

Regression Model for the Bagging Fatigue of Knitted Fabrics Produced from Viscose/Polyester Blended Rotor Yarns

Abstract

The aim of this work was to predict the bagging fatigue percentage of knitted fabrics produced from viscose/polyester blended rotor yarns using blend ratios and structural cell stitch lengths as predictor variables. A simplex lattice design was used to determine the combinations of blend ratios of the fibre types. Knitted fabrics with three different structures were produced from viscose/polyester blended rotor yarns. Mixture-process crossed regression models with two mixture components and one process variable (structural cell stitch lengths, blend ratio) were built to predict the bagging fatigue percentage. All statistical analysis steps were implemented using Design-Expert statistical software. The correlation coefficient between the bagging fatigue percentage predicted and the bagging fatigue percentage observed was 0.983, indicating the strong predictive capability of the regression model built.

Key words: knitted fabric, fabric structure, bagging, experimental design, blended yarns.

Introduction

Blending different types of fibres is widely practiced to enhance the performance and aesthetic qualities of fabric. Blended yarns from natural and man-made fibres have the particular advantages of successfully combining good properties of both fibre components, e.g. comfort in wear with easy-care properties. Furthermore, the viscose/polyester blend has many advantages such as less pilling, less static electrification, easier spinning, and more evenness for the sliver, roving and yarn. These benefits also permit an increased variety of products and better marketing advantages [1].

Bagging is the three dimensional deformation of a sheet under a force normal to its plane. In the field of clothing, however, the term is used for permanent deformations of certain parts of a garment such as the sleeves around the elbow and the trousers around the knee [2]. Bagging results from the lack of dimensional stability or recovery when repeated or prolonged pressure is exerted on a fabric [2].

In order to evaluate bagging behaviour, several methods for determining woven and knitted fabric bagging behaviour have been developed [3 - 9]. Most publications focus on measuring residual bagging height and related woven fabric mechanical properties. Zhang [10, 11] expressed the residual bagging height as a percentage by dividing the non-recovered bagging height by the predetermined bagging height and studied the relation between the residual bagging height they obtained from their experiments and the woven fabric mechanical properties they

derived from the KES-FB tests. Abghari et al. [12] used bagging resistance, bagging fatigue, residual bagging height and residual bagging hysteresis to characterise fabric bagging behaviour, and they also simulated it with Finite Element Analysis. In comparison to knitted fabric, yarns in a woven fabric structure are tightly held, which leads to it having a more stable structure. Therefore the bagging behaviour of knitted fabrics is different from woven fabrics.

Yaida [13] worked with immediate recovery values in percent on an Instron tensile tester to evaluate bagging in knitted fabrics. Uçar et al. [14] studied the bagging of a set of knitted fabrics and predicted the bagging height for knitted fabrics from different fabric mechanical properties.

The aim of this work was to predict the bagging fatigue percentage of knitted fabrics produced from viscose/polyester blended rotor yarns using blend ratios and structural cell stitch lengths as predictor variables. A simplex lattice design was used to determine the combinations of blend ratios of the fibre types.

Experimental

A simplex lattice design with one replication at each design point was constructed to determine the combinations of blend ratios of two fibre types [1, 11, 12]. Let X_1, X_2, \dots, X_p denote the proportions of 'p' components of a blend, then:

$$0 \leq X_i \leq 1 \quad i = 1, 2, \dots, p$$

A $\{p, m\}$ simplex lattice design for 'p' components has the ratios of each component, taking $m + 1$ equally spaced values from 0 to 1.

$$X_i = 0, 1/m, 2/m, \dots, 1 \quad i = 1, 2, \dots, p \quad (1)$$

The number of design points in an A{p, m} simplex lattice design is,

$$N = \frac{(p + m - 1)!}{(m)!(p - 1)!} \quad (2)$$

In this study, an A{2, 4} simplex lattice design, shown in **Figure 1**, was used to determine viscose/polyester blends. The design points (blend ratios) used in this study are shown in **Table 1**.

Viscose and polyester fibres were processed and blended on a traditional short-

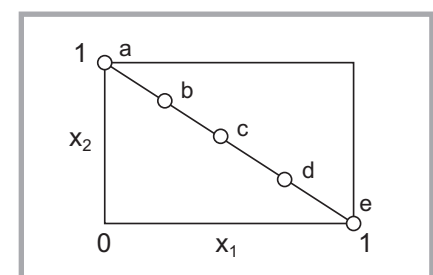


Figure 1. Simplex lattice design for viscose/polyester blended yarn [1].

Table 1. Design points (blend ratios) used in this study.

Design points	Blend ratios, %	
	Viscose	Polyester
1	0	100
2	25	75
3	50	50
4	75	25
5	100	0

Table 2. Machine setting of rotor spinning.

Machine parameters	Descriptions and conditions
Rotor diameter, mm	26
Rotor rotational speed, r.p.m.	53000
Twist per meter, t.p.m.	950
Opener type	OK61 (for synthetic fibres)
Total draft	178
Navel type	(Steel); 8 flutes, 4 flutes and without flutes
Yarn linear density, Ne	30
Delivery speed, m/min	75
Sliver linear density, g/m	3.5

Table 3. Some properties of knitted fabrics.

Property	Interlock (S ₁)	Half milano interlock (S ₂)	Half cardigan interlock (S ₃)
Surface Weight, g/m ²	243.06	250.13	257.32
Thickness, mm	0.809	0.896	0.996
WPC	14.7	10.89	12.8
CPC	12.44	8.27	8.07
SD, loop/cm ²	182.86	90.06	103.29
SCSL, cm	2.54	6.54	6.24

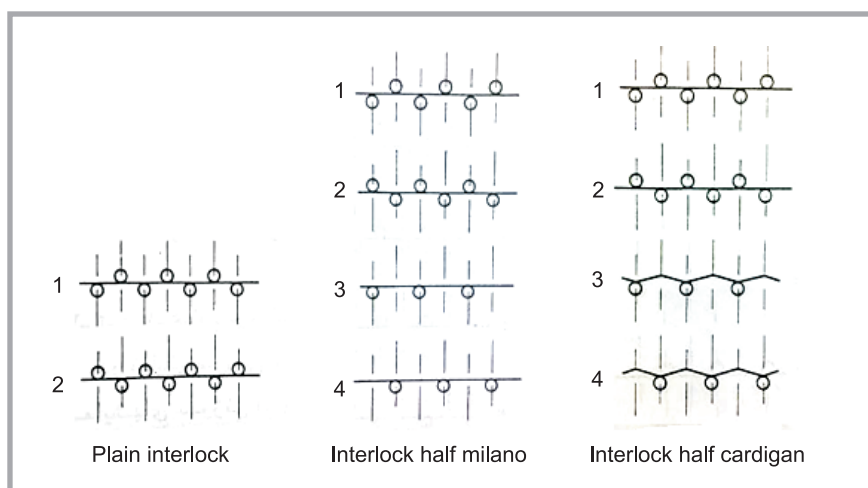


Figure 2. Three structures of the knitted fabrics.

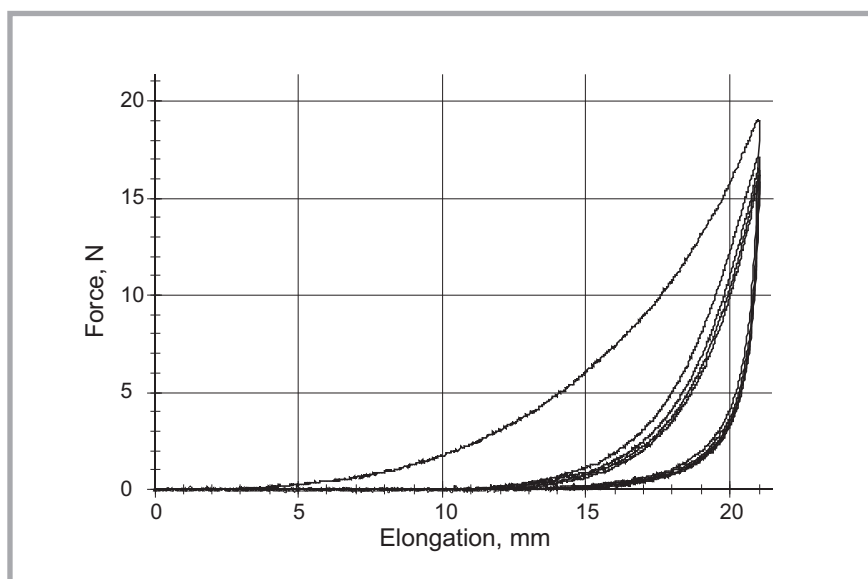


Figure 3. Typical force-traverse for five cyclic bagging tests.

staple (carding) spinning mill. The processing steps for both viscose and polyester were modern short-staple preparation and carding systems. The fibres were processed in these systems using standard mill procedures, adjustments and practices. The blending of fibres was carried out after carding at the first passage in the drawing frame. The second passage was used to improve the homogeneity of the blend. Slivers with different blend ratios were used to produce yarns on an Elitex rotor-spinning machine with a linear density of Ne 30. Viscose/polyester blended slivers were spun on a rotor spinning machine at standard atmospheric conditions (temperature of 20 ± 2 °C and relative humidity of $65 \pm 2\%$). Production parameters in this system are given in **Table 2**.

The viscose/polyester blended yarns (20 tex) spun on a rotor spinning machine were used to knit all samples. Using a double jersey circular knitting machine (Mayer & Cie, E20, 30”), three interlock knit structures: plain interlock, half milano interlock and half cardigan interlock were produced. The structures of the knitted fabrics are shown in **Figure 2**. Moreover details of the fabrics knitted are illustrated in **Table 3**.

Each of the knitted fabrics contained different fibre blend ratios and different fabric designs, hence the effect of fabric structure and material (fibre type) could be investigated. To prepare the wash-and-dry relaxation samples, the fabrics were washed in a domestic washer at 40 °C for 30 minutes with commercial detergent and tumble dried at 70 °C for 15 minutes in an electrically heated dryer after they had been dry relaxed. This procedure was repeated three times. Before measurements were taken, the samples were conditioned for 24 hours in a standard atmosphere. The wale and course count per 100 cm of fabric was measured and then converted to the wale and course count per cm. The stitch length of the knitted fabrics was measured to determine the unit stitch length. The stitch length from an average of ten measurements from each sample was used in the following equation to obtain the structural cell stitch lengths (SCSL) [15]:

$$SCSL = (Tl/N) \times N_t \text{ in cm} \quad (3)$$

Where Tl - total length of thread used in one cycle of knitting, N - tex of yarn, and

N_t = number of needles needed for the minimum repeat unit of knitting.

Weights were obtained from an average of three measurements of each sample using the balance, and are reported in g/m^2 . The fabric weights, knit densities and *SCSL* of each sample are shown in **Table 3**.

Most of the testing parameters are the same as in the test method presented by Zhang et al. [6, 9]. An exception is the predetermined bagging height. Zhang used 12 mm as the predetermined bagging height. The 12 mm deformation corresponds to approximately 10% elongation [13]. Although this is sufficient for the woven fabrics, knitted fabrics are subjected to much higher deformations during use. Kirk et al. [16] pointed out that when performance is the primary requirement, the available stretch level should be 20 to 30%, but when comfort is the primary requirement, the stretch level should be 25 to 40%. For these reasons, a deformed bagging height of 21 mm, corresponding to approximately 25% elongation was used. A typical force-traverse for five cyclic bagging tests is shown in **Figure 3**.

The maximum load, corresponding work of loads and bagging fatigue percentage in the first and last cycles are calculated using the following formula:

$$B_f = (W_f - W_l) / W_f \times 100 \text{ in \%} \quad (4)$$

Where: B_f - bagging fatigue in %, W_f - work of first cycle's loading, W_l - work of last cycle's loading.

The bagging fatigue percentage, which is the percentage of loss of energy after repeated bagging deformation in a fabric, is obtained.

Results and discussion

Best-fitting regression models that define the relationship between independent variables (blend ratios and fabric structure) and the response variable (fabric bagging height) are selected and estimated using Design-Expert software (**Table 4**). It is indicated that combined models that include both blend variables and the process variable are adequate to predict the response variables [1]. An ANOVA Table for the regression model and its estimated coefficients are shown in **Tables 5** and **6**.

Table 4. Bagging fatigue percentage of knitted fabrics with different structures and blend ratios.

Run	Polyester ratio	Viscose ratio	SCSL, cm	Bagging fatigue, %
1	1.000	0.000	6.24	66.39
2	0.000	1.000	2.54	74.91
3	0.750	0.250	2.54	67.54
4	0.500	0.500	6.24	72.75
5	0.000	1.000	6.51	79.51
6	0.250	0.750	6.51	75.63
7	0.750	0.250	6.51	69.12
8	0.250	0.750	6.24	74.62
9	0.500	0.500	6.51	73.76
10	0.000	1.000	6.24	76.22
11	0.750	0.250	6.24	68.28
12	1.000	0.000	2.54	64.73
13	0.250	0.750	2.54	73.25
14	1.000	0.000	6.51	67.35
15	0.500	0.500	2.54	72.51

Table 5. ANOVA Table for the regression model; model terms with p -value < 0.05 are considered significant.

Source	Sum squares	df	Mean squares	F-Square	P-value
Model	240.90	3	80.30	60.95	0.0018
Linear mixture	229.08	1	229.08	173.80	0.0010
AC	1.96	1	1.96	1.49	0.2483
BC	6.22	1	6.22	4.79	0.0525
Residual	14.49	11	1.32		
Cor Total	255.39	14			

Table 6. Regression model and its estimated coefficients.

Component	Estimated coefficient	df	Standard error	95% CI- low	95% CI- high
A-Polyester	66.00	1	0.55	64.79	67.21
B-Viscose	76.86	1	0.55	75.65	78.08
AC	0.64	1	0.52	-0.51	1.79
BC	1.14	1	0.52	-0.015	2.29

The Model F-value of 60.95 implies the model is statistically significant.

The bagging of viscose/polyester knitted fabrics can be predicted for different blend ratios and fabric structures using equation (5):

$$\begin{aligned} \text{Bagging fatigue percentage} = \\ = 66.00 A + 76.86 B + \\ + 0.64 A C + 1.14 B C \end{aligned} \quad (5)$$

where A, B and C indicate the polyester percentage, viscose percentage and SCLS of the knitted fabric, respectively. **Figure 4** (see page 70) illustrates regression curves fitted to experimental observations. The correlation coefficient between the bagging fatigue percentage predicted and the bagging fatigue percentage observed is 0.983, indicating the strong predictive capability of the regression model built.

Figure 5 (see page 70) shows changes in the bagging fatigue percentage of differ-

ent knit structures produced from different blend ratios.

The two main causes of fabric bagging behaviour are the stress relaxation of fibres owing to the fibre's viscoelastic behaviour and friction between fibres and yarns, due to frictional restraints in the fabric structure. Fibre-yarn mechanical properties and fabric structural properties, such as fabric thickness, weight, the tightness factor and interlacing points are the important factors influencing the bagging behaviour of a fabric [17].

As the percentage of polyester in the blend increases, the fabric bagging fatigue percentage decreases. Bagging fatigue includes the ability of elastic recovery. For polyester fibres the elasticity ratio is high and the viscoelasticity ratio is low. In contrast, for viscose fibres the elasticity ratio is low and the viscoelasticity ratio is high. In addition, the relaxation time for polyester fibres

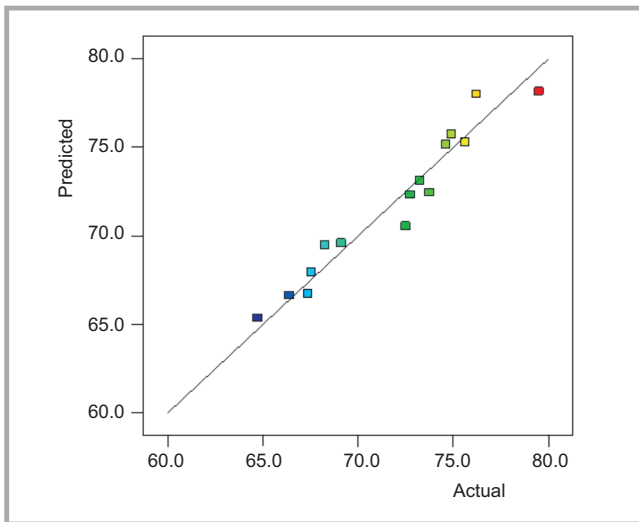


Figure 4. Regression line between predicted and actual bagging fatigue percentage.

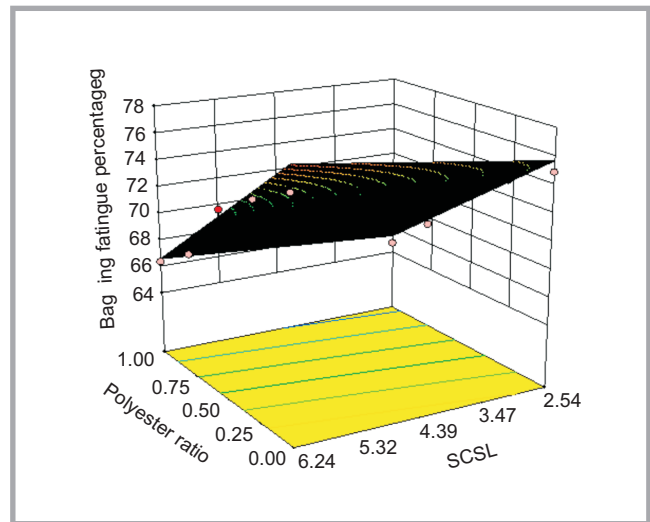


Figure 6. Bagging fatigue percentage of knitted fabrics in relation to different blend ratios and SCSL of knitted fabrics.

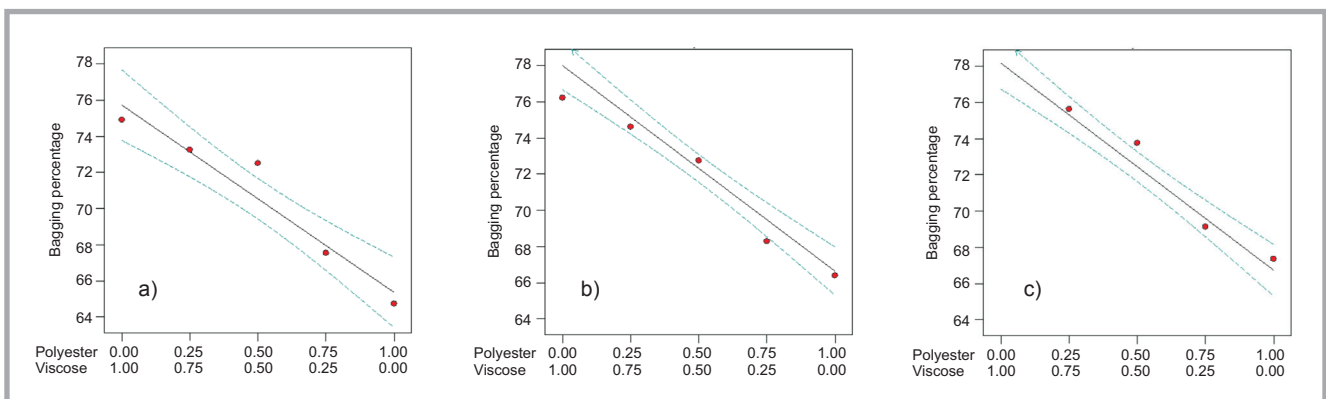


Figure 5. Bagging height of different fabric structures; a) plain interlock, b) interlock half milano, c) interlock half cardigan.

is higher than for viscose fibres. The relaxation time is in agreement with the corresponding fabric bagging fatigue. It can be stated that when the value of the relaxation time is small, which means the stress relaxation of the fibre is fast, then the bagging fatigue is larger [16].

The finding reveals that the bagging fatigue percentage of knit structures changes in the following order:

Interlock < half cardigan interlock < half milano interlock

As already mentioned, friction between yarns in the fabric structure and fabric structural properties, such as the tightness factor and interlacing points play an important role in this case. A plain interlock structure has higher stitch density than other structures. An increased tightness factor also increases fabric recovery after deformation due to its spring-like behaviour, which leads to a decrease in bagging fatigue [14]. Moreover the

structures produced from miss stitches represent a higher bagging fatigue percentage than those produced from tuck stitches, which can be due to the fact that structures with fewer interlacing points between stitches will tend to recover less deformation due to more frictional resistance, thus increasing the bagging fatigue percentage. On the other hand, an increase in the SCSL values of the fabrics will increase the bagging fatigue percentage, as is seen in **Figure 6**. Knitted fabric with a plain interlock structure produced from 100% polyester yarn has the lowest bagging fatigue percentage.

Conclusions

The bagging properties of viscose-polyester knitted fabrics are modelled through a validated regression model, in which blend ratios and fabric structure are the predictor variables. The model has a strong prediction capability, indicated by a high, positive correlation between bag-

ging fatigue percentage values predicted and bagging fatigue percentage values observed. Using this regression model, one can predict the bagging of viscose/polyester knitted fabrics for unobserved blend ratios and fabric structure within the design space used in this study. As the percentage of polyester in the blend increases, the fabric bagging fatigue percentage decreases, which can be due to a higher viscoelastic modulus and smaller relation time of the viscose fibres. Moreover the finding reveals that the bagging fatigue percentage of interlock fabrics is higher than for structures produced from miss and tuck stitches. Knitted fabric with a plain interlock structure produced from 100% polyester yarn has the lowest bagging fatigue percentage.

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INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES

LABORATORY OF BIODEGRADATION

The Laboratory of Biodegradation operates within the structure of the Institute of Biopolymers and Chemical Fibres. It is a modern laboratory with a certificate of accreditation according to Standard PN-EN/ISO/IEC-17025: 2005 (a quality system) bestowed by the Polish Accreditation Centre (PCA). The laboratory works at a global level and can cooperate with many institutions that produce, process and investigate polymeric materials. Thanks to its modern equipment, the Laboratory of Biodegradation can maintain cooperation with Polish and foreign research centers as well as manufacturers and be helpful in assessing the biodegradability of polymeric materials and textiles.

The Laboratory of Biodegradation assesses the susceptibility of polymeric and textile materials to biological degradation caused by microorganisms occurring in the natural environment (soil, compost and water medium). The testing of biodegradation is carried out in oxygen using innovative methods like respirometric testing with the continuous reading of the CO₂ delivered. The laboratory's modern MICRO-OXYMAX RESPIROMETER is used for carrying out tests in accordance with International Standards.



The methodology of biodegradability testing has been prepared on the basis of the following standards:

- **testing in aqueous medium:** 'Determination of the ultimate aerobic biodegradability of plastic materials and textiles in an aqueous medium. A method of analysing the carbon dioxide evolved' (PN-EN ISO 14 852: 2007, and PN-EN ISO 8192: 2007)
- **testing in compost medium:** 'Determination of the degree of disintegration of plastic materials and textiles under simulated composting conditions in a laboratory-scale test. A method of determining the weight loss' (PN-EN ISO 20 200: 2007, PN-EN ISO 14 045: 2005, and PN-EN ISO 14 806: 2010)
- **testing in soil medium:** 'Determination of the degree of disintegration of plastic materials and textiles under simulated soil conditions in a laboratory-scale test. A method of determining the weight loss' (PN-EN ISO 11 266: 1997, PN-EN ISO 11 721-1: 2002, and PN-EN ISO 11 721-2: 2002).



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The following methods are applied in the assessment of biodegradation: gel chromatography (GPC), infrared spectroscopy (IR), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM).

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