Indian Journal of Fibre & Textile Research
Vol 46, September 2021, pp. 251-259

Influence of seam structural parameters on seam strength under unidirectional and multi-directional load exertions

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Received 2 February 2020; revised received and accepted 17 February 2021

In the present study, seam failure mechanism has been investigated as a result of fabric exposure to unidirectional and multi-directional loads, considering the seam structural parameters, such as stitch type and length. To this end, three common groups of fabrics, namely worsted, shirting and dress woven, have been examined and the effect of seam properties and its interaction with fabric type is analysed through the measurement of seam's unidirectional and multi-directional strengths and the seam efficiency. The results show that stitch type and length have a significant effect on the tensile properties of seams. Suitable selection of stitching parameters can enhance the seam performance at unidirectional and multi-directional loadings and improvement of the seam efficiency.

Keywords: Bursting strength, Stitch type, Stitch density, Seam efficiency, Tensile strength

1 Introduction

During wearing garments and performing physical activities, the seams in various parts of the garment are subjected to multi-axial loads. In order to maintain the appearance and also the efficiency of the clothing, seams are required to have sufficient tolerance against the applied loads. Since investigation of the seam strength in a particular direction cannot present the seam performance when exposed to concurrent multi-directional loads, it is necessary to study the seam strength through the evaluation of their bursting behavior. In this regard, some previous research works have focused on the tensile of various kinds of seams.

Gurarda[1] analyzed the effect of fabric structure and sewing yarn properties, through the measurement of seam strength and seam slippage to identify the suitable sewing conditions and acceptable seam performance. It was revealed that by increasing the sewing yarn count, seam strength and seam efficiency are improved. Moreover, the use of elastic yarns enhances the seam performance due to their flexibility. The seam quality is also affected by the fabric structural parameters, such as weave structure and yarn density[1]. Sundaresan *et al*.[2] investigated the influence of sewing yarn structural parameters on the seam strength and quality. It was concluded that the sewing yarn strength and abrasion resistance are affected by the fibre length and fineness, the numbers of single plies in the consequent yarn and also the amount of yarn twist[2]. Mukhopadhyay *et al*.[3] analyzed the effect of laundry on the tensile performance of seams consisted of three different 3-plied sewing yarns. Analysis of the results revealed that an increase in the stitch density and sewing yarn linear density leads to a rise in the seam strength. Moreover, the tensile modulus, seam strain, seam strength and seam efficiency were reduced due to laundering[3]. Al Sarhan[4], showed that for various tested stitch types in the evaluation of the seam performance for joining micro-polyester woven fabrics, the stitch density in the seam area and the weft density of the fabric have a prominent role in determining the seam strength[4]. Sular *et al.*[5] studied sewing performance of cotton and polyester fabrics sewn with core-spun polyester and mercerized cotton yarns through the measurement of seam strength and strain, seam efficiency and also the seam slippage. The best sewing performance was obtained for high-density fabrics sewn with core-spun polyester yarns[5]. In a study carried out by Tsui *et al*.[6], the type of seam failure was divided into two groups, failure due to the yarn and failure due to the fabric breakage. It was also concluded that the load exertion direction can effectively influence the seam strength[6]. Amirbayat[7] investigated the effect of cutting direction and the angular positions of the two fabrics, which are sewn together. It was revealed that the highest seam

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strength is obtained during the joining of fabrics with similar angular location[7]. Crow and Dewar [8] conducted a thorough investigation on the stresses in clothing, considering the seam strength. The resultant stress in the clothing is a consequent of the garment size, the individual muscle volume and the intensity of the body physical activities. The maximum stress was recorded for the tight clothing. It was also recommended to consider 57- 66% seam efficiency for the light weight fabrics and 52- 54% seam efficiency for the heavy fabrics[8]. Kovalova *et al.*[9] analyzed that the behavior of the sewing seam is subjected to the multi-axial stress. During the load exertion, the seam was observed using high speed camera and theoretical calculation of the stress was carried out by using Finite Element Method. Based on the measurements of the strength of the material in different directions and also the threads load bearing in the form of loop, the whole assembly was gathered to make a numerical model[9].

As it was mentioned, it is important to measure and analyze the tensile behavior of various types of stitches with different densities, which are applied for joining fabrics with diverse end uses. It should be noted that not only seam and fabric characteristics, but also their response to the amount and condition of the tensile load application define the seam strength and consequently its efficiency.

Hence, in this investigation, the effect of sewing parameters on the seam strength under the both unidirectional and multi-directional load exertion has been studied. Bursting test has been utilized as a method of multi-directional load exertion. Moreover, the seam efficiency is compared with the tensile seam efficiency during the application of the bursting force.

2 Materials and Methods

2.1 Materials

Since during wear, garment’s seams encounter both single and multi-directional loads, its resistance against load in various directions determines the garment’s durability. In order to investigate the influence of stitch geometry and density on the seam strength, two common stitch types in clothing manufacturing process were considered which are lockstitch and double chain stitch. Furthermore, based on the possibility to set stitch length on the sewing machine, stitch lengths of 2, 3 and 4 mm for lock stitch and 2.5 and 4 mm for double chain stitch were utilized. Three woven fabrics with different applications for clothing were selected to prepare the samples. Specifications of the selected fabrics are shown in Table 1.

The Durkopp Adler 272 and Juki MF-7700 sewing machines were employed to prepare lockstitch and double chain stitch respectively. A 100% polyester spun sewing thread with a count of 40/2 Nm was utilized to prepare the test samples.

2.2 Sample Preparation

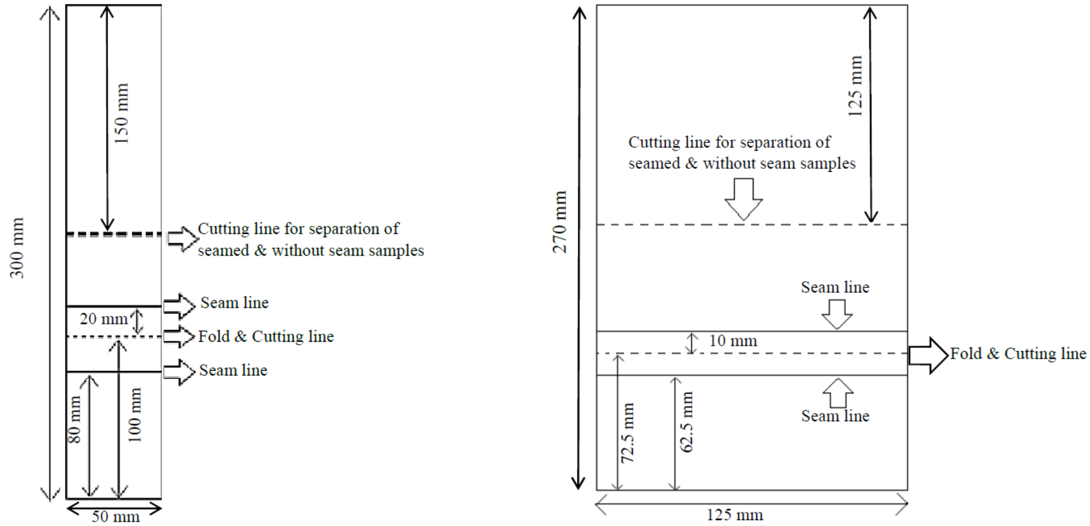
To assess the effect of stitch type and density on the seam failure under unidirectional loading, fabric strips were cut in both warp and weft directions with a dimension of 300×50 mm^2. Then the fabric strips were folded 100 mm from one end and a seam is made with a distance of 20 mm to the folded edge. Then the fold edge is cut away to leave 20mm seam allowance. Before the test, the samples were cut into two parts; one with the seam and the other without the seam. In each condition, five specimens were prepared. The same method was applied to prepare the samples for bursting test but with different dimensions according to the testing clamp size. For the bursting test, fabric strips were cut in both warp and weft directions with a dimension of 270×125 mm^2. Then the fabric strips were folded 72.5 mm from one end and a seam is made with a distance of 10 mm to the folded edge. Then the fold edge is cut away to leave 10mm seam allowance. Before the test, the samples were cut into two parts, viz one with the seam and another one without the seam. The sample size and preparation diagram for both tensile and bursting tests are shown in Fig. 1.

2.3 Test Procedure

In order to examine the seam strength under one-directional loading, a constant rate extension tensile testing machine Kardotech was used. The test procedure was performed based on the ASTM D1683 test method with a gauge length of 75mm and the elongation speed of 100mm/min. The specimen should be positioned in the clamps in a way that the seam line is placed in the center of the gauge length with the similar distances to both clamps. On the

Table 1 — Fabric characteristics

Fabric code	Weave pattern	Fabric type	Weight, g/m^2	Warp density, cm^{-1}	Weft density, cm^{-1}	Thickness, mm
A	Plain	Worsted	232.65	14	9	0.747
B	Plain	Shirting	76.78	57	36	0.133
C	Twill 3/1	Dress	207.17	52	36	0.399



(a) (b)

Fig. 1 — Sample preparation diagram (a) tensile test and (b) bursting test

purpose of studying the seam strength under multi-directional loading, the bursting strength of the seams was studied. Special clamp for ball bursting test was assembled on the Kardotek tensile testing machine. Since there is no distinct standard test method for measuring the seam bursting behavior, ASTM D6797 standard test method for bursting strength of fabric (CRE ball burst test) was applied. The diameter of the ball that exerts pressure on the seam was 20mm. The sample should be placed in the clamp in a way that the seam is positioned in the center of the clamp and the ball contacts with the seam line. The same test speed of 100mm/min was utilized for assessing the seam bursting. The bursting strength of the fabric was measured both for sewn and unsewn samples.

3 Results and Discussion

3.1 Comparison of Fabric Strength with Seam and without Seam

Regardless of the stitch type and length, firstly the influence of seam existence on the fabric strength has been considered. From the force-extension graphs (Fig. 2) of the worsted fabric in the warp direction, in both sewn and unsewn states, it can be observed that sewing the fabric leads to the reduction in fabric strength considerably. In other words, in an unsewn fabric, all the threads resist against the tensile load along their axis simultaneously. However, cutting fabric and then sewing two parts to each other, destroys the yarn's integrity against the tensile load, and the load will be exerted on the seam line. In the seam line, tensile force was exerted on the sewing thread in each stitch, perpendicular to the seam direction. Since the tensile load is endured by the limited number of stitch, the seam strength is lower noticeably than the fabric strip.

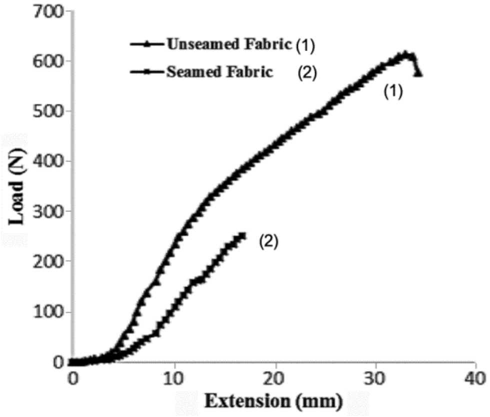


Fig. 2 — Comparing fabric strength with seam and without seam

3.2 Assessment of Seam Strength considering the Fabric Type and Stitch Properties

Since seam is consisted of at least sewing two fabric strips, the strip direction and fabric type may affect the seam strength. In Figs 3 and 4, breaking load of various fabrics in both warp and weft directions are compared in various sewing conditions.

According to Figs 3 and 4, it can be observed that for all samples, the seam strength in weft direction is higher than in warp direction. In fact, seam in warp and weft directions is referring to the condition that seam is formed in the related direction and load is applied perpendicular to the seam line. Since the warp density is higher than the weft density, in seams that are in the weft direction, higher numbers of threads

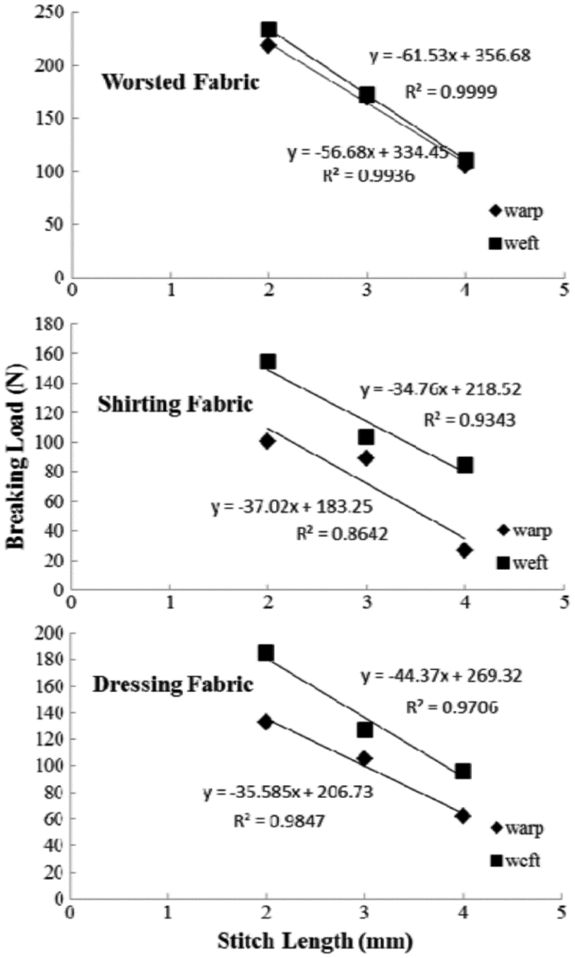


Fig. 3 — Effect of stitch length for seam strength of lock stitch

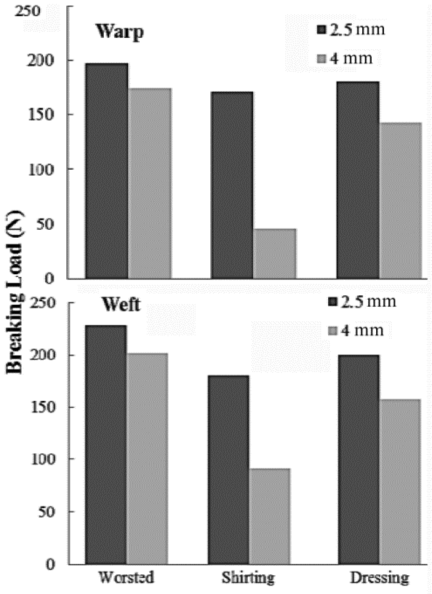


Fig. 4 — Effect of stitch length for seam strength of double chain stitch

exist in each stitch, which lead to the higher friction forces between sewing thread and warp yarns. This phenomenon postpones the seam failure and thus the higher seam strength is obtained.

The comparison of the fabric type reveals that worsted and shirting fabrics have the highest and lowest seam strengths respectively. This outcome may be due to the difference in fabric weight and thickness. In the same sewing condition, heavy and thick fabrics present more resistance against the tensile load.

Stitch type that determines the sewing thread interlacement can influence the seam strength as well. Lockstitch and double chain stitch as common stitch types, which are utilized in sewing fabric piece in a garment, are considered in this investigation. According to the results in both fabric directions and all fabric specimens, double chain stitch seams to have higher strength than lockstitch. These results could be related to the both stitch structures.

These results could be related to the both stitch structures. In double chain stitch, in each needle penetration point, needle thread is interlaced with the two consecutive looper threads; however, lockstitch interlaced with one spool thread. In addition, in double chain stitch, looper thread forms a loop shape, but in lockstitch both sewing threads are placed on the fabric straight. Regarding these two points, under the tensile load, double chain stitch resists against the exerted load due to the elongation of the loops and more interlacement between threads, consequently it has higher seam strength.

Stitch length is another critical factor that affects the seam strength. The impact of stitch length variation on the seam strength is also presented in Figs 3 and 4. It is observed that the increase in the stitch length leads to the seam strength reduction in both stitch types.

It should be noted that stitch length is the distance of two successive needle penetration points. In each point, irrespective of the stitch type, both sewing threads interlaced with each other and fabric. Hence, increase in the stitch length is followed by lower number of sewing thread and fabric interlacements.

In the seam line, the employed tensile load is tolerated by sewing threads and fabric interlaced points, as shown by following equation:

$$F_i = \frac{F}{\frac{100}{l} + 1} \quad \dots (1)$$

where F_i is the load exerted on each needle penetration point; F, the tensile load applied on the seam; and l, the stitch length.

Consequently, stitch length decrement results in the reduction of applied load on each stitch and delays the seam failure.

3.3 Tensile Seam Strength Estimation

Based on the loop strength and stitch density, it is possible to estimate the seam strength by following equation:

$$F_{estimated} = \frac{stitch}{cm} \times loop\ strength \times sample\ width \times C \quad \ldots (2)$$

where C is the loop strength related to the stitch type and it is equal to 1.5 and 1.7 for lockstitch and chain stitch respectively [10]. Loop strength of the applied sewing thread is obtained as 989 cN. Analysis of results reveal that although the Eq. (2) overestimates the seam strength, there is a good correlation between the measured and the estimated seam strength. In fact, this equation does not consider the role of fabric and its structural parameters. Since the seam strength is the result of the fabric and sewing thread interaction with each other, fabric structural factors, such as weave pattern, density, constituent's count and friction coefficient, have an essential part on the seam strength.

In order to obtain the tolerated tensile force by each stitch, the seam strength is divided by the number of the stitches that attached two fabric strips and the results are shown in Table 2. In the following sections, the unidirectional and multidirectional tensile load tolerated by a stitch will be compared.

3.4 Tensile Seam Efficiency

In order to investigate the seam effect on the fabric's strength reduction, it is possible to use the seam efficiency as an index, as shown in following equation:

$$\text{Tensile seam efficiency} = (\text{strength of seamed fabric}) / (\text{strength of fabric without seam}) \times 100 \quad \ldots (3)$$

In fact, this parameter implies that how can seam and related factors reduce the fabric strength. Undoubtedly, during sewing the fabrics, it is desirable to select suitable factors to prevent the fabric strength drop. In comparison of the breaking load of fabrics in both warp and weft direction, it is observed that for all samples as it is anticipated, fabric breaking load in warp direction is higher than in weft direction, which is related to the difference in the warp and weft density.

Moreover, dressing and shirting fabrics have the highest and lowest breaking loads respectively. By consideration of the results of seam efficiency of all specimens, it is perceived that dressing fabric, that has the highest breaking load, provides the lowest seam efficiency. In addition, seams with double chain stitch have higher seam efficiency and decrease in the stitch length raise the seam efficiency. In other words, every element that improves the seam strength increases the seam efficiency as well. In fact, this parameter states the best sewing condition to prevent the fabric strength descent. In this regard, sewing with double chain stitch provides better seam efficiency. Furthermore, in both lockstitch and double chain stitch, decrease in the stitch length improves the seam efficiency.

3.5 Evaluation of the Bursting Behavior of Seam

While wearing a garment, various seam paths, which are situated in different parts of the clothing, such as the sleeve and trousers' seams, may be subjected to multi-directional forces. Thus, in this part of the paper, the bursting behavior of the seams is evaluated as a measure of its performance in case of toleration of instant multi-directional loads. Interpretation of results is individually carried out regarding two structural parameters of seam which are stitch length and type (lockstitch and double chain

Table 2 — Tensile force applied to each stitch

Stitch type	Stitch length mm	Number of stitches	Seam strength per stitch, N					
			Warp			Weft		
			Worsted	Shirting	Dress	Worsted	Shirting	Dress
Lockstitch	L2	25	8.74	3.92	5.32	9.33	6.05	7.4
	L3	16.7	10.16	5.19	6.2	10.34	6.25	7.64
	L4	12.5	8.5	2.18	4.82	8.9	6.58	7.71
Double chain stitch	C2.5	20	9.88	8.56	9.03	11.43	9.12	10.03
	C4	12.5	13.92	3.65	11.41	16.16	7.7	12.56

stitch). It should be noted that for the lockstitch seam, the stitch lengths of 2, 3 and 4 mm (L2, L3 and L4), and for the double chain stitch seams, the stitch lengths of 2.5 and 4mm (C2.5 and C4) are analyzed. The seams with the mentioned characteristics are sewn both in the warp and weft directions.

As it is clear in Fig. 5, in both warp and weft directions, reducing the stitch length results in an improvement in the seam resistance against bursting. In other words, by decreasing the stitch length and apparently increasing the stitch density, due to the rise in the number of contact points of sewing yarns with each other and the growth of interaction between sewing yarn and fabric, the exerted bursting load is contributed over the greater numbers of contacting points, which act as the stress concentration zones. This fact delays the seam breakage due to bursting.

In the next stage, according to the bursting value shown in Fig. 5, the effect of stitch type is studied on the bursting results. Analysis of the results reveals that among samples with nearly similar stitch densities, the bursting strength of the double chain stitch is greater than the lockstitch, which is related to the stitch formation condition. As it is mentioned earlier, due to the loop formation at the entanglement sequence of needle and looper's thread, while applying force in various directions, a portion of force is used for straightening of the loop, which results in higher extensibility of the stitch and consequently an improvement in the bursting resistance of the seam. On the contrary, in the lockstitch structure, the sewing yarn has a straight form, which results in lower bursting strength.

Finally, in order to calculate the bursting force exposed to each stitch along the seam, it is necessary to find the number of stitches in the loading zone, which is a circle with diameter of 44 mm. By dividing the total bursting force to the number of stitches, the bursting force applied to individual stitches is estimated and the results are shown in Table 3. In the proceeding parts, bursting and tensile breaking force per stitch will be compared with each other.

3.6 Seam Bursting Efficiency

In order to examine the seam effect on the fabric's bursting strength decrease, due to the presence of various kinds of stitches with different stitch densities, the seam bursting efficiency is defined as an index using the following equation:

Seam bursting efficiency = (bursting strength of seamed fabric)/(bursting strength of fabric without seam) × 100 … (4)

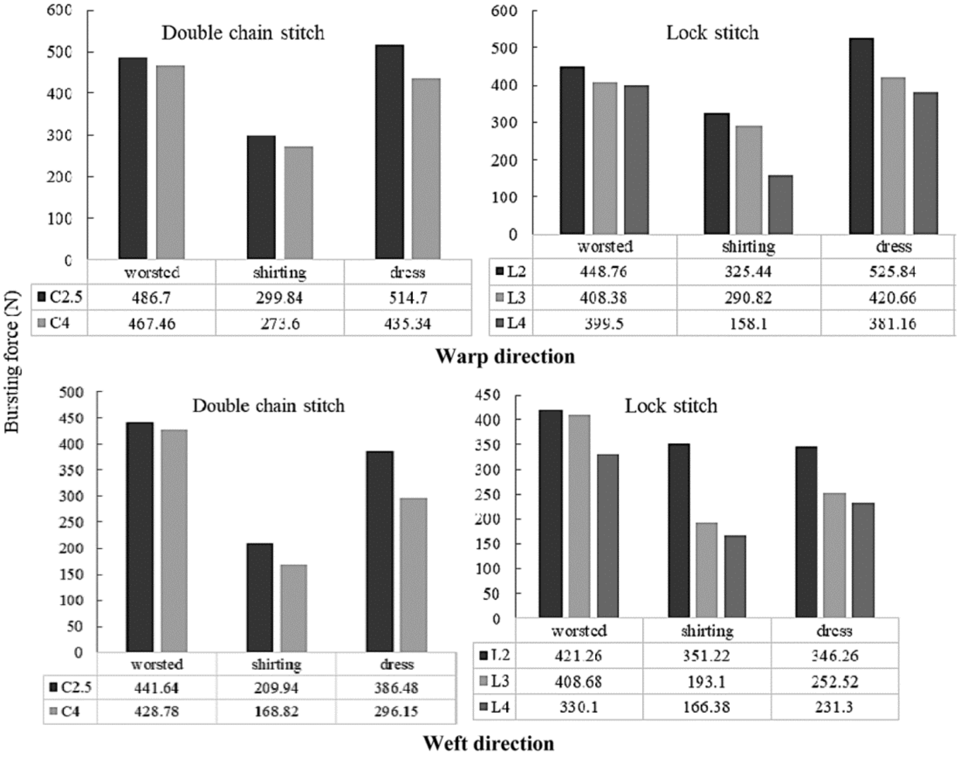


Fig. 5 — Effect of stitch length (mm) on seam bursting force (N) in both warp and weft directions

Table 3 — Bursting force applied to each stitch

Stitch type	Stitch length mm	Number of stitches in the bursting zone	Bursting force per stitch (N)					
			Warp			Weft		
			Worsted	Shirting	Dress	Worsted	Shirting	Dress
Lockstitch	L2	22	20.40	14.79	23.90	19.15	15.96	15.74
	L3	14.7	27.78	19.78	28.62	27.8	13.14	17.18
	L4	11	36.32	14.37	34.65	30.01	15.13	21.03
Double chain stitch	C2.5	17.6	27.65	17.04	29.24	25.09	11.93	21.96
	C4	11	42.40	24.87	39.58	38.98	15.35	26.92

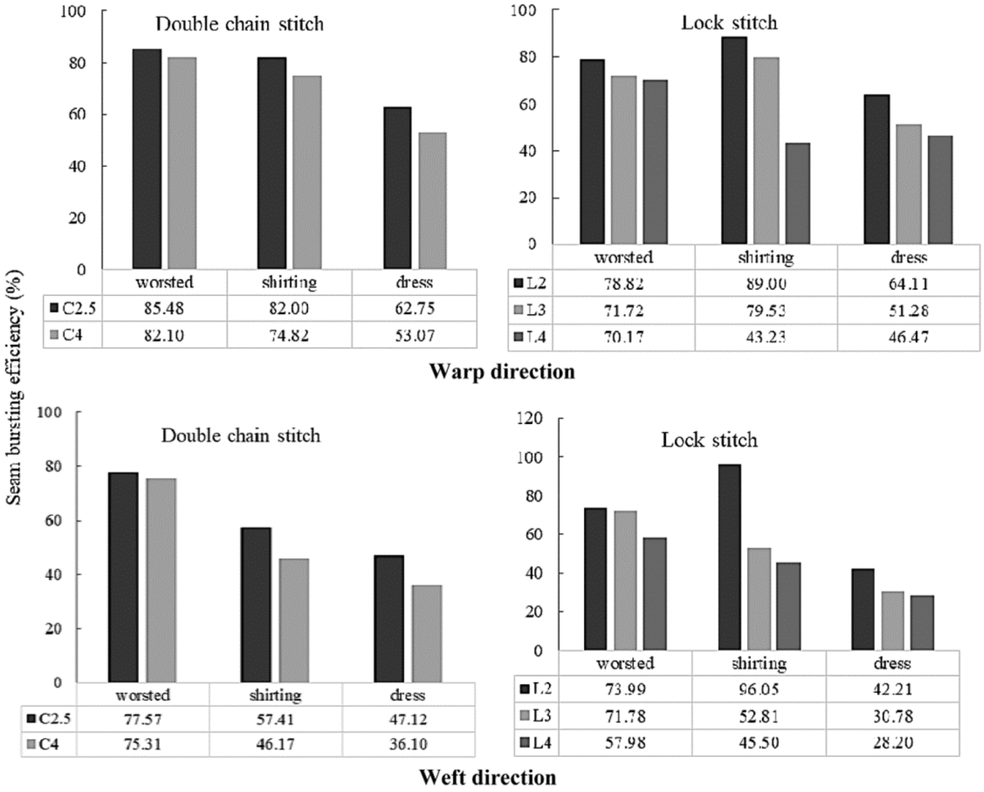


Fig. 6 — Effect of stitch length (mm) on seam bursting efficiency (%) in the warp and weft directions

In order to calculate the seam bursting efficiency, first the bursting strength of the fabric without the seam is measured for the worsted, shirting and dress fabrics, which are found to be 569.37, 365.68 and 820.27 N respectively. Therefore, the dress fabric, which consisted of filament yarns, has the highest bursting strength.

It is apparent that the bursting strength of fabric is lower than the seamed fabric, because the seam weakens the fabric cohesion and evenness. However, a higher seam efficiency means that the seamed fabric bursting strength is nearly similar to the fabric bursting strength. In other words, for a fabric, the best seam feature collection should be in a manner which boosts the seam bursting resistance and its efficiency.

The results of seam bursting efficiency are also compared by considering two points of view, viz stitch length and type. Thus, the value of seam bursting efficiency for various groups of fabrics, with regards to stitch length and type, in case of situation of seam in both warp and weft directions are shown in Fig. 6.

As it is apparent in Fig. 6, for all fabric groups and for a specific stitch type, by diminishing the stitch length and hence increasing the stitch density, the value of seam bursting efficiency is improved. This phenomenon is the outcome of the growth in the number of connection points of yarns and fabric.

Moreover, the comparison of the seam bursting efficiency of different stitch types reveals that the double chain stitch has the higher efficiency as compared to the lockstitch. This finding is in accordance with the structural quality and higher elasticity of double chain stitch, which has already been discussed.

Considering the results in Fig. 6, the lowest bursting efficiency is achieved for the dress fabric due to its higher fabric bursting strength. Therefore, it can be concluded that more care should be taken during the selection of the stitch parameters for this kind of fabric.

On the whole, it seems that for elastic fabrics and for the seams which are more often subjected to tensile loads, the use of double chain stitch with higher stitch density would be a good choice.

3.7 Comparison of Seam Bursting and Seam Strength

In order to compare the required load to break seam under both unidirectional and multidirectional loading procedure, the load used on a stitch has been calculated (Tables 2 and 3). The correlation of these values for worsted fabric is evaluated and it is observed that the increase in tensile strength leads to the bursting load increment. This phenomenon, as described previously, is related to the stitch type, density and interaction with fabric. However, the point that should be regarded is that the magnitude of the exerted load per stitch is lower in unidirectional tensile test in comparison with the multidirectional bursting test.

In evaluation of the seam strength, the load is applied perpendicular to the seam. On the other hand, in multidirectional bursting test, the load is exerted in all directions. However, the resultant forces, which are perpendicular to the seam line, are effective in the seam failure. In this regard, higher multidirectional load is required to obtain the sufficient tensile load at right angles to the seam directions. This outcome reveals that in a cloth, the seams, which are encounter to perpendicular forces during wear, are more prone to fail and need more attention during the sewing factor selection. The inspection of seam efficiency and bursting efficiency also confirms this trend.

4 Conclusion

With regard to the importance of the seam behavior during the application of unidirectional and multi-directional loads, in this study, the effect of seam structural parameters on the resultant strength has been investigated due to the application of tensile and bursting strength.

It is concluded that, on the whole, the presence of seam leads to a considerable decrease in the strength in both tensile and bursting tests. Thus, it is necessary to thoroughly study the various structural properties of the seams, such as the stitch type and density and its interaction with the utilized fabric to optimize the seam strength. The highest and lowest seam strengths are obtained for the worsted and shirting fabrics respectively, which are sewn along the weft direction. Besides, the seam strengths are estimated with the consideration of stitch density, loop strength and stitch type; the acceptable correlations are found between measured and estimated results.

In comparison of the seam type, for all the studied fabrics which are sewn along the warp and weft directions, the double chain stitch seam exhibits better tensile and bursting strengths due to the elongation of the loops in the stitch structure and greater entanglement between the threads. Moreover, in the analysis of the effect of stitch density, it is revealed that for all the fabrics and both stitch types, an increase in the stitch density results in a rise in the strength while unidirectional and multi-directional loadings.

In this study, the seam tensile and bursting efficiency are also calculated and the lowest seam efficiency is obtained for the dressing fabric regarding its higher strength. Furthermore, by rising the stitch density, the value of seam bursting efficiency is enhanced which is a consequence of the increase in the number of joining points of yarns and fabric. The double chain stitch is the stitch type, which presents better seam tensile and bursting efficiency.

In order to compare the seam behavior subjected to unidirectional and multi-directional loads, the bursting and tensile forces applied to each stitch are estimated. Higher quantities of load are required during the bursting test compared to one directional tensile loading. It should be noted that the bursting and tensile seam efficiency are also in accordance with each other.

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