Defects on the Surface of Nylon-6 Tyre Yarn as Revealed by Scanning Electron Microscope*

C P GARG†, J K NIGAM‡ & RAMESH KUMAR§

Sir Padampat Research Centre, J.K. Synthetics Ltd, Kota 324 003

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The surface defects on nylon-6 tyre yarns created in various stages of yarn processing have been studied using a scanning electron microscope. The causes for the defects have been analyzed and a possible relationship with the behaviour of the yarn in rubber application has been proposed.

Surface morphology is one of the important factors responsible for adhesion of cord to the rubber. The study of surface morphology was found to be very important for knowing the extent and the nature of defects of the tyre yarn which affect the bond strength of the cord with the rubber.

At the time of spinning and draw-twisting, grooves, cracks, openings and striations are developed in the fibre. The monomer or low molecular weight fractions can come out very easily from such portions and affect the adhesion characteristics of the cord.

In the present investigation scanning electron microscopy (SEM) has been used to study the defects on the surface of nylon-6 tyre yarn.

Experimental Procedure

The following four samples of nylon-6 tyre yarn (204 filaments, 1260 denier) were examined under the SEM:
(1) as-spun yarn, (2) hot-stretched yarn (drawn 4.2 times at 175°C), (3) twisted and double-plied yarn (1260 D × 2), and (4) twisted and double-plied yarn heat treated at 200°C for 15 min under tension in an oven. All the samples were conditioned at 65% RH and 20°C ± 1°C before they were subjected to SEM analysis.

The samples were mounted on a stub coated with gold to avoid charging while examining under the SEM.

Diameter and birefringence were measured with the help of Leitz polarizing microscope using micrometer eye-piece and Berek compensator. The crystallinity was determined by the density method.

Results and Discussion

Data on diameter, crystallinity and birefringence are given in Table 1.

SEM micrographs of all the samples (Figs 1-4) showed similar type of defects, like grooves, cracks, striations, openings and foreign material. The frequencies of different defects are given in Table 2.

It is seen from Table 1 that the heat-treated yarn has higher denier and higher diameter compared to untreated yarn. This is expected, since at higher temperature, fibre shrinks to some extent under normal tension. In the treated yarn, the crystallinity is higher. This is also expected, because at higher temperature, partial melting of the existing crystals takes place and at the same time new bigger crystals are formed.

The defects listed in Table 2 can be important in understanding the development of defects and change in the morphology of nylon cord yarn during spinning, hot-stretching, twisting, cabling and heat-treating of the fibre, which, in turn, may be responsible for the loss of strength and changes in other characteristics. The following comments can be made to explain the above observations.

In sample 1, the grooves occur along the filament very frequently, but openings and cracks are less frequent (Fig. 1). Grooves and openings may be due to the following reasons:

1. The partial choking of the spinnerette holes by small particles may produce a groove along the filament.
2. The solid particles in the cooling air in the spinning line may be embedded into the polymer before its solidification and just below the spinnerette. When the filament is partially stretched due to take-up tension, these solid particles might make small grooves on the adjacent filament body.
3. The openings observed on the as-spun filament body may be due either to mechanical damage or incomplete formation of the round filament. The incomplete formation of round filament is possible because of the grooves formed due to partial choking.
of spinnerette hole or freezing of solid particles in the cooling chimney.

In sample 2, grooves, openings, cracks and foreign material are found very frequently (Fig. 2). Some striations parallel to the fibre and spots are also seen. The frequency of defects in stretched yarn increases because of mechanical damage due to friction between filaments containing solid particles while stretching. The solid particles embedded in the filament body may come out producing openings on the filament surface. During stretching, the monomer and the spin finish come out of the filament body, resulting in minute

Table 1—Fibre Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>As-spun yarn</th>
<th>Stretched yarn</th>
<th>Twisted double-plied yarn</th>
<th>Twisted, double-plied, heat-treated at 200°C for 15 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denier/filament (denier)</td>
<td>24.55</td>
<td>6.24</td>
<td>6.39</td>
<td>6.64</td>
</tr>
<tr>
<td>Diameter, μ (μm)</td>
<td>54.263</td>
<td>27.988</td>
<td>26.846</td>
<td>37.845</td>
</tr>
<tr>
<td>Degree of crystallinity, %</td>
<td>28</td>
<td>36</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Birefringence (N)</td>
<td>0.0180</td>
<td>0.0565</td>
<td>0.0569</td>
<td>0.0567</td>
</tr>
</tbody>
</table>

Table 2—Defects Observed by Scanning Electron Microscopy

<table>
<thead>
<tr>
<th>Defects</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grooves</td>
<td>Along the filament</td>
<td>Very frequent</td>
<td>Deep grooves</td>
<td>Deep grooves,</td>
</tr>
<tr>
<td></td>
<td>very frequently</td>
<td></td>
<td>very frequent</td>
<td>very frequent</td>
</tr>
<tr>
<td>Cracks</td>
<td>Rough surface</td>
<td></td>
<td>More rough surface</td>
<td>Very rough surface</td>
</tr>
<tr>
<td></td>
<td>Smooth surface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foreign material</td>
<td>Occasional</td>
<td>Very frequent</td>
<td>Frequent</td>
<td>Frequent</td>
</tr>
<tr>
<td>Striations</td>
<td>Striation parallel</td>
<td></td>
<td>Deep striation</td>
<td>Present</td>
</tr>
<tr>
<td></td>
<td>to the fibre axis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spots</td>
<td>Nil</td>
<td>Some spots</td>
<td>Some spots</td>
<td>Some spots</td>
</tr>
</tbody>
</table>

Fig. 1—Scanning electron micrograph of as-spun nylon-6 tyre yarn (× 1000)

Fig. 2—Scanning electron micrograph of the hot-stretched (drawn 4.2 times at 175°C) nylon-6 tyre yarn (× 2500)
holes which appear as spots in the SEM micrographs. This will result in weakening of the bond between rubber and cord.

In samples 3 and 4, the grooves and striations are very deep and the surface is very rough as seen in Fig. 3 and Fig. 4a, b, c. To make the cord, the yarn is first twisted at a very high tension and then plied giving opposite twist. During this process, the disorientation of the molecules takes place. The cracks, grooves and striations, initiated on the fibre surface during stretching, propagate into the core due to high tension, resulting in deepening of these defects. It is noted that sample 4 is similar to sample 3, except that the surface is very rough. This may be due to a combination of factors, for example partial melting of filaments and foreign materials or due to the loss of finish or monomer from the surface of the cord during heat treatment.

Scanning electron microscopy can also be used to study the mechanical damage caused to the fibre. As an example, Fig. 5 indicates the mechanical damage caused to the cord during stretching. In this case, an opening is seen in the cord and material has come out from the opening and has got attached to the other fibre. This will result in weak spots in the cord, which change its strength and other characteristics like adhesion.

Fig. 3—Scanning electron micrograph of twisted and double-plied nylon-6 tyre yarn (x 1300)

Fig. 4—Scanning electron micrograph of twisted and double-plied nylon-6 tyre yarn treated at 200°C for 15 min [(a) x 2400; (b) x 1200; and (c) x 650]
Conclusion
SEM can be used for controlling the quality of the tyre cord during processing and for studying the damages caused to the fibre during processing. The presence of excess monomer on the surface of the cord, which results in poor adhesion, can also be seen by studying SEM photographs.

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References