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Comparative Performance of Textured Yarn Drawn through Apron and Godet in Draw Texturing Machine

Abstract
Over the past 20 years, in filament draw texturing, very few developments and innovations have been introduced into production machineries. The growing demand for energy efficiency, faster production rates and greater production flexibility have prompted our investigation into non-traditional approaches to improve yarn control during the texturing. Instead of aprons, small individually driven godets are a solution for high-speed manufacturing, yarn control and energy saving. The drawing godets, where the yarn can be considered an elastic coupling element between two consecutive godets, pose a new challenge for consistency in velocity control. Though some machinery manufacturers have introduced the godet system, the yarn quality produced by the godet system is not systematically evaluated and compared vis-à-vis the apron system. The current study prepared textured yarns in both apron and godet systems while maintaining the same texturing parameters. Differences in the yarn's bulk, modulus, breaking elongation, tenacity and boiling water shrinkage were assessed and compared. Woven and knitted fabrics were prepared from textured yarns, and a comparative analysis of fabric properties was performed with respect to their tearing strength, air permeability, drape and dyeability. Better quality of yarn and fabrics can be prepared in the godet system, which is energy saving, of higher speed and requires low maintenance technology in comparison to the apron system.

Keywords: draw texturing, godet, apron, texturing, bulk, false twist texturing, yarn control

Izvleček
V zadnjih dvajsetih letih je bila strojna oprema za raztezno teksturiranje filamentnih prej zelo malo posodobljena ali inovirana. Naraščajoče zahteve po energetski učinkovitosti, višji produktivnosti in proizvodni prilagodljivosti so spodbudile našo raziskavo o netradicionalnih pristopih k izboljšanju kontrole preje med teksturiranjem. Majhne, individuvalno gnane galete namesto jermenov so rešitev za visokohitrostno proizvodnjo, kontrolo preje in varčevanje z energijo. Raztezne galete, kjer je prejo mogoče obravnavati kot elastični spojni element med dvema zaporednima
Comparative Performance of Textured Yarn Drawn through Apron and Godet in Draw Texturing Machine

1 Introduction

In the field of texturing, false-twist technology is the most popular and dominant technology for providing bulk and/or stretch to synthetic yarns. False twist texturing is a process in which a bundle of continuous filament yarn is subjected to drawing and twisting while being heated simultaneously and then twisting in the reverse direction as the strand of filaments is gradually cooled. The process is also called simultaneous draw texturing. The resulting yarn develops stretch and bulk, known as textured yarn. Partially oriented yarn (POY) is the standard feed material for texturing machines [1].

Over the past 20 years, very few developments and innovations have been introduced into production machines in filament draw texturing. The increasing need for energy saving, higher production speed and low maintenance has brought us to think about unconventional solutions for yarn control during the whole texturing process sequence. Though there are several studies available in the literature on the effects of various process parameters of texturing on yarn properties, limited information is available on the effect of the drawing system itself on yarn properties [2–7]. There are four T’s, i.e. Twist, Time, Temperature and Tension, which are found to be important parameters affecting textured yarn properties and are widely studied by various researchers [3, 8–10]. Each of these parameters is important to get a perfect textured yarn with the desired physical properties.

The draw ratio is one of the essential parameters that decide the desired textured yarn denier from the supply of POY. The draw ratio is altered by adjusting the speed of the input and intermediate roller [9]. The intermediate roller speed is generally kept constant and the input roller speed is altered to attain the desired draw ratio. Figure 1 presents the line diagram of a conventional texturing machine.
All the feed, intermediate and output roller systems (also called shafts) have two rollers, a steel roller and a rubber-coated nip roller. The rubber-coated nip roller is used to grip the yarn better during the texturing and control the yarn tension. The POY from the spool enters the input roller. It is drawn between the input and intermediate roller, where drawing, heating, cooling and simultaneous false twisting are done to get the desired yarn with bulk and texture. After the intermediate roller, the yarn is passed through the secondary heater to set the yarn, then passed through the output roller, and finally onto the winding drum to form the package via oil roll [10].

The input, intermediate and output rollers control the yarn tension during the texturing process. The yarn tension must be uniform at every location at all positions. Any tension variation can create yarn defects like tight spots, bulk variation and low strength characteristics. Such tension variation can happen due to the poor grip of the outgoing yarn from one pair of rollers to the next. The improper grip can be due to the less spring load of the roller holder, bad condition of the nip roller, groove formed in the nip roller, improper roller hardness, the created gap between the steel and nip roller, roller vibrations etc. Cases become severe at higher texturing speeds and for finer denier yarns [10, 11].

There have been further developments in the roller systems (shafts). In the intermediate roller section, two wrappings are applied on the nip rollers for a better grip, as shown in Figure 2 [12]. However, many accessories are involved in maintaining the wrappings and attracting many other drawbacks. Roller gaps, vibrations and groove formations disturb the yarn path and the tensions causing defective yarn formation. Frequent buffing is another drawback that causes additional cost hikes. Cases become severe at higher texturing speeds and for finer denier yarns [12, 13].

To get rid of all of these, industries initially opted for the apron system in the intermediate zone; however, later, the aprons were put in the input and output zones. Figure 3 shows the apron assembly in the texturing machine. Each assembly consists of a rubber belt mounted on the main steel roller with the help of two crowned rollers at both sides of the belt. A spring-loaded apron holder pressures the belt. The apron rollers are crowned for uniform pressure distribution by accurate alignments and prevent any deflection. The crowned rollers are small tom-tom-shaped rollers designed especially for better grip not to allow the belt to come out from the steel roller.

With further development, the concept of godet in draw texturing machine was first brought in the year 2003 for better drawing among the input and intermediate zones where the slippage is just eliminated with stress-free yarn feeding with uniform and consistent yarn evenness of the textured yarn [14]. The godets are individually motor-driven and steel-made chrome-plated rollers and are a one-time investment only. Here, the godet replaces conventional rollers to transport the yarn upstream and downstream to the texturing zone. Figure 4 shows the godet system in the texturing machine. It is claimed that the godet system provides better yarn quality and process stability, and guarantees reduced energy and spare part consumption.
2 Materials and methods

Polyester POY (dtex 161.1/34 semi-dull) was used as feed yarn. Trial 1 was made on a texturing pilot machine with an apron system. Trial 2 and Trial 3 were made on a texturing machine equipped with a godet system but with different draw ratio levels. Detailed machine parameters are shown in Table 1.

The yarn samples prepared from Trial 1 (apron system), Trial 2 (godet system) and Trial 3 (godet system) were used in a circular knitting machine to prepare single jersey fabrics using the same machine parameters.
2.1 Measurement of birefringence and molecular orientation

In line with Ehringhaus, the compensation method was used for filament birefringence determination using an advanced polarising microscope (Radical RXLr-5 POL). The diameter of the filament was measured microscopically using an eye-piece micrometre. The measurements were performed at a wavelength of 546.1 nm (white light), and the birefringence ($n = \Delta/d$) was calculated using the measured retardation ($\Delta$) and fibre thickness ($d$).

\[ \theta = \frac{\text{Specific volume of textured yarn}}{\text{Specific volume of parent filament yarn}} \]  

The specific volume of yarn ($v$) is given by Equation 2:

\[ v = \frac{\pi d^2 l}{4m} = \frac{\pi d^2}{4T_t \times 10^{-3}} \]

where $d$ is the mean yarn diameter in meter, $l$ is the length of the sample in meter, $m$ is the mass in gram, and $T_t$ is the linear density of the yarn in tex. The mean diameter of yarn samples was measured by using a Leica optical microscope (DM 2500P) with 40× magnification. The yarn diameter was measured by using annotation in the image processing software.

2.2 Measurement of yarn bulk

The yarn bulk after the texturing was characterised by bulking factor ($\theta$), which is defined as the ratio of the specific volume of the textured yarn to the specific volume of the parent filament yarn before the texturing, as shown in Equation 1:

\[ \theta = \frac{\text{Specific volume of textured yarn}}{\text{Specific volume of parent filament yarn}} \]  

The specific volume of yarn ($v$) is given by Equation 2:

\[ v = \frac{\pi d^2 l}{4m} = \frac{\pi d^2}{4T_t \times 10^{-3}} \]

2.3 Measurement of linear density

To measure linear density, 100 m length of yarns was wound on a wrap reel with 1 m circumference and weighed on an electronic analytical balance with a sensitivity of 0.1 mg. Linear density in dtex was calculated. The average linear density was taken from five samples.

2.4 Measurement of tensile properties

The tensile properties of textured yarns were measured with an Instron 3356 Tensile Tester. The instrument operates at a constant rate of extension principle. Following ASTM D 2256 with a gauge length of 50 cm, the cross-head moving speed was adjusted to give a yarn failure time of 20 s ± 3 s [15]. Thirty tests were conducted for each yarn package, and the average tenacity, elongation and modulus results were obtained.
2.5 Measurement of boiling water shrinkage

The boiling water shrinkage test was performed according to the DIN 53866 standard [16]. Six specimens were tested. Tensioning weight of 0.125 cN/tex was applied to the yarn, which was 1 m in length, and a hank was formed. The first length in this condition was recorded as $l_1$ and then the load was removed. The yarn was wetted in a soap solution (1 g of soap/1 L water) and left in the solution at 100 °C for 15 min and then dried for one hour at 60 °C, after which the yarn was hung for 1 h on the device. Afterwards, the same weight was applied to the yarn, and the length was recorded as $l_2$. Boiling water shrinkage was calculated with Equation 3:

$$\text{Boiling water shrinkage (\%) } = \frac{l_1 - l_2}{l_1} \times 100 \quad (3)$$

2.6 Measurement of woven fabric properties

A universal tensile tester was used to measure the fabrics’ tearing strength using the tongue (single rip) tearing strength approach in accordance with the ASTM D2261 standard [17]. Samples measuring 20.3 cm (8 inches) long by 7.6 cm (3 inches) wide were cut from both warp and weft directions, with an additional 7.6 cm (3 inches) cut made for tear propagation. The jaws were 7.6 cm (three inches) apart from one another. A 5.1 cm/min (2-inch per minute) test speed was used. The average tearing strength was computed after five samples were examined in both warp and weft directions. The ASTM D737 test standard, which measures the airflow rate under constant air pressure drop, was used to measure the air permeability of all fabrics using an air permeability tester FX3300 [18]. For each fabric, five samples were measured in order to get an average value. The Cusick drape tester measured the three-dimensional fabric drape due to gravity. The experimental method involved hanging a 15 cm radius fabric specimen over, a 9 cm radius supporting disc. A parallel light source inside the drape tester formed a shadow from the draping specimen onto a piece of paper; the shadow pattern on the paper was traced out and drape coefficient was then calculated [14].

2.7 Dyeing and colour measurements

Dyeing was performed in a sample jet dyeing machine (ATAC, Turkey) with the following dyeing parameters. Dye (CI Disperse Blue 56) concentration: 2% on the weight of fabric, dispersing agent (Disperol PE, Unichem): 2 g/L, acetic acid: 1 g/L to maintain pH between 5 and 5.5, M : L 1 : 10, temperature: 120 °C, pressure: 2 N/m², fabric speed: 30 m/min, time 1 h. After the dying, samples were thoroughly rinsed and treated with a solution containing 2 g/L NaOH and 2 g/L Na₂S to remove loose dye molecules from the fabric surface. Finally, the fabrics were rinsed again and dried for further testing.

The colour strength of dyed fabrics was measured with a Datacolour SPECTRUM 650 TM spectrometer. The $K/S$ values of the dyed fabrics were measured over the visible wavelength range 400–700 nm. This $K/S$ ratio is related to the reflectance $R$ of an opaque colourant layer and is expressed with Equation 4:

$$\frac{K}{S} = \frac{\text{Coefficient of absorption}}{\text{Coefficient of scattering}} = \frac{(1-R)^2}{2R} \quad (4),$$

where $K$ is the absorption coefficient, $S$ is the scattering coefficient and $R$ is the reflectance value at maximum absorbance wavelength. The surface colour strength, i.e. $K/S$ value, is directly proportional to the concentration of dye molecules on dyed textile samples as well as attributed to higher light absorption.

3 Results and discussion

In all three trials conducted, no package fault was found. The resultant yarn linear density, tenacity, breaking elongation, modulus and boiling water shrinkage of control yarn and three textured yarns are shown in Table 2.
Table 2: Yarn properties before and after texturing trials

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Yarn samples</th>
<th>Linear density (den)</th>
<th>Tenacity (g/den)</th>
<th>Breaking elongation (%)</th>
<th>Initial modulus (g/den)</th>
<th>Boiling water shrinkage (%)</th>
<th>Bulk factor (θ)</th>
<th>Birefringence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control yarn (POY)</td>
<td>149.21 (4.32)</td>
<td>1.79 (0.09)</td>
<td>327.00 (9.12)</td>
<td>8.07 (0.10)</td>
<td>33.33 (1.12)</td>
<td>0</td>
<td>0.09</td>
</tr>
<tr>
<td>2</td>
<td>Trial 1 (apron system)</td>
<td>91.78 (2.01)</td>
<td>3.78 (0.12)</td>
<td>64.51 (1.88)</td>
<td>13.17 (0.19)</td>
<td>23.33 (0.98)</td>
<td>16.4 (1.01)</td>
<td>0.12</td>
</tr>
<tr>
<td>3</td>
<td>Trial 2 (godet system I)</td>
<td>85.46 (1.22)</td>
<td>3.88 (0.11)</td>
<td>46.02 (1.11)</td>
<td>12.10 (0.14)</td>
<td>20.00 (0.98)</td>
<td>14.4 (0.95)</td>
<td>0.13</td>
</tr>
<tr>
<td>4</td>
<td>Trial 3 (godet system II)</td>
<td>88.33 (1.23)</td>
<td>3.78 (0.12)</td>
<td>52.99 (1.21)</td>
<td>11.00 (0.11)</td>
<td>16.67 (0.88)</td>
<td>18.7 (1.12)</td>
<td>0.12</td>
</tr>
</tbody>
</table>

(Standard deviation is shown in brackets.)

3.1 Linear density of yarns prepared from apron and godet system

It can be seen from Table 2 that the linear density of the control POY decreased significantly (p-value < 0.05) after the texturing. Among the three trials of texturing, the linear density of Trial 1 was found to be the highest. This indicates that the linear density of the yarns in the apron system is higher than that of the godet system. This is due to the godet system’s higher yarn tension ($T_1$) compared to the apron system despite the draw ratio being maintained constant.

3.2 Linear density of yarns prepared from godet system with different draw ratio

It was observed that the linear density of yarn from Trial 3 was significantly higher (p-value < 0.05) than from Trial 2. This is due to the decrease in yarn tension ($T_1$) from 40 to 30 cN as a result of the decrease in draw ratio from 1.85 to 1.78. The linear density of the yarn increases with decreasing yarn tension.

3.3 Tenacity of yarns prepared from apron and godet system

Table 2 shows that after the texturing, the tenacity of the control POY increased by more than twice. The godet system (Trial 2) produced yarn that is stronger than that of the apron system (Trial 1). The godet has a wrapping system which provides a better yarn tension control with no slippage, resulting in higher and uniform tension and thus in better molecular orientation and good mechanical strength. However, in the apron system, there is no such yarn tension control system. As a result, there is the development of low yarn tension with inconsistency causing poor molecular orientation and inferior mechanical strength. Moreover, the life of apron is shorter in comparison to godet.

The improvement in the tenacity of yarns after the texturing is due to a higher level of yarn tension resulting in the improvement in molecular orientation along with filament axis, which is evident from the data of birefringence, as shown in Table 2. The higher the value of birefringence the better will be molecular orientation. The birefringence of control POY was 0.09 and rose to 0.12 after Trial 1 (apron system) and to 0.13 after Trial 2 (godet system). Therefore, at higher levels of yarn tension, the molecular orientation of textured yarns improved, resulting in better tenacity, which happened with the textured yarn prepared from the godet system. In the case of the godet system itself, if the draw ratio decreased, yarn tenacity decreased. This can be verified with the tenacity results of Trial 3 and Trial 2, where the tenacity of yarn from Trial 3 was lower than that of Trial 2.
3.4 Breaking elongation of yarns prepared from apron and godet system

It can be observed that the yarn breaking elongation decreased significantly after the texturing. The reduction of the breaking strain was due to the formation of a more crystalline structure of the filament yarns caused by better heat treatment in the secondary heater zone [3]. At a higher level of crystallinity, the scope for molecular movement is smaller, which gives a stiffer mechanism in the filament structure, attributing to low tensile strain.

In comparison to the apron system, there was a more significant reduction of breaking elongation in the case of the godet system. On the other hand, in the godet system, yarn breaking elongation increased if the draw ratio decreased and D/Y increased. The decrease in breaking elongation is attributed to the higher crystallinity of the yarn structure.

3.5 Initial modulus of yarns prepared from apron and godet system

The initial modulus of the yarn increased significantly after the texturing, which is due to a remarkable reduction of breaking elongation and increment of tenacity. The modulus of the yarn textured in the apron system was found to be higher than that of the godet system. Therefore, it is evident that the yarns textured from the godet system are more flexible than that of the apron system. In the godet system, if the draw ratio decreased or D/Y increased, the yarn modulus decreased.

3.6 Boiling water shrinkage of yarns prepared from apron and godet system

The boiling water shrinkage significantly reduced after the texturing. Compared to the apron system, shrinkage was found greater in the godet system. Even in the godet system, if the draw ratio decreased and D/Y increased, yarn shrinkage was found to be more prominent.

The chain folding of macromolecules in the amorphous phase to form a crystalline structure as a result of increasing chain mobility caused boiling water shrinkage. The entropic relaxation of excited stretched chains resulting from macromolecule rearrangements caused by internal stress during orientation is the mechanism responsible for the shrinkage of the oriented polymer structure above the glass transition temperature. In contrast to amorphous polymers, semi-crystalline polymers exhibit crystallisation during these rearrangements [3, 15].

Figure 6: Optical microscopy images of textured samples (40× magnification)
3.7 Optical microscopic images of textured yarn samples

The mean yarn diameters of all yarn samples were measured in the microscopic images by using image processing software. The microscopic images of all yarn samples are shown in Figure 6. It can be seen that the control yarn has straight monofilaments without any crimp in the yarn body. After the texturing, the straight configuration of the filament changes to a curly configuration, generating crimps in the yarn structure. The yarns are thus becoming bulkier in structure. The bulk factor ($\theta$) of all yarn samples was calculated with Equation 1. The results are shown in Table 2. The bulk factor of textured yarn from Trial 1 (apron system) is higher than that of Trial 2 (godet system). However, in Trial 3, the bulk factor improved and rose to 18.7, the highest among all. This was due to low draw ratio and yarn tension in Trial 3.

3.8 Properties of woven fabrics prepared from textured yarns

The yarn samples prepared from Trial 1 (apron system), Trial 2 (godet system) and Trial 3 (godet system) were used as weft in a waterjet loom to prepare plain woven fabrics. The speed of manufacturing (550 rpm), reed (72/3), picks/meter (3150), ends/meter (4252) and warp yarn linear density (80 den, 72 intermingling filaments) was kept similar for the preparation of fabric samples. Areal density (g/m²), air permeability, drape and tearing strength were measured and compared for all three fabric samples. The results are shown in Table 3. It can be seen that there is no significant variation in the areal density and tearing strength of the woven fabrics prepared with yarns from three different trials. However, the air permeability and drape coefficient of the fabrics differ significantly. The air permeability of the fabrics prepared from yarn textured in the apron system (Trial 1) was higher than that of the godet systems, which may be due to the differences in fabric porosity. The drape coefficient of the fabric from Trial I is lower than that of the godet systems due to comparatively loose or open fabric structure.

3.9 Dyeability of knitted fabrics prepared from textured yarns

The yarn samples prepared from Trial 1 (apron system), Trial 2 (godet system) and Trial 3 (godet system) were used in a circular knitting machine to prepare single jersey fabrics using the same machine parameters. The knitted fabrics were prepared continuously and later dyed with a disperse blue dye, keeping the same dyeing conditions in an HTHP dyeing machine. The appearance of the fabric samples is shown in Figure 7. The darkest shade was found in the case of Trial 1, followed by Trial 3 and Trial 2. The $K/S$ values obtained from the computer colour-matching instrument for all these samples are shown in Table 4. The dye sorption of the yarn can deeply affect the end-product quality and can show the texturing process parameter variations. A small alteration in orientation and crystallinity may change dye diffusion. Dye sorption increases with increasing mobility of the amorphous chains, and dye diffusion depends on the orientation of the amorphous chain segments [9]. The decrease in the colour strength ($K/S$) in the godet system (Trial 2 and Trial 3) in comparison to the apron system (Trial 1) can be attributed to the higher amorphous orientation due to increased yarn tension during the
texturing in the godet systems. Between Trial 2 and Trial 3, colour strength is lower in the case of Trial 2 sample, which is due to the increased drawing ratio, resulting in better amorphous orientation. Oriented amorphous material inhibits dye molecule diffusion, thus lowering the dye uptake [3].

![Figure 7: Dyed knitted fabrics prepared from textured yarns](image)

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Fabric name</th>
<th>K/S value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Trial 1 (apron system)</td>
<td>3.232</td>
</tr>
<tr>
<td>2</td>
<td>Trial 2 (godet system I)</td>
<td>1.218</td>
</tr>
<tr>
<td>3</td>
<td>Trial 3 (godet system II)</td>
<td>2.132</td>
</tr>
</tbody>
</table>

4 Conclusion

The linear density of the yarn decreased significantly after the texturing of the control POY. The decrement of linear density was found to be higher in the case of the apron system than that of the godet system of drawing. If the draw ratio decreased, the linear density of yarns increased. The tenacity of yarn produced in the godet system was better than that of the apron system. If the draw ratio decreased, the tenacity of yarn decreased. The breaking elongation of yarn after texturing drastically reduced. In the case of the godet system, the reduction was even greater than that of the apron system. The initial modulus of the yarn increased significantly after the texturing. The initial modulus in the apron system was found to be higher than that of the godet system. The boiling water shrinkage was greater in the godet system than in the apron system. Yarn bulk was found to be higher in the apron system than that of the godet system. No significant variations in areal density and tearing strength of the woven fabrics prepared with yarns from three different Trials were found. However, the air permeability and drape coefficient of the fabrics differed significantly. The air permeability of fabrics prepared with yarn textured in the apron system was significantly higher, and the drape coefficient was significantly lower than that of the godet systems. The dyeability of the knitted fabric prepared with yarns from the apron system was significantly better than that of the godet system.

Therefore, it can be concluded that the tensile strength and flexibility of textured yarn prepared with the godet system is better than the one prepared with the apron system. Though the bulk of the yarn in the godet system is inferior to the apron system, it can be improved by altering texturing parameters such as the draw ratio, D/Y ratio, heater temperature etc. Overall, better quality of yarn and fabrics can be prepared in the godet system, which is energy saving, of higher speed and requires low maintenance technology in comparison to the apron system.
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Statements and Declarations
No funding was received to conduct this study. The authors have no competing interests to declare that are relevant to the content of this article. There is no conflict of interest.

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