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Effect of yarn count and loop length on needle penetration force and needle cut index in single jersey fabrics

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The present study embodies the sewability of single jersey knitted fabric based on needle penetration force and needle cut index. Four types of single jersey fabric, viz. 100% cotton, polyester/cotton, polyester/lycra, and cotton/lycra, are taken for investigation. The materials are prepared on circular knitting machine by varying the yarn count and loop length. The influence of various parameters, viz. type of fibre, yarn count and loop length, on needle penetration force and needle cut index have been analyzed. In addition, the influence of seam direction on the needle cut index is also studied. A 3-level factorial design is employed to analyse the influence of there parameters. The statistical analysis shows that yarn count and loop length has a significant effect on needle penetration force and needle cut index. It has been observed that in all single jersey knitted fabrics, cotton-lycra and polyester-lycra half plated fabrics have higher value of needle penetration force than cotton and polyester/cotton. The test results also show that for both coarser yarn and finer yarn count, longer loop length gives a lower value of needle penetration force. The needle cut index decreases with increase in the yarn count and loop length. Also it is observed that, the needle cut index is more in wale direction as compared to that in course direction. It is also concluded that cotton fabric samples are more susceptible to needle damages as compared to their counterparts.

Keywords: Loop length, Needle penetration force, Needle cut index, Single jersey, Yarn count

1 Introduction

Single jerseys knitted garments are very popular in the modern fashion scenario as compared to woven structures. Single Jersey is the most common type of knitted fabric which is used to make underwear, outer clothing, leisure wear, sportswear and T-shirts. It is due to the ease of production, excellent elasticity and ability to resist wrinkling, but nowadays the requirement is not the only durability of garment, but it also has functional, comfort and handles properties[1,2]. In the garment industry, a lot of faults are observed in knit fabric from its manufacturing process to dyeing, finishing, and sewing which are unacceptable. These faults affect the quality of the knit fabric which ultimately creates a significant impact on the profit percentage. Quality in apparel product is very important, and product quality always means seam quality. The seam quality mainly depends on the strength, durability and the appearance of the seam itself[3,4]. A good quality seam must have flexibility and strength with no seaming damages. The needle penetration force and needle cut index are the parameter used to measure the seam quality[5,6]. During stitch formation, the fabric may get damaged due to mechanical damage or thermal damage. When fibre, yarns, and filaments break due to sewing action, it is referred to as mechanical damage[7]. Mechanical damages are caused when fabric restrict the penetration of a sewing needle. The needle penetration force does not only depend upon the spaces in the fabric but also needle profile, needle size, sewing machine setting and sewing material[8,9]. Sewing needle penetration forces and fabric deformation during sewing are effective factors for seam performance.

Illeez *et al.*[10] studied about improving sewability properties of various knitted fabrics with the softeners. The results revealed that the softener macro silicone emulsion had the lowest needle penetration force both inwale and course directions. Another study on investigation of knitted fabric sewability by Parthasarathi and Dheepika[11] concluded that the needle optimization helps to reduce the damages. The sewability based on needle penetration force of 1×1 rib knitted fabrics was done by Deniz and Gamze[8]. It was observed that in both walewise and coursewise directions as needle gauge becomes higher, the needle penetration force increases.

Needle cut is another important factor affecting seam performance. The quantitative value of needle cut index

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is used to determine the intensity of the needle cut damages in fabric. The needle cutting or yarn severance is due to the stiffness of yarn in fabric and a lack of mobility of yarn in fabric structure when sewing needle sews the fabric. Khadamalhosseini *et al.*[12] did the modeling of impact damage of sewing machine needle on woven fabric by the finite element method. It was concluded thatwith increase in needle diameter, fabric damages increase. Influence of fabric finishes on the seam quality of cotton/lycra denim fabric was investigated by Vino *et al.*[9]. They observed that better sewability was detected with needle size 14 and 16 for unfinished and finished cotton/lycra denim fabrics respectively. The needle cutting index was better for the unfinished fabric than finished denim fabric.

Needle cut is a significant sewing damage which occurs during woven and knitted garment construction. It is observed that the needle cut index has been studied earlier in woven fabrics and limited work is available about needle cut in knitted fabric. Hence, a critical and comprehensive approach is required to know more about the reduction of needle cut in knitted fabrics. The present study focuses on the effect of yarn count and loop length on needle penetration force and needle cut index in different single jersey fabrics.

2 Materials and Methods

2.1 Preparation of Single Jersey Fabric Samples

The single jersey fabric samples were prepared with 100% cotton, polyester/cotton, polyester-lycra, and cotton-lycra by varying yarn count and loop length. The detail of physical properties of single jersey fabrics are given in Table 1. All the single

Table 1 — Physical properties of single jersey fabric specification and properties

Fibre	Fabric code	Count, Ne/dtex	Stitch length, mm	Courses / inch	Wales / inch	Fabric mass, g/m^2	Thickness, mm
100 % Cotton	C1	24	2.6	54	34	182	0.99
	C2	24	3.0	48	38	176	0.65
	C3	24	3.4	48	35	171	0.59
	C4	30	2.6	54	41	178	0.92
	C5	30	3.0	52	38	151	0.64
	C6	30	3.4	50	38	139	0.57
	C7	34	2.6	61	39	177	0.91
	C8	34	3.0	59	37	150	0.64
	C9	34	3.4	56	33	137	0.55
Polyester/cotton (70/30)	PC1	24	2.6	71	40	186	0.67
	PC2	24	3.0	65	37	167	0.63
	PC3	24	3.4	62	35	165	0.61
	PC4	30	2.6	69	47	163	0.65
	PC5	30	3.0	60	36	157	0.64
	PC6	30	3.4	58	35	155	0.63
	PC7	34	2.6	64	43	127	0.62
	PC8	34	3.0	49	39	126	0.61
	PC9	34	3.4	43	35	124	0.61
Polyester-lycra	PL1	24/40	2.6	95	57	237	0.70
	PL2	24/40	3.0	74	41	239	0.72
	PL3	24/40	3.4	70	39	245	0.73
	PL4	30/40	2.6	96	59	231	0.68
	PL5	30/40	3.0	94	55	235	0.69
	PL6	30/40	3.4	92	54	240	0.72
	PL7	34/40	2.6	97	61	229	0.67
	PL8	34/40	3.0	95	59	233	0.68
	PL9	34/40	3.4	95	57	238	0.70
Cotton-lycra	CL1	24/40	2.6	71	47	237	0.90
	CL2	24/40	3.0	71	41	241	0.92
	CL3	24/40	3.4	69	38	252	1.07
	CL4	30/40	2.6	72	49	236	0.88
	CL5	30/40	3.0	69	47	238	0.91
	CL6	30/40	3.4	68	47	248	1.03
	CL7	34/40	2.6	72	51	230	0.87
	CL8	34/40	3.0	70	50	233	0.89
	CL9	34/40	3.4	69	48	245	1.01

C–100% cotton, PC–Polyester/cotton, PL–Polyester/lycra, and CL–Cotton/lycra.

jersey fabric samples were prepared with three different levels of yarn count and loop length. The fabric samples were produced on a circular knitting machine (MV4-Mayer and Cie) of gauge 28. The spandex yarn of 40 denier was used to produce the cotton-lycra and polyester-lycra half plated knitted fabrics. The finishing process of raw materials was done according to industrial parameters. The finished fabric samples were conditioned for 24 hour sat standard temperature (27±2°C) and relative humidity of (65±2%) before sewing operation.

The standard method, ASTM D-3887 was used to measure knit fabric wales per inch (WPI) and courses per inch (CPI) and fabric thickness (mm) was determined according to ASTM D 1777. Knitted fabric areal density was calculated according to ASTM D3776 and ASTM D 3887 was used for knit fabric loop length (mm) measurement. The scheme of experimental runs was done accordance with 3-level factorial experimental design using Design Expert 6 software. The levels of process variable as shown in Table 2 were chosen based on the literature survey and parameters used by the knitting industries.

Table 2 — 3-level factorial design

Factors	Coded levels		
	-1	0	+1
Yarn count (A) , *Ne*	24	30	34
Loop Length (B), mm	2.6	3.0	3.4

2.2 Measurement of Needle Penetration Force

The needle penetration force on single jersey knitted fabrics was measured on Instron tensile testing machine. The fabric sample was held on the bottom jaw and the sewing needle was fastened to the upper jaw as shown in Fig. 1. The position of fabric surface was changed during the test procedure to have different data for all possible needle piercing position onto the fabric sample. To simulate the movement of the sewing needle in the sewing machine, penetration was performed five times for each fabric surface. The needle insertion speed was 305 (mm/min) and depth of needle insertion into the fabric structure was 12 (mm). The average of five readings for each sample was used to develop a regression equation by using design expert software.

2.3 Measurement of Needle Cut Index

The seam damage by needle action during the sewing process is known as needle cut. Needle cut is the process of the breaking of yarns in the fabric as the needle enters the seam. The needle cut index is measured according to ASTM-D 1908 test method. Needle cut index is calculated as:

$$\text{Needle cut Index} = \frac{\text{No.of loops cut/inch}}{\text{No.of loops in fabric/inch}} \times 100 \qquad \ldots (1)$$

According to ASTM 1908, test specimens were prepared from each fabric samples in the course and wale direction. Then all fabric samples were sewn with 24 Tex/ 3ply spun polyester sewing thread (breaking strength 28.59 cN/tex, breaking elongation 15.04 %, and initial modulus 136.5 cN/tex), and 90/14 needle size on an over-lock sewing machine (3000 rpm). ISO-514 stitch type was applied using 12 stitches/inch. The sewn fabric surface was analyzed for needle cut index using an imageanalyzer system (Leica).The quantitative value of needle cut index is used to determine the intensity of the needle cut damages in fabric. The average of five readings for each sample in the course and wale direction was used to develop a regression equation by using design expert software.

3 Results and Discussion

3.1 Influence of Yarn Count and Loop Length on Needle Penetration Force

The statistical analysis shows that the yarn count and loop length have a significant effect on needle penetration force as shown in Table 3. The polynomial regression equations are developed along with the interaction between the yarn count and loop

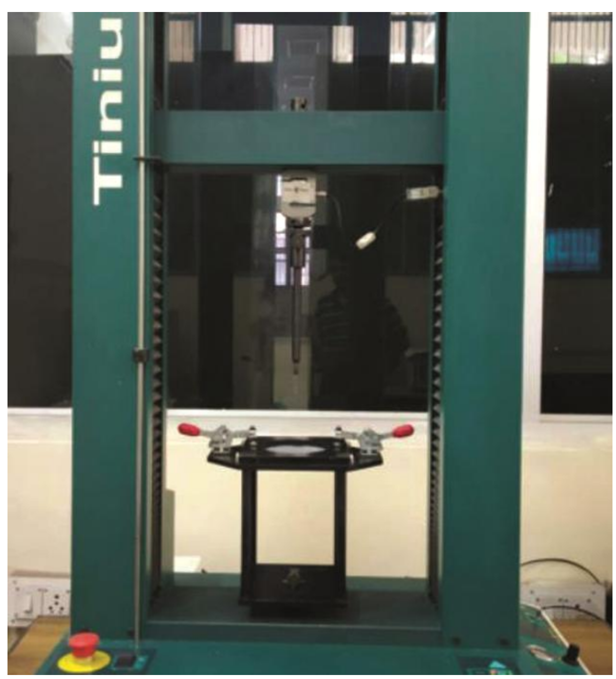

Fig. 1 — Instron tensile tester machine with a needle bar attachment

Table 3 — Regression equations for different properties

Property	Fabric	Regression equations	R^2	F- value
Needle penetration force (NPF), N	100 % cotton	$NPF = +3.18 - 0.035 * A - 0.035 * B - 0.015 * A^2 + 4.655E - 003 * B^2 + 0.000 * A * B$	0.9824	77.93
	Polyester/cotton	$NPF = +2.39 - 0.033 * A - 0.028 * B - 7.586E - 003 * A^2 - 2.586E - 003 * B^2 + 0.000 * A * B$	0.9526	77.93
	Polyester+ lycra	$NPF = +3.48 - 0.043 * A - 0.032 * B - 0.030 * A^2 + 0.015 * B^2 + 0.015 * A * B$	0.9920	173.97
	Cotton+ lycra	$NPF = +3.97 - 0.067 * A - 0.055 * B + 5.862E - 003 * A^2 + 0.011 * B^2 + 0.028 * A * B$	0.9713	47.39
Needle cut index (NCI), % (Course)	100 % cotton	$NCI = +2.72 - 0.14 * A - 0.79 * B + 0.61 * A^2 + 0.22 * B^2 - 0.018 * A * B$	0.9419	9.72
	Polyester/cotton	$NCI = +1.59 - 0.23 * A - 0.55 * B + 0.21 * A^2 + 0.044 * B^2 + 0.028 * A * B$	0.9998	6045
	Polyester+ lycra	$NCI = +2.19 - 0.12 * A - 0.58 * B + 0.10 * A^2 - 0.14 * B^2 + 0.18 * A * B$	0.9604	33.92
	Cotton+ lycra	$NCI = +0.18 + 0.043 * A - 0.79 * B + 2.08 * A^2 + 0.79 * B^2 + 0.065 * A * B$	0.9019	12.88
Needle cut index (NCI), % (Wale)	100 % cotton	$NCI = +2.83 + 0.038 * A - 0.86 * B + 2.33 * A^2 + 0.023 * B^2 - 0.21 * A * B$	0.9559	13.00
	Polyester/cotton	$NCI = +1.81 - 0.15 * A - 0.55 * B + 0.62 * A^2 + 0.32 * B^2 - 0.14 * A * B$	0.9432	23.23
	Polyester+ lycra	$NCI = +3.19 - 0.26 * A - 0.93 * B + 0.12 * A^2 - 0.12 * B^2 - 0.067 * A * B$	0.9956	317.29
	Cotton+ lycra	$NCI = +2.16 - 0.13 * A - 0.31 * B + 0.47 * A^2 + 0.64 * B^2 + 0.055 * A * B$	0.9246	17.16

A – Yarn count (Ne) and B–loop length (mm).

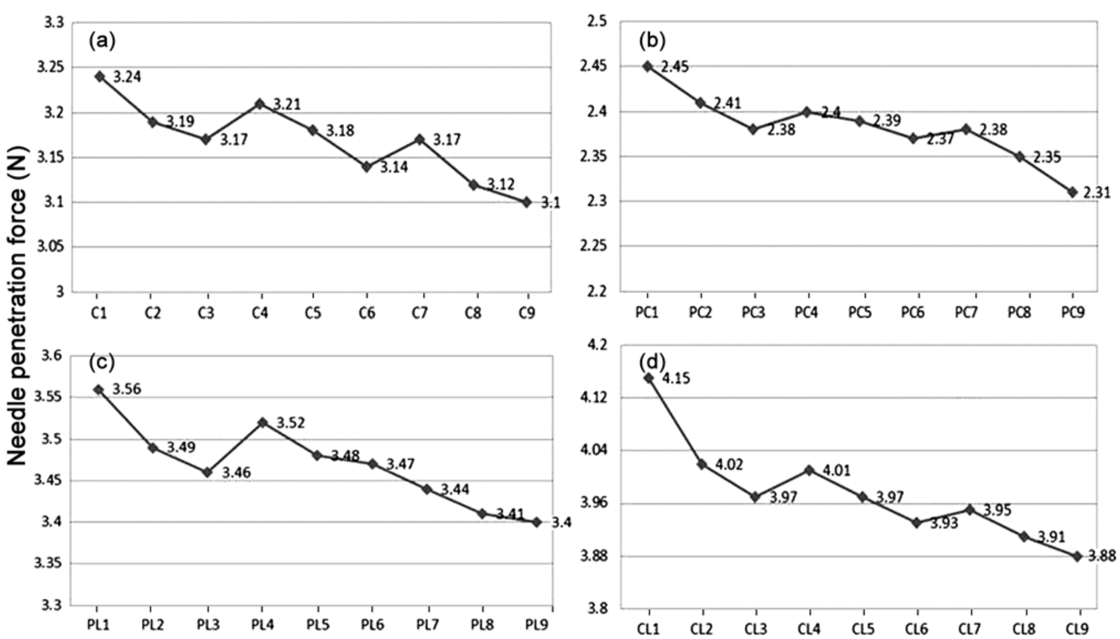

Fig. 2 — Needle penetration force (NPF) for (a) 100% cotton, (b) polyester/cotton, (c) polyester-lycra, and (d) cotton-lycra fabric samples

length. All regression equations and F-value are given in Table 3, at 95% confidence level. It is observed that the yarn count and loop length do not have any combined influence (A×B=0) on NPF in case of 100% cotton and polyester-cotton fabrics.

As shown in Fig. 2, the yarn count and loop length increase, and needle penetration force decreases in all the knitted fabrics. With the increase in yarn count, yarn becomes finer and tightness factor decrease, leading towards open structure. Also, as the loop length increases the structure become more open and there is less restriction on yarn movement in the fabric. Thus, there is less frictional contact between yarn and sewing needle. Among 100% cotton and polyester/cotton blend fabrics, polyester/cotton has the least values of needle penetration force. This may be due to the fact that polyester fibre, being a synthetic and fine fibre which, has less bending rigidity than cotton fibre and hence experiences less needle penetration force. Cotton has rough surface as compared to polyester and provides more surface area for frictional contact. So, cotton exhibits more needle penetration force as compared to polyester/cotton fabrics.

In lycra knitted fabric samples, cotton-lycra shows more needle penetration force than polyester-lycra. This happens as the loop length increases fabric volume and fabric weight increases, which leads to compacting of the fabric structure. As cotton loop has more bending rigidity than polyester, the volume and weight are more in case of cotton-lycra fabric. Hence, the needle penetration force increases as fabric becomes compact and fabric components cannot move easily.

It is observed that out of all plain knitted fabrics, highest value of needle penetration force is obtained in cotton-lycra fabrics and lowest value in case of polyester/cotton fabric. This happens because in half plated knitted structure, lycra filament tends to contract the knit loops but the yarn without lycra plated develops enormous surface appearance. Thus, this enormous surface have maximum frictional contact and increasing the needle penetration force during the sewing process. The polyester/cotton fabric samples have the lower values of needle penetration force due to the same reason explained earlier. The value of needle penetration force in all knitted fabrics decreases when longer loop length is combined with coarser yarn count and finer yarn count.

3.2 Needle Cut Index

Needle cut index is the ratio of number of loops cut per inch to the number of loops in fabric per inch. As shown in Fig. 3, the needle cut mainly occurs at the penetration point of the sewing needle.

3.2.1 Effect of Yarn Count and Loop Length on Needle Cut Index

The test results show that there is significant effect of yarn count and loop length on needle cut index. The polynomial regression equations (R^2 values) and F-value are given in Table 3.

The surface plots are extracted for analyzing the relationship between loop length and yarn count (Fig. 4). It is observed that at higher value of loop length and medium value of yarn count, the needle cut index decreases for 100% cotton and polyester/cotton knitted fabrics. This may happen that as loop length increases fabric becomes less compact and has low frictional characteristics. With increase in yarn count yarn becomes finer and has less friction than coarser yarn, due to which friction between sewing needle and fabric is low. Further increase in yarn count, makes the yarn more delicate towards sewing needle penetration and increases the chances of needle cut. In case of polyester-lycra fabrics, with finer yarn count and longer loop length, needle cut index decreases. This happens due to the more stretch abilityand recovery behaviour of polyester as compared to cotton. Also the knit loops are tightly packed in case of shorter loop length due to which sewing needle experiences more frictional force to pass through the yarn loop. Therefore, with longer loop length and finer yarn count, sewing needle easily enters the fabric without damaging the fabric structure. In case of cotton-lycra fabrics, needle cut index initially decreases and then again increases with increase in the yarn count and loop length. This is because with increase in yarn count and loop length, the lycra contract the knit loop and structure becomes more compact. So, may be, the yarn leads to the rupture in fabric structure as frictional force increases during the sewing process. Also, it is observed that the needle cut index is more in wale direction than in course direction for all types of fabrics. This happens, as in knitted structure each stitch is interloping vertically with the previous stitch in wale direction, so there are more chances of the loop to rupture due to the consecutive loop in one row.

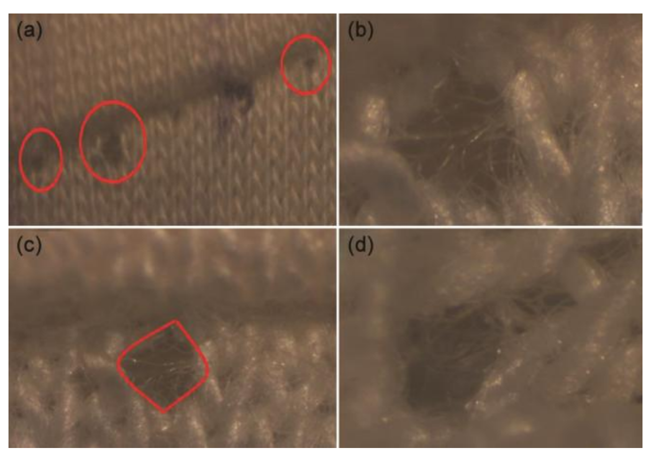

Fig. 3 — Appearance of needle cut in course direction of fabric C1: (a) needle hole along the seam line, (b) loop rupture behaviour in single needle hole; and fabrics CLI: (c) needle hole along the seam line, (d) loop rupture behaviour in single needle hole

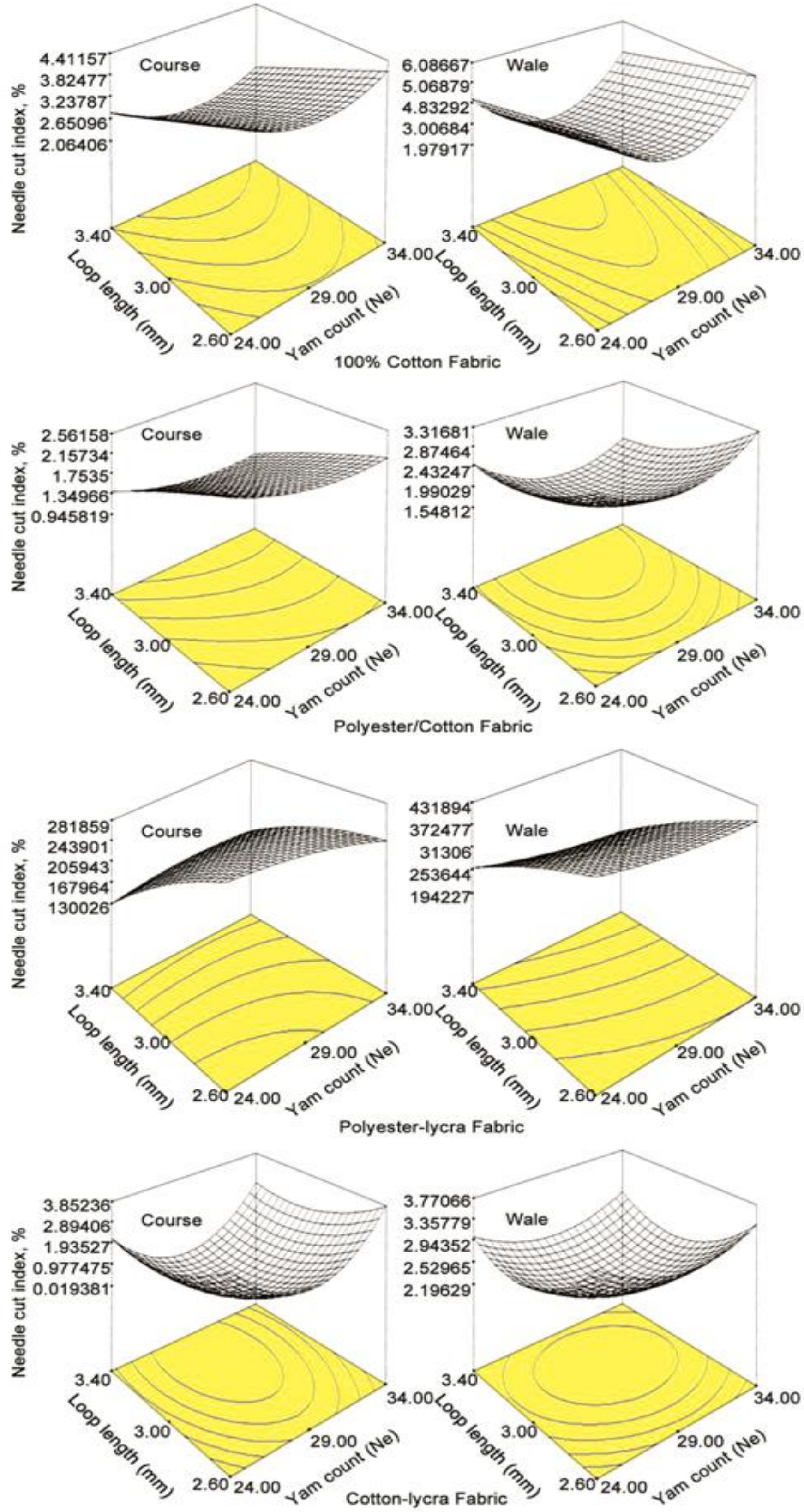

Fig. 4 — Needle cut index of different fabric samples

The polyester/cotton blend fabrics show lowest value of needle cut index as compared to other knitted fabrics. During the sewing operation, in case of polyester/cotton fabric knit loop in fabric structure moves over each other to change their arrangement and are forced out of the path of the needle. So, it experiences some stretch and extension. The extension force does not reach to the breaking load of the yarn easily because of greater ability of polyester to withstand repeated distortion created by sewing needle. In the case of cotton, the extension force reaches to the breaking load of the yarn, thus loops break and result in a hole at the seam line in the fabric. So, cotton fabric exhibits more damages than polyester/cotton blend.For half plated knitted fabrics, lower needle cut index is obtained than 100% cotton fabrics but more than polyester/cotton fabrics. The half plated knitted structure has a wavy and rougher surface but also has good elastic properties as compared to cotton fabrics. So, when the needle penetrates into the fabric surface it's easy to displace the yarn loop to another place rather than rupturing of the loop.

4 Conclusion

4.1 The yarn count and loop length parameters have a statistically significant impact on both needle penetration force and needle cut indexfor single jersey knitted fabric. With increase in yarn count and the loop length, needle penetration force value for all type of single jersey fabrics decreases. The value of needle penetration forcedecreases with longer loop length both in case of coarser and finer yarn count. On the other hand, the needle cut index initially decreases and then again slightly increases with increase in the yarn count in case of 100% cotton and cotton-lycra fabric samples. The needle cut index decreases with increase in loop length for all single jersey fabric samples except for cotton-lycra fabric samples. Also, the needle cut index is higher in wale direction than in course direction in all the samples.

4.2 The needle penetration force and needle cut index are affected by fibre type, yarn count and loop length. Among the all knitted fabrics, polyester/cotton single jersey fabrics with finer yarn count and longer loop length give better seam performance.The polyester/cotton blended yarn has high elongation and recovery properties than 100% cotton but lower than half plating fabrics. Due to its ability to withstand repeated distortion created by sewing needle, it gives good quality of seam. But in case of half plating fabric, cotton or polyester yarn breaks before rupture of lycra filament in knitted structure. Thus, cotton-lycra and polyester-lycra fabrics have lower seam performance than polyester/cotton fabrics.

4.3 In all single jersey knitted fabrics, cotton-lycra and polyester-lycra fabrics have higher value of needle penetration force than cotton and polyester/cotton, which could be due to voluminous increase of lycra fabric structure which increases fabric weight. The optimum of yarn count and loop length helps to reduce the penetration force. Also it is observed that half plated knitted fabric exhibits more penetration force but lower needle cut index as compared to cotton fabrics. In half plating fabric samples, with increase in yarn count and loop length fabric weight as well as compactness of fabric increases due to lycra insertion.

4.4 100% cotton single jersey fabrics have higher needle cut index among all other fabrics. On repeated distortion generated by sewing needle in sewing process, cotton has less capability to survive because of low elongation and recovery propertiesof cotton fibre. The cotton single jersey fabric samples are more susceptible to needle damages. This happens, when cotton fabric dry out it becomes brittle and usually lose strength during the sewing process. So, sew ability of 100% cotton single jersey fabrics is poor. To improve the sew ability of cotton fabric, proper maintained relative humidity.

References

1 Sadek R, El-Hossini A M, Eldeeb AS & Yassen AA, *J Eng Fibers Fabrics*, 7 (2) (2012) 11.
2 Abdessalem SB, Abdelkader YB, Mokhtar S & Elmarzougui S, *J Eng Fibres Fabrics* 4 (4) (2009) 30.
3 Choudhary AK, Sikka, MP and Bansal P, *Res J Text Apparel*, 22 (2) (2018) 109.
4 Parthasarathi V, Revathy S, Praveena R & Saranya S, *Int J Appl Eng Tech*, 4 (1)(2014)32.
5 Stylios G K & Zhu R, *J Text Inst*, 2 (1998) 411.
6 Maarouf MA, *J Basic Appl Sci Res*, 5 (10) (2015) 24.
7 Thilagavathi G & Viju S, *Process Control in Textile Manufacturing* (Woodhead Publishing Series in Textiles), (2013). 428. doi:10.1533/9780857095633.3.428.
8 Deniz MA & Gamze GB, *Autex Res J*, (2019) 1. DOI: 10.2478/aut-2019-0007.
9 Vino N, Kumar GR & Das S, *Pak Text J*, 67 (1) (2018) 62. DOI: 10.13140/RG.2.2.32982.96322, 62-68.
10 Illeez AA, Dalbasi ES & Kayseri GO, *Procedia - Social Behavioral Sci*, 195 (2015) 2786.
11 Parthasarathi V & Dheepika SP, *J Text Fashion Tech*, 2 (2016) 1.
12 Khadamalhosseini N, Mohammad NI, Masoud L & Saeed SN, *J Text Polym*, 1 (2013) 19.