Optimization of process parameters in air-jet texturing of polyester/viscose blended yarns

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The effect of process parameters on properties of polyester/viscose blended air-jet textured yarns has been studied. It is observed that with the increase in texturing speed the yarn physical bulk reduces, and instability and tenacity increase. With increasing air pressure or overfeed, the physical bulk and instability increase, whereas tenacity reduces. Regression equations for the prediction of air-jet textured yarns properties have also been derived. On the basis of the regression equations the optimum process parameters for producing good quality air-jet textured yarns have been obtained, considering that the yarns with lowest instability, and high bulk and tenacity are desirable. Yarn instability is accorded the highest weightage while bulk is given intermediate and tenacity the lowest weightage in order to find out the combination of parameters that will produce yarns of low instability, high bulk and high tenacity values.

Keywords: Air-jet texturing, Polyester/viscose blended yarn, Physical bulk

1 Introduction
Air-jet texturing is one of the several processes used to convert synthetic filament yarns to textured yarns and is the most versatile of all known texturing methods. The air-jet texturing process is widely known for its ability to produce continuous filament yarns with spun yarn like appearance. The process converts flat filament yarns into bulky spun like yarns. It involves overfeeding of multifilament supply yarns from a creel into an air-jet via an optional yarn wetting device. Action of the compressed turbulent cold air stream causes overfed individual filaments to form loops and entangle with each other. Air-jet texturing is a mechanical method and, therefore, thermoplastic and non-thermoplastic filament yarns can be used for air-jet texturing. Air-jet texturing thus provides excellent potential for combining two or more multifilament yarns into a more or less intimately blended and coherent structure. In the present study, an attempt has been made to predict the optimum process parameters on the basis of yarn physical bulk, instability and tenacity for producing good quality polyester/viscose blended air-jet textured yarns.

2 Materials and Methods
2.1 Raw Materials
Two types of fully oriented yarns (FOY), namely polyester of 80/75 dtex (72/75 denier) and viscose of 80/24 dtex (72/24 denier), were used for air-jet texturing. The average tenacity values of the polyester and viscose yarns were 3.96 cN/dtex (CV% 3.57) and 1.55 cN/dtex (CV% 9.28) respectively.

2.2 Preparation of Textured Yarn Samples
Initially, before the actual textured yarn preparation, the supply yarns were run through the air-jet texturing machine individually as well as in 50/50 blend to understand the behavior of the yarns under actual running conditions and to select the range of process parameters that successfully runs for the yarns on the machine. This was done on the basis of the behaviour of the yarns during texturing and also on the basis of the resultant yarn properties (physical bulk, instability and tenacity). The ranges of process
parameters found to be suitable were:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low (coded -1)</th>
<th>Medium (coded 0)</th>
<th>High (coded +1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/c speed, m/min</td>
<td>300</td>
<td>400</td>
<td>500</td>
</tr>
<tr>
<td>Overfeed, %</td>
<td>14.7</td>
<td>24</td>
<td>33.3</td>
</tr>
<tr>
<td>Air pressure, bar</td>
<td>7</td>
<td>8.5</td>
<td>10</td>
</tr>
</tbody>
</table>

Within this range three different values for each parameter at equal intervals were taken as high, medium and low (coded as +1, 0, -1) values as shown in Table 1 and these values were used in different combinations according to Box Behnken 3 level design (Table 2) to prepare the yarn samples for the study. The combinations were used randomly according to random number table as 1, 14, 7, 4, 12, 10, 18, 2, 16, 19, 3, 9, 15, 11, 6, 17, 5, 8, 13 for sample preparation to avoid any biasness of sampling. Five different blends along with 100 % polyester and 100 % viscose filament yarns were taken for the study. Blending was carried out by feeding the required number of yarn combinations to the jet according to Table 3. The following machine parameters were kept constant for all the samples:

- M/c used: Eltex AT/HS
- Nozzle used: Hemajet S325
- Winding underfeed: 0.7%
- Mechanical stretch: 4.7%
- Stabilizing temperature: 200°C
- Water application: 1 L/h at 1 bar pressure

The polyester yarns were fed through a wetting head before entry to the jet, whereas the viscose yarns were fed dry to the jet because during the initial trials it was observed that the wet viscose filaments have a tendency to stick to each other inside the jet inhibiting proper separation of filaments and this results in lesser loop formation (poor texturing effect). The moistened viscose filaments also give rise to breakage in the nozzle.

2.3 Methods

2.3.1 Physical Bulk

Physical bulk of air-jet textured yarns was measured using the package density method. Packages of equal diameter were wound using parent and air-jet textured yarns under constant tension of 3 cN at a speed of 300 m/min for 30 min in a spindle driven winder. Following formula was used to measure physical bulk:

\[
\text{Physical bulk} = \frac{\text{Density of parent yarn package (g/cm}^3) \times 100}{\text{Density of textured yarn package (g/cm}^3)}
\]

2.3.2 Instability

The instability of the air-jet textured yarns was measured using Du Pont’s weight hanging method. A basic load of 0.0088 cN/dtex (0.01 gf/den) was applied to the yarn and a mark was made at 100 cm distance from the clamp. Yarn was then subjected to
an additional load of 0.44 cN/dtex (0.5 gf/den) for 30 s. The permanent extension in the length of the yarn measured after 30 s of the removal of the heavy load was taken as a measure of instability. Ten readings were taken from a sample package to estimate instability and between each successive reading nearly 5 m yarn was unwound from the package and discarded.

2.3.3 Tensile Properties

Tensile properties of all the textured yarns were measured according to ASTM test method D2256-02 in Instron (Model 4411) with 500 mm gauge length, 300 mm/min crosshead speed and 0.048 cN/dtex (0.055 gf/den) pretension level. Thirty samples from each package were tested to obtain average tensile properties.

2.4 Optimization of Texturing Process Parameters

2.4.1 Determination of Regression Equations for Prediction of Yarn Properties

Regression equations for prediction of physical bulk, instability and tenacity for all the blends were derived using backward elimination method. In this method, we start with a model possibly loaded with redundant regressor variables and try to strip it down to the really meaningful core, based on partial F-statistic. The partial F-statistic shows the highest ‘partial correlation’ with the response after accounting for the effects of other variables already in the model. Prediction in real life textile applications is becoming essential and common. Prediction of expected behaviour/performance of a process or product, before it is made, is required to minimize or reduce the set-up cost and set-up time. Alternatively, there could be situations where a decision is required to be taken based on the past data; here a normal human brain has limitations of drawing out inferences. Ability to predict properties of yarns accurately has become a challenge due to the highly non-linear interactive behaviour of fibres and yarns, especially under dynamic conditions.

2.4.2 Optimization of Process Parameters

The optimum process parameters for different blends were determined with the help of the regression equations by assigning 3:2:1 weightage to instability (lower value), physical bulk (higher value) and tenacity (higher value) of the yarns. The optimization process also involves selection of parameters on the basis of lower air pressure, considering the process cost.

3 Results and Discussion

The regression equation used for the prediction of physical bulk, instability and tenacity of the air-jet textured yarns is given below:

\[ Y = C_0 + C_1X_1 + C_2X_1^2 + C_3X_2 + C_4X_3 + C_5X_1^3 + C_6X_2^2 + C_7X_2X_3 + C_8X_3X_2 + C_9X_1X_3X_2 + C_{10}X_1^2X_2 + C_{11}X_1X_3^2 + C_{12}X_2X_3^2 + C_{13}X_2X_1^2 + C_{14}X_3X_1^2 + C_{15}X_2^2X_3 + C_{16}X_2X_3X_1 \]

where \( Y \) is either physical bulk, instability or tenacity; and \( X_1, X_2 \) and \( X_3 \) are the values of overfeed (%), air pressure (bar) and texturing speed (m/min) respectively. The coefficients \( C_0, C_1, \ldots, C_{16} \) for each properties of each blend were determined separately.

The corresponding significance tests of the model equations carried out on the basis of coefficient of determination \( (R^2) \), F-statistic and model significance for each blend are given in Table 4.

To visualize the ‘quality of the fit’ of a regression equation, a plot of observed vs. predicted response is used with a fitted straight line giving the correlation coefficient \( R \) or coefficient of determination \( R^2 \). For a given model, larger the value of \( F_{\text{statistic}} \) the higher is the confidence level for the significance of the model, i.e. a higher probability of rejection of null hypothesis \( (H_0) \). The \( F_{\text{significance}} \) value shows the probability of being wrong in concluding that there is an association between the dependent and independent variables (i.e. the probability of falsely rejecting the null hypothesis or committing a Type I error, based on \( F \)). The smaller the \( F_{\text{significance}} \) value, the greater is the probability that there is an association and it indicates high model significance. A value of 0.05 indicates a significant model at the 95% confidence level. The confidence interval for the regression line gives the range of values that defines the region containing the true mean relationship between the dependent and the independent variables, with the specified level of confidence.

It is observed from Table 4 that the equations for physical bulk for all the blends except for 50/50 P/V are well fitted with very low \( F_{\text{significance}} \), high \( F \)-statistic and high \( R^2 \) values. Low \( F \)-statistic and high \( F_{\text{significance}} \) for 50/50 P/V blend are indicative of poor model fit.

The equations for instability are also found to be very well fitted except for 67/33 P/V and 100% polyester. Although the equation for 67/33 P/V is significant at 99% confidence level but a comparatively low value of \( F \)-statistic indicates
some lack of fit. The equation for 100% polyester shows significant lack of fit with very high $F_{\text{significance}}$ and very low $F$-statistic. Also, a low $R^2$ value confirms this.

The equations for tenacity for most of the blends are well fitted except for 100% viscose and 67/33 P/V. The $R^2$ values and the $F$-statistic for these two blends are low. Particularly, the equation for tenacity of 67/33 P/V shows poor fit with low $F$-statistic and low model significance (high $F_{\text{significance}}$ value).

### 3.1 Effect of Blend Proportion and Process Parameters on Physical Properties

The results of the effect of process parameters and blend proportion on the predicted properties of the blended yarns are discussed in the following sections. In order to observe the effect of one process parameter on any yarn property the other two parameters are kept at their central values.

#### 3.1.1 Physical Bulk

Physical bulk is an important characteristic of air-jet textured yarn and is affected by the yarn surface characteristics, fibre properties and dimensions, and frequency of the loops protruding out of the core. It plays a decisive role in determining the thermal and mechanical behaviour of fabrics made from these yarns. Bulk characteristics of woven fabrics also have significant influence on fabric hand. So, the factors which affect the bulk of the yarns should be studied critically. It is observed from (Fig. 1a) that as the texturing speed increases, the physical bulk of the yarn reduces. At higher machine speed the residence time of the filaments inside the jet would be lower. In this situation the filaments are taken up before proper loop formation. Hence, the effectiveness of texturing reduces. Mutual displacement between the filaments reduces and a consequent decrease in the loop formation tendency is observed.

Figure 1(b) shows that an increase in air pressure increases the physical bulk of the yarn. As the air pressure increases, the air velocity at the exit, the degree of non-uniformity in the velocity distribution and the turbulence increase; the filament separation and the longitudinal displacements of the filaments with respect to each other become more effective, and hence the filaments travel and change their positions at greater rate resulting in better loop formation. Figure 1(c) shows that the physical bulk increases with the increase in overfeed, initially at a slow rate and then at higher rate at higher overfeed levels. When the overfeed is low, the excess length of filament available to form loops and arcs is less with very few loops on the surface. As the overfeed is increased, more excess lengths of filaments are available to form loops. Consequently, the surface of the yarn is covered with many slack and large loops, which possibly results in a higher rate of increase in physical bulk.

#### 3.1.2 Instability

The bulkiness of an ideal good quality air-jet textured yarn can be made to remain virtually
unchanged at loads corresponding to those normally imposed in fabric production and during wear. But a close examination of an air-jet textured yarn reveals that some of the loops that characterize such yarns can be pulled out under tension during processing and use. Loops that can be pulled out easily under low tensions have a detrimental effect on the fabric forming process. The stresses applied to the yarn during the fabric manufacturing process would result in a non-uniform reduction in yarn bulk and as a consequence the fabric irregularity would be increased. Therefore, a close look on the factors affecting the stability of these yarns is important. Figure 2(a) shows that the yarn instability increases with texturing speed in most of the cases. Since the resultant forces and moments on the filaments are mainly generated by the relative velocity between the filaments and the surrounding air flow, lower forces and moments are exerted on the individual filaments at higher texturing speeds. These lower fluid forces cause poor entanglement and formation of more loosely held loops. Secondly, as the texturing speed is increased, the effectiveness of texturing reduces because of lesser time available for the filaments inside the jet, allowing less filament mutual displacement which results in large and unstable loop formation. This also increases the instability of the yarn.

It is observed from Fig. 2b that instability shows an increase with increasing air pressure. This can be attributed to the formation of higher number of small loops at increased air pressure, more filament migration and a reduced number of straight filaments in the yarn, which, in turn, contributes to increased yarn instability. It may be argued that with large number of loops there will be fewer unlooped filament segments at any cross-section to take the strain, and consequently some of these may break early; this could cause neighboring loops to be pulled out, which would result in high instability. For 100% viscose yarn, the instability is found to be very high. In this study the viscose yarns were dry textured and dry texturing results in yarn with less structural integrity, regardless of the yarn material.

Figure 2(c) shows that the instability of the blended yarns increases with increase in overfeed in most of the cases. This may be attributed to higher number of loops being formed, which increases the tendency of higher number of loose loops to remain in the yarn. As a result higher instability is observed in the yarns.
3.1.3 Tenacity

In a textured yarn, as the filaments are randomly entangled and some of these local entanglements and loops are removed under an applied load, the deformation of a textured yarn starts with permanent elongation. All filaments exhibit loops and entangled sections intermittently along their lengths, but these are separated by straight portions of filaments. At any section of the yarn, at any particular instance, only these straight portions will bear the applied load. A good quality air-jet textured yarn, i.e. one with many small, compact, entangled loops, will also exhibit a large decrease in tenacity (maximum specific stress that is developed in a tensile test to rupture) when compared with the straight filament supply yarn from which it is produced. In other words, the higher the reduction in tenacity, the better is the textured yarn quality.

It is observed from Fig. 3a that as the texturing speed increases, the tenacity of the yarn increases. With increasing process speed the filaments get less time inside the jet for mutual displacement and as a result the effectiveness of texturing reduces. As a consequence the structure becomes more like untextured yarns with more straight filaments along the yarn axis as shown by lowering of bulk in Fig. 1a. So, the contribution of the relatively straight filaments, available to carry the applied load, in the yarn increases which contributes to higher strength in the yarn.

Figure 3(b) shows that the tenacity of the blended textured yarns decreases with increase in air pressure, except for 100% polyester yarn. As the air pressure inside the jet increases during texturing, the air velocity at the exit of the jet, the asymmetry in the air velocity distribution and the turbulence increase. Filament separation and longitudinal displacement of the filaments with respect to each other become more effective, and filaments change their positions at higher frequency. This leads to better loop formation and texturing, which results in a smaller number of straight filaments at the yarn core to bear the load and hence a consequent reduction in tenacity with increasing air pressure is observed.\(^7,8\)

Figure 3(c) shows that the reduction in tenacity occurs as the overfeed is increased. At high overfeed, because there are adequate extra lengths of filaments available for loop formation the number of loops formed increases and at the same time the loop size is also larger.\(^5\) This provides lesser straight portion of filaments in the yarn core to bear the applied load.
Fig. 3—(a) Effect of texturing speed on predicted tenacity of P/V blended yarns at 8.5 bar air pressure and 24% overfeed; (b) effect of air pressure on predicted tenacity of P/V blended yarns at 400 m/min texturing speed and 24% overfeed; and (c) effect of overfeed on predicted tenacity of P/V blended yarns at 8.5 bar air pressure and 400 m/min texturing speed [─ 0/6 blend (1), ----- 1/5 blend (2), —— 2/4 blend (3), —— 3/3 blend (4), ——- 4/2 blend (5), ---- 5/1 blend (6) and ———— 6/0 blend (7)]

3.2 Optimum Process Parameters for Blended Air-jet Textured Yarns

The most important properties that characterize air-jet textured yarns are instability, physical bulk and tensile properties of the yarns. Higher bulk and lower instability values have traditionally been used as indicators of the quality of air textured yarns. However, there is no agreement about the definition of overall quality in published literature. A further complication is that, what may be considered as good quality for one end use may not be the acceptable quality for another end-use. The instability of air-jet textured yarn means the retention of the texture (loops) under applied load, such as those encountered during further processing of the yarns. This may be dependent on the integrity of the core structure, which, in turn, may be dependent on the effectiveness of texturing, fibre-to-fibre frictional relationship and extent of removal of the surface finish during texturing. If the loops of air-jet textured yarns are pulled out during further processing, the yarn bulk will be reduced and if this bulk reduction takes place selectively in certain section of the yarn, the irregularity of the product will increase. Therefore, while considering the quality of the fabrics produced from air-jet textured yarns, instability should be given a high weightage.

The physical bulk may be considered a characteristic of the number, type and frequency of loops on the textured yarn surface indicating the voluminosity of the yarn, which is considered to be one of the major yarn properties affecting the fabric comfort properties produced from these yarns. It is generally observed that the higher the physical bulk of an air-jet textured yarn, the higher is the instability. Higher physical bulk is considered advantageous from fabric comfort point of view, but when considering the quality aspect of the fabric (higher instability indicates poor fabric quality) the physical bulk can be assigned lower weightage than the instability of the yarns.

The tensile properties are of particular importance in any yarn to withstand the stress and strain during further processing and use. Generally, air-jet textured yarns are inelastic and have lower tensile strength at break than their untextured counterparts. The reduced mechanical properties are due to the yarn structure of these air-jet textured yarns. The average strength values generally obtained from filament yarns are more than sufficient than is required for apparel use.
Piller et al.\textsuperscript{10} further ascertained that the tenacity of air-jet textured yarns satisfy the requirements for knitting and weaving machines. So, the tenacity of the textured yarns may have relatively lesser importance out of these three properties. Based on the above argument, in this study instability (minimum), physical bulk (maximum) and tenacity (maximum) of the yarns are given 3:2:1 weightage while determining the optimum yarn quality.

Firstly, the range of each process parameters (overfeed, air pressure and texturing speed) is divided into 11 equal intervals and the values of instability, bulk and tenacity are predicted for all the possible combinations of values of process parameters. Secondly, the maximum and minimum values of bulk and tenacity are found out. The instability values within the range of 0 and 1 are accepted and negative values are considered as ‘0’. Each instability, bulk and tenacity values are then assigned weightage according to the equations given below (for 3:2:1 weightage combination):

\[ W_{\text{Instability}} = (1 - \text{Instability}) \times 300 \]

\[ W_{\text{Bulk}} = \frac{\text{Bulk} - \text{Bulk}_{\text{min}}}{\text{Bulk}_{\text{max}} - \text{Bulk}_{\text{min}}} \times 200 \]

\[ W_{\text{Tenacity}} = \frac{\text{Tenacity} - \text{Tenacity}_{\text{min}}}{\text{Tenacity}_{\text{max}} - \text{Tenacity}_{\text{min}}} \times 100 \]

Thirdly, these individual weightage values are added up to get the cumulative weightage values for each process parameter combination. Finally, these cumulative values are arranged in descending order. Now, the maximum cumulative value will give the best parameter combination for producing optimum quality textured yarns. This is done with the help of a Turbo C program.

Table 5—Optimum process parameters used for producing blended air-jet textured yarns and the predicted values of properties

<table>
<thead>
<tr>
<th>Blend (P/V)</th>
<th>Optimum process parameter</th>
<th>Predicted values of properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air pressure, bar</td>
<td>Overfeed, %</td>
</tr>
<tr>
<td>0/6</td>
<td>7.3</td>
<td>33.3</td>
</tr>
<tr>
<td>1/5</td>
<td>7</td>
<td>20.3 (20)</td>
</tr>
<tr>
<td>2/4</td>
<td>9.7</td>
<td>14.7</td>
</tr>
<tr>
<td>3/3</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>4/2</td>
<td>7</td>
<td>20.3 (20)</td>
</tr>
<tr>
<td>5/1</td>
<td>7</td>
<td>14.7</td>
</tr>
<tr>
<td>6/0</td>
<td>7</td>
<td>33.3</td>
</tr>
</tbody>
</table>

Values in parentheses are the nearest values that are practically possible to set in the texturing m/c.

Table 6—Values of instability, physical bulk and tenacity of textured yarns produced under optimum process conditions

<table>
<thead>
<tr>
<th>Blend (P/V)</th>
<th>Instability, %</th>
<th>Physical bulk, %</th>
<th>Tenacity, cN/dtex</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/6</td>
<td>0.39</td>
<td>192</td>
<td>1.49</td>
</tr>
<tr>
<td>1/5</td>
<td>0.27</td>
<td>197</td>
<td>1.87</td>
</tr>
<tr>
<td>2/4</td>
<td>0.36</td>
<td>190</td>
<td>1.89</td>
</tr>
<tr>
<td>3/3</td>
<td>0.38</td>
<td>208</td>
<td>2.18</td>
</tr>
<tr>
<td>4/2</td>
<td>0.61</td>
<td>209</td>
<td>2.40</td>
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<tr>
<td>5/1</td>
<td>0.64</td>
<td>209</td>
<td>2.96</td>
</tr>
<tr>
<td>6/0</td>
<td>0.45</td>
<td>210</td>
<td>3.56</td>
</tr>
</tbody>
</table>

Table 5 shows the optimum process parameters determined by the above-mentioned program to achieve minimum instability, maximum bulk and maximum tenacity in the textured yarns with 3:2:1 weightage to the respective properties.

3.2.1 Checking the Accuracy of Optimization Process

Blended air-jet textured yarns were produced using the optimum process parameters as mentioned in the previous section. The yarns were then tested for the actual values of instability, physical bulk and tenacity. The results are given in Table 6. It can be observed from Tables 5 and 6 that the predicted values of physical bulk and tenacity of the air-jet textured yarns under optimum processing conditions are sufficiently close to the actual values of the properties obtained under these processing conditions. The instability values of the predicted and the actual values for instability of yarns produced at optimum processing conditions does not show good correlation.

4 Conclusions

Increasing texturing speed reduces the yarn physical bulk and increases the instability and tenacity. With the increase in air pressure or overfeed,
physical bulk and instability increase and tenacity reduces.

This study reports the optimum air-jet texturing process parameters to be used to produce P/V blended air-jet textured yarns with 3:2:1 weightage to low instability, high physical bulk and high tenacity of the yarns. It is also observed that lower texturing speed is necessary for producing good quality air-jet textured yarn for any blend.

Generally, the prediction of optimum process conditions to achieve low instability values in the air-jet textured yarns does not seem to be very effective. For 50/50 P/V and 67/33 P/V blends the predicted values of instability under optimum process conditions are found to be higher than the actually observed values, whereas the predicted values of physical bulk are lower than the actually obtained values under the same processing conditions. This means that these two blends behave better than expected during the air-jet texturing process. The predicted values and the actual values of the physical bulk and tenacity of the yarns produced at optimum processing conditions are found to be closely correlated. It is also found that 100% viscose and 100% polyester yarns require high overfeed to generate high bulk and low instability in the textured yarn.

References