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Effects of Different Stitch Types and Stitch Combinations on the Seam Bursting Strength and Seam Strength of Workwear

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ABSTRACT

Workwears are produced to protect the wearer against occupational or environmental hazards. One of the shared properties of several workwear types is resisting external forces during occupation. As for workwear fabrics, the seams of the workwear should be strong enough to resist uniaxial or multiaxial forces to maintain the properties in the cut and sewn parts of the garment. Therefore, in this study, effects of different stitch types and their combinations on the workwear seam strength and bursting strength were evaluated. According to results, a 2-step failure was observed at the seam strength tests of samples those contained stitch combinations. Here, the main function of the second stitch row was to form a safety stitch rather than increasing the overall performance. Contrarily, usage of stitch combinations obviously contributed to the seam bursting strengths. In this case, the stitch rows responded to the bursting forces together therefore the bursting failures occurred in 1-step.

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KEYWORDS

Seam bursting, seam strength, workwear, stitch types, stitch combinations

1. INTRODUCTION

Fabrics can be gathered together via different assembling methods in order to form 3-dimensional garments and other textile end-products. Stitching is the most common assembling method, as it is easy to apply, cheap and suitable for most of the applications [1, 2]. In textile industry, six standard classes of stitches are used as chain stitch, hand stitch, lock stitch, overlock stitch, multi-yarn chain stitch and cover stitch [3, 4]. These stitch types provide advantages in different applications. For example, lock stitch is a universal stitch type that can be applied to both woven and knitted fabrics. It has low yarn consumption and it is very secure. In contrast, single yarn chain stitch is preferred for temporary seams as it is easy to unstitch [1, 2].

For workwear, thicker and heavier fabrics are preferred in order to resist external forces during occupation and to provide protection to the wearer. Specialty fibers or traditional synthetic/natural fibers can be utilized for these fabrics in order to balance the performance and the cost of the end-product [5-7]. As for workwear fabrics, seams of the workwear should be strong enough to resist the forces. Therefore, seam properties of workwear should be investigated properly in order to maintain the unsewn fabric properties.

In the literature, there are many research studies that subjected the seam strength of different classical fabrics for various end-products [8-21]. Lock stitch was used in most of these studies, as the lock stitch machine is the most available sewing machine. Also, in recent years, effects of other stitch types on the seam strength and other seam properties were evaluated [22-26]. On the other hand, there is a very limited number of research studies on the bursting strength of sewn fabrics. In one of the related studies, effects of different seam types (sewn with stitch type ISO 401) on the multiaxial strength of selected woven and knitted fabrics were determined [27]. In another study, the multiaxial seam strength of sewn automobile seat covers (sewn with lock stitch) was determined by a self- developed bursting apparatus [28]. Rajput et al studied the effects of 3 stitch types, 3 fabric types and sewing yarn fineness on the hydraulic bursting strength of knitted fabrics [29]. Yesilpinar investigated the effect of different sewing

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techniques (lock stitch techniques) on the bursting strength of apparel fabric [30].

As seen from the literature search, seam properties of workwear are very important as they ensure the continuity of the fabric properties in the joint areas. Although the uniaxial seam strengths of different fabrics were determined in several studies, seam efficiency of different stitch types and multiaxial strength (bursting strength) of workwear fabrics have not been studied in details, yet. Therefore, the main goal of this study was to evaluate the effects of different stitch types and stitch combinations on the uniaxial seam strength and bursting strength (multiaxial seam strength) of sewn workwear fabrics. This study differs from the literature as it determines the bursting strength of seams and as it compares 7 types of different stitch types/combinations for workwear.

2. MATERIALS AND METHODS

2.1 Materials

A cotton/polyester blend fabric was used as it was suitable to be used for workwear [6, 7, 31]. Properties of the fabric are given in Table 1. Sewing yarn was a 2 ply, 60 tex polyester corespun yarn that was also suitable for workwear (Coats Epic). Breaking strength of the sewing yarn was 34.5 N and breaking strain was 29 % (tested according to TS EN ISO 2062 [32]).

2.2 Methods

2.2.1 Sample preparation

For this study, both reference (non-sewn) samples and sewn samples were prepared in order to make comparisons. Overall, 7 types of seams were produced by using different stitch types and their combinations as shown in Table 2. As the basic stitch types; lock stitch, 2-yarn chain stitch and 3-yarn overlock stitch were used. Stitch combinations were also formed by using “2-row lock stitch”, “2-row-2-yarn chain stitch”, “3-yarn overlock + lock stitch” and “3-yarn overlock + 2-yarn chain stitch”. The sample codes, stitch schematics and important stitch dimensions such as seam allowance and distances between stitch rows are given in Table 2. Stitch densities for all types of stitches were 3 stitches/cm. Seam allowances were folded in the back side of fabric and ironed before conditioning the test samples.

For all samples, seams were formed both in warp direction and weft direction as shown in Figure 1. Seam strength and bursting strength tests of samples were performed for warp and weft samples. All the samples were conditioned under standard atmosphere conditions (20±2ºC, 65±4 % relative humidity) for 24 h before the tests.

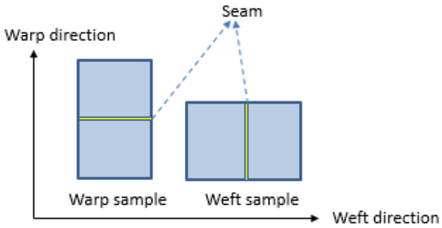


Figure 1. Seam placements and sample definition [33]

2.2.2 Seam strength

Seam strength of samples were determined according to TS EN ISO 13935-2: 2014 standard [34], utilizing Instron 4411 Tensile Tester. Seam strength, strain and failure type of samples were recorded. Also, non-sewn samples were exposed to the same test as reference fabric. Tests were repeated 5 times for each sample type. Representation of seam strength test can be seen in Figure 2.

2.2.3 Seam efficiency calculation

Seam efficiency of samples were calculated by using reference sample strength and seam strengths of sewn samples, by using Equation 1 (ASTM D1683/D1683M – 17 [35]).

Table 1. Fabric properties

Raw material	Weave	Unit mass (g/m^2)	Thickness (mm)	Warp density (yarns/cm)	Weft density (yarns/cm)
35% cotton 65% polyester	2/2 warp rib	280	0.46	55.1	19.1

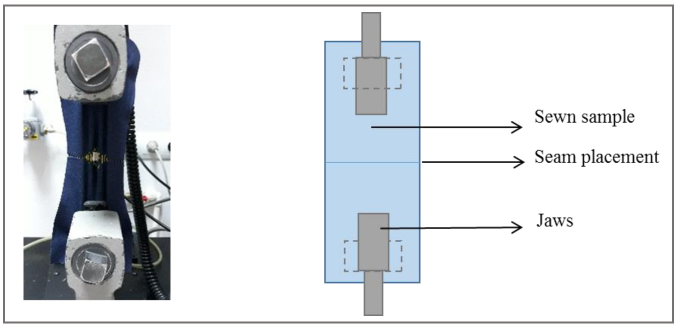
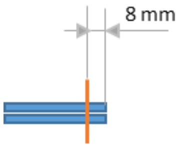
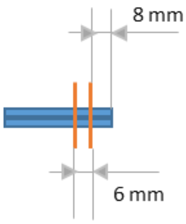
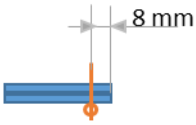
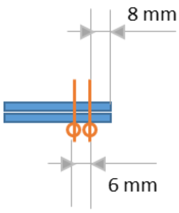
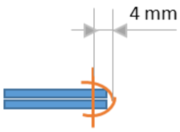
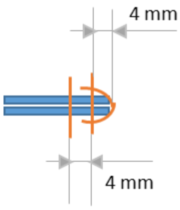
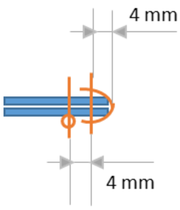


Figure 2. Real image and pictorial representation of uniaxial seam strength test

Table 2. Sample codes and seam/stitch information of sewn samples

Main stitch type	Sub stitch type	Stitch schematics and dimensions	Sample code
Non-sewn reference sample	-	-	No seam
Lock stitch (301)	1-row		Lock1
	2-rows		Lock2
Chain stitch (401)	1-row		Chain1
	2-rows		Chain2
Overlock stitch	3-yarn 1-row		Ov3
	5-yarns 2-rows (3-yarn ov.+ 301)		Ov3Lock
	5-yarn 2-rows (3-yarn ov.+ 401)		Ov3Chain

$$\text{Seam efficiency } (\%) = E(\%) = \frac{\text{Seam strength}}{\text{Fabric strength}} * 100 \quad (1)$$

2.2.4 Bursting strength

Bursting strength of samples were determined according to ASTM D6797 − 15 standard [36], utilizing Instron 4411 Tensile Tester with a ball-burst attachment. Sample size was kept as 14 cm x 14 cm and the test speed was 300 mm/min. Tests were repeated 5 times for each sample type. Bursting strength, movement distance of the ball apparatus when the sample bursted, and the failure type of specimens were recorded as the test outputs. Representation of seam bursting strength test can be seen in Figure 3.

2.2.5 Seam bursting efficiency calculation

Seam bursting efficiency of samples were calculated as given in Equation 2, similar to the standard seam efficiency equation given in Equation 1. "Seam bursting efficiency" was derived by the author in order reveal how the seams were durable against bursting when compared to non-sewn reference samples.

2.2.6 Statistical analysis

SPSS Package Program version 22 was utilized to compare the seam strength, strain, bursting strength and bursting height results of different sample types, statistically. In the first step, normality of data was examined by considering Shapiro-Wilk test, histograms, variation coefficients (%), Skewness/Kurtosis values and Q-Q plots. For normally distributed data, One-way ANOVA analysis were performed. For pairwise comparisons, Tukey and Games-Howell tests were used, for homogeneous and non-homogenous variance, respectively.

For data, which were not-normally distributed, Kruskal-Wallis analysis were performed. Pairwise comparisons of not-normally distributed data was made by using Mann Whitney U test.

3. RESULTS AND DISCUSSION

3.1 Seam Strength and Seam Efficiency Results

Seam strength results of samples are given in Table 3, with standard deviation values. The samples which were sewn with stitch combinations (Lock2, Chain2, Ov3Lock and Ov3Chain) failed at 2 steps. At the first step, the inner stitch row broke and the second stitch row that was near to the seam allowance edge, remained safe. These samples were clamped to the machine and a second test cycle was applied in order to break the second row of stitches. Therefore, seam strength results are given for first breaking cycle and second breaking cycle for these samples. Also, seam efficiency results of the samples are given in Table 4. The strain, seam strength and seam efficieny values given for second cycle were directly obtained from the second cycle breaks, so that they were not cumulative data. As the seam break downs were independent in the test cycles, the first cycle and second cycle seam properties are evaluated separately, rather than computing overall seam strength, strain or seam efficiency values.

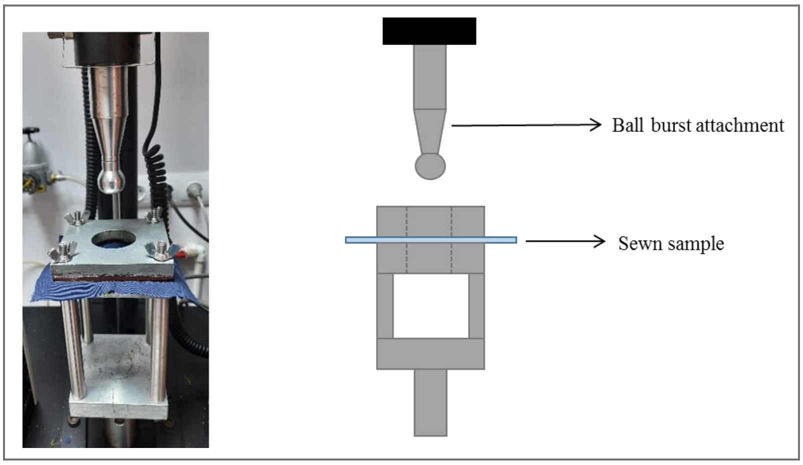


Figure 3. Real image and pictorial representation of bursting (multiaxial seam strength) test

$$\text{Seam bursting efficiency (\%)} = \text{BE (\%)} = \frac{\text{Seam bursting strength}}{\text{Fabric bursting strength}} * 100 \tag{2}$$

Table 3. Seam strength results of samples

	Seam strength- First cycle				Seam strength - Second cycle			
	Warp		Weft		Warp		Weft	
Sample code	**Mean (N)**	**St. Dev. (N)**	**Mean (N)**	**St. Dev. (N)**	**Mean (N)**	**St. Dev. (N)**	**Mean (N)**	**St. Dev. (N)**
No seam	1107.00	32.24	855.52	15.76	/	/	/	/
Lock1	404.98	33.46	389.30	23.06	/	/	/	/
Lock2	466.28	17.85	392.76	31.36	522.52	29.76	348.76	155.55
Chain1	486.02	39.04	437.80	43.99	/	/	/	/
Chain2	479.78	34.82	384.62	20.41	560.48	72.03	481.02	25.95
Ov3	490.80	85.32	383.88	22.27	/	/	/	/
Ov3Lock	419.08	19.21	381.96	16.48	490.04	43.49	435.52	35.14
Ov3Chain	494.04	31.36	464.54	15.08	555.73	37.07	442.80	39.68

Table 4. Seam efficiency results of samples

Sample code	Seam efficiency- First cycle		Seam efficiency- Second cycle	
	Warp (%)	Weft (%)	Warp (%)	Weft (%)
No seam	/	/	/	/
Lock1	36.58	45.50	/	/
Lock2	42.12	45.91	47.20	40.77
Chain1	43.90	51.17	/	/
Chain2	43.34	44.96	50.63	56.23
Ov3	44.34	44.87	/	/
Ov3Lock	37.86	44.65	44.27	50.91
Ov3Chain	44.63	54.30	50.20	51.76

Seam strength results of samples are visualized for first breaking cycle, in Figure 4.a. According to results, strength of non-sewn samples was 1107 N in warp direction and 856 N in weft direction and they were significantly higher when compared to sewn samples' results (Sig. values< 0.05). Seam strength of sewn samples were lower than 555 N in both warp and weft directions (Table 3) and the highest seam efficiency was calculated around 55% (Table 4). The highest seam strength and seam efficiency values were obtained for Ov3Chain samples in first cycle of tests. The seam strength increment of Ov3Chain sample was statistically significant when compared to non-sewn, Lock1 and Ov3Lock samples (Sig. < 0.05). Ov3Chain sample contained the stitch combinations of 3-yarn overlock stitch and 2-yarn chain stitch. In the literature, it is generally called as safety stitch [37]. The 2-yarn chain stitch is known to provide strength, elasticity and durability for this stitch combination [2]. Our results are partly supported by the studies in the literature. In the study of Ates et al, seam strength of denim fabrics sewn with "chain stitch + overlock stitch" was found higher when compared to its counterpart with "lock stitch + overlock stitch" [24]. Similarly, in our study, when the overlock stitch was combined with lock stitch and chain stitch (Ov3Lock and Ov3Chain, respectively), higher strength of chain stitch contributed to the overall seam strength of samples and seam strength differences were statistically significant (Sig. values< 0.05).

In general, usage of 2-row lock stitch and 2-row-2-yarn chain stitch did not cause any statistically significant increment in seam strengths when compared to 1 row stitched counterparts (Lock1 and Chain1) (Sig. values> 0.05).

When the 3 basic stitch types (Lock1, Chain1 and Ov3) were compared, the queue was generally Ov3>Chain1> Lock1. Similar to our study, seam strength of sewn fabrics with chain stitch were found higher when compared to that of sewn fabric with lock stitch [25]. However, in our study, after considering standard deviation values and statistical analysis, it was resulted that the effects of basic stitch types were not statistically significant on the seam strengths of samples, in general (Most sig. values> 0.05).

For all samples, seam strengths of warp samples were higher than weft samples. In addition, for all samples, stitches were broken during the sample failure.

Strain results of samples are given in Figure 4.b and Table 5. As for seam strength results, strain results for 2-row stitch combinations (Lock2, Chain2, Ov3Lock and Ov3Chain) were obtained for 2 cycles of tests (Table 5).

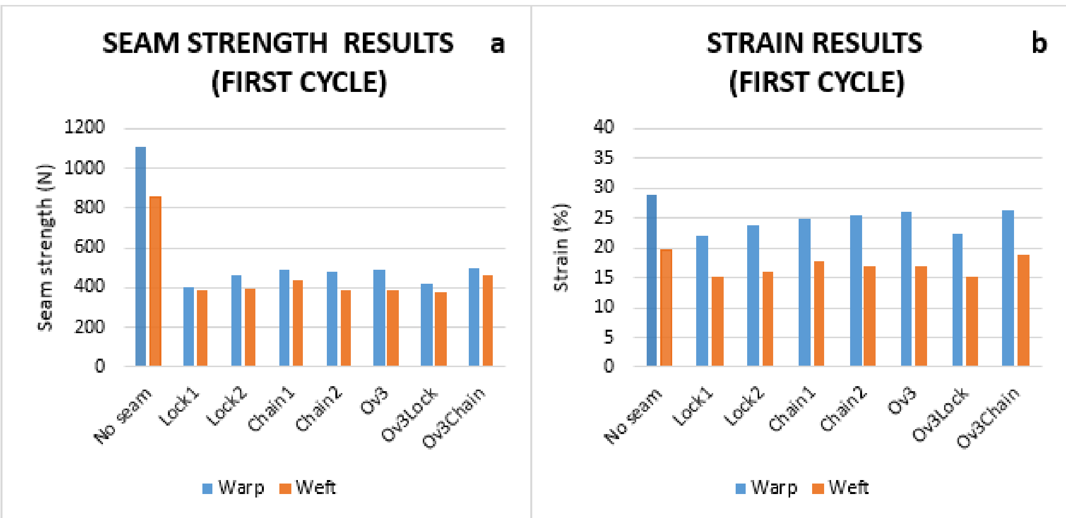


Figure 4. Seam strength results of samples for first breaking cycle

Table 5. Strain results of samples

Sample code	Strain - First cycle				Strain - Second cycle			
	Warp		Weft		Warp		Weft	
	Mean (%)	St. Dev. (%)	Mean (%)	St. Dev. (%)	Mean (%)	St. Dev. (%)	Mean (%)	St. Dev. (%)
No seam	29.02	5.56	19.50	0.38	/	/	/	/
Lock1	22.02	1.07	15.05	0.56	/	/	/	/
Lock2	23.83	0.89	15.89	0.72	35.15	2.05	22.67	6.3
Chain1	24.83	2.44	17.85	0.68	/	/	/	/
Chain2	25.51	1.43	17.00	0.92	34.76	3.34	27.35	1.01
Ov3	26.04	2.12	16.97	1.10	/	/	/	/
Ov3Lock	22.42	0.57	15.22	0.49	28.20	1.55	21.86	1.46
Ov3Chain	26.32	3.67	18.79	4.01	29.97	1.09	22.50	0.81

Strain of non-sewn samples were around 29 % and 20 % in warp and weft directions, respectively. For sewn samples, strain values decreased to some extent in the first cycle. The lowest strain values were obtained from Lock1 and Ov3Lock samples, as for seam strength values. In parallel, the highest strain values were obtained for Ov3Chain samples that also exhibited the highest seam strength. In general, strain results of samples in warp direction were similar to each other (Sig. values> 0.05) whereas strain of non-sewn sample was higher than sewn samples in weft direction (Sig. values< 0.05).

Strain values of samples sewn with stitch combinations, increased in the second cycle. A similar trend was also observed for seam strength results. It can be due to the supporting effect of remaining stitches of first row that were not broken in the first test cycle. At the first breaking cycle, all of the stitches of first row were not broken during seam failure. In order to simulate the real repetitive usage conditions, samples were clamped to the machine and tested in the second cycle, without removing the remaining stitches of first row. When the second breaking cycle was carried out for these samples, the load was beared by mainly the second stitch row. Nevertheless, the remaining stitches from the first breaking cycle is thought to bear some load during the second cycle, too. This is thought to be the reason of higher seam strengths and strains for the second test cycle of stitch combinations.

3.2 Bursting Strength and Seam Bursting Efficiency Results

Normally, bursting strength test examines the strength of samples in all directions so that the test is not repeated for warp and weft directions. However, in this study, the bursting test samples were prepared to have seams in warp and weft directions, as shown in Figure 1. Therefore, the bursting strength and bursting height of sewn samples are given for warp and weft samples, in Table 6. As there were no warp-weft samples in non-sewn sample, its result is given in black colour (Figure 5). Also, the data is visualized in Figure 5. The seam efficiencies of samples against bursting are also calculated and given in Table 7.

Different than seam strength tests, all the samples including 1-row basic stitches (Lock1, Chain1 and Ov3) and 2-rows stitch combinations (Lock2, Chain2, Ov3Lock, Ov3Chain) bursted in only one step.

Bursting strength of non-sewn reference fabric was 1898.75 N (Table 6). For the 3 basic stitch types (Lock1, Chain1 and Ov3), bursting strength in warp and weft directions were lower than that of non-sewn samples. Ov3 sample exhibited the lowest bursting strength among these 3 stitch types (Figure 5.a) and the bursting strength differences of Ov3 sample with the other sample types were statistically significant for both warp and weft samples (Sig. values< 0.05). On the other hand, bursting strength of

Table 6. Bursting strength and bursting height results of samples

Sample code	Bursting strength				Bursting height			
	Warp		Weft		Warp		Weft	
	Mean (N)	St. Dev. (N)	Mean (N)	St. Dev. (N)	Mean (mm)	St. Dev. (mm)	Mean (mm)	St. Dev. (mm)
No seam	1898.75	114.39	1898.75	114.39	39.07	13.55	39.07	13.55
Lock1	1751.60	252.34	1447.80	157.84	33.44	2.13	32.42	1.05
Lock2	2529.00	230.19	2367.80	342.34	35.87	3.11	39.75	2.64
Chain1	1771.80	208.62	1527.80	84.14	31.41	2.52	32.55	0.86
Chain2	2462.40	218.50	2319.40	287.31	38.04	1.66	41.01	3.96
Ov3	1309.20	109.62	1075.40	102.40	31.49	1.17	29.32	1.19
Ov3Lock	2368.00	212.00	1675.20	138.89	35.82	1.09	34.62	1.89
Ov3Chain	2398.60	114.72	1770.20	15.00	37.10	1.55	35.11	1.90

samples sewn with stitch combinations (Lock2, Chain2, Ov3Lock and Ov3Chain) exhibited higher bursting strength when compared to non-sewn samples, especially for the warp samples (Sig. values< 0.05). A similar result was obtained by Yesilpinar, when she compared the bursting strength of 1-row lock stitched samples with 2-rows lock stitched counterparts [30]. In contrast with the seam strength tests, the second row of stitches in the combinations supported the seam line against bursting, importantly. As for seam strength results, chain stitch containing samples (Chain1, Chain2, Ov3Chain) exhibited higher bursting strength when compared to lock stitch containing counterparts (Lock1, Lock2, Ov3Lock), but this time the differences were less and not statistically significant (Sig. values between Lock1/Chain1, Lock2/ Chain2 and Ov3Lock/Ov3Chain were higher than 0.05). In the literature, the bursting strength of lock stitched samples were found slightly higher than chain stitched samples, but this study was made on knitted fabrics and bursting test procedure was different [29].

For stitch combinations, seam efficiencies against bursting were higher than 100% (Table 7). For all samples, bursting strength of warp samples were higher than weft samples.

Also, when compared to seam efficiencies given in Table 4 (36-55%), seam bursting efficiencies were clearly higher (56-133%) (Table 7).

During bursting tests, generally stitches were broken for 1 row stitch types (Lock1, Chain1, Ov3). Different than the seam strength tests, fabric tear near the seamline accompanied the stitch breakages or only the fabric tear near the seamline was observed in the bursting failure of combination stitches (Lock2, Chain2, Ov3Lock, Ov3Chain).

On the other hand, bursting height of non-sewn reference sample was 39 mm. Only Lock2 and Chain2 samples exhibited higher bursting height for weft samples when compared to non-sewn samples but the differences were not statistically significant (Sig. values > 0.05). It could be advantageous for workwear as the seam line could resist to bursting in higher elongations. For all sewn samples, the bursting heights for warp and weft samples were close to each other.

Table 7. Seam bursting efficiency

	Seam bursting efficiency	
Sample code	**Warp (%)**	**Weft (%)**
No seam	/	/
Lock1	92.25	76.25
Lock2	133.19	124.70
Chain1	93.31	80.46
Chain2	129.69	122.15
Ov3	68.95	56.64
Ov3Lock	124.71	88.23
Ov3Chain	126.33	93.23

4. CONCLUSIONS

In this study, the effects of different stitch types and their combinations were determined on the seam strength and seam bursting strength of workwear fabric.

In seam strength test, a two-step failure was observed for samples that contained stitch combinations. In the available experimental studies in literature, this phenomenon was not mentioned for stitch combinations. It is an important feature for workwear, because the garment can still provide protection to the wearer after the first row of stitches broke, until the seam is repaired. In addition, it is beneficial to highlight that, the main function of the second row of stitch was to form a safety stitch rather than increasing the overall seam performance. In warp and weft directions, the maximum seam efficiency difference for different stitch types/combinations was around 12%. Seam efficiency values of all samples were around 36.6-44.6 % in warp direction and 44.6-54.3 % in weft direction, for the first breaking cycle. For the stitch combinations, seam efficiency values increased in the second cycle for some amounts. According to the literature, seam efficiency values are dependent on a variety of factors such as fabric structure, seam type, stitch type, stitch density, sewing yarn properties, sewing needle properties etc. and seam efficiency values around 60-80 % are common [3, 38]. Seam efficiency result of the samples prepared in this study are close to the 60% boundary. As the fabric strengths in warp and weft directions were quite high, seam strengths obtained in this study would be acceptable for many uses. Nevertheless, to increase the seam efficiency values, some seam parameters can be differed in the further studies.

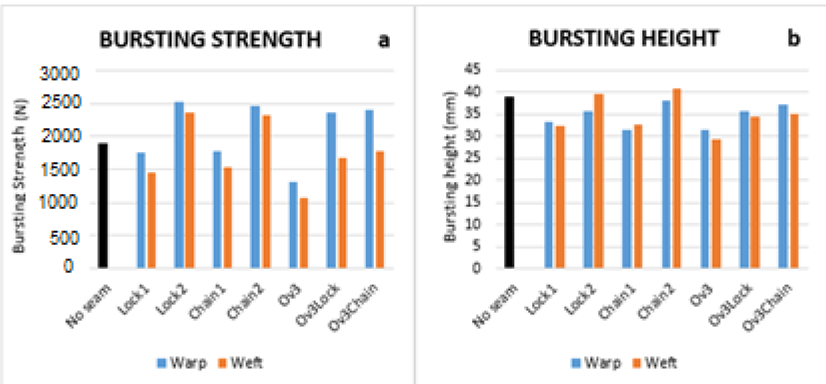


Figure 5. Bursting strength and bursting height results of samples

Different than uniaxial seam strength tests, all the sewn samples bursted in only one step independent of including 1-row stitches or 2-rows stitch combinations. Also, the contribution of the second stitch row was clearly observed for the samples containing stitch combinations. For these samples, seam bursting efficiency was higher than 100%, because of the supporting effect of second row of stitches and the seam allowances, in the bursting area. As for seam strength efficiencies, in general, chain stitch containing samples exhibited slightly higher seam bursting efficiencies and bursting heights.

In both seam strength and bursting strength tests, some amounts of higher results were obtained for warp samples. It was a reflection of higher fabric strength in warp direction [39]. It is known that, warp yarns are selected as higher strength yarns in order to bear the loads during warping and weaving processes. Also, higher yarn densities are used in warp direction. As a result, both fabric strength and seam properties are affected from the yarn properties and fabric structural parameters in warp and weft directions.

The information obtained from this study is beneficial for the seam selection of the workwear to obtain more resistant seams by forming seam combinations. Also, the information inferred from this study can be used for other garment types where the seams are exposed to high uniaxial or multiaxial forces such as in crotch zone.

In the further studies, lock stitch or chain stitch can be selected and, the seam strength and seam bursting properties of workwear with lapped seam types of selected stitches can be studied. Different than this study, the seam rows in the stitch combinations can act together to result with a higher seam strength/efficiency for the lapped seams.

Acknowledgement

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