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Effect of material and fabric parameters on fatigue value of weft knitted fabrics

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The effect of material type, fabric structure, stitch, and cycle number of tensile fatigue has been studied on dynamic fatigue behavior of interlock weft knitted fabrics in course direction. To investigate the effect of controllable factors on fatigue value, Taguchi method has been used. The fatigue value has been defined as the percentage of variation in bagging resistance of knitted fabrics before and after tensile fatigue cyclic loading. A signal to noise ratio analysis has been adopted to identify the most effective parameters on fatigue value and also to determine the best factor levels for producing knitted fabrics with lowest value of fatigue. According to the SN ratio analysis, fabric structure shows the dominant effect on fatigue value followed by stitch density, number of cyclic loads and blend ratios.

Keywords: Bagging, Fatigue behavior, Interlock weft knitted fabric, Tensile fatigue cyclic loading

1 Introduction

Aesthetic appearance is one of the most important criteria for consumers in judging the total wear performance of clothing. The appearance of a garment deteriorates during wear, often without suffering any structural damage[1]. Fatigue is the rupture or decay of the mechanical properties of a material after the application of repeated stress[2]. Since weft-knitted fabrics are more likely to undergo repeated loading rather than static loading during wear, their fatigue behavior is very important[1]. Knitted fabrics used for apparel undergo a high number of large elongations during body motion. The reduction in fabric elasticity during usage is one of the most important problems that could affect the long-term reliability of knitted garment[3]. Different parameters, such as material type, yarn and fabric structure as well as conditions of tensile cyclic loading, play a basic role in fatigue behavior of textile materials. Some researchers have evaluated fatigue behavior of different fabric structures. Jeddi *et al.*[4] investigated the effect of structure of warp knitted fabrics on their fatigue behavior. They observed that the final deformation and tensile modulus of fabrics increases as the number of fatigue cycles rises, during which the tensile breaking extension decreases.

Kobliakov *et al.*[5] studied the tensile fatigue of woven and weft knitted fabrics under different strokes and frequencies of cyclic straining. They found that by increasing the stroke, fabric deformation increases and by increasing the frequency of cyclic loading, this deformation decreases. Tensile properties and fatigue behavior of different two-guide bar warp knitted fabrics produced from polyester textured yarns was studied by Otaghsara *et al.*[2]. They reported that there is no distinguished trend between the cyclic stress and the course density of warp knitted fabrics. Ben Abdessalem *et al.*[3] studied the behavior of plain cotton knitted fabrics under a large number of cyclic elongations. They discussed the dimensional behavior of plain knitted fabrics after cyclic loading. Literature review shows limited studies available on the dynamic fatigue behavior of weft knitted fabrics. Therefore, this investigation is aimed at studying the effect of material type, fabric structure, stitch density as well as number of tensile fatigue cyclic loading on fatigue behavior of interlock weft knitted fabrics. Selected structures have been traditionally used for sport wears which undergo repeated stresses during physical activity of body. To investigate the effectiveness of mentioned parameters, Taguchi methodology has been used. In addition, the optimum conditions to minimize the fatigue value have also been determined.

2 Materials and Methods

2.1 Production of Weft Knitted Samples

Cotton/polyester blended yarns (20 Ne) with two different blend ratios (25/75 and 50/50) spun on a ring spinning machine were used to knit all samples. A double jersey circular knitting machine (Mayer & Cie,

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E20 and 30”) was used to knit three interlock structures, namely a plain interlock, a half cardigan interlock and a half milano interlock. The schematic diagram of fabric structures are illustrated in Fig. 1. Since it was not possible to get the same level of stitch density with different structures, stitch density was varied in low, medium, and high level, and the obtained stitch density was used[6]. Parameters of knitted fabrics were given in Table 1. To prepare the wash-and-dry relaxation samples, the fabrics were washed in a domestic washer at 60°C for 30 min with commercial detergent and tumble dried at 70°C for 15 min in an electrically heated dryer after they had been dry relaxed. This procedure was repeated three times.
Before measurements, the samples were conditioned for 24 h in a standard atmosphere. Wale and course count per 100 cm of fabric was measured and then converted to wale and course count per cm. Fabric thickness and weight were measured according to ASTM D1777 and ASTM D3776 respectively.

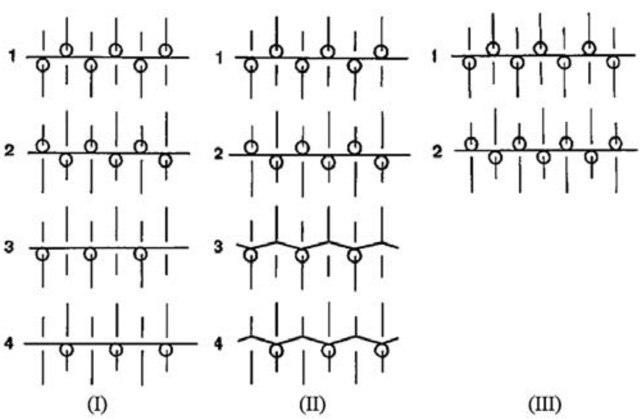

Fig. 1—Structures of knitted fabrics (I)—half milano interlock, (II)—half cardigan interlock, and (III)—plain interlock [numbers in figures are course number for a repeat]

Table 1—Specifications of knitted fabrics

Sample code	Fabric weight g/m^2	Wales per (WPC)	Courses per cm (CPC)	Stitch density (WPC ×CPC)	Thickness mm
A	351	11.00	11.50	126.5	0.947
B	323	10.87	9.66	105	0.995
C	285	8.37	9.30	77.8	1.042
D	263	7.50	7.00	52.5	1.050
E	292	8.00	8.60	68.8	1.077
F	331	8.91	11.50	102.4	1.087
G	308	11.75	12.58	147.8	0.967
H	284	11.25	8.33	93.7	0.975
I	307	11.75	10.75	126.3	0.965

2.2 Experimental Design

In order to determine the optimum process conditions and examine the effect of each controllable factor on a particular response, Taguchi’s experimental design was used. This experimental design involves orthogonal arrays to organize the factors affecting the process and the levels at which they should be varied[7]. The controllable factors, considered in this research, were fabric structure, stitch density, blend ratio, and number of tensile fatigue cyclic loads on knitted fabrics. Accordingly, L9 orthogonal array (Table 2) was chosen because it requires only nine runs for combinations of two factors (blend ratio, and fatigue cycle number) varied at two levels and other controllable factors varied at three levels. The numbers in each column indicate the levels of specific factors. The percentage of variation in bagging resistance of knitted fabrics before and after tensile fatigue cyclic loads was considered as response and as a criterion to evaluate the fatigue behavior of weft knitted fabrics after tensile cyclic loading. Table 3 shows the levels of four selected controllable factors. However, while conducting the experiments the test runs were randomly made to avoid the unidentified noise sources, which were not considered but could have an adverse impact on the response characteristic.

Three readings (corresponding to the three replications) were recorded for each experimental

Table 2—L9 Taguchi array and levels of controllable factors for each knitted fabric sample

Run	Sample code	Fabric structure	Stitch density	Blend ratio	Cycle number
1	A	I	I	I	I
2	B	I	II	II	II
3	C	I	III	II	III
4	D	II	I	I	III
5	E	II	II	I	I
6	F	II	III	II	II
7	G	III	I	II	II
8	H	III	II	I	III
9	I	III	III	II	II

Table 3—Different levels of controllable factors

Levels	Fabric structure	Stitch density	% Blend ratio	Cycle number
I	Plain interlock	High	75/25	500
II	Half cardigan interlock	Medium	50/50	1500
III	Half milano interlock	Low	-	3000

condition in Taguchi technique. The variation in response was also examined using an appropriately chosen SN ratio. Generally, the SN ratio was the ratio of the mean (signal) to the standard deviation (noise). Three standard SN equations were used to classify the objective function as 'larger the better', 'smaller the better', or 'nominal the best'. However, regardless of the type of performance characteristic, a larger SN ratio was always desirable[7]. Data were analyzed by Minitab.14 software[8].

2.3 Tensile Fatigue Cyclic Loading

A purposed-built instrument for tensile fatigue of fibrous materials under cyclic loads has been used in this study. The structure of this instrument is shown in Fig. 2 (A). This apparatus was designed in such a way that it could control the number of cyclic loads, the rate of elongation and the loads frequency. The schematic design of instrument is presented in Fig. 2 (B).

The inverter (**4**) which controls the speed of motor (**5**) determined frequency of cyclic loads. Each sample was clamped by two jaws, one of them was fixed [fix clamp (**1**)] and another one was kept movable [movable clamp (**2**)]. The rate of elongation, which was in accordance to the rate of movement of movable clamp, was controlled by position sensor [3-a in Fig 2(B)] and the initial length of sample to be loaded was determined by the position sensor [3-b Fig 2(B)]. In other words, these sensors controlled the cyclic motion of movable clamp, in such a way that when it reached each sensor, the direction of movement was reversed. The movable and fix clamps were mounted on two parallel rail bars[9,10].

The loading frequency was set at 120 cycles per minute based on the estimation of number of fabric deformations in apparel of a person during jogging. The fabric dimension was 30×15cm. The rate of elongation was constant and selected to be 5cm. The samples were subjected to fatigue using 500, 1000 and 1500 cyclic loads respectively.

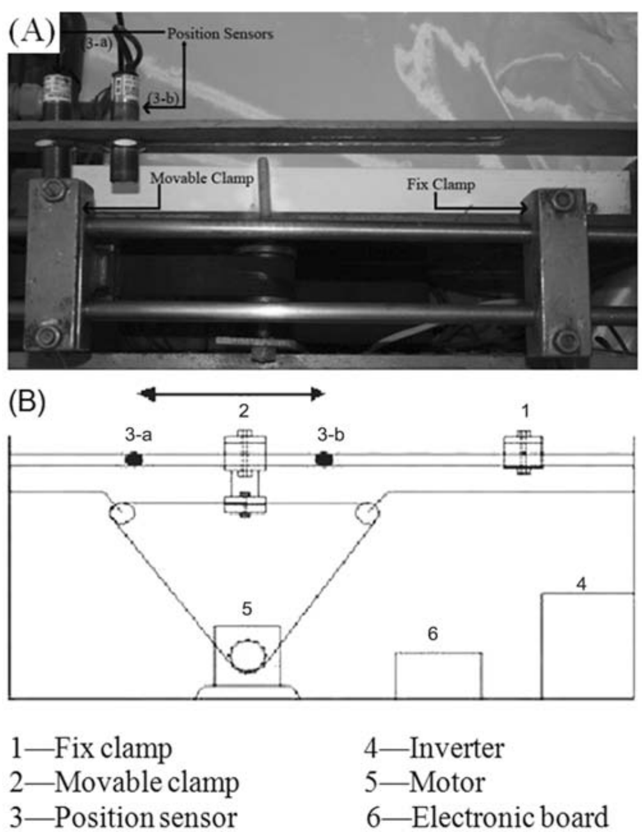

Fig. 2—(A) Apparatus used for tensile fatigue cyclic loads; (B) Schematic diagram of apparatus (ref. 8)

2.4 Bagging Test

To determine an index for comparing the fatigue behavior of different knitted fabrics, bagging resistance of the fabrics before and after cyclic loading were measured and the fatigue value [F.V(%)] of a sample was defined as follows:

$$\text{F.V}(\%) = \frac{A - B}{A} \quad \ldots (1)$$

where A is the bagging resistance before cyclic loads; and B, the bagging resistance after cyclic loads.

According to Fig. 3, the apparatus used for bagging test was attached to the Zwick tensile tester which works based on constant rate of elongation (CRE) method. Each sample which had a diameter of 110 mm, was placed in a circular clamp with an inner diameter of 56 mm. It was then deformed by a steel

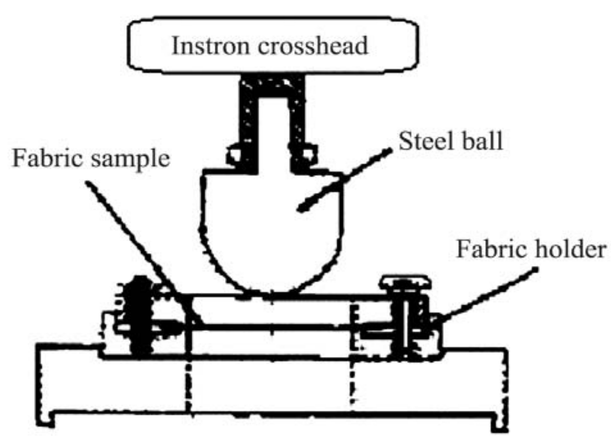

Fig. 3—Apparatus to measure the bagging resistance

ball with a diameter of 48 mm[11]. Bagging height of 21 mm was selected, corresponding to approximately 25% elongation of samples[12,13]. The steel ball displaced the fabric by 21 mm at a cross-head speed of 20 mm/min. Fabric samples were imposed to one load cycle, and bagging resistance[14] of fabrics was calculated according to Eq. (2). The average of seven measuring results was reported. The required energy for fabric deformation in first cycle reflects the ability of fabric to resist bagging deformation at the initial stage. In order to compare the fabrics with different structural features, the specific work of fabric deformation which was defined as the deformation work at first loading cycle divided by the sample weight, was used as bagging resistance, as shown below:

$$\text{Bagging resistance} = \frac{\text{Work of first cycle's loading (N.m)}}{\text{Sample weight (g/m}^2\text{)}} \quad \ldots (2)$$

3 Results and Discussion

According to Taguchi's method, a smaller-the-better analysis is used. The lower the fatigue value, the better is the fabric performance. A SN ratio analysis has been adopted to identify the most effective parameter and to determine the best factor levels to produce knitted fabrics with lowest value of fatigue. The empirical relationships between fatigue value and four controllable factors are analyzed using Minitab software.

A SN ratio analysis has been adopted to interpret the results. This analysis is based on combining the data associated with each level for each factor. The difference between the average results for the highest and the lowest average response has been considered as criterion to evaluate the effect of that factor on fatigue value. The greatest value of this difference is related to the strongest effects of that particular factor. Response for signal-to-noise ratios for the fatigue tests at course direction is given in Table 4. According to the level average analysis, factor 'fabric structure' shows the strongest effect with a delta of 11.41 on fatigue value.

Table 4—Response table for signal-to- noise ratios (average response value)

Factors	Signal-to-noise ratio				
	I	II	III	Delta	Rank
Fabric structure	-10.78	-17.97	-22.19	11.41	1
Stitch density	-12.65	-21.33	-16.96	8.67	2
Blend ratio	-16.07	-18.12	-	2.05	4
Cycle number	-12.69	-18.61	-19.64	6.95	3

Factor 'stitch density' is found second one with a delta of 8.67 and is followed by factors 'cycle number' and 'blend ratios' with a delta of 6.95 and 2.05 respectively.

The effect of different controllable factors on the SN-ratio values is shown in Fig. 4. The results reveal that the plain interlock fabric represents the lower fatigue value compared with other structures. Hasani *et al*.[12] reported that tensile properties such as work of tensile (WT) and tensile resiliency (RT) of plain interlock are higher than half milano interlock and half cardigan interlock. Higher values of RT correspond to higher resiliency of fabric after load removal. This property might cause increase in fabric recovery after deformation due to its spring-like behavior, which leads to a decrease in fatigue values. Thus, plain interlock fabric shows the lowest fatigue values as could be seen in Fig. 4 and Table 4. On the other hand, the presence of the higher number of loops which causes to higher yarn resistance provides a spring-like structure for plain interlock. This characteristic may increases the resilience of fabric after applying the cyclic loading. Naturally, plastic deformation of this fabric is lower than other said structures. This could be another reason for difference of bagging resistance before and after applying the cyclic loading and subsequently reduction of fatigue value.

Stitch density plays an important role in fatigue value of the fabrics. According to Fig. 4 the reduction on fatigue value by increasing the stitch density is observed. According to results reported by Ucar *et al.*[14] and Alimaa *et al*.[15], an increase in stitch density increases the loop curvature in three dimensions and increased loop curvature causes the

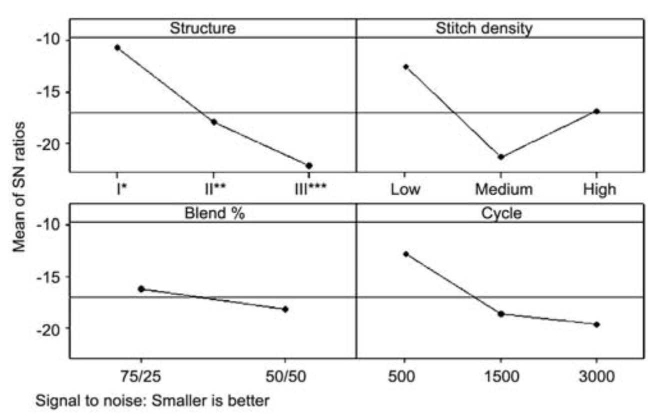

Fig. 4—Effect of different controllable factors on SN-ratio values [* Plain interlock, ** Half cardigan interlock and *** Half milano interlock]

fabric to behave more like a spring. Choi and Ashdown[6] reported that the tensile resilience of the interlock fabrics increases when the stitch density increases. This could be a reason for increase of fabric elasticity by increase of stitch density. Thus, such a fabric recovers more easily than a more slack structure and shows less plastic deformation[16].

As shown in Fig. 4 and Table 4, more number of cyclic loading causes the increase in fatigue value. This might be due to more decay of the mechanical properties of a material after the application of repeated stress. The results reveal that the fabric produced from higher ratio of polyester shows lower fatigue values after applying the cyclic loading. This could be due to higher elastic modulus of this than cotton.

4 Conclusion

The results show that the plain interlock fabric represents the lowest fatigue value as compared to other structures. Reduction in fatigue value is also gained by the increase in stitch density. Fabrics produced by higher ratio of polyester show lower fatigue values after applying the tensile fatigue cyclic loading. More number of cyclic loading refers to higher fatigue value.

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