Enhancing tensile properties (yarn strength) of Polyester filament drawn yarn

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Abstract
This article 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 high end textile applications. The results obtained showed that the most effective and significant parameters influencing fiber overall orientation with Two stage draw Process, draw ratios and the drawing temperatures. Birefringence is affected positively by the type of process and draw ratios.
Keyword: Draw Ratio, POY, HOY, FDY, Single stage and Two Stage drawing, Tenacity, Elongation, Birefringence, Catalyst, TiO2, Esterification, Polymerization

I. Introduction

In general, the process for producing polyester yarn consists of spinning the molten 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 in high end textile applications like sewing thread, rope, net 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 4,000 meters per minute. At this speed, tenacities are in the range of about 3.8 to 4.4 grams per denier. To produce high end textile yarns having tenacities of about 7.5 grams per denier, the draw ratio and runnability are main drawback where in normal single stage drawing we cannot go above draw ratio i.e. 2.5. At higher draw ratios lot of other problems likes yarn breakage & quality related problems like broken filaments aggravates. This limiting factor of draw ratio and runnability overcome by the inducing two stage draw process where with minor modification in the process the draw ratios are divided into two parts i. e. first draw and second draw and the textile yarn of more than 7.5 tenacity can be produced. Even to maintain the productivity winding speed also kept around 3000 to 3300 mpm which was also one of bottleneck with respect to production rate of such high strength yarns. This research discloses an improved modified process for producing high strength polyester yarn wherein spinning speeds are substantially increased, yet physical properties of the yarn so produced remain high with modification from single stage draw process to two stage draw process. 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 3000 meters per minute. The advantages of such a process lie of course in a vastly increased production rate for textile yarn, with corresponding reductions in processing costs over the presently used process.

II. 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 high end textile yarn such as sewing thread, net and ropes. 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 two stage draw process modification is done. 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 spinning speed is in excess of 3000 meters per minute 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 spinnarette and producing filaments thereby; drawing the yarn through two stage draw process by means of three sets of hot Godet rolls; combining said polyester filaments into a spun yarn; and winding said spun polyester on a winder at a speed of at least 3000 meters per minute.

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 conventional single stage draw process; Fig. 2 is a schematic of the drawing process of the two stage draw process of instant invention & Fig. 3 is a Comparism of Single stage v/s Two Stage Draw Process given.

III. Process Description

Polyester is produced by CP (continuous polymerization) process using PTA (purified Terepthalic Acid) and MEG (Mono Ethylene Glycol). The old process is called Batch process using DMT (Dimethyl Terephthalate) and MEG. Catalysts like Sb_2O_3 (Antimony Trioxide) are used to start and control the reaction. TiO_2 (titanium Dioxide) is added to make the polyester fiber / filament dull. Spin finishes are added at melt spinning and draw machine to provide static protection and have cohesion and certain frictional properties to enable fiber get processed through textile spinning machinery without any problem. PTA which is white powder is fed by a screw conveyor into hot MEG to dissolve it. Then catalyst and TiO_2 are added. After that Esterification takes place at high temperature. Then monomer is formed. Polymerization is carried out at high temperature (290 to 300 degree centigrade) and in almost total vacuum. Monomer gets polymerized into the final product, PET (Poly ethylene Terephthalate). This is in the form of viscous liquid. This liquid is them pumped to melt spinning machines. These machines may be single sided or double sided and can have 36/48/64 spinning positions. At each position, the polymer is pumped by a metering pump-which discharges an accurate quantity of polymer per revolution (to control the denier of the fiber) through a pack which has sand or stainless steel particles as filter media and a spinnarette which could be circular or rectangular and will have a specific number of holes depending on the technology used and the final denier being produced. Polymer comes out of each hole of the spinnarette and is instantly solidified by the flow of cool dry air. This process is called quenching. The filaments from each spinnarette are collected together to form a small bundles of filaments called yarn. Which is passed through the finish tip which is having supply of spin finish: and this bundle of filaments is then passed to the winding section through inter floor tube. Finally all such number of filament bundles of one position is wound on Godet rolls and then wound on paper tube on Winder in take up section. Also depending upon the process i.e. whether it is POY and FDY the take up section is designed. In case of POY the yarn is taken from spinning directly on the 1st cold godet and then on 2nd cold godet and between both godet rolls the yarn pass through interlacer which is having a supply of compressed air of around 1.5 to 2.5 kg/cm2 which gives interlace in the yarn. For POY yarn the yarn is wound with winding speed of 2800 to 3200 mpm. In case of FDY process the yarn is first taken on 1st set heated godet rollers where the yarn is heated up to its Glass transition temp facilitating the drawing process and then taken it on the 2nd set of heated godet rollers. The 2nd set of godet rolls run at higher speed than the 1st set which depends how much draw is applied according to the required final yarn properties. The 2nd set of godet rolls heat setting to the yarn and having temp ranging from 140 to 180 degrees depending upon the shrinkage required in the final yarn. Between 2nd set of godet rollers the yarn is passed through the interlacer to impart interlaces in the yarn. The higher compressed air pressure is required in FDY compared to POY as the FDY yarn is final yarn which requires more (20 to 25 nips/meter) interlaces in the yarn.

IV. Best Mode For Carrying Out The Invention

Polyester yarn used as sewing thread, net and ropes as high end textile uses must have physical properties imparting high strength. For above uses, polyester filaments must have a tenacity of at least about 7.5 g/d and elongation of about 10%. As discussed above, this type of yarn is to be contrasted with normal 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 4,000 meters per minute, heretofore the spinning of high end textile 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 which allow increased spinning speeds without a reduction in physical properties. Two stage Drawing Process studied w. r. to Model. Detailed study of Model has been done on following points

1. Schematic Model prepared and checked on machine whether the two Stage model can be prepared by combining two positions and will act as a single position for the invention purpose.
2. Model Description, since Multistage Draw Process was not available feasibility checked whether two stage drawing can be developed by modifying existing facility.
3. Hardware Modification: Model features, combining two positions into Single position multistage drawing process by skipping/modifying some hardware.

4. Software Modification: Logic of Two Stage Drawing, - Feasibility checked on Machine whether Logic i.e. Software can be developed from One Stage Drawing to Two Stage Drawing.

Details of the work done

Plan of Work for Two Stage Draw Process finalized.
Two Stage Draw Process.
Model Study.
Model Formulation.
Logic Development.
Logic Testing.
Trials & Experiments.
Testing Physical properties.
Molecular Orientation Testing.
Interpretation of Results.

Model Description:

The Two Stage Process model successfully designed and developed. Fig 2 gives details of schematic view of Two stage Draw Process. Two Stage facility created by combining two positions of FDY machine. The Godet rolls of adjacent positions were used to create the 2nd draw zone. The PLC base special logic preparation designed in order to run the position on FDY machine.

Model Features:

The temp profile kept on the basis of actual trial experience and based on some literature.
The maximum draw ratio kept in first zone & little draw kept in second zone.
The temp & Draw both adjusted according to the tensions in the yarn & ease for string up since the yarn should get wound on Winder without any abnormality.

Logic Preparation.

Schematic Model of Two Stage Drawing on FDY Machine.

Trails, Experiments & Results. Details of Trails, Experiments & Results have been studied.

Trial analysis and Observations:-

With the Model mentioned in the Study various trials carried out with combinations of different deniers & number of filaments.

Sr No	Denier/ Fils→ Doff No→ Paper tube color→	125/36 7925, 26 Vel Black	110/36 7938, 39 Vel Red	90/36 7943, 44 Blue	120/48 7928, 29 Vel Green	170/48 7936, 37 Red
	Throughput	27.08	23.98	19.62	23.36	37
1	MP rpm	15.45	13.60	11.12	13.30	21.07
2	FP	20	17.71	14.49	18	25.05
3	GR Set 1	600	612	634	650	630
4	GR Set 2	2500	2500	2500	2300	2400
5	GR Set 3	3330 3300	3370 3340	3370 3340	2990 2950	3265 3265
6	Wdg Speed	3250	3340	3340	2950	3265
7	Draw Ratio 1	4.17	4.08	3.94	3.5	3.89
8	Draw Ratio 2	1.33	1.35	1.35	1.31	1.51
9	Total Draw ratio	5.55	5.51	5.32	4.60	5.9
10	Temp GR Set 1	110	110	110	110	110
11	Temp GR Set 2	150	140	140	140	140
12	Temp GR Set 3	200	200	200	180	200
13	Tenacity	7.83	8.06	7.81	5.91	7.05
14	Elongation	9.91	11.14	11.70	16.73	10.96
15	T10	7.64	7.90	7.59	5.51	6.87
16	Shrinkage	4.44	4.03	4.23	4.84	4.23

The Draw Ratio in first draw zone is applied between 3.5 to 4.1
The Draw Ratio in second draw zone is applied around 1.3 to 1.5
The total draw ration is for all trials varied between 4.6 to 5.9
The temp kept for GR set 1 is around 110 degrees, for GR set 2 is between 140 to 150 degrees & in final i.e. GR set3 temp between 180 to 200 degrees. This entire temp setting done according to some basic data & runnabilty of the yarn.
The Winding speed is kept around 2950 to 3350 mpm depending upon the runnabilty.

The higher total draw has reflected into higher tenacity of the yarn.
The higher tenacity value yarn has given lower elongation & shrinkage values.

Interpretation of Results: With Two Stage Draw process we can enhance the Tenacity of Polyester filament yarn up to 7.8 compared to normal 4.0 to 4.5. The higher Draw Ratios gives high tenacity, low elongation & low Shrinkage yarn because of high tenacity results mainly due to ultra-high orientation. And because of orientation low elongation & low Shrinkage results.

Bi-Refringes Value Test Results: - In order to see the orientation of molecular chains above different samples were tested for Bi Refringes value and the results have been found as below.

No	Denier	Draw Ratio	Tenacity	Bi-Refringes Value
1	150/36	HOY	3.8	0.118
2	150/48	FDY-1.4	4.4	0.115
3	110/48	FDY Hi Ten - 2.88	5.1	0.192
4	125/36	Two stage – 5.55	7.83	0.204

1. 150/36 highly Oriented yarn which was produced on POY machine shows lowest Bi Refringes value because of very low orientation of molecular chains.
2. 150/48 fully Drawn Yarn with nominal draw ratio of around 1.4 gives the Bi Refringes value of 0.155 because of moderate orientation.
3. 110/48 fully Drawn Yarn with higher Draw Ratio i.e. 2.88 gives the higher value of Bi Refringes because of the more orientation of molecular chains.
4. 125/36 fully Drawn Yarn which is produced with two Stage process gives highest Bi Refringes value because of ultra-orientation of the molecular chains.

Comparism of Single & Two Stage Draw Process.

Single Stage Drawing	Two Stage drawing
1. Draw is induced in only one or single stage. 2. Can result in filament breakage. 3. Limited orientation of the fibers. 4. Not allowing time for morphological changes. 5. Limitation in producing high tenacity, high modulus and low break at elongation of fibers.	1. Draw is induced in two years. 2. No Filament breakage. 3. Maximum orientation of fibers is achieved. 4. Allowing time to morphological changes. 5. Production of ultra-orientation, improved tensile modulus, high tenacity, low elongation and low boil off shrinkage.

Schematic Diagram of Single Stage Drawing on FDY machine.

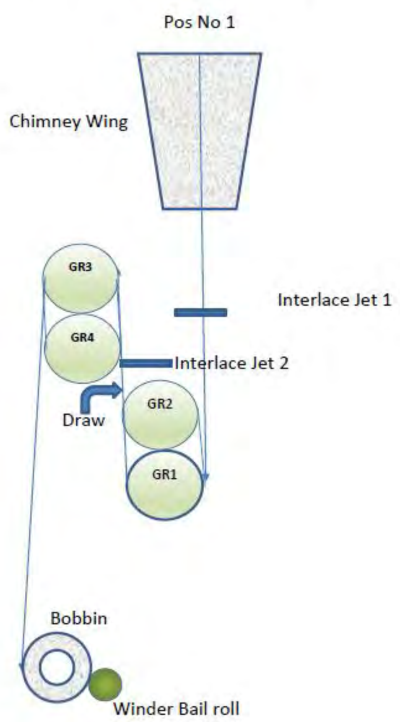

Fig 1: Single Stage draw process schematic diagram.

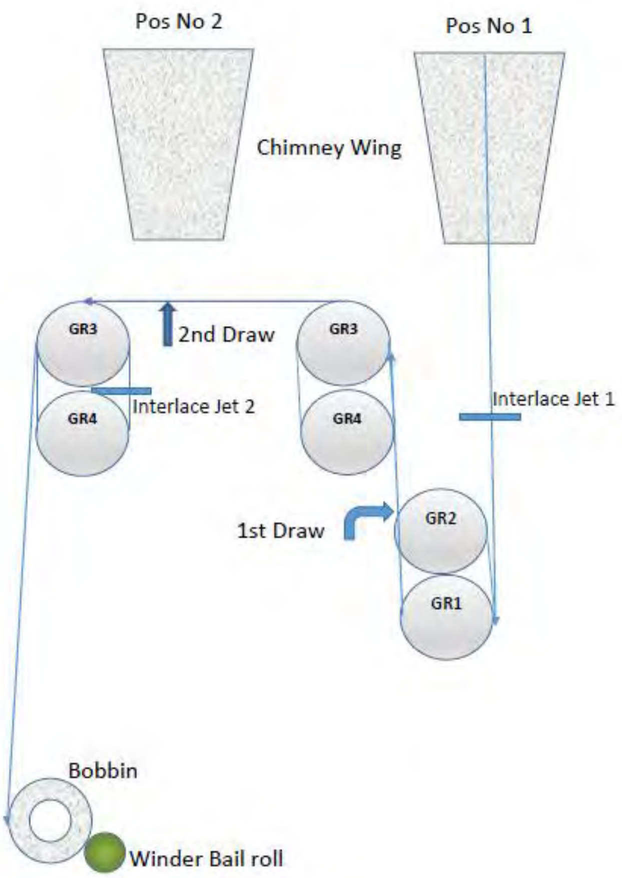

Fig 2: Two Stage draw process schematic diagram.

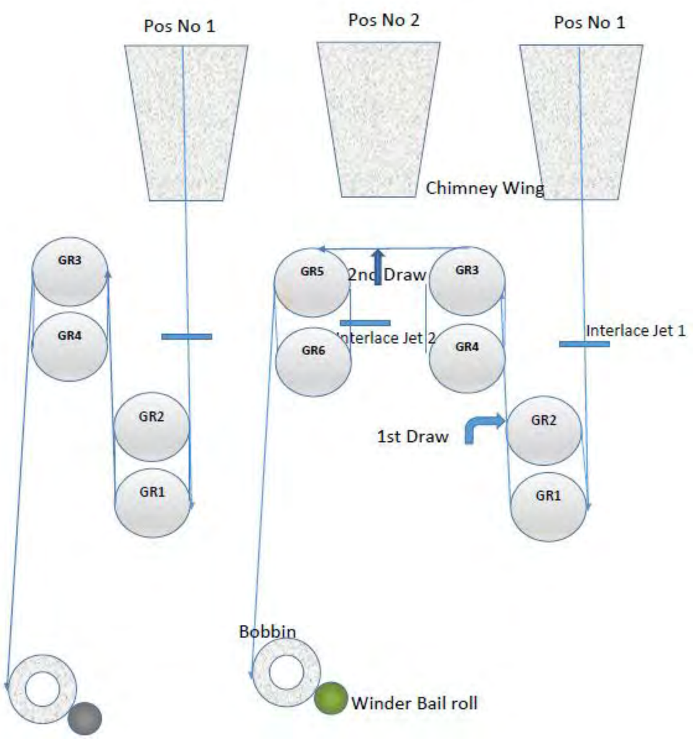

Fig 3: Comparison of single stage & Two Stage draw process

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