STUDIES ON COMPRESSIBILITY OF WOVEN TERRY FABRICS

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Abstract

Compression is a decrease in intrinsic thickness with an appropriate increase in pressure. The compressibility of the terry fabric depends on fibre properties, yarn parameters, weaving parameters, loop length, loop density, loop geometry and post weaving treatment. In this research, all the factors responsible for fabric compression are studied. It has been observed that loop density, loop length, loop shape factor, pile yarn twist, pile yarn count, fibre length and pile yarn structure has a significant effect on the compression behaviour of the terry fabric. With increase in the loop shape factor, loop length and loop density, the linearity of compression curve, resilience increases and specific compression energy reduces which depict that the fabric is getting better in terms of softness to touch.

Introduction

Compression is a decrease in intrinsic thickness with an appropriate increase in pressure. Intrinsic thickness can be defined as the thickness of the space occupied by a fabric subjected to barely perceptible pressure [1]. Compression is one of the important properties of terry fabric, in addition to friction and bending. Since static compression gives an indication of the material’s mechanical springiness, the understanding & measurements of fabric compression have become increasingly important. Easily compressible fabric is likely to be judged as soft, possessing a low compression modulus or high compression. The low-load compression behaviour of woven fabrics is very important in terms of handle and comfort [2]. Fabric compression, surface and bending properties are the three most important properties for predicting overall handle and associated quality attributes. The limit of compressibility depends on the yarn arrangement while the yarn structure is less important [3]. Mechanical comfort of fabric is becoming more demanding as the users are getting more and more quality conscious [4, 5]. The properties of terry fabric depend not only on their raw material, but also on the structure. There are some other factors, such as surface characteristics, pile geometry, loop length, pile density, loop shape that must be studied for their influence on compression properties of terry fabrics. Hence, the effect of various fibre, yarn and fabric variables on compression properties has been studied. In addition to this, the key variables contributing to the compression behaviour have been optimized by using Box and Behnken design of experiments.

1 Materials and Methods

1.1 Materials

A wide range of terry fabric samples were produced on the rapier and air jet weaving machines under industrial manufacturing conditions. Samples were developed by selecting key variables which include pile yarn ply as single, two plies and four plies; fibre mix as 100% cotton J-34,100% cotton MCU-5, J-34+PVA, MCU-5+bamboo; low twist yarn, normal twisted yarn, zero twisted yarn; combed yarn and carded yarn; ring spun yarn and rotor spun yarn and fabric parameters such as pick density, pile height, pile ratio, loop density and fabric areal density.

1.2 Methods

1.2.1 Compression properties testing

Compression properties were measured on KES-FB3. The instrument gives linearity of compression, compression energy and compression resilience apart from thickness of the sample. The compression jaw works on a test area of 2 cm^2 with a compression velocity = 0.02 mm/sec.

1.2.2 Optimization of variables for compression properties

Three most important variables were selected by using Johnson's relative weight analysis method. Using Box-Behnken [6] design of experiments, these variables were optimized for the better compression properties. The details of Box-Behnken design are given in Table 1 and 2.

Tab. 1: *Variables and their levels in Box-Behnken Design*

Variable	**-1**	**Levels**	
		0	**+1**
Independent Variables			
A=Loop Density [Loop/Inch^2]	40	45	50
B=Loop Length [mm]	12	15	18
C=Loop Shape Factor	0.48	0.55	0.62
Dependent Variables			
Y_1= Linearity of compression curve			
Y_2 = Compression energy [gf.cm/cm^2]			
Y_3 = Compression resilience [%]			

Source: Own

Tab. 2: *Box-Behnken Experimental Design with Measured Responses*

Loop density	**Loop length**	**Loop shape factor**	**LC**	**WC**	**RC**
0	-1	-1	0.28	1.29	57.2
-1	-1	0	0.31	1.20	61.8
-1	0	-1	0.34	1.16	63.2
0	1	-1	0.35	1.13	65.4
-1	1	0	0.38	1.04	68.5
0	-1	1	0.41	1.00	71.5
1	-1	0	0.42	0.90	74.8
-1	0	1	0.45	0.78	76.4
1	0	-1	0.46	0.75	78.3
0	0	0	0.51	0.72	80.3
1	1	0	0.52	0.69	82.1
0	1	1	0.54	0.64	83.1
1	0	1	0.57	0.55	84.2

Source: Own

2 Results & Discussion

2.1 Effect of different variables on the compression characteristics of terry fabrics

The effect of different fibre, yarn and fabric variable on the compression characteristics has been studied and its results are described in this section. Values of compression resilience are scaled down by 10 times and the values of frictional roughness are scaled up 10 times to make them presentable with other properties. WC is the specific compression energy that is the ratio of compression energy to the change in fabric thickness during the compression test.

2.1.1 Effect of fibre quality

Pile yarn having blend of J-34 and Bamboo fibre improves the compression properties of terry fabrics. The results from this blend are even better than from MCU-5 cotton yarn. This may be due to the fact that mixing high staple length bamboo fibre increases the average staple of the blend and forms a softer yarn. The loops produced from this yarn have a high loop shape factor and better orientation.

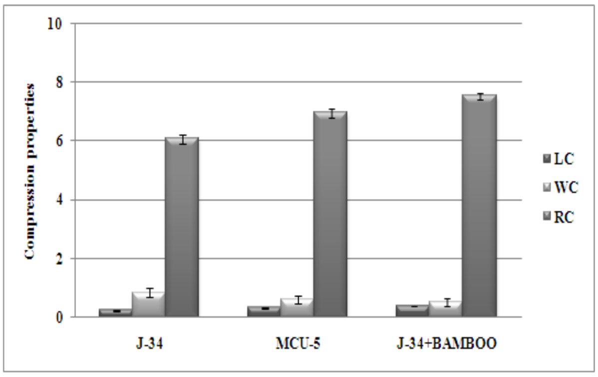

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Fig. 1: *Effect of fibre quality on compression properties*

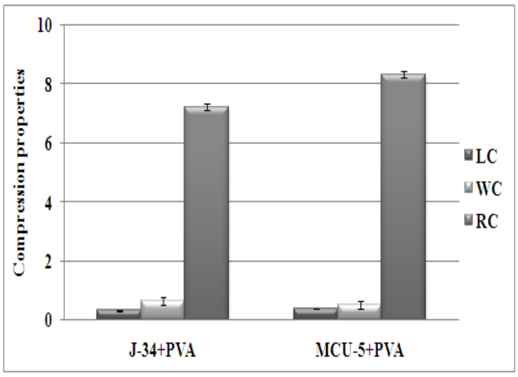

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Fig. 2: *Effect of fibre quality on compression properties*

Figure 2 shows that mixing PVA with cotton improves the compression properties and the effect of fibre length is more pronounced than the effect shown in Figure 1.

2.1.2 Effect of ring and rotor yarn

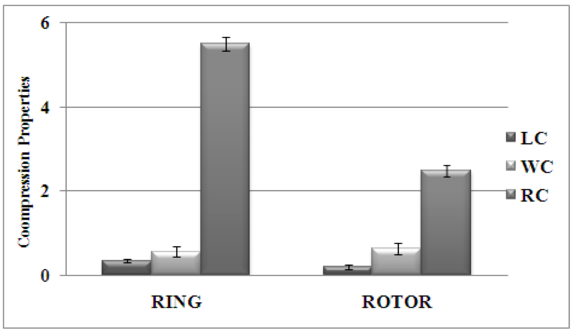

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Fig. 3: *Effect of ring and rotor yarn on the compression properties*

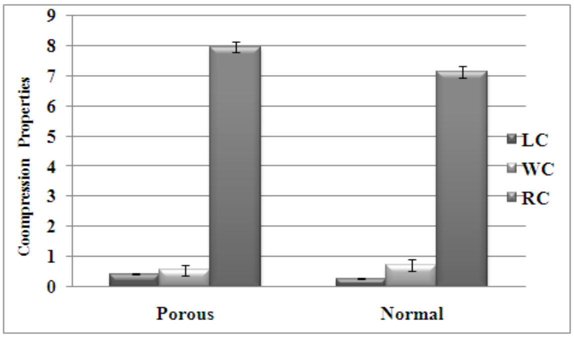

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Fig. 4: *Effect of porous yarn on the compression properties*

Fabric produced using ring pile yarn (Figure 3) shows high LC, RC and low WC. This behaviour shown by ring pile yarn fabric compared to the rotor yarn fabric is due to the fact that the rotor yarn loops were fallen on the fabric surface due to high twist and this is not a good quality sign for a terry fabric. The improved compression properties of ring pile terry fabric may be due to the core twist structure and high twist of the rotor yarn.

2.1.3 Effect of porous yarn

Terry fabric produced using porous pile yarn (Figure 4) exhibits high LC, RC and low WC compared to those produced by using normal pile yarn. The reason behind this superior compression behaviour is because of the bulky yarn structure. Bulky yarn produces soft, stable and well oriented loops on the fabric surface which gives improved compression behaviour to the terry fabric.

2.1.4 3.2.4 Effect of pile yarn count

Terry fabric produced using finer pile yarn count (Figure 5) exhibits better compression characteristics. LC, RC increases and WC reduces with increase in pile yarn fineness. The reason behind this behaviour may be due to the fact that finer pile yarn produces loops with high loop shape factor. These loops are easily compressible, which leads to better surface and compression behaviour of terry fabrics.

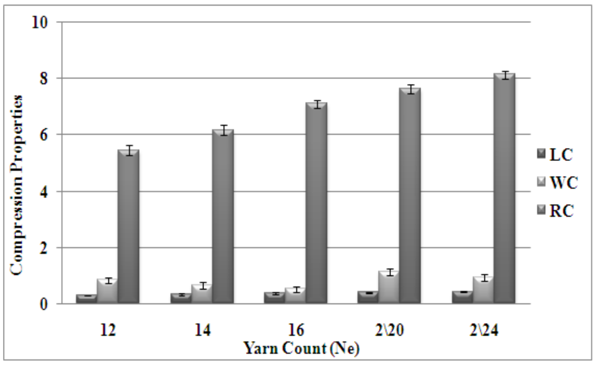

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Fig. 5: *Effect of yarn count on compression properties*

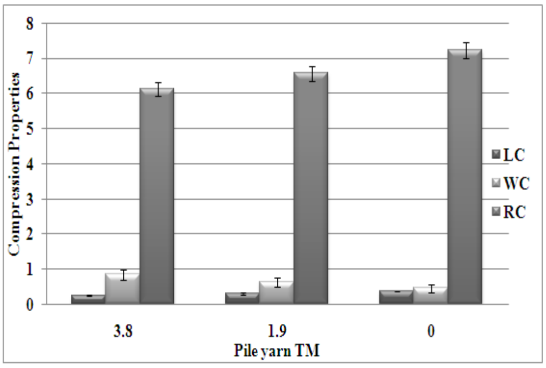

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Fig. 6: *Effect of pile yarn twist on the compression properties*

2.1.5 Effect of pile yarn twist

Terry fabric produced from zero twisted pile yarn (Figure 6) exhibits high LC, RC and low WC. The reason behind this improved in surface and compression characteristics of terry fabrics may be due to the fact that the zero twisted yarns are more bulky than normal twisted yarns. Microscopic examination reveals that the fibres are almost parallel and the structure is open, which leads to a fluffy fabric surface. This type of fabric surface is more uniform and offers lower resistance to movement than those of high twisted pile yarn fabric.

2.1.6 Effect of wrap yarn

It has been observed earlier that terry fabric produced from zero twisted yarn exhibits better compression behaviour than that from high twisted pile yarn fabric. Here it has been tried to further enhance the said characteristics using a special pile yarn known as wrap yarn. Figure (7) clearly shows that the terry fabrics produced from wrap pile yarn have better compression properties than that from zero twisted pile yarn. This may be attributed to the structure of the wrap yarn. Similarly to the zero twisted yarn, the fibres are almost parallel to each other in wrap yarn. But the body of the yarn is bounded with the wrapper yarn that leads to the production of well stable and uniformly oriented loops of the fabric surface.

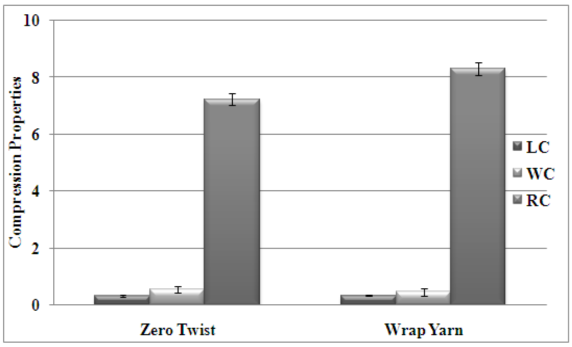

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Fig. 7: *Effect of wrap yarn on the compression properties*

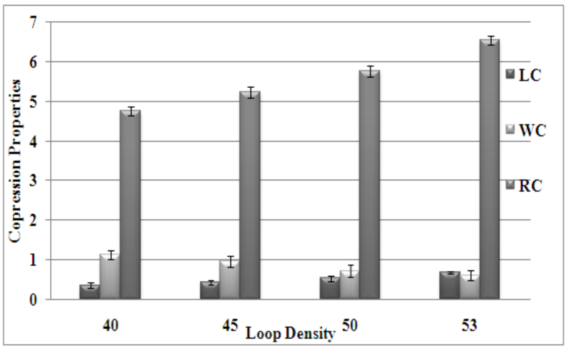

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Fig. 8: *Effect of loop density on the compression properties*

2.1.7 Effect of loop density

Terry fabrics having high loop density exhibit high LC, RC and low WC as shown in Figure 8. LC, RC increases and WC reduces with increase in loop density. In high loop density terry fabrics, loops remain very close to each other and cover the ground fabric very well, which may be the reason for its improved compression characteristics. It can be seen from Figure 8 that increasing loop density beyond the rate of change in the compression properties reduces a bit. The reason behind this may be the fact that with the increase in loop density the fabric compactness increases and beyond certain point it becomes dominant.

2.1.8 Effect of loop length

Figure 9 shows that the terry fabrics having loops of high length exhibit high LC, RC and low WC. Increasing loop length from 8.5 mm to 15 mm increases LC, RC and reduces WC but increasing loop length to 18 mm the trend of change in the properties reversed. This may be attributed to the fact that loop of 18 mm length may not hold itself standing straight and falls down on the fabric surface leading to matting. This matting makes the fabric compact which causes the deterioration in compression properties. This depicts that the loop length should be optimized for increasing the performance of terry fabrics in terms of compression properties.

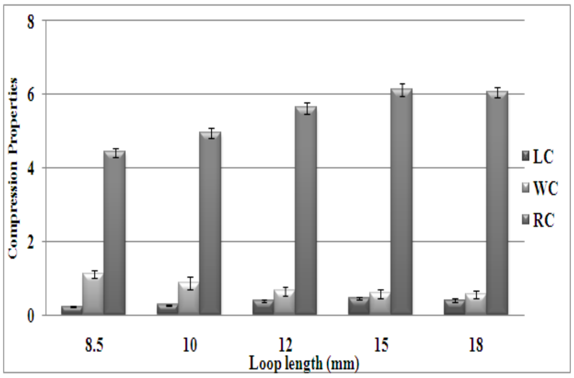

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Fig. 9: *Effect of loop length on the compression properties*

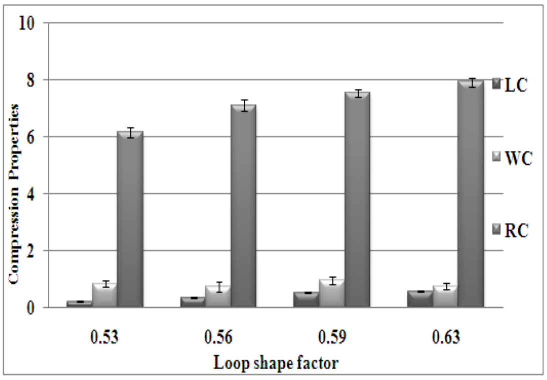

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Fig. 10: *Effect of loop shape factor on the compression properties*

2.1.9 Effect of loop shape factor

Terry fabrics having loops of high shape factor exhibit high LC, RC and low WC as shown in Figure 10. This improved performance of such fabrics may be attributed to the fact that loops of high shape factor covers the ground fabric well and are stable in nature. Moreover, low force is required for the compression of such loops.

2.2 Statistical analyses for the relative importance of predictor variable

2.2.1 Relative importance of predictable variable for linearity of compression curve

The relative importance of predictor variable is calculated using Johnson's relative weight analysis [7, 8]. The predictor variables are: X_1=Loop shape factor, X_2= Loop density (loop/inch^2), X_3=Loop length (mm), X_4= Pile yarn TM, X_5=Pile yarn Count (Ne). The results of the analysis are given in Table 3, which clearly shows that variable X_2 is most important having ε equals to 0.361 followed by X_1 and X_3.

Tab. 3: *Percentage and rank of predictor importance*

Variable	RIW (ε)	% Contribution*	Rank**
X_1	0.258	30.1	2
X_2	0.361	42.1	1
X_3	0.162	18.9	3
X_4	0.016	1.9	5
X_5	0.060	7.0	4

* Percentage contribution is calculated by dividing the individual estimated RIW score by the sum of total score for all predictor and multiplying by 100.

** Rank is assigned by comparing the estimated RIW score. The rank of 1 indicates the most important predictor; the rank of 2 indicates second most important predictor and so on.

Source: Own

2.2.2 Relative importance of predictable variable for linearity of compression energy

The results of the analysis are given in Table 4 which clearly show that variable X_2 is most important having ε equals to 0.354 followed by X_1 and X_3.

Tab. 4: *Percentage and rank of predictor importance*

Variable	RIW (ε)	% Contribution*	Rank**
X_1	0.254	28.68	2
X_2	0.354	39.87	1
X_3	0.180	20.49	3
X_4	0.017	1.95	5
X_5	0.082	9.23	4

Source: Own

2.2.3 Relative importance of predictable variable for linearity of compression resilience

The results of the analysis are given in Table 5 which clearly show that variable X_2 is most important having ε equals to 0.342 followed by X_1 and X_3.

Tab. 5: *Percentage and rank of predictor importance*

Variable	RIW (ε)	% Contribution*	Rank**
X_1	0.286	29.68	2
X_2	0.342	35.53	1
X_3	0.161	16.73	3
X_4	0.009	0.89	5
X_5	0.065	6.79	4

Source: Own

2.3 Optimization of key variables to achieve desired compressibility

The results of the previous section show that the loop density, loop shape factor and loop length are the important variables among selected five. Using Box-Behnken design of experiments, these key variables have been optimized in this section.

2.3.1 Optimization of loop density, loop shape factor and loop length for linearity of compression curve

Analysis of variance for linearity of compression depicts that the proposed model is significant at 95% level. Model F-value of 24.32 implies that there is only 0.012% change that a “Model F-value” this large could occur due to the noise.

The p-value for any model term less than 0.05 suggest that the particular model term is significant at 95% level of confidence. In this case A, B, C and B2 are significant model terms.

Final Equation in Terms of Actual Factors:

LC = – 5.7121 + 0.08125 * Loop density + 0.2245 * Loop length + 7.4694 * Loop shape factor + 0.0005 * Loop density * Loop length + 1.25e-15 * Loop density * Loop shape factor + 0.0714 * Loop length * Loop shape factor – 0.0009 * Loop density^2 – 0.009 * Loop length^2 – 6.8878 * Loop shape factor^2

The effect of loop density, loop shape factor and loop length have been found significant at 95% level of significance (Figure 11, 12, 13). The effect of loop density and loop shape factor on linearity of compression curve has been found linear, while the effect of loop length is non-linear. These relationships among variables and response have been shown in the surface graphs.

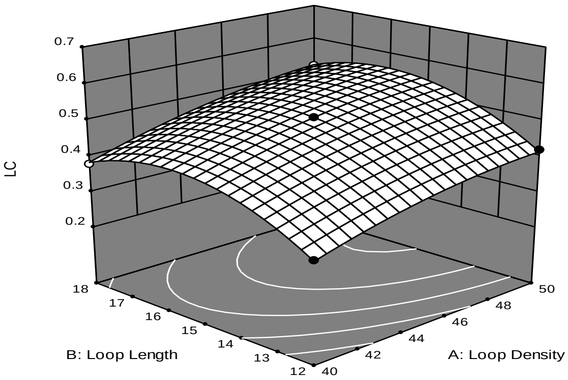

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Fig. 11: *Effect of loop length and loop density*

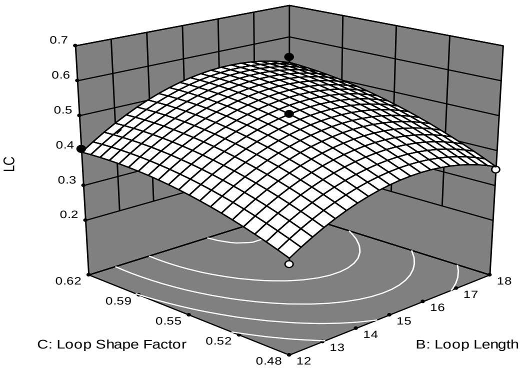

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Fig. 12: *Effect of loop shape factor and loop length*

Figure (14) shows that the maximum linearity of compression curve can be achieved at loop density, loop shape factor and loop length of 49.71, 16.12 and 0.61 respectively.

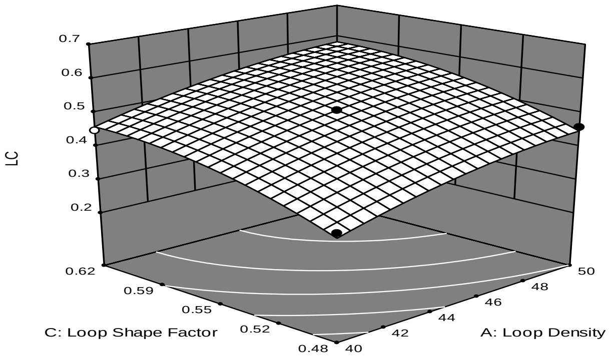

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Fig. 13: *Effect of loop shape factor and density*

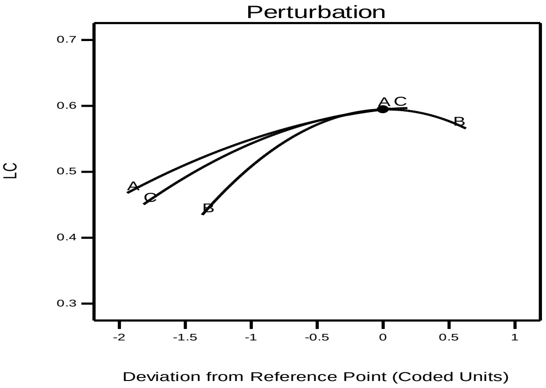

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Fig. 14: *Perturbation plot for optimizing predictor variables for LC*

2.3.2 Optimization of loop density, loop shape factor and loop length for compression energy

Analysis of variance for linearity of compression depicts that the proposed model is significant at 95% level. Model F-value of 29.23 implies that there is only 0.0091% change that a “Model F-value” this large could occur due to noise.

The p-value for any model term less than 0.05 suggests that the particular model term is significant at 95% level of confidence. In this case A, B, C, and B2 are significant model terms. C^2 is not significant but may be considerable.

Final Equation in Terms of Actual Factors:

RC = – l 634.506 + 8.1029 * Loop density + 23.1863 * Loop length + 1073.342 * Loop shape factor + 0.015 * Loop density * Loop length – 5.2142 * Loop density * Loop shape factor + 4.0476 * Loop length* Loop shape factor – 0.047 * Loop density^2 – 0.8222 * Loop length^2 – 734.694 * Loop shape factor^2

The effect of loop density, loop shape factor and loop length has been found significant at 95% level of significance (Figure 15, 16, 17). The effect of loop density and loop shape factor on linearity of compression curve has been found linear while the effect of loop length is non-linear. These relationships among variables and response have been shown in the surface graphs.

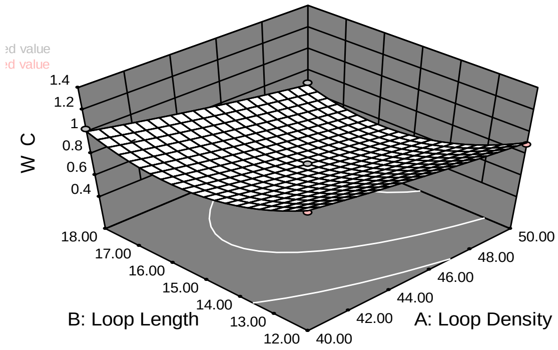

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Fig. 15: *Effect of loop length and loop density*

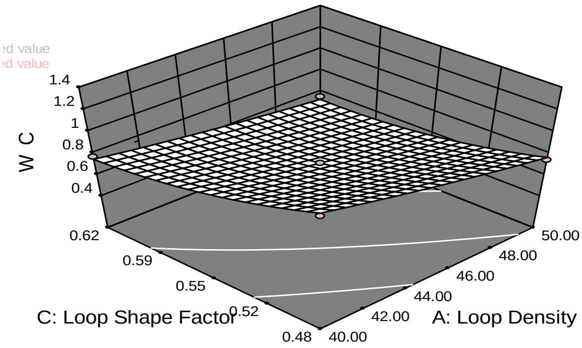

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Fig. 16: *Effect of loop shape factor and loop density*

Figure 18 shows that the maximum linearity of compression curve can be achieved at loop density, loop shape factor and loop length of 49.71, 16.12 and 0.61 respectively.

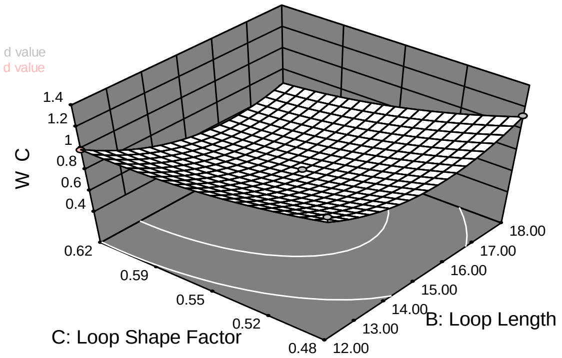

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Fig. 17: *Effect of loop length and loop shape factor*

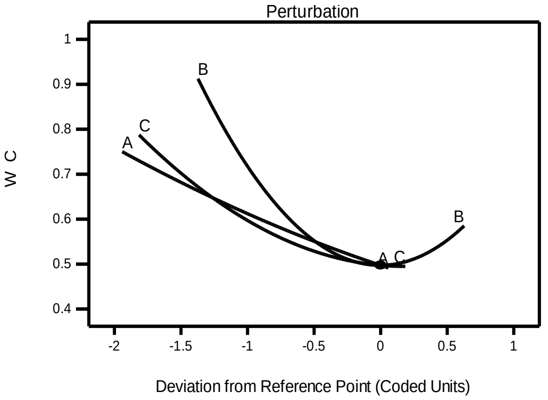

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Fig. 18: *Perturbation plot for optimizing predictor variables for WC*

2.3.3 Optimizing loop density, loop shape factor and loop length for linearity of compression resilience

Analysis of variance for linearity of compression depicts that the proposed model is significant at 95% level. Model F-value of 11.92 implies that there is only 0.0329% change that a “Model F-value” this large could occur due to noise.

The p-value for any model term less than 0.05 suggests that the particular model term is significant at 95% level of confidence. In this case A, B, C, and B^2 are significant model terms.

Final Equation in Terms of Actual Factors:

WC = – 634.506 + 8.1029 * Loop density + 23.1863 * Loop length + 1073.342 * Loop shape factor + 0.015 * Loop density * Loop length – 5.2143 * Loop density * Loop shape factor + 4.0476 * Loop length * Loop shape factor – 0.047 * Loop density^2 – 0.8222 * Loop length^2 – 734.694 * Loop shape factor^2

The effect of loop density, loop shape factor and loop length have been found significant at 95% level of significance (Figure 19, 20, 21). The effect of loop density and loop shape factor on linearity of compression curve has been found linear while the effect of loop length is non-linear. These relationships among variables and response have been shown in the surface graphs.

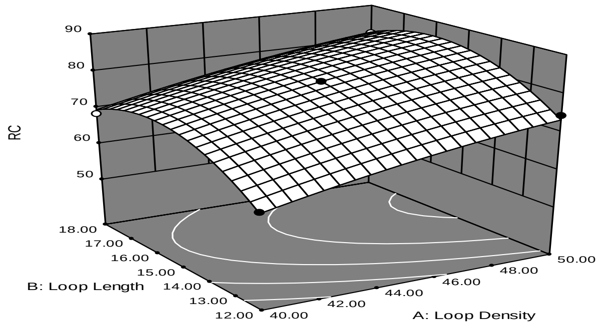

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Fig. 19: *Effect of loop shape factor and loop density*

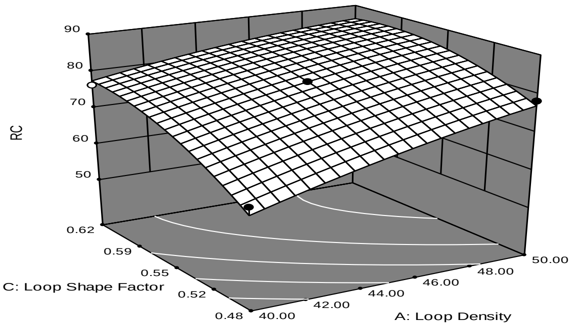

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Fig. 20: *Effect of loop shape factor and loop density*

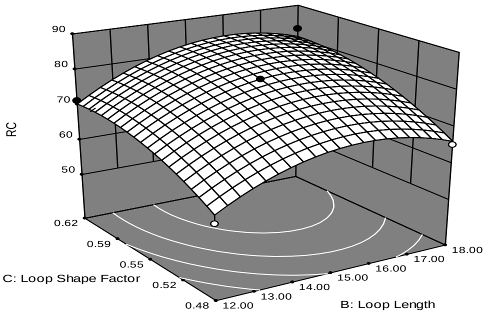

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Fig. 21: *Effect of loop shape factor and loop density*

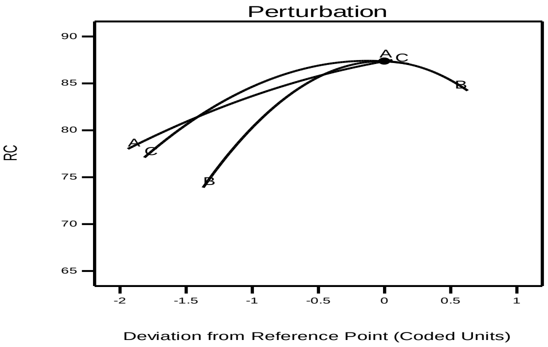

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Fig. 22: *Perturbation plot for optimizing predictor variables for RC*

Figure 22 shows that the maximum linearity of compression curve can be achieved at loop density, loop shape factor and loop length of 49.71, 16.12 and 0.61 respectively.

Conclusions

Loop density, loop length, loop shape factor, pile yarn TM, pile yarn count, fibre length and pile yarn structure are the important variables that affect the compression properties of terry fabric. Loop density, loop shape factor and loop length have a significant effect on the compression behaviour of terry fabric. With the increase in the loop shape factor, loop length and loop density, the compression resilience and linearity of compression curve increases which tells us that the fabric is going better in terms of softness to touch. Pile yarn produced from ring spinning, zero twist, MCU-5 cotton, porous yarn, finer yarn produces better terry fabric in terms of compression properties. Terry fabrics having loop density of 49.71, loop length of 16.12 mm and loop shape factor of 0.61 exhibit the best compression behaviour.

Literature

[1] TAYLOR, P. M.; POLLET, D. M.: Static low load lateral compression of fabrics, *Textile Research Journal*, Vol. 72(11), pp. 983-990, (2002).

[2] BEHERA, B. K.; SHARMA, S.: Low-stress behaviour and sewability of suiting and shirting fabrics, *Indian Journal of Fibre and Textile Research*, Vol. 23(4): 233-241, (1998).

[3] MATSUDARIA, M.; QIN, H.: Features and Mechanical parameters of a fabric's compressional property, *Journal of Textile Institute*, Vol. 83, pp. 476-486, (1995).

[4] LAROSE, P.: Observations on the compressibility of the pile fabrics, *Textile Research Journal*, Vol. 23, pp. 730, (1953).

[5] MATSUDAIRA, M.; QIN, H.: Features and Characteristic Values of Fabric Compression Curves, *International Journal of Clothing Science and Technology*, Vol. 6 No. 2/3, pp. 37-43, (1994).

[6] BOX, G. E. P.; HUNTER, J. S.; HUNTER, W. S.: *Statistics for experimenters*. Wiley-Interscience, New York, (2005).

[7] BRAUN, M. T.; OSTWALD, F. L.: The dominance analysis approach to comparing predictors in multiple regression, *Behavioral Research Methods*, Vol. 43, pp. 331-339, (2011).

[8] KRAHA, A.; TUMER, H.; NIMON, K.; ZIENTEK, L. R.; HENSON, R. K.: Tools to support interpreting multiple regression in the face of multi co-linearity, *Quantitative Psychology and Measurement*, Vol. 3, No. 2, pp. 1-16, (2012).

STUDIE STLAČITELNOSTI FROTÉ TKANIN

Stlačitelnost tkanin je pokles skutečné tloušťky s odpovídajícím zvýšením tlaku. Stlačitelnosti froté tkaniny závisí na vlastnostech vláken, parametrech příze, parametrech tkaní, délce smyčky, hustotě smyčky, geometrii smyčky a úpravách po tkaní. V popsaném výzkumu jsou studovány všechny faktory, které se na stlačitelnosti tkaniny podílejí. Bylo zjištěno, že hustota smyčky, délka smyčky, tvar smyčky, zákrut příze, jemnost vlasu, délka vlákna a jemnost příze mají významný vliv na chování komprese froté tkaniny. S nárůstem faktoru tvaru smyčky, délky a hustoty smyčky, se linearita kompresní křivky se zvyšování odolnosti a konkrétní kompresní energie snižuje, což svědčí o tom, že látka se na dotek zjemňuje.

STUDIEN ZUR KOMPIMIERBARKEIT GEWOBENER FROTTEETEXTILIEN

Unter Kompression versteht man die Abnahme der spezifischen Dicke auf Grund eines angemessenen Anwachsens des Drucks. Die Komprimierbarkeit von Frotteegeweben hängt von den Fasereigenschaften, den Garnparametern, den Gewebeparametern, der Krümmungsdichte, der Krümmungslänge, der Krümmungsgeometrie und der späteren Gewebebehandlung ab. In dieser Studie werden alle für die Kompression von Textilien verantwortlichen Faktoren untersucht. Es wurde dabei beobachtet, dass die Krümmungsdichte, die Krümmungslänge, die Krümmungsform, die Florgarndrehung, die Florgarnanzahl, die Faserlänge und die Florgarnstruktur eine bedeutende Auswirkung auf das Kompressionsverhalten von Frotteegeweben ausübt. Mit einem Anstieg des Krümmungsformfaktors, der Krümmungslänge, der Krümmungsdichte und der Linearität der Kompressionskurve steigt die Belastbarkeit und die Kompressionsenergie geht zurück, was zeigt, dass der Stoff in Bezug auf die Weichheit besser wird.

BADANIE ŚCIŚLIWOŚCI TKANIN FROTTE

Ściśliwość tkanin to zmniejszenie faktyczej grubości przy adekwatnym zwiększeniu nacisku. Ściśliwość tkaniny frotte zależna jest od właściwości włókien, parametrów przędzy, parametrów tkania, długości pętli, gęstości pętli, geometrii pętli i obróbek następujących po tkaniu. W opisanych badaniach przeanalizowano wszystkie czynniki wpływające na ściśliwość tkaniny. Stwierdzono, że gęstość pętli, długość pętli, jej kształt, skręt przędzy, delikatność włosu, długość włókna i delikatność przędzy mają znaczący wpływ na kompresję tkaniny frotte. Wraz ze wzrostem czynnika kształtu pętli, jej długości i gęstości, liniowość krzywej kompresji wraz z rosnącą odpornością i konkretną energią kompresji zmniejsza się, co wskazuje na to, że tkanina jest na dotyk delikatniejsza.