EUROPEAN PATENT APPLICATION

A process is described for the production of high strength polyester yarn wherein the conventional spin draw process has been modified. Yarn having a tenacity of at least 7.5 g/d and an elongation of at least 9% may be spun using this process at a speed of at least 1900 meters per minute. The yarn may be used in tire cord and other industrial applications.

Figures 1 and 2 illustrate in schematic form the general process steps of spinning and drawing respectively. Polyester in the form of melt extrudable polyethylene terephthalate (PET) is charged to a hopper 12 which empties into a screw extruder 14 which thereupon mixes and heats the polyester to a temperature of about 287°C.

The now molten polyester is pressure fed by the extruder to a spinnarette 16 having a plurality of capillaries 17 through which the polyester is extruded. The number of capillaries can vary from about 50 to over 100. The extruded filaments are maintained at a temperature near the melting point of PET by a quench delay collar 20 often referred to simply as a quench collar. The filaments are then quenched by an inert gas or air stream 22 of ambient temperature before passing though a chute 24. The filaments 18 are now in a solid state.

At the end of the chute 24 is a tray and kiss roll 26 which applies a conventional spin finish compound to the filaments. The filaments are then converged at point 28 into yarn 30, which is thereafter transported by a pretension godet 32, godets 34 and guide rolls 36 to winder 38, where the yarn is wound and may be either stored for future drawing or may be used as feed immediately to the drawing process in continuous fashion.

The drawing process is illustrated in Figure 2. Yarn 30 from winder 38 passes between pretention rolls 42 and over guide roll 44 to top godet 46. The yarn then travels around draw pin 50 which localizes the draw at a point just below top godet 46. The amount of draw is governed by the relative rotational speeds of top godet 46 and a bottom godet 56, the latter rotating at a high speed than top godet 46.

After passing over draw pin 50, the yarn 30 passes over a platen 52 before being wound on the bottom godet 56. Rolls 48 and 58 separate the wraps and keep them from rubbing against each other. Platen 52 is heated to a temperature of about 215°C. to about 230°C. From the bottom godet, the now drawn yarn passes through guide loops 60 and is wound onto a spool 62. The yarn is now ready for use at this point.

/...
This invention lies in the art of polyester processing. More specifically, it deals with an improved process for the manufacture of high strength polyester yarn. This improved process allows higher rates of production of yarn with physical properties suitable for use in industrial applications.

In general, the process for producing polyester yarn consists of melt extruding the polymer through a shaped orifice having a plurality of capillaries, solidifying the filaments so produced to form a yarn, then applying a finish composition to the yarn surface and drawing the yarn at high temperatures either immediately or at a later time. Variations in the processing conditions determine the physical properties of the yarn and thereby the application.

For instance, yarn used as reinforcement in articles such as tires or fan belts must have high strength, that is, tenacities of at least 7.5 g/d, while the most important characteristic for fine denier textile yarn is the capability for accepting a dye uniformly, fiber strength being of secondary importance. Textile grade yarn having good dye uniformity can be produced at winding speeds in excess of 3,000 meters per minute. At this speed, tenacities are in the range of about 2 to 4 grams per denier. To produce industrial yarns having tenacities of about 7.5 grams per denier, the winding speed must be considerably reduced, viz., to about 700 meters per minute or less.
This lower winding speed has been the bottleneck which has heretofore determined the rate of production of such yarn, as the drawing process, whether performed immediately subsequent to winding or at a later time, may be carried out at high speeds.

This invention disclose an improved process for producing high strength polyester yarn wherein spinning speeds are substantially increased, yet physical properties of the yarn so produced remain high. In particular, with this process, polyester yarn may be produced having tenacities of greater than 7.5 grams per denier at a spinning speed of at least 1500 meters per minute. The advantages of such a process lie of course in a vastly increased production rate for industrial yarn, with corresponding reductions in processing costs over the presently used process.

While the prior art teaches improvements in various types of polyester yarn processing, none teach process modifications resulting in both high production rates and high strength yarn. U.S. Patent 2,604,667 deals with a process for producing undrawn polyester yarn with relatively high tenacity in the "as spun" state. However, the yarn so produced is suitable for textile use and similar uses only as tenacities are below about 6 g/d. U.S. Patent 2,604,689 describes a process for manufacture of polyester yarn having tenacities of below about 3 g/d. Because this patent does not teach the manufacture of high strength yarn it is not pertinent. U.S. Patent 3,715,421 deals with a process for continuous spin draw of polyethylene terephthalate. In particular it discloses the use of a novel continuous process for spinning and drawing PET yarn. In this process, a series of feed and draw rolls are used to produce a high amount of tension in the yarn filaments. While the final wind-up speed after drawing may be in excess of 2,000 meters per
minute, this corresponds to a spin velocity of 400 meters per minute and a draw ratio, of between 5 and 8. Thus this patent does not teach high speed spinning of any kind.

U.S. Patent 2,918,346 teaches the use of sequential, inert baths during drawing of high density tows of polyester yarn to substantially reduce the incidence of non-orientation. As this patent does not concern itself with increasing the spinning speed, it also is not pertinent. U.S. Patent 2,965,613 relates to novel copolyesters of terephthalic and isophthalic acid and ethylene glycol. The invention does not relate to any process for the production of polyester yarn. U.S. Patent 3,946,100 is concerned with a process for the production of polyester yarn including a conditioning step just after the solidification. The yarn so produced has physical properties below those required for use as a high strength reinforcing yarn.

U.S. Patent 3,361,859 discloses a process for retarding the cooling of spun filaments after spinning to give a polymer having lower orientation. Spinning speeds used are well below that claimed by this invention.

U.S. Patent 4,195,052 describes a process for making industrial yarn wherein the filaments are melt spun and uniformly quenched under high stress conditions. A two-step draw process produces a yarn having at least 85% of the maximum draw ratio. There is no teaching of high speed spinning.

**DISCLOSURE OF INVENTION**

In light of the foregoing, it is an object of the present invention to provide high strength polyester yarn and a process for manufacture thereof in which spinning speeds are substantially increased
It is another object of the present invention to provide a high strength polyester yarn and a process for the manufacture thereof, as above, in which only minor modifications need be made in the manufacturing process.

It is another object of the present invention to provide a high strength polyester yarn and a process for manufacture thereof, as above, with the yarn having improved physical properties over conventional made yarn and is suitable for use in tires.

It is another object of the present invention to provide a high strength polyester yarn and a process for manufacture thereof, as above, in which the spinnarette diameter is increased, the top godet temperature reduced and an infrared quench delay collar is used.

It is another object of the present invention to provide a high strength polyester yarn and a process for manufacture thereof, as above, in which the spin speed is in excess of 1,500 meters per second and the tenacity is greater than 7.5 grams per denier.

These objects and others which will become apparent as the detailed description proceeds are achieved by: a process for the production of high strength polyester yarn comprising the steps of: extruding molten polyester through a plurality of spinnarettes having a diameter of between about 0.75 and 2.5 millimeters, and producing filaments thereby; delaying the quench of said polyester filaments by means of an infrared quench delay collar positioned immediately downstream of said spinnarettes; combining said polyester filaments into a spun yarn; and winding said spun polyester on a winder at a speed of at least 1,500 meters per minute.

In general, a high strength polyester comprising: the yarn produced by the process
consisting of: extruding molten polyester through a plurality of spinnarettes having a diameter of between about 0.75 and 2.5 millimeters, and producing filaments thereby; delaying the quench of said polyester filaments by means of an infrared quench delay collar positioned immediately downstream of said spinnarette; combining said polyester filaments into a spun yarn; winding said spun polyester on a winder at a speed of at least 1,500 meters per minute; and drawing said spun polyester in either a continuous or discontinuous fashion.

BRIEF DESCRIPTION OF DRAWINGS

For a complete understanding of the objects, techniques, and structure of the invention, reference should be had to the following detailed description and accompanying drawings, wherein:

Fig. 1 is a schematic representation of the spinning process of the instant invention;

Fig. 2 is a schematic of the drawing process of the instant invention;

Fig. 3 is a plot of the relationship between polymer throughput rate and efficient draw ratio versus winding speed of yarn; and

Fig. 4 is a plot of spun birefringence versus winding speed.

BEST MODE FOR CARRYING OUT THE INVENTION

Polyester yarn used as tire cord or for other industrial uses must have physical properties imparting high strength. For tire cord, polyester filaments must have a tenacity of at least about 7.5 g/d and elongation of about 9%. As discussed above, this type of yarn is to be contrasted with textile grade yarn wherein the primary consideration is not
strength but is the ability to uniformly accept a dye. While it is conventional to spin textile grade polyester yarn at speeds in excess of 3,000 meters per minute, heretofore the spinning of industrial yarn has been limited to below about 700 meters per minute. This has been necessitated by the fact that the physical properties of polyester yarn greatly deteriorate at the higher spinning speeds.

This invention however provides for improvements to the spinning and draw twisting steps which allow increased spinning speeds without a reduction in physical properties. Figs. 1 and 2 illustrate in schematic form for the general process steps of spinning and drawing respectively. Polyester in the form of melt extrudable polyethylene terephthalate (PET) is charged to a hopper 12 which empties into a screw extruder 14 which thereupon mixes and heats the polyester to a temperature of about 287°C.

The now molten polyester is pressure fed by the extruder to a spinnarette 16 having a plurality of capillaries 17 through which the polyester is extruded. The number of capillaries can vary from about 50 to over 100. The extruded filaments are maintained at a temperature near the melting point of PET by a quench delay collar 20 often referred to simply as a quench collar. The filaments are then quenched by an inert gas or air stream 22 of ambient temperature before passing through a chute 24. The filaments 18 are now in a solid state.

At the end of the chute 24 is a tray and kiss roll 26 which applies a conventional spin finish compound to the filaments. The filaments are then converged at point 28 into yarn 30, which is thereafter transported by a pretension godet 32, godets 34 and guide rolls 36 to winder 38, where the yarn is wound and may be either stored for future drawing.
or may be used as feed immediately to the drawing process in continuous fashion.

The drawing process is illustrated in Fig. 2. Yarn 30 from winder 38 passes between pretension rolls 42 and over guide roll 44 to top godet 46. The yarn then travels around draw pin 50 which localizes the draw at a point just below top godet 46. The amount of draw is governed by the relative rotational speeds of top godet 46 and a bottom godet 56, the latter rotating at a higher speed than top godet 46. The difference in speed determines the draw ratio, that is, the degree of stretch induced in the yarn 30 relative to the predrawn dimensions.

After passing over draw pin 50, the yarn 30 passes over a platen 52 before being wound on the bottom godet 56. Rolls 48 and 58 separate the wraps and keep them from rubbing against each other. Platen 52 is heated to a temperature of about 215°C to about 230°C. From the bottom godet, the now drawn yarn passes through guide loops 60 and is wound onto a spool 62. The yarn is now ready for use at this point.

The instant invention provides for various improvements to the above-described process which allows spinning and drawing of high strength industrial polyester yarn. The first modification involves dimensional changes in the capillaries 17. While conventional capillary diameters vary, they are generally between about .3 and about .5 millimeters. The instant invention increases capillary diameter to between about 0.75 and 2.5 millimeters, preferably between about 1.0 and 2.0 millimeters with about 1.52 millimeters being most preferred. The length to diameter ratio of the capillary remains the same as in the conventional process at about 2 to 1.

As discussed in the examples below, tests conducted at spinning speeds of approximately 1900
meters per minute showed that spun yarn tenacities were greatly increased when larger diameter capillaries were used. Heretofore, it had been expected that the use of larger diameter capillary would result in increases in the molecular orientation of the filaments or spun yarn birefringence. Birefringence as measure of molecular orientation is defined as retardation per unit thickness of fiber.

It has been unexpectedly observed however, that at a constant winding speed, berefringence values do not vary significantly with the capillary diameter. This can be seen with reference to Table I. The relationship between larger capillary diameter and improvement in yarn tenacity may be attributed to a reduction in the jet velocity and a corresponding increase in the drawn down ratio.

Draw down ratio refers to the quotient of the winding speed divided by the jet velocity, where the jet velocity in meters per minute equals the through-put, c.c./min., divided by the area of spinnarette aperature. Increased draw down results in increased filament or thread line tension. This increased thread line tension correspondingly imparts greater thread line stability to the polymer melt flow at the exit of the capillaries 17.

The increase in tension so achieved is generally expected to be accompanied by an increase in molecular orientation or spun yarn birefringence, as mentioned above. The high degree of birefringence in the spun yarn has heretofore resulted in unacceptable physical properties for industrial applications.

Molecular orientation can be reduced however by the use of an infrared quench delay collar. The quench collar, be it of infrared design or of the conventional resistance heater design imparts thermal energy to the filaments 18 undergoing deformation caused by draw down. This increases or maintains
chain mobility which correspondingly reduces some of the orientation caused by the draw down.

Heretofore however, use of conventional resistance type quench collars were found to be inadequate at higher winding speeds. The transfer of heat to the filaments with a convective resistance heat collar is a slower process of heat transfer than with the infrared collar which transmits heat in the form of light waves having wave lengths ranging from about 3 to about 20 microns. Polyester filament readily absorbs light waves in the range of 3 to 4 microns. Because of the higher winding speeds, the residence time in the quench collar is greatly reduced, thus the efficiency of heat transfer in the collar must be correspondingly increased. This increase is achieved with the use of infrared quench collars.

The effects of using an infrared quench collar can be seen in Table II. Yarn was produced at winding speeds of 1,900 m/min. using both convective and infrared quench collars. Note that tenacity was increased significantly when both the infrared collar and the larger capillary diameter were used.

As stated above, while it was observed that the birefringence did not change with increased capillary diameter at constant winding speeds, birefringence values have been observed to increase as the winding speed increases. Changes in birefringence represent morphological changes in the polyester yarn. These changes directly effect the physical properties of the yarn after it is drawn.

Polyester yarn having birefringence values of greater than 0.0025 have heretofore been unsuitable for industrial applications, that is, their tenacities and elongation values after drawing have been below the minimum required for such use. It has been discovered however that the reason for this decrease in physical properties at the drawing stage may be
attributed to the changes in rate of crystallization which occurs when the spun yarn is heated above its glass transition temperature.

The rate of crystallization varies depending upon the temperature, reaching a peak and then declining with increased temperature. Increased birefringence has been found to decrease the peak crystallization temperature. In the drawing process, it is required for crystallization not to occur prior to the actual drawing of the yarn. Thus, the temperature of the top godet 46 has been found to be critical to proper drawing of high birefringence yarn.

The temperature of the top godet 46 must be sufficiently low so that the rate of crystallization of the yarn 30 is low enough so that physical properties of the yarn after drawing are unaffected. Prior to this invention, the top godet 46 was heated to a temperature of about 110°C. At this temperature, unacceptable crystallization occurred in the spun yarn. By maintaining the top godet at a temperature of around ambient to 80°C, and preferably from about 35°C to about 80°C, the rate of crystallization is sufficiently low so that acceptable, high strength yarn is produced after drawing.

The variation of the peak crystallization rate temperature with birefringence can be seen with reference to Table III. Note that at the birefringence values normally encountered in low speed spinning, the crystallization exotherm is centered at a point somewhere above 110°C. However, as the birefringence value of the spun yarn increases beyond about .01, the crystallization rate is seen to increase at a point below about 110°C, which, as above, is the temperature of the top godet 46 in the conventional, prior art process.

Table IV illustrates the effective top roll temperature on yarn physical properties. The tenacity
other, the top godet temperature was left at ambient room temperature. Improved yarn physical properties were obtained with the top godet of the draw twister left at ambient, viz., tenacities and elongations of 7.4 g/d and 14.9% versus 6.6 g/d and 14.3% for a top godet at 110°C. Table IV summarizes the results of this experiment.

EXAMPLE IV

PET polymer having an I.V. of 0.90 was spun at 1,900 m/min. Simultaneous use of an infrared quench collar, capillaries having a diameter of 1.524 mm and maintenance of top godet temperature at ambient, gave yarn physical properties of 9.4 g/d at 11% elongation. Table V summarizes the results of this experiment.
## TABLE I
EFFECT OF CAPILLARY DIAMETER OF SPINNARETTE ON THE BIREFRINGENCE VALUE

<table>
<thead>
<tr>
<th>Spinnarette Dia. Millimeters</th>
<th>Birefringence</th>
<th>Take-up Speed M/min</th>
<th>Spun Denier</th>
<th>Jet Velocity M/min</th>
<th>Draw Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>.762</td>
<td>.0093</td>
<td>1000</td>
<td>3000</td>
<td>2.72</td>
<td>368</td>
</tr>
<tr>
<td>.762</td>
<td>.0108</td>
<td>1000</td>
<td>3000</td>
<td>2.72</td>
<td>368</td>
</tr>
<tr>
<td>.762</td>
<td>.0100</td>
<td>1000</td>
<td>3000</td>
<td>2.72</td>
<td>368</td>
</tr>
<tr>
<td>Average</td>
<td>.0100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.381</td>
<td>.0101</td>
<td>1000</td>
<td>3000</td>
<td>10.87</td>
<td>92</td>
</tr>
<tr>
<td>1.143</td>
<td>.0102</td>
<td>1000</td>
<td>3000</td>
<td>1.21</td>
<td>826</td>
</tr>
</tbody>
</table>
and elongation are significantly improved over what is observed for top roll temperatures maintained at 110°C.

Data from Table IV also indicate that acceptable yarn physical properties are obtained when the platen 52 is maintained at a temperature of 225°C and the bottom roll 56 is maintained at a temperature of 140°C. These temperatures are consistent with those observed in processes of the prior art. That is, a platen temperature of about 215°C to about 230°C and a bottom godet temperature of about 110°C to about 145°C. Table V summarizes the results of the combinations of large diameter capillaries or spinnarettes, infrared quench collars, and ambient or slightly heated top godet temperatures. The last column wherein all of these modifications are incorporated in the process, shows the best physical properties.

Fig. 3 shows extruder throughput rates and efficient draw ratio versus winding speed. This figure shows that for a given spinnarette diameter, the throughput through the spinnarettes is non-linear with winding speed. That is, a diminishing return of polymer throughput rate is observed with increasing winding speed because the draw ratio at which maximum efficiency is achieved is reduced correspondingly. The efficient draw ratio is defined as the ratio needed to obtain optimum yarn physical properties and draw twister performances.

Fig. 4 plots spun birefringence versus winding speed. At a winding speed of approximately 1900 meters per minute the birefringence reaches a value in excess of .02 and thus, from the above discussion, it is noted that a high rate of crystallization is reached at this winding speed.

The following examples further illustrate the process of high speed winding,
EXAMPLE I

Polyethylene terephthalate polymer (PET) having an intrinsic viscosity (I.V.) of approximately 0.90 was melt extruded using a sinnarette having a standard capillary diameter of 0.381 mm. Spinning speeds of 620 and 1,900 meters per minute were used. The spun yarns were then drawn at conventional draw twister conditions. The yarn tenacity and elongation were 8.8 g/d and 14% respectively for 760 m/min. and 6.6 g/d and 14.4% respectively for the 1,900 m/min. winding speed. This example is summarized in Table II.

EXAMPLE II

PET polymer having approximately 0.90 I.V. was melt extruded and wound at 1,900 m/min. The capillary diameter of the spinnarette used was 0.381 mm. Two types of quench collars were used, one adapted with the convection heating elements (resistant type) and one with the infrared elements. The spun yarns were then drawn on the draw twister using conventional conditions. The yarn tenacity and elongation were 6.6 g/d and 14.3% respectively when the infrared collar was used. The convection collar gave yarn tenacity of 5.54 g/d and yarn elongation to break of 12.0%. This example is summarized in Table II.

EXAMPLE III

PET polymer, 0.90 I.V. was melt extruded through a spinnarette with a 0.381 mm. capillary diameter. The spun yarn was quenched with a convection type quench collar and wound at 1,900 m/min. The spun yarn was drawn at two different draw twister conditions. In one case, the temperature of the draw twister top godet was 110°C and in the
<table>
<thead>
<tr>
<th>Quance Collar Type</th>
<th>Convective (control)</th>
<th>Convective</th>
<th>Infrared</th>
<th>Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capillary Dia., mm (in).</td>
<td>0.381</td>
<td>0.381 (0.015)</td>
<td>0.331</td>
<td>1.524 (0.06)</td>
</tr>
<tr>
<td>Quench Collar Temp., °C (°F)</td>
<td>300</td>
<td>327 (620°)</td>
<td>371</td>
<td>371</td>
</tr>
<tr>
<td>Thruput, kg/hr (lbs./hr)</td>
<td>10.5</td>
<td>12.8 (28.06)</td>
<td>20.0</td>
<td>20.0 (42.9)</td>
</tr>
<tr>
<td>Winding speed, m/min.</td>
<td>620</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
</tr>
<tr>
<td>Spun Birefringence</td>
<td>0.0022</td>
<td>0.0287</td>
<td>0.018</td>
<td>0.018</td>
</tr>
<tr>
<td>Draw Ratio</td>
<td>5.8</td>
<td>2.24</td>
<td>3.14</td>
<td>3.14</td>
</tr>
</tbody>
</table>

**Yarn Properties**

<table>
<thead>
<tr>
<th>Denier</th>
<th>1000</th>
<th>997</th>
<th>1013</th>
<th>1058</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile, kg.</td>
<td>8.799</td>
<td>5.534</td>
<td>6.713</td>
<td>8.21</td>
</tr>
<tr>
<td>Tenacity, g/d</td>
<td>8.8</td>
<td>5.54</td>
<td>6.6</td>
<td>7.8</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>14.0</td>
<td>12.0</td>
<td>14.3</td>
<td>15.2</td>
</tr>
<tr>
<td>Birefringence</td>
<td>Crystallization Exotherm Centered At</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.004</td>
<td>138°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.003</td>
<td>135°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.010</td>
<td>131°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.038</td>
<td>107°C</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>.050</td>
<td>106°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.055</td>
<td>98°C</td>
<td></td>
<td></td>
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<tr>
<td>.218</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* *Journal of Applied Polymer Science; Vol. 16, 1972*

"Sticking Behavior of Preoriented PET Yarns" 
Richard G. Quynn
TABLE IV
EFFECT OF TOP ROLL TEMPERATURE ON YARN PHYSICAL PROPERTIES

<table>
<thead>
<tr>
<th>Spinnarette Capillary Dia., mm (in)</th>
<th>0.381 (0.015)</th>
<th>0.381</th>
<th>1.524 (0.060)</th>
<th>1.524</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drawtwister Conditions:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top Roll Temp., °C</td>
<td>110</td>
<td>Ambient</td>
<td>110</td>
<td>Ambient</td>
</tr>
<tr>
<td>Platen Temp., °C</td>
<td>225</td>
<td>225</td>
<td>225</td>
<td>225</td>
</tr>
<tr>
<td>Bottom Roll Temp., °C</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Delivery Speed, m/min</td>
<td>315</td>
<td>315</td>
<td>315</td>
<td>315</td>
</tr>
<tr>
<td>Draw Ratio</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
</tr>
<tr>
<td><strong>Yarn Properties:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denier</td>
<td>1013</td>
<td>1022</td>
<td>1070</td>
<td>1058</td>
</tr>
<tr>
<td>Tensile, kg.</td>
<td>6.713</td>
<td>7.529</td>
<td>7.575</td>
<td>8.21</td>
</tr>
<tr>
<td>Tenacity, g/d</td>
<td>6.6</td>
<td>7.4</td>
<td>7.1</td>
<td>7.8</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>14.3</td>
<td>14.9</td>
<td>12.3</td>
<td>15.2</td>
</tr>
<tr>
<td>Spun Birefringence</td>
<td>0.018</td>
<td>0.018</td>
<td>0.018</td>
<td>0.018</td>
</tr>
</tbody>
</table>
### TABLE V
SUMMARY OF THE RESULTS - SPINNING SPEED
OF 1900 METERS PER MINUTES

<table>
<thead>
<tr>
<th>Spinnarette</th>
<th>.381 mm x .762 mm x 97 Holes</th>
<th>1.524 mm x 3.048 mm x 97 Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quench Collar</td>
<td>Convective 110° IR 110° IR Ambient IR 110° Ambient IR 3.51</td>
<td></td>
</tr>
<tr>
<td>Top Roll Temp, °C.</td>
<td>2.24 3.14 3.14 3.14 3.51</td>
<td></td>
</tr>
<tr>
<td>Draw Ratio</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Yarn Properties

<table>
<thead>
<tr>
<th></th>
<th>.381 mm x .762 mm x 97 Holes</th>
<th>1.524 mm x 3.048 mm x 97 Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity, g/d</td>
<td>5.5 6.6 7.4 7.8 9.4</td>
<td></td>
</tr>
<tr>
<td>Elongation, %</td>
<td>12.0 14.0 15.0 15.0 11.0</td>
<td></td>
</tr>
</tbody>
</table>
From the examples given above and with reference to the above discussed Tables, it can be seen that a considerable advancement of the art has been achieved by this invention. High strength polyester yarn suitable for use in tire cord and other industrial applications can be manufactured at rates heretofore unknown with resulting reductions in cost. While the examples illustrate the use of a winding speed of 1900 meters per minute, it will be appreciated that even higher winding speeds may also be utilized, although the increase in production rate at these higher speeds diminishes with increasing speed. The practical limit on winding speed is dictated by the capacity of the equipment used. Generally, the spin speed can range from 1,500 to 3,500 meters per minute with from about 1,900 and 2,500 meters per minute being preferred.

The teachings of this invention can be applied to either a two stage spin and draw process or to a one stage spin and draw process.

While in accordance with the Patent Statutes, only the best mode and preferred embodiments have been disclosed, it is to be understood that the invention is not limited thereto or thereby. Thus, for a fuller understanding of the scope of the invention, reference should be made to the following claims.
WHAT IS CLAIMED IS

1. A process for the production of high strength polyester yarn characterized by:
   extruding molten polyester through a plurality of spinnarettes having a diameter of between about 0.75 to 2.5 millimeters, and producing filaments thereby;
   delaying the quench of said polyester filaments by means of an infrared quench delay collar positioned immediately downstream of said spinnarettes;
   combining said polyester filaments into a spun yarn; and
   winding said spun polyester on a winder at a speed of at least 1,500 meters/minute.

2. A process for the production of high strength polyester yarn according to Claim 1, characterized in that said process further comprises:
   unwinding said polyester yarn and passing said yarn over a top godet having a temperature of between about ambient and 80°C.;
   passing said yarn over a bottom godet maintained at a temperature of about between 110°C. and 145°C.; and
   winding said drawn polyester on a spindle.

3. A process for the production of high strength polyester yarn according to Claim 2, characterized in that said infrared quench delay collar emits light waves having a wave length of from about 3 to about 20 microns.
4. A process for the production of high strength polyester yarn according to Claim 3, characterized in that said top godet temperature is between about 35°C. and 80°C., and after passing said yarn over said top godet, including passing said yarn around a draw pin, passing said yarn over a platen having a temperature of about between 215°C. and 230°C., and then passing said yarn to said bottom godet.

5. A process for the production of high strength polyester yarn according to Claim 1, characterized in that said polyester is polyethylene terephthalate.

6. A process for the production of high strength polyester yarn according to Claim 5, characterized in that the tenacity of said polyester yarn after drawing is between about 7.5 and 9.5 and the elongation of said yarn is between about 9.0% and 14.0%.

7. A high strength polyester yarn, characterized by:

- the yarn produced by the process, comprising:
  - extruding molten polyester through a plurality of spinnaretttes having a diameter of between about 0.75 and 2.5 millimeters, and producing filaments thereby;
  - delaying the quench of said polyester filaments by means of an infrared quench delay collar positioned immediately downstream of said spinnarette;
  - combining said polyester filaments into a spun yarn;
- winding said spun polyester on a winder at a speed of at least 1,500 meters per minute; and
- drawing said spun polyester in either a continuous or discontinuous fashion.
8. A high strength polyester yarn according to Claim 7, characterized in that said drawing process comprises:

unwinding said polyester yarn and passing said yarn over a top godet having a temperature of between about ambient and 80°C.;

passing said yarn over a bottom godet maintained at a temperature of about between 110°C. and 145°C.; and

winding said drawn polyester on a spindle.

9. A high strength polyester yarn according to Claim 8, characterized in that said infrared quench delay collar emits light waves having wave lengths of from about 3 to about 20 microns.

10. A high strength polyester yarn according to Claim 7, characterized in that said polyester is polyethylene terephthalate.

11. A high strength polyester yarn according to Claim 10, characterized in that said yarn can be used as tire cord.
EXTRUDER THROUGHPUT RATES, LBS/HR AND EFFICIENT DRAW RATIO VS WINDING SPEED, M/MIN

500 DENIER - 97 FILAMENTS
I.R. QUENCH COLLAR
SPINNERETTE: 0.06"X 0.120"X 97 HOLES

FIG. 3
FIG. 4

SPUN BIREFRINGENCE VS WINDING SPEED, M/MIN

0.025 0.05 0.1 0.2 0.3 0.4

3000 2500 2000 1500 1000 500