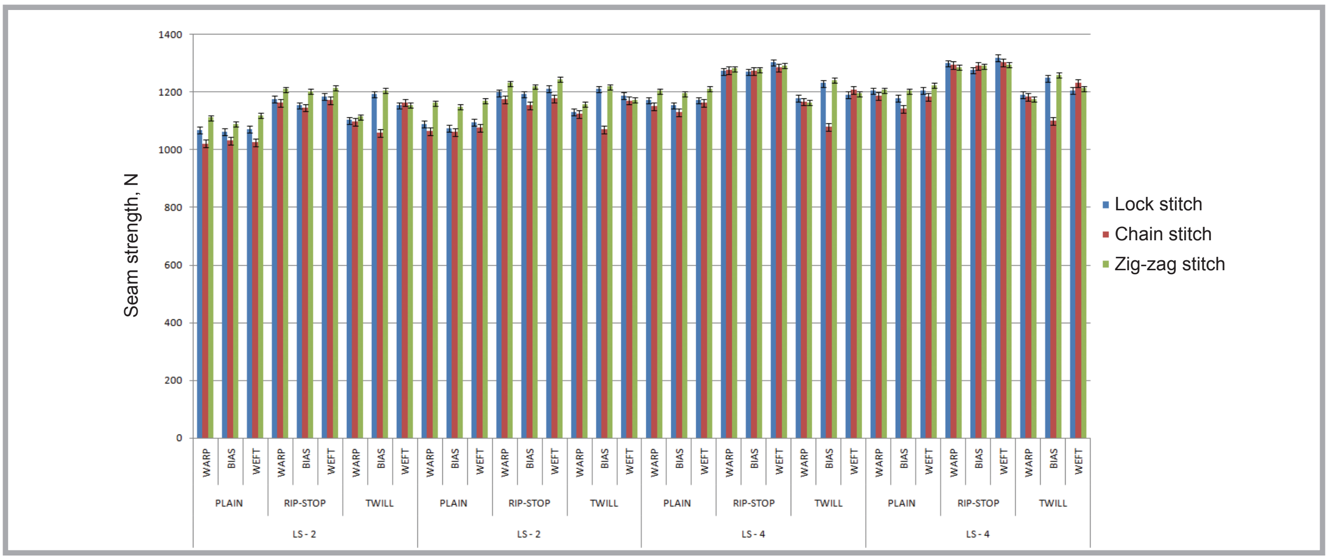

***Figure 5.** Effect of stitch type, number of rows, weave type, seam directions and sttich density on seam strength.*

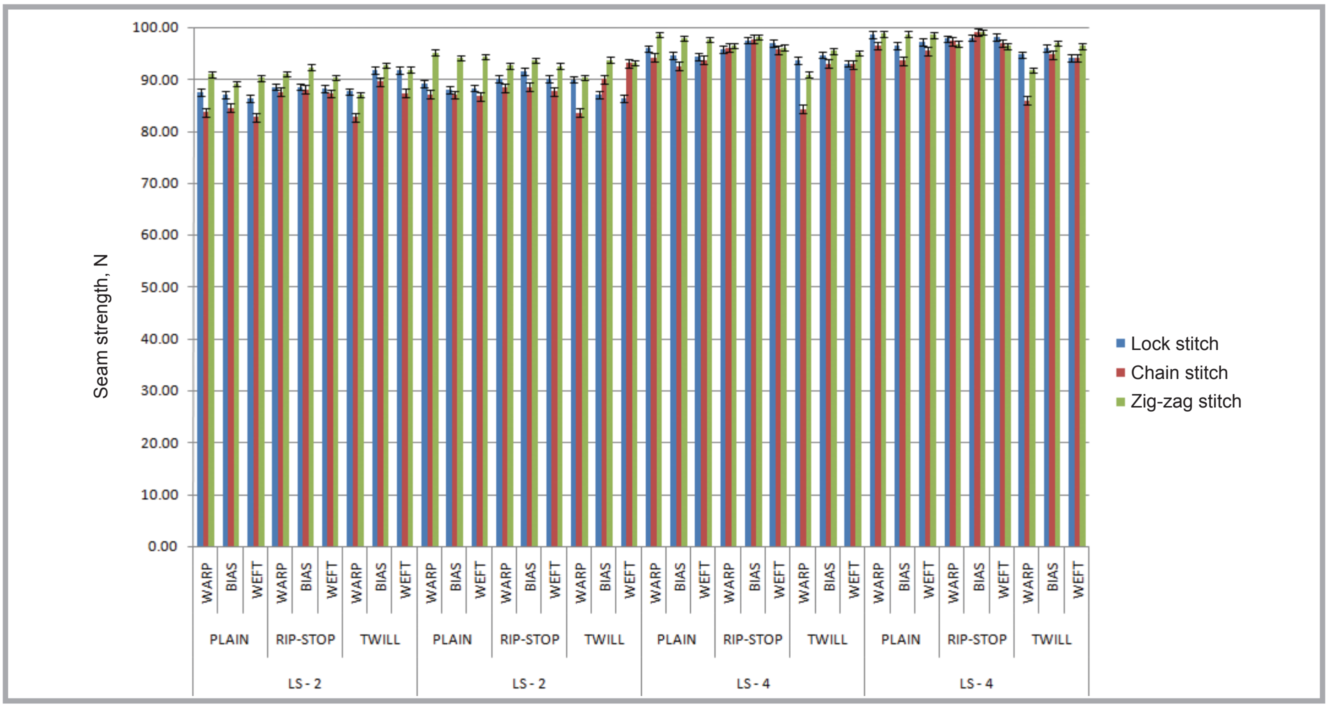

***Figure 6.** Effect of stitch type, number of rows, weave type, seam directions and stitch density on seam efficiency.*

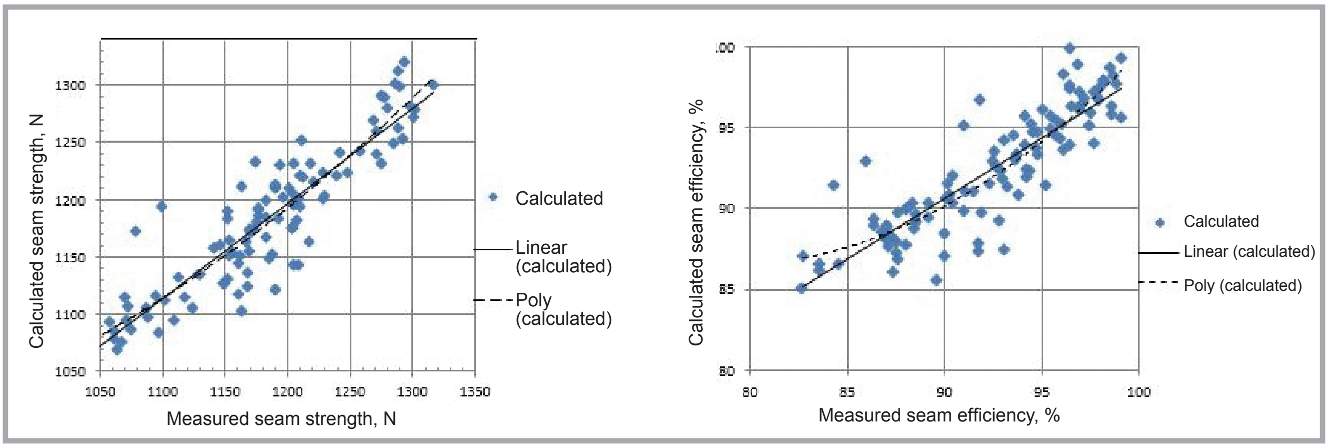

***Figure 7.** Scatter graph between calculated and measured seam strength and seam efficiency.*

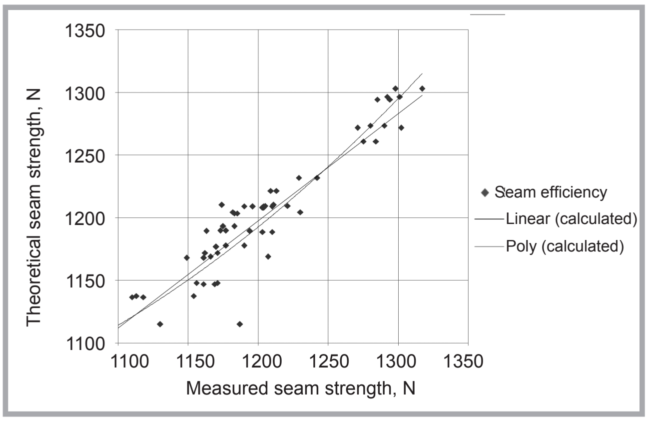

Figure 8. Scatter graph between theoretical and measured seam strength for plain, rip-stop and twill weaves.

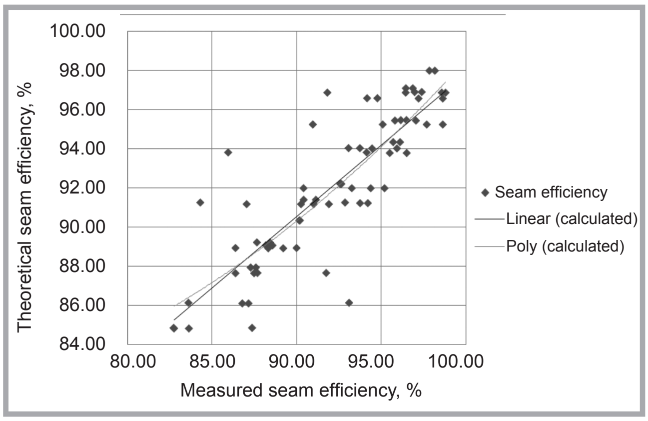

Figure 9. Scatter graph between theoretical and measured seam efficiency for plain, rip-stop and twill weaves.

needles (***Table 5***). The calculations yield equations with a high degree of correlation, though different for different fabrics. The multiple correlation is higher for the seam strength than for seam efficiency, which is because the seam efficiency has a component – the breaking strength of the actual fabric. This is correlated to the cover factor but not to the theoretical damage predictions. Therefore the poor prediction of fabric strength lowers the estimate of seam efficiency.

Each of the fabrics gives a different equation for the seam strength and seam efficiency. However, the general structure of each set of three fabrics is similar, with only the actual coefficient varying. The accuracy calculated is highest for the plain weave, followed by the rip-stop, and is lowest for the twill weave. This is due to the way in which the individual yarn threads break and slip to generate the seam break. ***Table 6*** shows the values used to construct simple regression equations to predict the seam strength and seam efficiency using theoretical damage and the cover factor.

Tables 5 and ***6*** above and the graphs below (***Figures 8*** and ***9***) give strength to the idea that differences between the patterns of variation in cotton are due to the differing styles of seam failure. The tables and graphs above provide strong support to the idea that an increase in stitch density and rows of stitches eventually reaches a point where an increase in these two parameters actually begins to weaken the seams produced. The shape of the scatter and the small variation between the linear and second order polynomial lines of best fit between the computed and actual data is support for the adequacy of the predictor equations.

Table 4. *Coefficient of the regression equation for seam strength and seam efficiency.* ***Note:*** *a_1 = -20.36 for rows of stitches, dimensionless; a_2 = -48.74 for stitch density, stitches per cm; a_2 = -36.74 for cut angle, radians; SS = Seam Strength, Newton; SE = Seam Efficiency, %.* ***Empirical equations for:*** *SS = $\text{Constant}_{(1-9)}$ – 20.36 a_1 – 48.74 a_2 – 36.74 a_3; SE = $\text{Constant}_{(1-9)}$ – 2.06 a_1 – 6.02 a_2 + 1.28 a_3*

Weave	Stitch	Predictor equations for seam strength, N and seam efficiency, %
Plain	Lock	SS = 1034.58 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 74.25 – 2.06a_1 – 6.02a_2 + 1.2a_3
Plain	Chain	SS = 1005.93 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 79.91 – 2.06a_1 – 6.02a_2 + 1.2a_3
Plain	Zig-Zag	SS = 996.36 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 77.30 – 2.06a_1 – 6.02a_2 + 1.2a_3
Rip-Stop	Lock	SS = 1024.75 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 72.76 – 2.06a_1 – 6.02a_2 + 1.2a_3
Rip-Stop	Chain	SS = 996.07 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 78.42 – 2.06a_1 – 6.02a_2 + 1.2a_3
Rip-Stop	Zig-Zag	SS = 956.50 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 75.81 – 2.06a_1 – 6.02a_2 + 1.2a_3
Twill	Lock	SS = 1012.78 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 72.15 – 2.06a_1 – 6.02a_2 + 1.2a_3
Twill	Chain	SS = 984.13 – 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 77.81 – 2.06a_1 – 6.02a_2 + 1.2a_3
Twill	Zig-Zag	SS = 944.56- 20.36a_1 – 48.74a_2 – 36.74a_3
		SE = 75.20 – 2.06a_1 – 6.02a_2 + 1.2a_3

Table 5. *Theoretical seam damage due to needle blade.*

Weave types		Theoretical damage, %			
		2 rows of stitches		4 rows of stitches	
		Stitches per cm		Stitches per cm	
		5	6	5	6
Plain, rip-stop and twill	Warp	14	16.8	28	33.6
	Weft	14	16.8	28	33.6

Table 6. *Simple equation to predict the seam strength and seam efficiency using theoretical damage and the cover factor.* ***Note:*** *d_1 = damage calculated, %; c_1 = cloth cover factor; SS = seam strength, Newton; SE = seam efficiency, %.*

Weave	Simple equations for seam strength, N and seam efficiency, %	Coefficient of multiple correlation	Coefficient of determinant	Standard error
Plain	SS = 5.60d_1 + 94.90c_1 – 1374.61	0.94	0.88	24.75
	SE = 0.46d_1 + 1.42c_1 + 45.37	0.93	0.87	1.49
Rip-stop	SS = 6.35d_1 + 92.88c_1 – 1353.28	0.90	0.81	34.43
	SE = 0.46d_1 + 3.12c_1 – 0.27	0.79	0.63	3.16
Twill	SS = 3.71d_1 + 84.80c_1 – 1054.65	0.95	0.90	17.58
	SE = 0.29d_1 + 0.222c_1 + 81.46	0.74	0.54	2.24

Summary

The following points can be made from the experimental data and their analysis:

- The ANOVA for seam strength and for seem efficiency clearly show that the parameters selected for the study are extremely significant.
- The fractions of the dependent variable variation explained by the independent variables chosen are very high (better than 0.7 in all cases and better than 0.9 for several)
- In all fabrics, the plain one seems to give the strongest seam with rip-stop in the middle, with the twill being the weakest. Lock stitch provides the strongest seam type, followed by the chain stitch, with zig-zag being the weakest seam.
- In considering seam efficiency, the plain fabric is the most efficient, with rip-stop in the middle, and twill fabrics the least efficient. This is in the same order as the seam strength, therefore this pattern is likely to arise from the basic nature of the fabrics. Of the stitch types, the chain stitch provides the highest efficiency, then zig-zag, and lock stitch is the least efficient.
- The seam strength and efficiency show a decrease with the number of rows of stitches and an increase in stitch density. This can be explained in terms of damage to the yarn sheets by the stitching needles, and a simple model to test this idea provides some evidence for the hypothesis.

Conclusions

In conclusion, it would seem that the behaviour of canopy seams under a load can be ‘engineered’ over a wide range by suitable selection of values of various parameters going into the construction of the seam. The regression equations give reference values which can be used as a fundamental guideline in understanding the load bearing capabilities of parachutes made of seamed cotton fabrics.

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