OPTIMISATION OF THE BEHAVIOUR OF SIZED WET SPLICED YARNS

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Abstract:

This work presents the contribution of optimisation analysis of the performance of wet pneumatic spliced cotton yarns using two different methods: the superimposed contours method and the function of desirability. Cotton yarn linear density (Y_c), length of splice (SL), duration of water joining (D_{wj}) and duration of air joining (D_{aj}) were optimised in the experimental field of interest. In this study regression equations expressing multi-component splice mechanical performances were elaborated by using the response surface method. In order to validate the results, a desirability function, multi-objective technique was used to select optimal parameter zones which give high splice behaviour. The results show that there are zones of compromise where wet pneumatic splice behaves better before weaving. In this work, the spliced yarn performance was optimised.

Key words:

Spliced cotton yarns, the superimposed contours method, the function of desirability method

Introduction

Wet-pneumatic splicing of warp and weft yarns is a technique based on the addition of water at the moment of the junction in order to improve the splice's resistance and appearance. Both ends of yarns are overlapped and held in a suitably shaped chamber or prism. A turbulent blast of air is then used to intermesh and entangle both the fibres and water.

Spliced yarn mechanical properties like breaking strength, elongation at break, and cyclical tensioning lifetime are the most important parameters affecting not only the quality and performance of the end-product but also the cost of the yarn-to-fabric process.

Studies have been carried out during the last thirty years on the effect of parent yarn structure and splicer parameters on the appearance and the mechanical properties of the pneumatic splice [3–7]. Kaushik [5] was interested in studying the performance of splices during warping and weaving.

Recently, we have proposed to optimise the properties of wet pneumatic splicing using an experimental design method [1 and 2]. Sizing is a treatment carried out on warp yarns before weaving to improve their mechanical properties [8–11]. Considering the splice as the weakest zone in the yarn, it will be interesting to examine the effect of splicing parameters on mechanical properties of both parent and spliced yarn. In our earlier work [1] we studied the strength of the denim spliced yarns before weaving. The results showed that there are some interesting splicing inputs which can affect the strength of sized splice.

In this paper, mechanical behaviours of both parent and wet spliced cotton denim yarns before and after sizing were compared using natural and synthetic sizes.

Materials and method

Three cotton denim yarns were used for the experiment in our study. The pneumatic splicer, a Schlafhorst Autoconer 338, produced all the spliced yarn joints in optimal conditions [12]. Two size formulations are used in this investigation: native and synthetic [1]. Table 1 presents the factors and levels used in the orthogonal analysis. A centred composite design with central points was built. The splices were then tested on a Lloyd tensile tester to determinate mechanical properties (retained breaking strength of splice, RSS; retained splice elongation at break, RSE). They are expressed by Equations 1 and 2 respectively.

$$RSS_{after\ sizing}(\%) = 100 \times \left(\frac{Str_{splice}}{Str_{parent\ yarn}} \right) \quad (1)$$

$$RSE_{after\ sizing}(\%) = 100 \times \left(\frac{El_{splice}}{El_{parent\ yarn}} \right) \quad (2)$$

where:

breaking strengths of splice and parent yarn respectively (N)
elongations at break of splice and parent yarn respectively (mm).

The overall physical parameters (RSS1 and RSE1) of sized splice using native glue were optimised. However those using synthetic sizes are represented by RSS2 and RSE2.

The length of each specimen is 100 mm according to Sharma and Kaushik [2, 3, and 5]. We tested 50 samples in each test of our experimental design. The experiments to produce splices were planned according to the central composite rotatable design for four variables: yarn count (Y_c), length of splice (SL) expressed as a function of contributor position in

Table 1. Input parameter levels.

Levels	Y_c (tex)	SL	D_{wj} (ms)	D_{aj} (ms)
1	29.4	1	20	60
2	64.7	2,5	410	240
3	100	4	800	420

Table 2. Responses obtained by using the desirability function of maximisation of the sized wet mechanical performances.

Input parameters		RSS1 (%)		RSE1 (%)		RSS2 (%)		RSE2 (%)	
		Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.
Thin yarn (Yc = 29, 4 tex)	SL	2.25	2	2.25	2	2.25	2.5	2.25	2.5
	D_{aj} (ms)	410	420	410	420	400	420	400	420
	D_{wj} (ms)	38	38	38	38	700	700	700	700
Desirability (%)		100.05	99.18	92.51	92.64	100.02	99.03	95.52	95.17
Middle yarn (Yc = 64, 7 tex)	SL	2.55	2.5	2.55	2.5	2.25	2	2.25	2
	D_{aj} (ms)	420	420	420	420	420	420	420	420
	D_{wj} (ms)	450	450	450	450	460	460	460	460
Desirability (%)		86.7	86.69	94.91	94.82	91.51	91.94	97.69	97.58
Thick yarn Yc = 100tex	SL	2.5	2.5	2.5	2.5	1.6	1.5	1.6	1.5
	D_{aj} (ms)	420	420	420	420	360	360	360	360
	D_{wj} (ms)	700	700	700	700	605	605	605	605
Desirability (%)		76.92	76.92	67.34	67.34	79.85	79.84	83.34	82.75

the splicer system, duration of water joining (D_{wj}), and duration of air joining (D_{aj}).

Additional tests (central observation points) were chosen in order to confirm and adjust experimental error. In this way, we were able to consider variations in the central observation point due to variations in the setting of the process and the machine variables.

In order to validate our optimisation results, the coefficient of determination (R^2), which indicates the amount of variation in the response, was discussed. The higher the value of R^2, the better the model fits the experimental data.

Then, a statistical test was carried out to determine whether the regression model, the linear term, and the quadratic term in this model are significant. The p-statistic was used. It helps to decide whether to reject or fail to reject a null hypothesis (the null hypothesis states that the effect is not significant). The p-value is the probability of obtaining a test statistic that is at least as extreme as the actual calculated value if the null hypothesis is true. A commonly used cut-off level for the p-value is 0.05. For example, if the calculated p-value of a test statistic is less than 0.05, we reject the null hypothesis (i.e. the effect is significant) [13].

We aim to optimise all the input parameters by satisfying the requirement for each parameter. The optimisation is accomplished by:

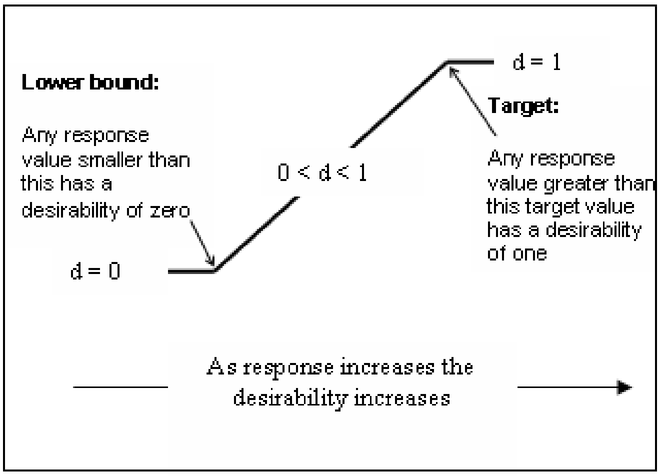

Figure 1. Maximising the desirability function.

- obtaining the individual desirability (d) for each response,
- combining the individual desirabilities to obtain the combined or composite desirability (D),
- maximising the composite desirability and identifying the optimal splice performance.

To obtain the individual desirability (d) for each parameter, goals are used. In our case one goal is used: maximising the parameters (the larger the better).

In the case of a parameter that we want to maximise we need to determine a target value and an allowable maximum value. The desirability that this parameter is below (resp. above) the target value is one; above (resp. below) the maximum acceptable value, the desirability is zero. The closer the parameter is to the target, the closer the desirability is to one.

Figure 1 shows the desirability function used to determine the individual desirability for a “larger is better” goal.

After calculating an individual desirability for each response and each input parameter, these corresponding desirabilities are combined to provide a measure of the composite, or overall, desirability of the splice. This measure of composite desirability (D) is the weighted geometric mean of the individual or elementary desirabilities for the parameters. The individual desirabilities are weighted according to the importance that we assign to each parameter [14].

Finally, Minitab software is employed to maximise the composite desirability and determine the optimal solution (optimal values of properties).

Results and discussion

The input database of our study is used for a central composite design in order to present the possible fields of change and the compromise zones. These zones of compromise are presented on white surfaces. Then, we are able to guarantee good behaviours of sized splices during spinning and weaving. These diagrams of superimposed contours define both the mechanical performance limits and the ranges within these responses which are optimum according to the input parameter levels.

There are two conditions which are used in this study:

- {(96% < RSS1 < 99%) and (96% < RSS2 < 99%)} and
- {(93% < RSE1 < 100%) and (93% < RSE2 < 100%)}.

Figure 2 shows whole graphs where the zones of compromise are posted in white. These results are given by Minitab software. These zones are advised for good mechanical performance of splices. The experimenter can, indeed, consider the values of the input parameters which maximise the tested mechanical properties.

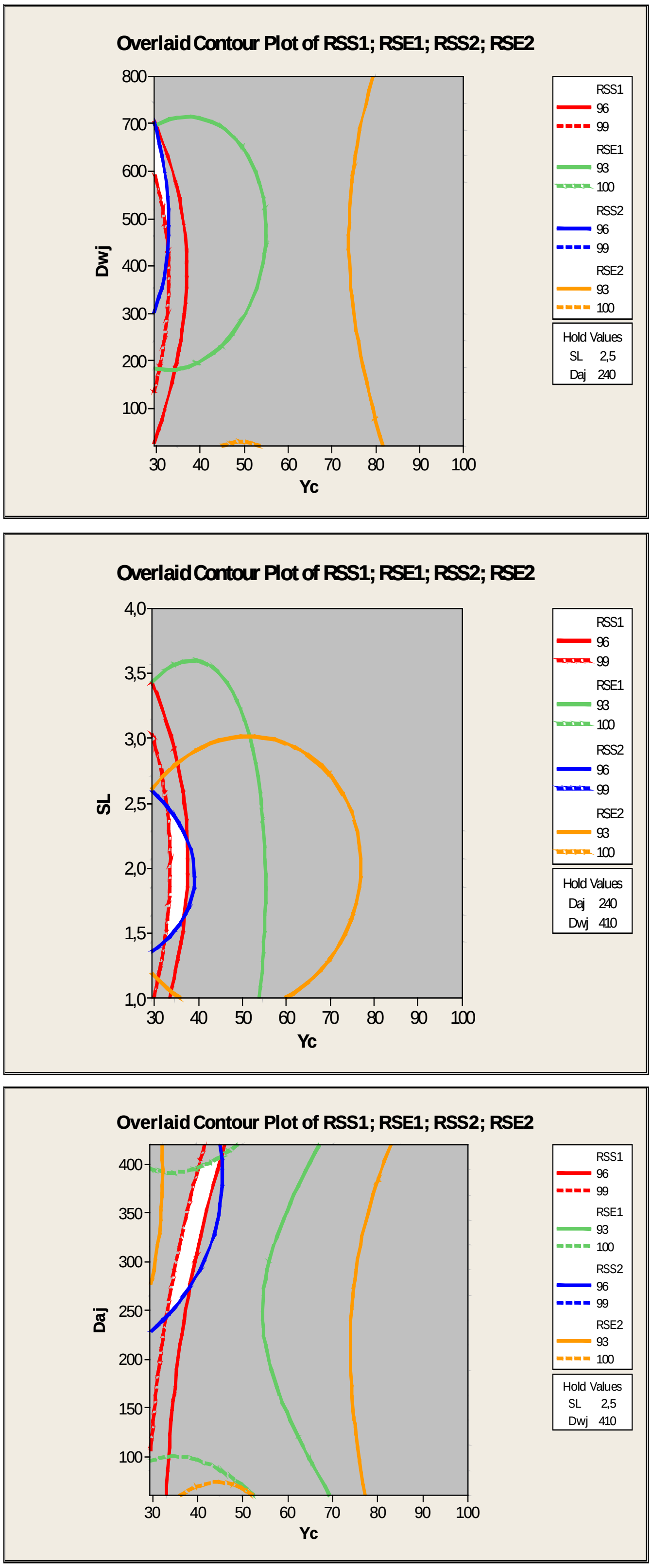

Figure 2. Superimposed diagrams of splice properties after optimisation

In the same way, we can note that quite precise intervals are created for each input parameter in order to optimise RSS (%) and RSE (%) at the same time:

$$*Y_c \in [30, 40]$$

$$*D_{aj} \in [250, 400]$$

$$*D_{wj} \in [500, 700]$$

$$*SL \in [1,5, 2,5]$$

- High values of R^2 (80.3–91.4) prove that good correlations between experimental results and the elaborated models are obtained.
- All regression models are significant (p-regression < 0.05 for some input parameters).
- For the RSS and RSE before sizing using native and synthetic size, only their quadratic terms Yc and SL are significant. However, their interaction terms are not significant (p-quadratic > 0.05). It may be concluded that these two parameters are important.
- The interaction between duration of water joining and duration of air joining is more important for splice properties. This may prove that it is better to choose their values in order to optimise splice mechanical properties after sizing.

Optimisation of splice performance using superimposed contours method and desirability function

Figure 2 shows the diagram of superimposed contours of all splice properties. The white areas are the high performance of the splice relative to the elementary desirability of each response.

To represent the evolution of the responses corresponding with each combination of sizes (RSS1, RSS2, RSE1, and RSE2), we used the function of desirability in order to optimise the mechanical properties of sized wet splices in the weaving process. Then, the adjustments estimated by industrially possible software Minitab are given in Table 2.

In the approach of optimisation by Minitab software, each value of response is transformed using a specific function of desirability. Weighting choice (ranging between 0.1 and 10) and the form of the function of desirability (function of maximisation) for each mechanical property were used.

Table 2 shows the mechanical properties given by Minitab 14 using the function of maximisation indicated above and following initial conditions:

- For the breaking strength: lower = 96% and target = 99 %.
- For elongation at break: lower = 93% and target = 100%.

In order to compare the theoretical and experimental results of optimisation of splice performance, we investigate input parameters which give theoretical and approximate experimental values.

The results show that there are small differences between these values. As a consequence, a good choice of input parameters in the experimental field of interest gives high splice performance before weaving.

Conclusions

In this study, we optimised the mechanical properties of wet pneumatic spliced yarns after sizing using the technique of superimposed contours and the desirability function. In more specific fields it is possible to improve the mechanical properties before weaving. This is due to the open structure, which allows a better penetration of the size.

The technique of superimposed contours and the desirability function enabled us to optimise the mechanical properties in a well defined experimental field. Using these findings, spinners can modify their adjustments so that they can make the best possible splices. Taking into consideration the criteria for each mechanical property, it is possible to fix the suitable experimental field for good behaviour of the spliced yarn before weaving.

The increases in both splice length and duration of water joining increase the splice's mechanical behaviour. The desirability function results show that the synthetic size gives better performance of wet spliced cotton yarns.

Finally, this study shows that it is usually possible to optimise spliced yarn behaviour using suitable splicing parameter values. This behaviour remains a function of choice of overall elementary desirabilities.

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