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Study of the Hairiness of Polyester-Viscose Blended Yarns. Part IV - Predicting Yarn Hairiness Using Fuzzy Logic

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Abstract
This paper is a continuation of studies on the hairiness of polyester-viscose blended ring spun yarns. The aim of this study is to predict the hairiness of polyester-viscose blended yarns using a fuzzy logic system. For this purpose, based on the ANOVA statistical test, some parameters that have more influence on yarn hairiness were selected: spindle speed, traveller count, and yarn count, which are taken into account as the inputs, and yarn hairiness is counted as the output in the fuzzy set. The hairiness of ring spun polyester-viscose blended yarns was successfully modelled using fuzzy logic. The results showed that the correlation coefficient between the predicted and experimental values of hairiness is acceptable (R^2 = 0.931).

Key words: *fuzzy logic, polyester-viscose blended yarn, yarn hairiness, spindle speed, traveller count, yarn coun.*

Introduction

Hairiness is usually characterised by the amount of fibres protruding out of the compact yarn body. Many parameters of the spinning process have an influence on yarn hairiness, as explained in previous studies [1 - 3]. The modelling of yarn properties using the relationship between fibre and yarn properties has been one of the most interesting topics in textile research. Therefore predictive models have been developed to forecast yarn properties such as hairiness, strength, evenness, and so on.

Majumdar and Ghosh [4] used the fuzzy expert system to model the tenacity of ring spun cotton yarns. They also mentioned different modelling methods to predict yarn properties. Majumdar [5] presented the modelling of cotton yarn hairiness using the adaptive neuro-fuzzy interface system. In his study, some cotton fibre properties such as the mean length, maturity, short fibre content and yarn linear density were used as inputs to the model. Chen et al [6] developed a new technique for optimising the estimation of the ease allowance of a garment using fuzzy logic and sensory evaluation. The effectiveness of their method was validated in the design of trousers of the jean type.

A fuzzy comprehensive evaluation technique for estimating the fabric handle of lightweight dress fabric was presented by Raheel and Liu [7]. They investigated the physical and mechanical properties of several lightweight fabrics and created a series of membership functions for the properties mentioned. By using the weighted factor and fuzzy transformation matrix, the fabric handle was calculated.

Lin et al [8] introduced an intelligent diagnosis system for fabric inspection by combining a conventional expert system and diagnostic system based on fuzzy set theory. It was claimed that this system could be used as an expert advisor for operators to find the causes of breakdowns. In another paper, Kayacan et al [9] reported the use of fuzzy logic to control the weft insertion system in air jet weaving looms. The influence of yarn properties (yarn linear density, twist factor) on weft yarn velocity has been investigated using fuzzy logic. The results obtained from the fuzzy logic model were compared with experimental results. They stated that the yarn speed could be determined in relation to the twist factor and yarn count by fuzzy logic.

Sarna et al [10] also used the fuzzy set theory to determine the maturity degree of cotton fibres based on the examination of cotton fractures using the scanning electron microscope (SEM) technique. The fuzzy set conception was adopted to analyse each image, considering the fracture category. They found that the method of analysis of SEM images with the application of a fuzzy set enables to carry out quantitative analysis of cotton fracture images.

Kuo et al [11] predicted the properties of a melt spinning system using fuzzy theory. In order to calculate the extruder screw speed, gear pump speed, and winder speed, a mathematical model, according to fuzzy theory, is suggested.

Çeven and Özdemir [12] used a fuzzy logic model to evaluate the influences of yarn parameters (yarn counts, pile lengths, and the twist level) on the boiling shrinkage behaviour of chenille yarns. Their results showed that the relationship between the experimental and predicted yarn shrinkage values is linear.

Description of fuzzy logic

Fuzzy logic was introduced by Lotfi Zahdeh [13] in 1965, and its application has been increased significantly in recent years. Fuzzy logic is based on human communication, and it is built on the structures of qualitative description used in everyday language. Fuzzy logic begins with the concept of a fuzzy set. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic [14, 15].

The fuzzy inference process includes five parts: fuzzification, logical operations (AND or OR), implication method, aggregation of the consequents via the rules, and defuzzification [14].

The first step is to take the inputs and determine the degree to which they are owned by each of the appropriate fuzzy sets via membership functions. A membership function (MF) is a curve that explains how each point in the input space is mapped to a degree of membership between [0, 1]. The MF can have various forms such as a *Triangle*, *Trapezoid* and *Gaussian*.

For example the *Gaussian* function depends on two parameters, the variance (σ) and mean (c), as below [14]:

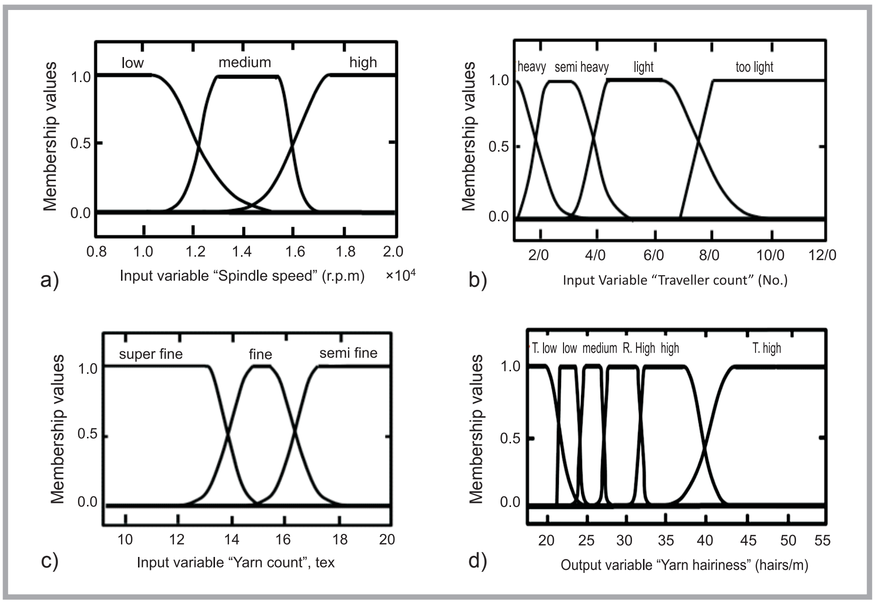

Figure 1. *Membership function of: a) spindle speed, b) traveller count, c) yarn count, d) yarn hairiness.*

Table 1. *Linguistic fuzzy sets for input and output parameters.*

Parameters	Range	Linguistic fuzzy sets
Spindle speed, r.p.m	8000 - 20000	low, medium, high
Traveller count (No)	1/0 - 12/0	heavy, semi heavy, light, too light
Yarn count, tex	8.0 - 20.0	super fine, fine, semi fine
Yarn hairiness, average hairs/m	17 - 54	too low, low, medium, rather high, high, too high

Table 2*. Selected fuzzy rules.*

Rules	Spindle speed	Traveller count	Yarn count	Yarn hairiness
1	low	semi heavy	semi fine	medium
2	high	light	fine	high
3	medium	semi heavy	fine	low
4	high	heavy	fine	rather high
5	medium	too light	semi fine	too high
6	high	semi heavy	fine	medium
7	medium	heavy	super fine	too low
8	low	light	fine	rather high
9	high	semi heavy	super fine	low
10	low	heavy	fine	too low
	⋮	⋮	⋮	
29	medium	light	super fine	low
30	low	semi heavy	super fine	too low

$$f(x;\sigma,c)=e^{\frac{-(x-c)^2}{2\sigma^2}} \qquad (1)$$

If-then rule statements are used to formulate conditional statements that include fuzzy logic. A single fuzzy if-then rule supposes the form:

“if *X* is *A* then *Y* is *B”*

where, *A* and *B* are linguistic values defined by fuzzy sets within the ranges of *X* and *Y*, respectively.

In general, the input to an if-then rule is the current value for the input variable, and the output is an entire fuzzy set.

Aggregation is the processes that represents the outputs of each rule, joined into a single fuzzy set. Aggregation only occurs once for each output variable, just before the fifth and final step (defuzzification).

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set), and the output is a single number. The aggregate of the fuzzy set includes a range of output values and hence must be defuzzified in order to determine a single output value from the fuzzy set [14].

Two types of fuzzy inference systems, in the *Matlab* Toolbox, can be performed: *Mamdani-type* and *Sugeno-type*. *Mamdani’s* fuzzy inference method is the most commonly seen fuzzy methodology, suggested in 1975 [14, 16].

The *Sugeno* method of fuzzy inference was introduced in 1985 [14], which is similar to the *Mamdani* method, in many respects. The first two parts of the fuzzy inference process are the same. The main difference between these methods is that the *Sugeno* output membership functions are either linear or constant. The *Mamdani-type* inference assumes the output membership functions to be a fuzzy set. There is a fuzzy set for each output variable after the process of aggregation that needs defuzzification. The parallel nature of the rules is one of the most important aspects of fuzzy logic systems [14].

Materials and methods

Fibre and roving properties, and preparation of yarn samples

Experiments were carried out using polyester-viscose blended yarns (80 : 20). The characteristics of fibre, roving, and yarn samples were presented previously [1]. The findings of previous researches [1, 2] indicate that several parameters such as the total draft, diameter of the balloon control ring, roving twist, yarn count, yarn twist, spindle speed, traveller weight, and so on, have a significant influence on the hairiness of blended polyester-viscose yarns. On the basis of the *ANOVA* statistical test, the traveller weight, spindle speed, diameter of the balloon control ring, and yarn count have the highest values of *Sum of Squares* (*S.S*) and *Mean Square* (*M.S*) among the parameters mentioned. As a result, it can be concluded that these parameters have more influence on yarn hairiness than other factors. However, according to the initial design of the ring spinning machine, the diameter of the balloon control ring rarely changes. Therefore, in this study the traveller count, spindle speed, and yarn count are selected and taken into account as inputs, with yarn hairiness being counted as an output in the fuzzy set.

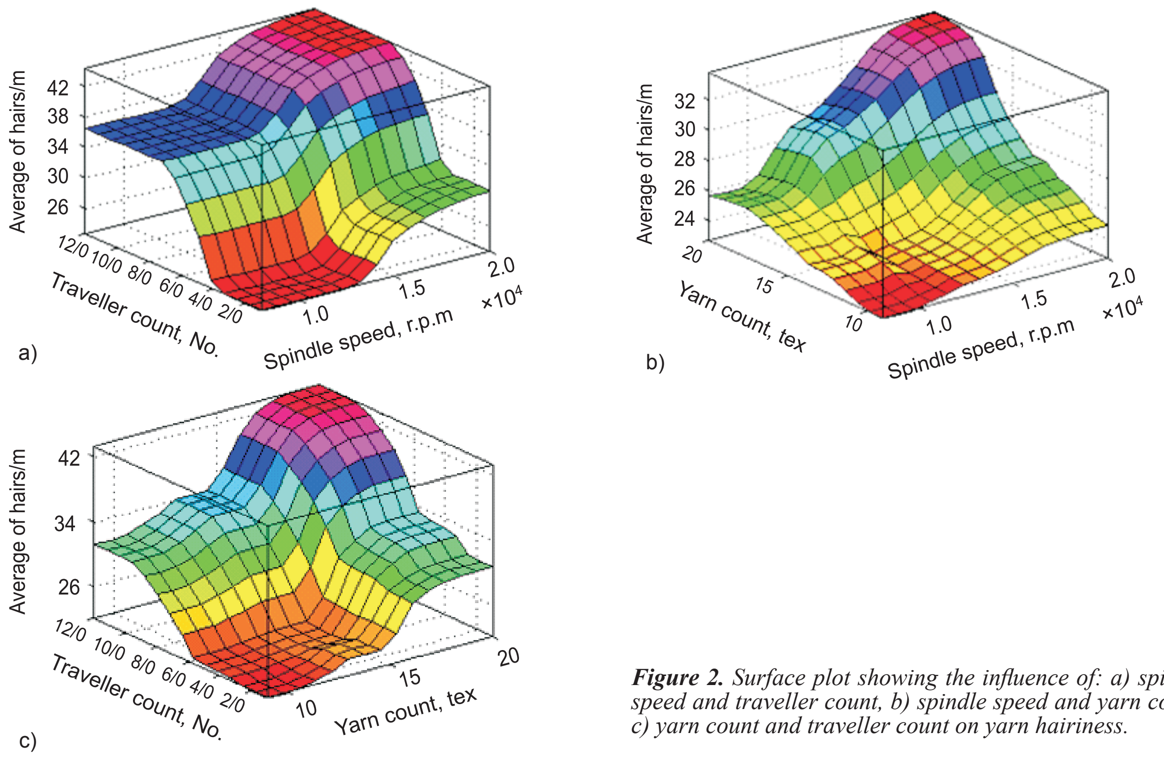

Figure 2. *Surface plot showing the influence of: a) spindle speed and traveller count, b) spindle speed and yarn count, c) yarn count and traveller count on yarn hairiness.*

Fuzzy set parameters

To create a fuzzy system, some linguistic fuzzy sets such as super fine, fine, semi fine and so on, were used for each of the input and output parameters (***Table 1***). Two types of membership functions (*Gaussian2mf* and *Trapmf*) were selected for inputs and outputs. ***Figures 1*** shows the membership functions for the spindle speed, traveller count, yarn count, and yarn hairiness. The input to the fuzzy operator is two or more membership values from the fuzzified input variables. The output is a single truth-value.

After fuzzifying, to simplify the expert system, the rules were developed, some of which are shown in ***Table 2***. In these rules, '*AND*' and 'OR' operations were used. The fuzzy '*AND*' and '*OR*' operators, respectively, select the '*Minimum*' and '*Maximum*' of the two values, as shown below [4]:

$$AND = \min\{\mu_A(x), \mu_B(x)\} \qquad (2)$$

$$OR = \max\{\mu_A(x), \mu_B(x)\} \qquad (3)$$

where, $\mu_A(x)$ and $\mu_B(x)$ are the output fuzzy set after aggregation of individual implication results.

Finally, a fuzzy hairiness model is developed using the Mamdani system.

Results and discussion

Operation of fuzzy logic

According to the first rule (***Table 2***), when the spindle speed, traveller count and yarn count are low, semi-heavy, semi-fine, respectively, the yarn hairiness is medium. Finally the last rule shows that if the spindle speed, traveller count and yarn count are low, semi-heavy, and super fine, respectively, the yarn hairiness is too low. For example, if the spindle speed is 13000 r.p.m., the traveller count - 3/0 No. and yarn count - 17 tex, then all thirty fuzzy rules (***Table 2***) are evaluated simultaneously to determine the yarn hairiness. After aggregation and defuzzication, the final crisp output of the fuzzy set is 27.9 hairs/m.

Influence of input parameters on yarn hairiness

Surface plots obtained from fuzzy logic are shown in ***Figure 2***. ***Figure 2.a*** shows that the hairiness increases when the traveller count and spindle speed increase; the hairiness is low when the traveller count and spindle speed values are low, and the highest values of hairiness are observed when both the spindle speed and traveller count are maximum, as expected (in this case, the yarn is semi fine).

Figure 2.b shows that yarn hairiness increases when the spindle speed and yarn count increase. It can be observed that when the values of spindle speed or yarn count are low, the increasing in yarn hairiness is not considerable. In contrast, the higher values of spindle speed and yarn count cause that the rate of yarn hairiness increases remarkably as expected (in this case, the traveller is semi heavy). ***Figure 2.c*** shows that yarn hairiness increases when the yarn count and traveller count increase (in this case, the spindle speed is medium).

From these surface plots, it can be surmised that the influence of the traveller count on yarn hairiness is more effective than that of other parameters (spindle speed and yarn count) because the highest values of yarn hairiness could be considered in ***Figures 2.a & 2.c***.

Validation of fuzzy logic

It is known that to verify the performance of fuzzy logic, if the numbers of data are sufficient, better results can be achieved. For this reason, the regression method is used. Linear and Nonlinear Regression estimate the coefficients of the equation, involving one or more independent variables that best predict the value of the dependent variable. The results of the regression of spindle speed and yarn count as independent variables, and yarn hairiness as a dependent variable show that the cubic nonlinear curve has the

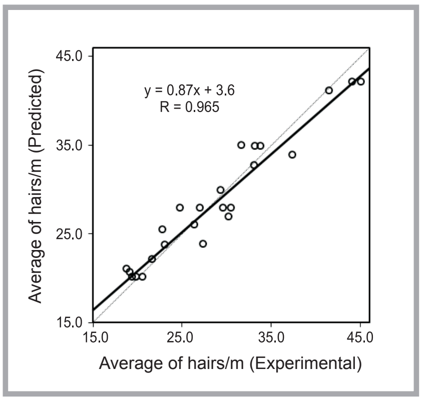

Figure 3. *Relationship between experimental and predicted hairiness.*

best correlation coefficient (0.890, 0.974 for the spindle speed and yarn count, respectively).

$$y = -2\times10^{-12}x_1^3 + 0.0025x_1 - 0.1735 \quad (4)$$

$$y = 0.0018x_2^3 - 0.2512x_2 + 20.2398 \quad (5)$$

where, y - yarn hairiness (average of hairs/m), x_1 - spindle speed in r.p.m, x_2 - yarn count in tex.

By using ***Equations 4 & 5***, the other values of hairiness can be calculated (***Table 3***). The prediction accuracy of the fuzzy logic model was evaluated by applying '*PF/3*' (Performance Factor [17]), as well as the correlation coefficient (R-value) between the predicted and experimental values. It is observed that the '*R-value*' is 0.965 ($R^2 = 0.931$) and '*PF/3*' - *7.206*. It can be concluded that the processed fuzzy logic can explain up to 93% of the total variability of yarn hairiness; on the other hand, it shows that the prediction accuracy of fuzzy logic is 93%. The Mean Square Error (*MSE*) between the experimental and predicted values is 4.116.

Table 3. *Input and output data; x_1 - spindle speed in r.p.m, x_2 - yarn count in tex, x_3 - traveller count, No., y - yarn hairiness, average of hairs/m.*

Samples	Input parameters			Output parameter
	x1	x2	x3	y
1	8000			18.80
2	10000			22.83
3	12000			26.37
4	14000	20	3/0	29.34
5	16000			31.63
6	18000			33.16
7	20000			33.83
8		8.0		19.15
9		9.5		19.40
10		11.0		19.87
11		12.5		20.62
12	13000	14.0	3/0	21.66
13		15.5		23.05
14		17.0		24.81
15		18.5		26.99
16		20.0		29.62
17			1/0	27.42
18			2/0	30.23
19			3/0	30.48
20	13000	20	4/0	33.12
21			6/0	37.39
22			8/0	41.49
23			10/0	44.23
24			12/0	45.22

Figure 3 shows the relationship between the experimental and predicted hairiness values. It can be seen that there is a good relationship between these values.

Conclusions

In this study, the hairiness of ring spun polyester-viscose blended yarns has been successfully modeled using the fuzzy logic system. An expert system was created by translating the comprehension and experience of the spinners into a fuzzy inference system. This system is easy to develop and could be modified if the processing factors are changed.

The result of the fuzzy logic system shows that the three parameters selected (traveller count, spindle speed, and yarn count) are suitable as input parameters to the model.

A suitable understanding of the interaction between the parameters mentioned and their influence on yarn hairiness was achieved by developing fuzzy rules. On the other hand, the fuzzy rules developed explain the roles of various input parameters on yarn hairiness.

The prediction exactness of the fuzzy system suggested is found to be high. The mean square error between the experimental and predicted values is 4.116, which is acceptable. Moreover, the *PF/3* value shows that the prediction accuracy of fuzzy logic is 93%.

The surface plots show that yarn hairiness increases when the spindle speed, traveller count and yarn count increase. However, the influence of the traveller count on hairiness is more considerable than the two other parameters. Moreover, at low values of these parameters, the increase in hairiness is not considerable.

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