Analyzing the Effect of Fiber, Yarn and Fabric Variables on Bagging Behavior of Single Jersey Weft Knitted Fabrics

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ABSTRACT

This research investigates the effect of fiber, yarn and fabric variables on the bagging behavior of single jersey weft knitted fabrics interpreted in terms of bagging fatigue percentage. In order to estimate the optimum process conditions and to examine the individual effects of each controllable factor on a particular response, Taguchi's experimental design was used. The controllable factors considered in this research are blending ratio, yarn twist and count, fabric structure and fabric density. The findings show that fabric structure has the largest effect on the fabric bagging. Factor yarn twist is second and is followed by fabric density, blend ratio and yarn count. The optimum conditions to achieve the least bagging fatigue ratio were determined.

Keywords: Fiber, yarn and fabric variables, Single jersey weft knitted fabrics, Bagging fatigue percentage

INTRODUCTION

Weft knitted fabric is widely used due to their formability and improved drape ability. However, the bagging phenomenon, which often occurs on the level of the knees and the elbows of apparels, is a problem of knitted fabrics during and after use. Fabric bagging is a three-dimensional residual deformation, which causes deterioration in the appearance of the apparel.

Several bagging studies have been presented in the literature [1, 2, 3, 4]. A few literatures have addressed the bagging deformation of knitted fabrics. Thomas [5] developed an apparatus to evaluate the bagging of knitted fabrics. He used an Instron tensile tester, and tensile stretch and recovery principles are the fundamentals used in this test. Yaida [6] has worked with immediate recovery values in percent to evaluate the bagging in knitted fabrics. He reported that there is no relation between the immediate recovery value in percent, and the density and compressive modulus. The relationships between residual bagging heights obtained from the fabric bagging test and the mechanical characterization determined from the KES-FB system was discussed by Ucar et. al [7]. Hasani et al. [8] analyzed the effect of blend ratios and fabric structure on the residual bagging height of knitted fabrics produced from viscose/polyester blended rotor yarns using image analysis technique. Jaouachi et al. [9] predicted the residual bagging bend height of knitting fabric using fuzzy modeling and neural network methods. Yeung and Zhang [10] developed a method to evaluate garment bagging by image processing with different modeling techniques. Ucar [7] reported that the elastic restraint and frictional resistance (fabric rigidity) have a significant effect on the fabric bagging. Also, Doustar et. al [11] reported that the shear rigidity and formability which is related to bending, shear rigidity and extensibility, are the most important mechanical properties that interpret the woven fabric bagging deformation. The results of this research show that with increasing cotton fabric weft density, the shear rigidity and formability significantly increase, whereas fabric bagging parameters including bagging fatigue decrease accordingly.

This work focuses on the effect of fiber, yarn and fabric variables such as blend ratio, yarn twist and count, fabric structure and fabric density on bagging behavior of weft knitted fabrics. Taguchi method was used to determine the optimized level of different variables to achieve the lowest bagging fatigue percentage. Also the rank of effectiveness of variables on the bagging of knitted fabrics was determined.

EXPERIMENTAL DESIGN

Cotton and polyester fibers were processed and blended on a ring spinning system. The specifications of the polyester and cotton fibers are shown in *Table I.* Cotton slivers were blended with polyester slivers in three different blend ratios (25/75, 75/25, 50/50) on the first drawing frame and blended slivers were passed through the second drawing frame.

TABLE I. Specifications of the fibers.

Fiber type	Fiber fineness	Mean length
Polyester	1.44 denier	38 mm
Cotton	3.5 μg/inch	28 mm

TABLE II. Setting parameters of spinning frame.

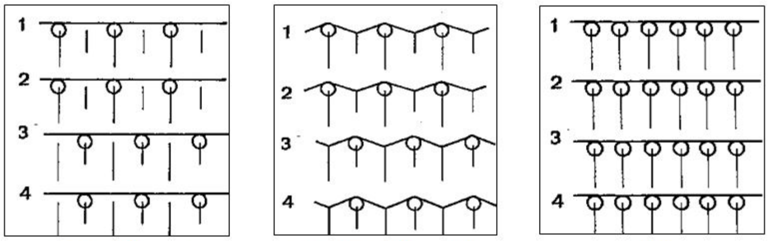
Setting parameters	Descriptions
Spindle speed (RPM)	7800
Twist factor	760, 668, 557
Ring diameter(mm)	60
Traveler No.	61
Roving No.(Hank)	1.05
Yarn No. (Ne)	20, 25, 30

The cotton/polyester blended slivers were used to produce three different yarn counts (20, 25 and 30 Ne). The yarns were spun with three twist factor (α_e =2.8, 3.1 and 3.75) on a ring spinning machine. The setting parameters of the ring spinning frame are presented in *Table II.*

Using a single jersey circular knitting machine (Falmac, E 22, 16” diameter) three single knit structures were manufactured. A plain, a double cross tuck and a double cross miss. The structure of the knitted fabrics is shown in *Figure 1*. Technical back of the knitted fabrics is illustrated in *Figure 2*. Wale and course counts per centimeter of the knitted fabrics were measured.

Different levels of variables considered in this paper are shown in *Table III.* Details of the knitted fabrics are given in *Table IV*. This experimental design involves using orthogonal arrays to organize the variables affecting the process and the levels at which they should be varied. The controllable variables which were considered in this research are material, yarn twist and count, fabric structure and density. A orthogonal array L_{27} shown in *Table IV* was chosen because it required only twenty seven runs for combinations of five controllable variables, material, yarn twist and count, fabric structure and fabric density varied at three levels.

To prepare the wet relaxation samples, the fabrics were washed in a domestic washer at 40°C for 30 minutes with commercial detergent and tumble dried at 60°C for 15 minutes in a dryer after they had been dry relaxed. This procedure was repeated three times. The samples were conditioned for 24 hours in a standard atmosphere. Details of the knitted fabrics are given in *Table V*. In order to estimate the optimum process conditions and to examine the individual effects of each of the controllable factors on a particular response, Taguchi’s experimental design was used.



(a) DCM: Double cross miss (b) DCT: Double cross tuck (c) Plain

FIGURE 1. Structure of knitted fabrics.

(a) DCM: Double cross miss (b) DCT: Double cross tuck (c) Plain

FIGURE 2. Technical back of single jersey knitted fabrics.

TABLE III. Levels of different variables**.**

Run	Material	Twist factor(α_e)	Structure	Fabric density (course/cm)	Yarn count (Ne)
Level 1	75p/25c	2.8	Plain	12	20
Level 2	50p/50c	2.8	Double cross tuck	12	25
Level 3	25p/75c	2.8	Double cross miss	12	30

TABLE IV. Orthogonal array for experiments.

Run	Material	Twist factor(α_e)	Structure	Fabric density (course/cm)	Yarn count (Ne)
1	75p/25c	2.8	Plain	12	20
2	75p/25c	2.8	Plain	12	25
3	75p/25c	2.8	Plain	12	30
4	75p/25c	3.1	DCT	10.5	20
5	75p/25c	3.1	DCT	10.5	25
6	75p/25c	3.1	DCT	10.5	30
7	75p/25c	3.75	DCM	9	20
8	75p/25c	3.75	DCM	9	25
9	75p/25c	3.75	DCM	9	30
10	50p/50c	2.8	DCT	12	20
11	50p/50c	2.8	DCT	12	25
12	50p/50c	2.8	DCT	12	30
13	50p/50c	3.1	DCM	12	20
14	50p/50c	3.1	DCM	12	25
15	50p/50c	3.1	DCM	12	30
16	50p/50c	3.75	Plain	10.5	20
17	50p/50c	3.75	Plain	10.5	25
18	50p/50c	3.75	Plain	10.5	30
19	25p/75c	3.1	DCM	10.5	20
20	25p/75c	3.1	DCM	10.5	25
21	25p/75c	3.1	DCM	10.5	30
22	25p/75c	3.1	Plain	9	20
23	25p/75c	3.1	Plain	9	25
24	25p/75c	3.1	Plain	9	30
25	25p/75c	3.75	DCT	12	20
26	25p/75c	3.75	DCT	12	25
27	25p/75c	3.75	DCT	12	30

DCT: Double cross tuck DCM: Double cross miss

TABLE V. Specifications of knitted fabrics.

Fabric Code	WPC	CPC	Thickness (mm)	Weight (g/m^2)
1	12	12	0.47	170
2	11.57	12	0.41	125.67
3	10.67	12	0.37	102.44
4	9.33	9	0.66	187.11
5	9	9.33	0.59	157.89
6	8.67	10.17	0.52	127.11
7	11.67	9	0.61	187.67
8	12	9	0.53	182.33
9	12	9.67	0.44	135
10	9.33	11	0.68	200.11
11	10	10.67	0.61	146.44
12	10.33	10	0.56	128.89
13	10.67	14	0.68	275.11
14	12	13.67	0.57	208.78
15	12	13.67	0.52	172.78
16	10	11	0.49	158.33
17	11	11	0.45	136.44
18	10.33	10.33	0.39	103.44
19	11.33	12	0.58	184.22
20	12	11.33	0.53	160.56
21	12	11.67	0.44	138.33
22	10	9.67	0.45	126
23	11	9	0.41	109.89
24	11	8.67	0.36	81.89
25	9	11	0.71	194.33
26	9.33	10.67	0.62	153.56
27	11	9.33	0.54	120.56

The testing parameters are the same as the test method used in our previous investigation [8]. To simulate the bagging phenomenon during wear, we used a testing apparatus similar in shape and size to that of Zhang et al. [2, 3]. The apparatus is attached to the Instron tensile tester. Each fabric sample has a diameter of 135 mm, and is placed in a circular clamp with an inner diameter of 56 mm. It is then deformed by a steel ball with a diameter of 48 mm. *Figure 3* shows a schematic drawing of the bagging test. According to Kirk et al. [12], bagging height of 21 mm, corresponding to approximately 25% elongation was used. The ball displaces the fabric by 21 mm at a cross-head speed of 20 mm/min and returns to its original position. This process is repeated five times. A typical force-traverse for five cyclic bagging tests is shown in *Figure 4*.

The maximum load and corresponding work of loads and bagging fatigue percentage at the first and last cycles is calculated. Bagging fatigue, which is the percentage of loss of energy after repeated bagging deformation in a fabric, can be obtained using following formula:

$$\text{Bagging fatigue (\%)} = \frac{\text{Work of first cycle's loading} - \text{Work of last cycle's loading}}{\text{Work of first cycle's loading}} \quad (1)$$

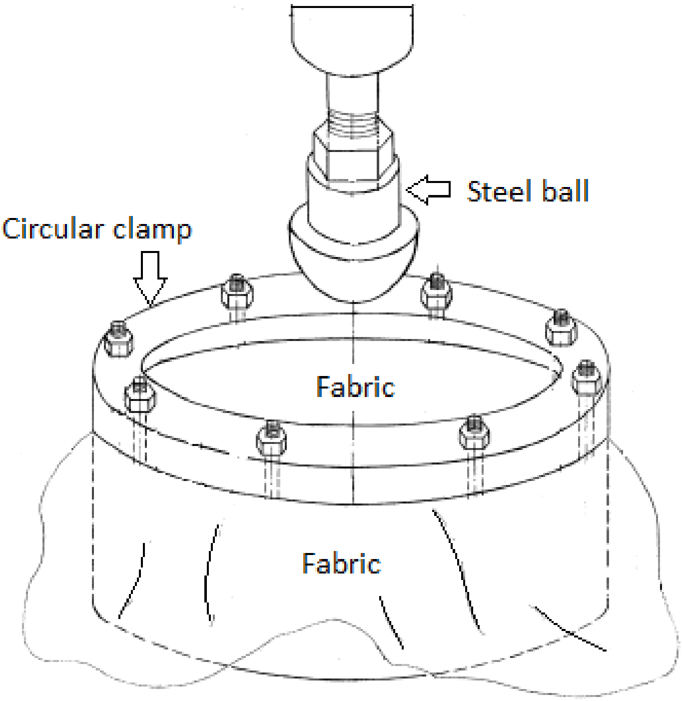


FIGURE 3. Schematic drawing of the bagging test principle.

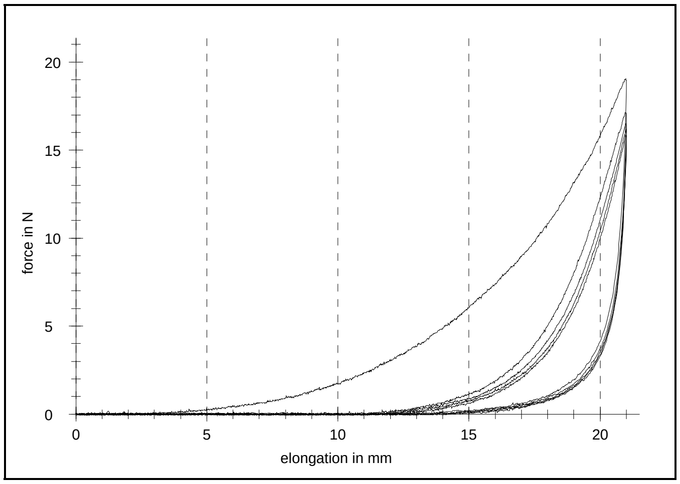


FIGURE 4. Typical force-traverse for five cyclic bagging tests.

Twenty-seven knitted fabrics were tested using a bagging test method. Bagging fatigue percentage, which is the percentage of loss of energy after repeated bagging deformation in a fabric, is obtained. The fabric thickness was measured with a thickness meter at pressure 5 kpa and the fabric weight was measured by a balance.

RESULTS AND DISCUSSION

In the first step of this investigation, the optimum process conditions are estimated and the individual effect of each controllable factor on a particular response is examined using Taguchi method.

According to Taguchi's method, a smaller-the-better analysis was selected: that is, the lower the fabric bagging fatigue percentage, the better [13]. The SN-ratio analysis was adopted to identify the strongest effects and determine the best factor levels for producing knitted fabrics that have considerably less bagging fatigue percentage. Furthermore, the optimum levels of fiber, yarn and fabric variables to achieve the less bagging fatigue percentage were determined.

Analysis of variance of SN-ratios calculated for fabric samples shows that all selected fiber, yarn and fabric factors have significant effect on bagging behavior of knitted fabrics. *Table VI* shows the results of analysis of variance.

A SN-ratio analysis was adopted to interpret the results. This analysis is based on combining the data associated with each level for each factor [13]. The difference in the average results for the highest and lowest average response is the measure of the effect of that factor. The greatest value of this difference is related to the largest effects of that particular factor [13]. The response table for SN ratios of the different fabric samples produced is given in *Table VII.*

TABLE VI. Analysis of Variance for SN ratios.

Parameter	Blend	Yarn twist	Fabric structure	Fabric density	Yarn count
F-value	0.89	1.65	12.1	0.77	1.58
P-value	0.43	0.224	0.001	0.479	0.236

TABLE VII. Response Table for Signal to Noise Ratios.

	Blend	Twist	Structure	Density	count
1	-36.87	-36.91	-36.24	-36.48	-36.83
2	-36.7	-36.72	-36.64	-36.57	-36.74
3	-36.5	-36.49	-37.18	-36.88	-36.49
Delta	0.37	0.43	0.94	0.4	0.35
Rank	4	2	1	3	5

According to the Response table, it can be seen that for all knitted fabrics, fabric structure has the largest effect on the fabric bagging. Factor "yarn twist" is second and is followed by fabric density, blend ratio and yarn count. The optimum conditions are determined by selecting the levels that show the highest SN-ratio responses in *Table VI.* Considering this principle, the recommended levels are summarized in *Figure 5*. Furthermore, this figure shows the effect of different fiber, yarn and fabric variables on the bagging fatigue percentage.

TABLE VIII. Optimum level of factors.

Factors	Blend	Twist factor	Fabric structure	Fabric density (course/cm)	Yarn count
	25%P-75%C	3.75	Plain	12	30

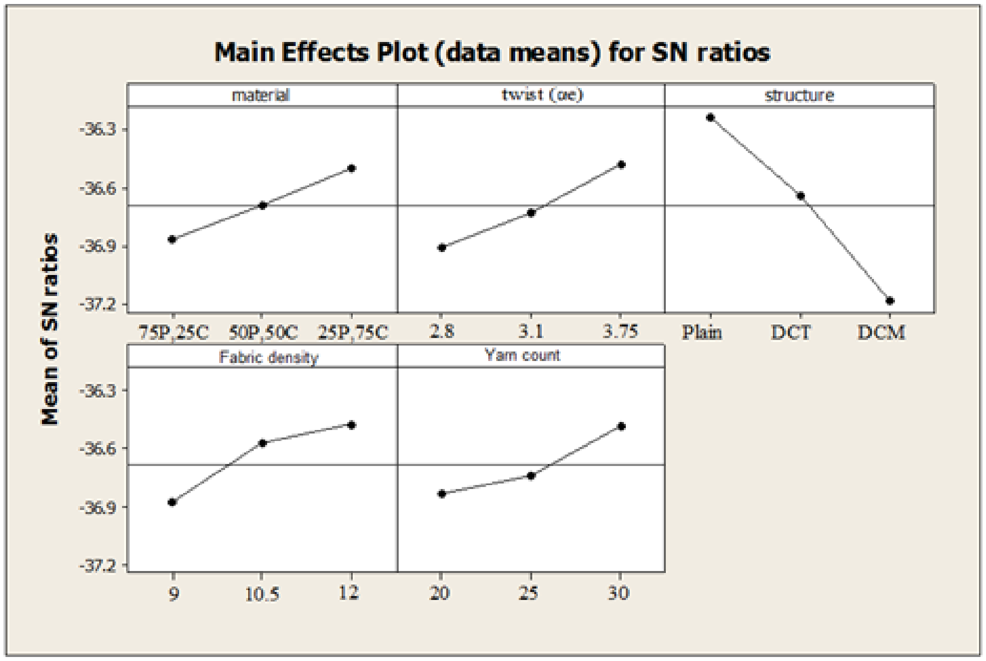


FIGURE 5. Optimum level of factors and the effect of different variables on bagging fatigue percentage.

Analysis the Effect of Material Type on the Fabric Bagging

The results of Taguchi analysis show that the yarn spun from 75% cotton and 25% polyester represents the lowest bagging fatigue percentage. Zhang et al. [4] point out that fiber viscoelastic behavior plays a key role in determining fabric rheological behavior in bagging. They reported that bagging resistance which is the ability of the fabric to resist bagging deformation is in this order, from the highest: silk fabric, cotton, viscose, polyester, wool, nylon. These results show that in fabric bagging, the contributions of elasticity and viscoelasticity are different from fiber to fiber. Therefore, it will be logic that the yarns with highest cotton percentage show the lowest bagging fatigue percentage.

Analysis the Effect of Fabric Structure on the Fabric Bagging

During bagging, a fabric is subjected to a complex pattern of loading. Bagging force induces internal stress at multi directions including shearing, tensile and bending. As already mentioned, pervious investigations [7, 11] show the relationship between bagging residual height and G, 2HG5, B, and 2HB. Also, shear rigidity and formability interpret the woven fabric bagging deformation. Also, Hasani [14] investigated the effect of some fabric structures such as plain, double cross tuck and double cross miss on their tensile properties. He reported that tensile linearity (LT) and Tensile resiliency (RT) values of plain fabrics are higher than two other structures. Also, he pointed out that the shear stiffness of samples with varying knit structures decrease in the following order: plain single jersey, double cross tuck, double cross miss, which can be due to higher loop intersection points in the plain knit structures.

Higher RT means that the structure has higher resiliency while removing the tensile force. Also, tensile linearity (LT) reflects the elasticity of the fabric, the higher the LT value the stiffer the material. This increases fabric recovery after deformation due to its spring-like behavior, which leads to a decrease in bagging fatigue percentage. Thus plain fabric represents the lowest bagging fatigue percentage. Frictional resistance as well as fabric rigidity is affected by shear stiffness. It seems that the slipperiness at loop intersection in a plain structure is less than other knit structures. Therefore, it presents higher resistance against bagging fatigue and helps the fabric to behave like a spring.

Analysis the Effect of Knit Density on the Fabric Bagging

The findings show that higher knit density cause to decreasing the bagging fatigue percentage.

Higher knit density increases resistance to slippage between yarns or fibers, warp-weft contact and fiber contact in the intersections. Therefore, an increase in knit density will cause to higher fabric rigidity. This increased tightness factor in the plain knit fabrics increases loop curvature in three dimensions, and increased loop curvature (increased fabric density) causes the structure to behave more like a spring [7]. Thus, such a fabric recovers more easily than a more slack structure.

Also, Hasani [14] pointed out that the mean value of linearity of load-extension (LT) and tensile resilience (RT) tend to increase as the knit density increases and vice versa. Alimaa et al. [15] reported that the response of the structure to bending deformation is like that of a spring, when density of fabric is increased. An increased tightness factor also increases fabric recovery after deformation due to its spring-like behavior, which leads to a decrease in bagging fatigue percentage.

Analysis the Effect of Yarn Twist on the Fabric Bagging

Figure 2 shows lower bagging fatigue percentage as the yarn twist increases. Permanent fabric deformation is affected mostly by inter-fiber friction. Yarn twist affects the friction coefficient at the loops intersections. Results of an investigation [14] show a slightly increase in shear rigidity, tensile linearity and tensile resilience as the yarn twist increase.

The flexural rigidity of a fabric is related to the yarn variables such as; yarn twist, material type and kind of the spinning system. In the same spinning system and material, an increase in yarn twist increases the inner friction of the fibers consequently the resistance of the yarn against bending. Therefore in higher yarn twist, the yarn tends to behave like a spring and shows more resistance against deformation.

Analysis the Effect of Yarn Count on the Fabric Bagging

The results show that the finer yarns represent lower bagging fatigue percentage. It can be due to this fact the finer yarn s have higher twist. Therefore the bagging resistance of this fabric is higher than those knitted from thicker yarns.

CONCLUSIONS

Bagging fatigue percentage, which is the percentage of loss of energy after repeated bagging deformation in a fabric, was obtained. Taguchi's experimental design was used to investigate the effect of fiber, yarn and fabric variables on the bagging behavior of weft knitted fabrics interpreted in terms of bagging fatigue percentage. The findings show that fabric structure has the largest effect on the fabric bagging. Factor yarn twist is second and is followed by fabric density, blend ratio and yarn count. The optimum conditions to achieve the least bagging fatigue ratio were determined. Also, due to higher tensile resiliency, tensile linearity and shear stiffness, plain knitted fabric represents the lowest bagging fatigue percentage. Furthermore, in higher yarn twist, the yarn tends to behave like a spring and shows more resistance against deformation. The results of Taguchi analysis show that the yarn spun from 75% cotton and 25% polyester represents the lowest bagging fatigue percentage. The results show that the finer yarns represent lower bagging fatigue percentage.

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