A Comparative study of contraction factor of weave structure: plain, twill, satin and their derivatives

Md. Yeasin Ali[1*], Md. Golam Robbani[2]

Abstract

The contraction properties of woven fabric are one of the major parameters that significantly depend on the weave structure of a fabric. It is well established that the contraction of yarns changes with changing the interlacement sequence or the weave structure. The comparative analysis and justification of warp contractions for different weave structures are studied in this research work. Eighty type fabrics with varying weave structure are carefully chosen and the average contraction factors are determined and compared with each other. The study found a significant variation of contraction among the weave structures. The plain weave showed the highest contraction factor and satin showed the lowest. But, for a few intermediate results especially of the derivatives of twill and matt fabrics, the variation of contraction factor cannot be explained by interlacement sequences only as the final packing of fabric after relaxation depend on several other factors which are also explained with relevant literatures. Some exception results are also experienced by very few fabric types.

Keywords: Contraction factor, weaving contraction, crimp, woven fabric, weave structure

1. Introduction

Weaving is a process where two sets of yarns are interlaced at the right angle to form a fabric. When the set of warp and weft yarn interlace with each other they follow a wavy path which shortens the length of yarn in fabric form compared to the length of yarn in the open form (Peirce, 1937). This shortening of the length of yarn in the fabric is called crimp. The length difference between yarn and fabric form compared to the length of fabric is expressed in percentage and known as crimp% ("ASTM D3883-04(2020)," 2020). When the difference between the length of yarn and the length of produced fabric is expressed as a percentage of the total length of warp yarn is called contraction factor or take-up percentage. These are the mentioned definitions related to crimp and contraction factor by the American Society for Testing Materials (ASTM) (Adanur, 2020)

The contraction factor has a great impact on the manufacturing stage and overall quality of the woven fabric. It has been well stablished that contraction factor has a direct relation with hygral expansion, extensibility, and swelling like the physical properties of woven fabric in dyeing and finishing processes (Garcia, Pailthorpe, & Postle, 1994). The mechanical and thermal properties of woven fabric are also affected by weave structures specifically by different contractions (Matusiak, Sikorski, & Europe, 2011; Skelton, 1967). They are also responsible for changing the bending properties, shear resistance, stiffness, and other mechanical properties of the fabric (Banerjee, Mishra, Ramkumar, & Fabrics, 2010; Peerzada & Khatri, 2012). As the transverse

[1] Department of Apparel Merchandising & Management, BGMEA University of Fashion & Technology (BUFT), Nishatnagar, Turag, Dhaka-1230, Bangladesh.

[2] Department of Apparel Manufacturing & Technology, BGMEA University of Fashion & Technology (BUFT), Nishatnagar, Turag, Dhaka-1230, Bangladesh.

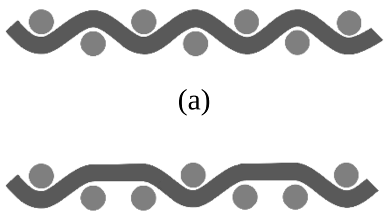
*Corresponding author email: yeasinali@buft.edu.bd

deflection of fabric is affected due to contraction factor. There is also a relation found between the contraction factor and the ability of the fabric to resist impact load. If the contraction of the fabric is higher, it will be more resistant to a ballistic load (Tan, Shim, & Zeng, 2005). Some studies also found that crimp in fiber form and contraction of fabric are also responsible for changing the comfort properties of the fabric.

Different weave structures show different contraction and they differ greatly in physical and chemical properties i.e., porosity, air permeability, moisture management properties, etc.(Backer, Zimmerman, & Best-Gordon, 1956; Fatahi & Yazdi, 2010; Zupin, Hladnik, & Dimitrovski, 2012). It has been reported that fabric with a high amount of contraction factor shows high values of softness, fullness and smoothness (Akter & Helali, 2021; Hoffman & Beste, 1951).

The contraction factor of warp yarn depends on ends per unit length, weft per unit length, warp yarn count, weft yarn count, weave design and amount of float (Maqsood, Hussain, Nawab, Shaker, & Umair, 2015).The contraction factor also affected by some other factors i.e., warp and weft yarn tension, fabric width, weft insertion system, and machine type, etc. (Yukhin & Yukhina, 1996). This contraction of warp yarn is an important parameter need to consider and predict before weaving. The required length of warp yarn is often based on previous experiences or trial and error methods. As this method is used only based on experience there is always a chance of fabric shortage, excessive fabric production or alteration in required quality (Maqsood et al., 2015).

The float of yarn in the interlacement of the fabric structure is one of the major factors that have a direct impact on yarn contraction (Jeon, Chun, & Hong, 2003) as well as on contraction with other factors; for instance, warp and weft yarn count (linear density), picks (weft yarn) density, ends (warp yarn) density, tension, etc. Depending on the methods of interlacement or amount of float the fabric structure can be classified as plain, twill, satin, or derivatives of these structures. As the float area change with varying the weave structure, there should be a change in fabric crimp and/or contraction factor.



(a)

(b)

Figure 1. High frequent interlacing (a) and less frequent interlacing (b)

The contraction of warp yarn in the woven fabric is affected directly by the weave structure, the weaving pattern or the pattern of warp and weft yarn interlacement (Adanur, 2020). Figure1 (a) the interlacement is pretty much identical to the plain structure where the fabric structure consists of the highest amount of interlacement and no free float (the zones where the warp and weft yarns do not touch and do not change the fabric side) thus, the yarn in plain weave has the highest amount of curvatures and therefore will obviously show a greater amount of contraction. On the other hand, in figure 1 (b) the weave consists of less interlacement with a regular free float and due to the less amount of curvatures, the weave in figure 1 (b) will show less contraction. As the curvature of yarn in fabric changes with changing the weaving pattern, and the weave structure, it is obvious that for different weave structures the contraction of yarn will change.

So, it is necessary to know how much the contraction change with varying the interlacing pattern means the weave structure for predicting the yarn required for a definite length of fabric production and for analyzing the properties affected by contraction factor. It is also well known that the plain shows the greatest, twill lower and satin derivatives show the lowest contraction factor, but there is no justification of this fact with proper research work. The objectives of this research work are; to collect the contraction data of different weave structures from the real production field and calculate the contraction factor of warp yarn, find out whether the variations of contraction factor of selected weave structures are significant or not and compare and analysis the variation in contraction factor for studied weave structures.

Thus, the aim of this research work is to study the contraction factor of warp yarn for different weave structures along with possible explanations for variation.

2. Materials and Methods

For conducting this study, eight type of weave structures with various float and interlacing sequences are selected and production data are collected from a reputed weaving industry in Bangladesh from the actual production line. All fabrics were manufactured in the 1st quarter of 2019 and collected from a single weaving machine model name TOYOTA air jet 610. The construction of all fabrics is 124×90/40×40 except one. Here, warp density = 124 ends per inch, weft density = 90 picks per inch, warp yarn count = 40 Ne (yarn linear density in English counting system), weft yarn count = 40 Ne, and fabric width = 56-57 inches. As in the rib structure, the subsequent two yarn of warp set interlace parallelly in weaving, in the practical field, the density of weft yarn in rib structure decrease to half of warp yarn density and a plied yarn of half linear density compared to warp yarn is used in the weft direction and create a weave visually resemble plain structure. For this reason, the construction of the rib fabric used for this experiment is 124×46/40×20/2, where, warp yarn density = 124 ends per inch, weft yarn density = 46 picks per inch, warp yarn count = 40 Ne, weft yarn count = 20/2 Ne (2 yarn of 40 Ne are twisted together) and fabric width = 56-57 inches.

The yarn used for producing all these fabrics is combed 100% cotton yarn and imported from India. After manufacturing, all fabrics were processed in the same finishing line consisting of singeing, desizing washing and stentering processes. After processing the fabrics were stored for 24 hours to 48 hours in standard testing conditions (65% ± 2 R.H & 26 ± 2^{0}C) and then measured the fabric length. The details of selected fabric types studied in this work are given in Table 1 and the length measurement data summary are given in table 2.

Table 1. Weave structures studied in this research.

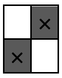
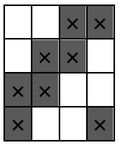
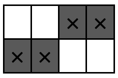
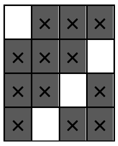
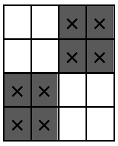
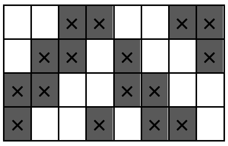
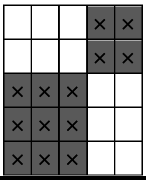
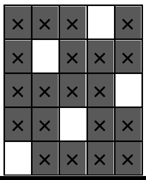
Name	Structural repeat	Interlacement ratio (warp + weft)	Name	Structural repeat	Interlacement ratio (warp + weft)
1. Plain		1+1	5. 2/2 Z Twill		0.5+0.5
2. Oxford (Weft rib) 1/1 (2)		1+0.5	6. 3/1 Z Twill		0.5+0.5
3. Matt 2/2 (2)		0.33+0.33	7. H. Bone 2/2 (8)		0.5+0.66
4. Matt 3/2 (3+2)		0.25+0.25	8. Satin (4/1)		0.4+0.4

Table 2. Fabric length, yarn length and contraction factor.

Weave Structure	Fabric No.	No. of Ends	Warp yarn length (yds)	fabric length (yds)	Contraction %	Mean Contraction %
Plain	A 1	6750	1535	1242	16.482	16.044
	A 2	6750	1847	1520	15.539	
	A 3	6750	1452	1154	17.769	
	A 4	6750	1853	1490	17.431	
	A 5	6966	1378	1087	18.215	
	A 6	7375	1562	1286	15.109	
	A 7	7440	3175	2598	16.913	
	A 8	7440	2307	1860	17.642	
	A 9	5590	3698	3189	12.683	
	A 10	7434	3572	3080	12.654	
Oxford	B 1	6030	3445	2944	13.382	15.331
	B 2	5990	1988	1604	17.304	
	B 3	5928	2423	2053	13.619	
	B 4	5984	2268	1895	14.683	
	B 5	5985	1987	1645	15.199	
	B 6	5985	2192	1827	14.827	
	B 7	5985	1464	1178	16.803	

	B 8	6075	1814	1491	15.601	
	B 9	6075	1464	1178	16.803	
	B 10	6032	1577	1299	15.092	
2/2 (2) Matt	C 1	7020	2417	2028	14.439	12.036
	C 2	7410	2430	2084	12.593	
	C 3	8047	4141	3735	8.838	
	C 4	6974	3335	2898	11.904	
	C 5	7368	4257	3838	8.903	
	C 6	7182	2996	2513	14.786	
	C 7	7074	3444	3056	10.105	
	C 8	7128	2256	1884	14.716	
	C 9	7410	2654	2291	12.170	
	C 10	7096	3335	2898	11.904	
3/2 (3+2) Matt	D 1	7995	2904	2556	10.606	12.862
	D 2	7995	2264	1997	10.027	
	D 3	8112	1960	1641	14.235	
	D 4	8112	2228	1923	11.894	
	D 5	7995	2323	1990	12.613	
	D 6	8060	3318	2906	11.212	
	D 7	8047	3267	2901	9.979	
	D 8	8250	2051	1672	16.529	
	D 9	8255	1869	1521	16.479	
	D 10	8019	2080	1727	15.048	
2/2 Twill	E 1	7410	1292	1033	16.950	14.796
	E 2	6840	1312	1089	13.948	
	E 3	6840	1607	1361	12.819	
	E 4	7434	1259	1016	16.124	
	E 5	7560	3647	3209	10.913	
	E 6	6804	3540	2994	14.294	
	E 7	6804	2107	1751	14.998	
	E 8	6804	1392	1134	15.661	
	E 9	6804	1813	1490	15.609	
	E 10	6804	1808	1467	16.648	
3/1 Twill	F 1	7493	3129	2682	13.007	13.531
	F 2	6963	1893	1561	15.425	
	F 3	7611	2628	2235	13.432	
	F 4	7540	2732	2302	14.275	
	F 5	6912	4051	3613	9.825	
	F 6	6912	2367	2003	13.688	
	F 7	6800	2312	1960	13.495	
	F 8	6800	2530	2168	12.727	
	F 9	7540	1824	1498	15.680	
	F 10	6912	1723	1446	13.755	
2/2 H. Bone	G 1	7434	3141	2740	13.175	14.058
	G 2	7560	1332	1156	11.765	
	G 3	5328	2160	1917	10.589	

	G 4	6912	2424	2086	14.286	
	G 5	6912	3712	3218	14.108	
	G 6	6912	4842	4210	14.062	
	G 7	6912	2552	2098	19.733	
	G 8	6912	4634	4002	14.793	
	G 9	7560	4360	3790	13.984	
	G 10	7560	2170	1867	14.087	
Satin	H 1	7068	3777	3297	11.649	11.073
	H 2	7068	4027	3617	9.188	
	H 3	7068	3445	3106	8.679	
	H 4	5850	1847	1540	14.456	
	H 5	6270	1410	1249	8.582	
	H 6	7932	2046	1717	14.125	
	H 7	6240	2964	2622	10.189	
	H 8	6435	2794	2413	12.205	
	H 9	6435	3940	3402	12.640	
	H 10	6867	4835	4359	9.018	

The relationship between the length of yarn and length of fabric produced from that particular length of yarn can be obtained by measuring the yarn entering the loom (yarn length in weavers' beam) and the length of fabric comes from the loom (fabric length in cloth beam after relaxation). In this research, to determine the contraction factor, the length of warp yarn in the warping process was measured and the length of fabric produced from that yarn length was measured after 24 hours of fabric manufacturing. Then, the contraction factor can be calculated from the following equation.

Contraction factor% = $(Y - F)/Y \times 100$, (1)

Where Y: Length of yarn used for weaving; F: Length of fabric produced from that length of yarn (Adanur, 2020).

But, after warping, the warp yarn needs sizing, drawing, denting and looming. For these preparation processes, an average of 40 yards of warp yarn become waste and hence the contraction factor was calculated after deducting 40 yards of yarn from the warp yarn length.

The mean contraction results for each weave structure are then calculated from the obtained results of 10 production line of each weave structure from the actual production stage. Then the variation in contraction factor of selected eight structures was compared and analyzed and the reasons for variation are also explained with relevant literature.

As there is a direct relationship between contraction and crimp, the crimp percentage is then calculated by the following relation and also analyzed and represent following.

Crimp % = $100T/(100-T)$ (2)

Here, T : Contraction factor or take-up %.

3. Result and discussion

The calculated results of the contraction factor of these weave structures with their average value and standard deviation are shown in the following table.

Table 3: Average contraction factor of selected eight weave structures.

Weave structure	Average value	St. Dev.
Plain	16.04	2.03
Oxford	15.33	1.32
2/2 Twill	14.80	1.86
2/2 H. Bone	14.06	2.38
3/1 Twill	13.53	1.62
3/2 (3+2) Matt	12.86	2.55
2/2 (2) Matt	12.04	2.23
4/1 Satin	11.07	2.24

To know whether the mean value of the contraction factor of selected fabric types varies significantly, an ANOVA test was performed using the null hypothesis that there is no significant difference among the contraction factors. The result obtained from the ANOVA test is shown in table 4.

Table 4. Result of the ANOVA test.

Source	DF	Sum of Square	Mean Square	F Statistic	P-value
Groups (between groups)	7	198.829737	28.4042481	6.666870	0.000004
Error (within groups)	72	306.756516	4.26050716		
Total	79	505.586252	6.39982598		

This ANOVA table is generated by STATISTICA12. Here the P-value is 0.000004, which is lower than the α-value (0.05). Since p-value < α, H_0 is rejected, whereas the null hypothesis (H_0) was, there is no significant difference among the means contraction factor of eight weave structures. As the alternative hypothesis is accepted, the difference among the mean contractions factor of studied weave structures is big enough to be statistically significant. When the results are represented by a barchart in a hierarchical order, the comparison among them can be visualized easily.

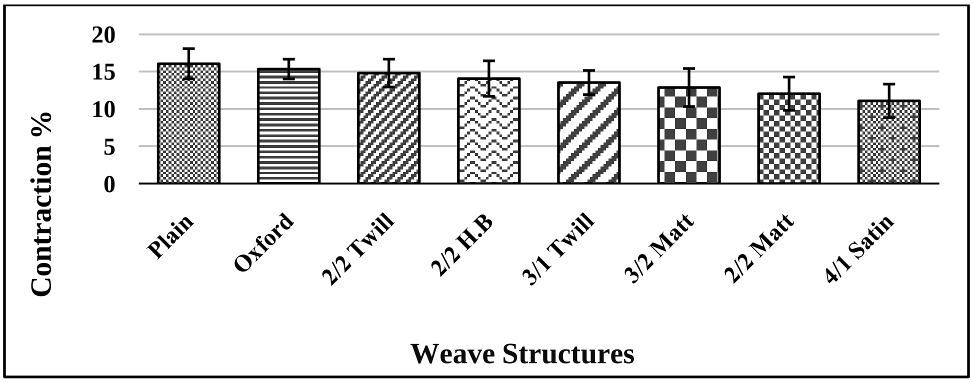


Figure 2. Contraction factors of selected weave structures.

Among all eight weave structures, the plain weave showed the highest contraction factor in warp yarn and satin (5 ends) showed the lowest result. The other weaves laid between these results. The possible reasons for the variation are explained below.

The plain weave showed the greatest contraction factor16.04%. As the interlacing ratio (ratio between the actual amount of interlacement and the highest amount of possible interlacement) (Belal, 2009) of plain weave is the highest (showed in table-1) compared to any other structures, the yarn followed the waviest path and the yarn also create the most frequent curvature along its path, this weave shows the highest contraction factor.

The oxford design, on the other hand, consists same interlacement ratio in warp direction but, less in weft direction 0.5, which means although the warp yarn passes with the curviest path, two warp yarns go parallelly in this structure and make the yarn more compact and less wavy compared to plain warp yarn. As a result, the oxford design showed comparatively less contraction 15.33% to the plain structure but it is still higher than other weave patterns.

The interlacement ratio and as the free field area of warp and weft thread of 2/2 twill and 2/2 herringbone design are the same, but they vary in contraction. The contraction behavior of 2/2 twill and 2/2 herringbone can be described by the skewness effect found in the woven fabric after relaxation. There is a tendency of skewness depending upon the weave structure used in woven fabric threads during relaxation, especially in twill weave (Alamdar-Yazdi & Polymers, 2005; Avanaki, Jeddi, & Polymers, 2014). In 2/2 twill weave, as the twill line went in one direction all over the fabric surface the distortion of warp yarn occurred seamlessly but in the herringbone weave, the twill line and weave reversed successively and it lowered the distortion and skewness tendency. As the distortion lower, the contraction also lowered for herringbone design compared to the twill weave of the same float.

Although the interlacement ratio of 2/2 twill and 3/1 twill is the same in both warp and weft directions (0.5), the free field in the 3/1 twill is greater than the 2/2 twill. So, there is a greater tendency to adjacent the weft yarn set (3 yarns) together in 3/1 twill than the two yarns set of 2/2 twill. J. B. Hamilton clearly mentioned this tendency(Hamilton, 1964). This is why the contraction factor of the 2/2 twill (14.8%) is greater than the 3/1 twill (13.53%).

In 3/2 (3+2) matt and 2/2 (2) matt structure, the interlacement ratio of 3/2(3+2) matt is lower (0.25 in both warp and weft direction) than 2/2(2) matt (0.33) and also the free field of 3/2(3+2) matt is higher than the 2/2(2) matt weave. But the contraction factor of 3/2(3+2) matt is higher (12.86) than 2/2(2) matt (12.04). This is obviously due to the symmetrical and balance interlacement of 2/2(2) matt. In 2/2(2) matt weave, the yarn in both warp and weft direction followed an identical and parallel path (always 2 floats) and that is why there is no distortion or tendency of skewness as described by J. B. Hamilton. In case of 3/2(3+2) matt, as the design is not balance compared to 2/2 twill, there is a tendency of the threads to bend greater in more floated area (3 floats) than the subsequent float (2 floats), the design of the 3/2(3+2) matt structure is not as compact as the 2/2(2) matt and hence the result.

The lowest result showed by satin weave can be understood easily by fabric geometry. As the interlacement of the satin weave is minimum and the threads in this structure follow the shortest and lowest wavy path compared to any other weave, the satin shows a minimum contraction of only 11.07.

The crimp percentage can be derived from the contraction result, with a simple conversion equation (2). The variation of crimp percentage of all studied weave structures also shows symmetrical results as contraction. Where the highest crimp possesses by plain weave and the lowest crimp comes from the satin weave.

Table 5. Crimp percentage of selected weave structures.

Weave structure	Contraction %	Crimp %
Plain	16.044	19.109
Oxford	15.331	18.107
2/2 Twill	14.796	17.366
2/2 H.B	14.058	16.358
3/1 Twill	13.531	15.648
3/2 (3+2) Matt	12.862	14.761
2/2 (2) Matt	12.036	13.683
4/1 Satin	11.073	12.452

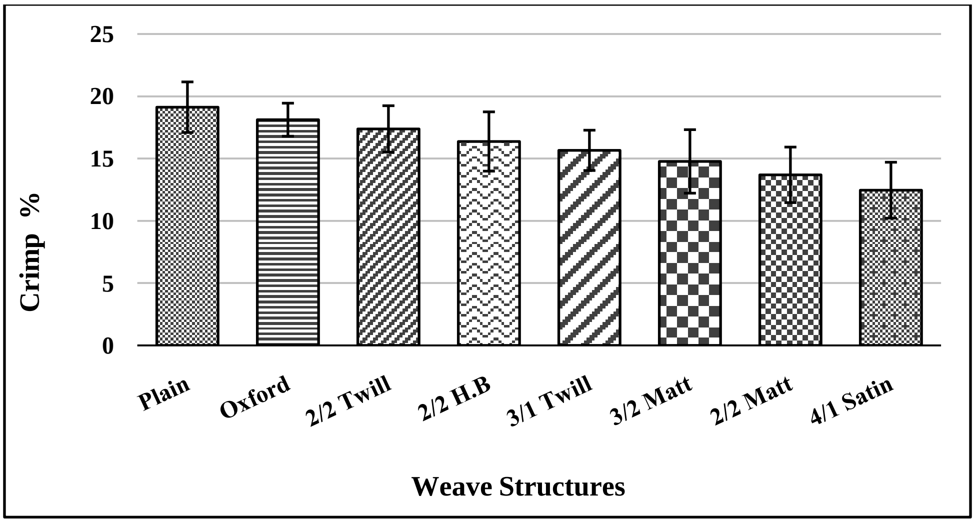


Figure 3. Comparison of crimp percentage of different weave structures

4. Conclusion

The contraction factor is an important aspect of both productions planning and designing of woven fabric. In this work, eighty fabric types of various weave structures have been taken from a real production line and compared variation in the contraction factor. The statistical test showed significant difference in the contraction factors among different weave structures. The plain structure showed the highest contraction factor and then the oxford, 2/2 twill, 2/2 (8) herringbone, 3/1 twill, 3/2 (3+2) matt, 2/2 (2) matt respectively. The Satin fabric showed the lowest result. From this study it can be concluded that the variation in contraction factor for varying weave structures does not only depend on any single parameter like the amount of float or interlacement ratio but rather depends on a variety of related factors i.e., amount &frequency of curvature, interlacing ratio, free field area, interlacement regularity within the repeat, weave compactness, the parallelism of threads, twill line, and skewness tendency, etc. Very few fabric types; for instance, E5, F5, and G7 showed exceptional result which varies greatly from the average value. Further study can be performed to investigate the influence of the yarn TPI, TM and elongation in overall fabric contraction. The findings of this research work can be used effectively to compare the contraction behavior of plain, twill, satin and other derivative weave structures as well as inproduction planning and manufacturing of woven fabric.

References

Adanur, S. (2020). Handbook of weaving: CRC press.

Akter, S., & Helali, M. M. (2021). The effect of mechanical crimp on the basic properties of jute yarn. Materials Today: Proceedings, 46, 425-432.

Alamdar-Yazdi, A. (2005). Behaviour of the twill weave woven fabrics during relaxation. Fibers and Polymers, 6(4), 306-312.

Avanaki, M. J., & Jeddi, A. A. (2014). Theoretical estimation of structural parameters in 2/2 twill woven structures. Fibers and Polymers, 15(9), 1956-1965.

Backer, S., Zimmerman, J., & Best-Gordon, H. W. (1956). The relationship between the structural geometry of a textile fabric and its physical properties: Part V. The interaction of twist and twill direction as related to fabric structure. Textile Research Journal, 26(2), 87-107.

Banerjee, P. K., Mishra, S., & Ramkumar, T. (2010). Effect of sett and construction on uniaxial tensile properties of woven fabrics. Journal of Engineered Fibers and Fabrics, 5(2), 155892501000500202.

Belal, S. A. J., (2009). Understanding textiles for a merchandiser: BMN Foundation.

Fatahi, I., & Yazdi, A. A. (2010). Assessment of the relationship between air permeability of woven fabrics and its mechanical properties. surfaces, 5(6).

Garcia, J. E., Pailthorpe, M. T., & Postle, R. (1994). Effects of dyeing and finishing on hygral expansion and other crimp-dependent physical properties of wool fabrics. Textile research journal, 64(8), 466-475.

Hamilton, J. B. (1964). 7—A general system of woven-fabric geometry. Journal of the Textile Institute Transactions, 55(1), T66-T82.

Hoffman, R. M., & Beste, L. F. (1951). Some relations of fiber properties to fabric hand. Textile Research Journal, 21(2), 66-77.Jeon, B. S., Chun, S. Y., & Hong, C. J. J. T. r. j. (2003). Structural and mechanical properties of woven fabrics employing peirce's model. 73(10), 929-933.

Maqsood, M., Hussain, T., Nawab, Y., Shaker, K., & Umair, M. (2015). Prediction of warp and weft yarn crimp in cotton woven fabrics. The Journal of The Textile Institute, 106(11), 1180-1189.

Matusiak, M., & Sikorski, K. (2011). Influence of the structure of woven fabrics on their thermal insulation properties. Fibres & Textiles in Eastern Europe, 19(5), 88.

Peerzada, M. H., Abbasi, S. A., &Khatri, A. (2012). Effect of weave structure on tensile strength and yarn crimp of three-dimensional fibre woven fabric. Science Internationalcomposites, 24(1),47-50.

Peirce, F. T. (1937). 5—The geometry of cloth structure. Journal of the Textile Institute Transactions, 28(3), T45-T96.

Skelton, J. (1967). 38—THE EFFECTS OF PLANAR CRIMP IN THE MEASUREMENT OF THE MECHANICAL PROPERTIES OF FIBRES, FILAMENTS, AND YARNS. Journal of the Textile Institute, 58(11), 533-556.

ASTM International. (2020). Standard Test Method for Yarn Crimp and Yarn Take-up in Woven Fabrics (ASTM D3883-04). Retrieved from https://www.astm.org/d3883-04r20.html

Tan, V. B. C., Shim, V. P. W., & Zeng, X. (2005). Modelling crimp in woven fabrics subjected to ballistic impact. International journal of impact engineering, 32(1-4), 561-574.

Yukhin, S. S., & Yukhina, Y. A. (1996). A theoretical consideration of the warp and weft contractions in woven fabrics. Journal of the Textile Institute, 87(3), 532-541.

Zupin, Ž., Hladnik, A., & Dimitrovski, K. (2012). Prediction of one-layer woven fabrics air permeability using porosity parameters. Textile Research Journal, 82(2), 117-128.