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Effect of Raw Material Parameters on the Performance of Mechanical Crimp Textured Yarn

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Abstract:-Mechanical crimp texturising method was developed with the virtue of imparting economy and versatility to the texturising process. Yarn produced by this technique has executed closer resemblance to preferable ring spun yarn structure as well as properties to flat multifilament yarn. Commercial success of this concept demands through study of impact of various raw materials, machine variables and process variables on the performance of this innovative yarn. This research work thereby designed to identify the influence of raw material variables on the mechanical crimp textured yarn performance. However, in order to avoid undue overlapping machine variables as well as process variables were kept constant. Empirically optimised values of these variables for polyester yarn have been adopted for this study. Fully drawn multifilament yarns belonging to two most commercially popular groups viz; Polyester and Nylon, were textured at three different false twist levels. These yarns were not only differing in terms of type of polymer group but also in terms of other contributing properties, viz; yarn fineness, filament fineness, cross sectional shape etc.. However values of these variables were purely restricted by the availability of variations from the manufacturer end. Comparative evaluation of texturising as well mechanical properties of these product yarns have been done. All the samples irrespective of the material have shown the rise in the percent bulk, linear density, percent extension, percent boiling water shrinkage with finer trilobal cross section filament yarn. However, at identical yarn fineness, number of filaments (dpf) has played a detrimental role than modulus of polymeric yarn.

Keywords:- Mechanical Crimp texturing, Techno-economics, Polyester, Polyamide, Mechanical properties, Bulk.

I. INTRODUCTION

Advent of texturising process in the man made textile field has moved the world into a new era. Synthetic yarn on texturising has overcome from their limitations and also retained their favourable characteristics. This has widened the spectrum of man made fiber/filament yarn application field[1-3]. However, earlier advent of false twist texturising was restricted for thermoplastic yarns only due to use of heat for setting deformation[1-7]. Later stage advent of air jet texturising has lifted up this restriction by offering purely a mechanical mode. Hence it has its own limitations of economy of the product. Main contributing factors for the higher cost are use of costlier compressed air and finer feeder yarn in addition to lower production rates due to mechanical mode[1-3,7-8]. So, Mechanical crimp texturising concept was thought off by the researchers. Details of Mechanical crimp texturising process and test procedures adopted for the evaluation of the product obtained have already been explored in the earlier publications. So, it has not been quoted here again[9-12]. Mechanical Crimp Textured yarn is similar to spun yarns in terms of its appearance and physical characteristics. This similarity in the appearance has aroused from the unique compact core and surface curls of different size, occurring at regular intervals along its length[9-10].

II. MATERIALS AND METHODS

The structural characteristics, percent instability, bulk, linear density and strength of the product yarn determine textured yarn performance. Such characteristics are affected by various process parameters, machine parameters and supply yarn properties. Machine parameters as well as process parameters have already been optimized for polyester yarn[9, 12]. Using these machine and process parameters, material parameters have only been varied in this research. This has done to identify material parameters' influence on the product yarn behaviour without any undue overlapping. The work was divided into two groups, viz;

A) Studying the effect of type of material, filament fineness (denier per filament), filament cross-section / type of finish (bright, dull, semi dull).
B) Studying the effect of fineness of multifilament yarn for other identical raw-material characteristics.

Materials:

The characteristics of raw materials chosen for the group: A are given in table 1. For the group: B only fully drawn polyester 100denier/48filaments yarn (group A) was used. It was used in single end (100d/48fils.), double end (200d/96fils.) and triple end (300d/144fils.) form to study the effect of yarn fineness.

Table-1 Properties of the Parent yarns.
(Group: A)

Sample Code	**Description of Parent Yarn**	**Elongation (%)**		**Tenacity (gpd)**		**Boiling Water Shrinkage (%)**	**U (%)**	**Spin finish (%)**
		Ep	Ef	Tp	Tf	8.5	1.80	0.90
N_1	160d/48fils,White, T	42	28.5	4.6	4.69	8.5	1.80	0.90
N_2	70d/24fils,White, T	42	29.3	4.8	4.92	8.5	1.80	0.90
N_3	44d/24fils, White, C	42	30.2	4.7	4.88	3.0	1.10	1.10
P_1	150d/72fils,Green,T	24	17.3	3.5	3.98	2.0	1.02	0.90
P_2	100d/48fils, White,C	35	24.8	3.6	4.20	5.6	3.20	0.95
P_3	70d/36fils, White,C	38	28.1	4.5	4.62	8.5	1.80	0.90

C = Circular, T = Trilobal, Ef = Extension of feeder yarn, Tf = Tenacity of feeder yarn, Ep = Elongation of parent yarn, Tp = Tenacity of parent yarn,gpd =gram per denier.

Methods:

All the materials selected for the study were processed at the constant speed of 100 m/min on the Mechanical crimp Texturising lab model machine with the constant pre twist factor of 24tex$^{1/2}$.turns/c.m. and optimum false-twist. The optimum false twist level K (twist per meter) has been calculated for all the samples using the empirical formula[9, 12] developed for polyester yarn (equation 1). Selection of under feed level was done as per mentioned in the earlier publication[12]. Under feed of the order of 15 percent was taken for 150denier/72filaments denier polyester yarn and 25 percent for rest of the samples based on the percentage extension of the parent yarn. Products so obtained have been checked for quality parameters like yarn appearance, mechanical properties, percentage boiling water shrinkage, percent instability, percent bulk, percentage change in the linear density and tube knitting and dyeing test as per the methods described in the earlier publications. Brief summary has been given in table 2

$$\mathbf{K\ (tpm) = 7151.7 - 53.9D + 0.2\ D^2 - 0.000255\ D^3} \quad \ldots\ldots\ldots\ldots.. \quad \text{Equation 1}$$

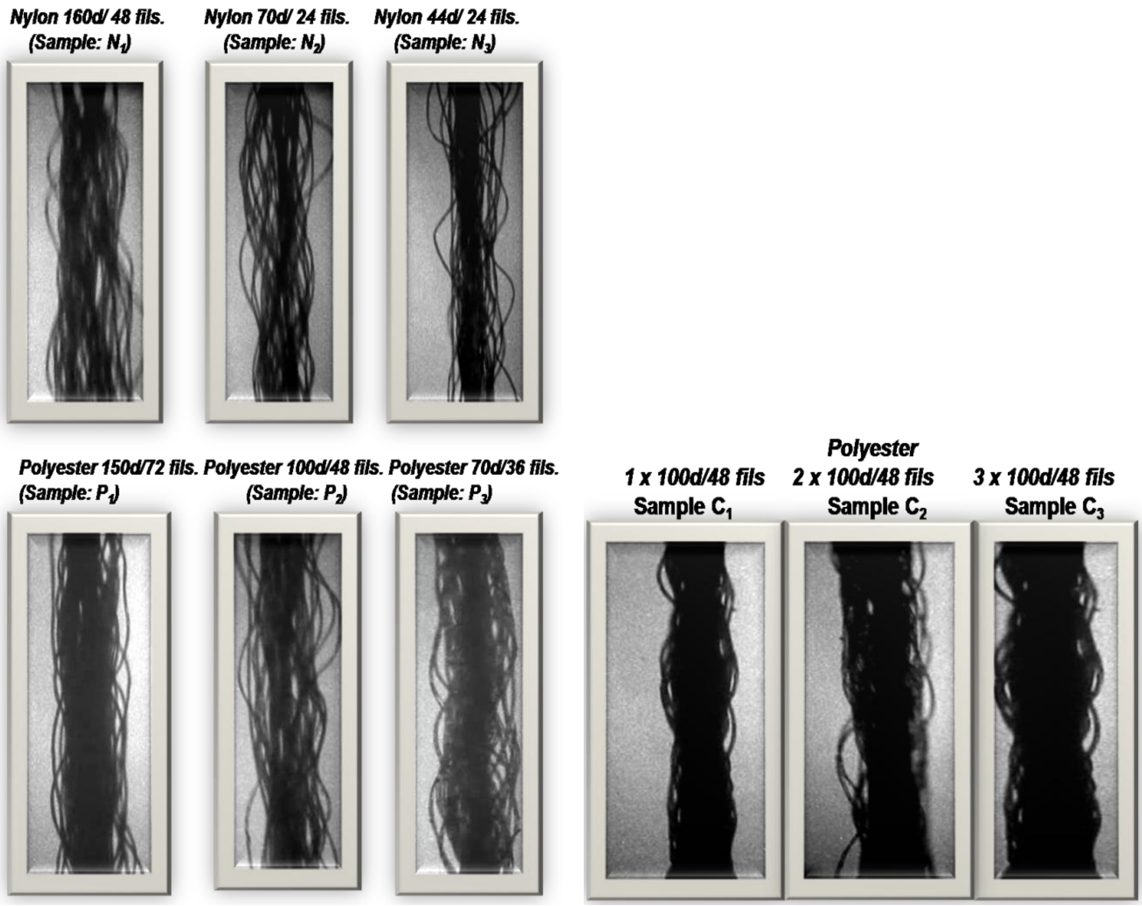
Table 2: Test Details

Type of Test	Test Method Details
Structural Characteristics	*Ermascope Projection Microscope (100 x)*
Physical Properties	
Denier	*BISFA method*[13] *(1 m Wrap reel + LIBRORAEL- 40SM Balance);*
Mechanical properties	
Tenacity and Breaking Extension	*Lloyd tensile tester (ASTM Standards D 2256-02)*[14] *Gauge length: 500 mm, Cross-head speed: 100 mm/min*
Texturising Properties	
Percent instability	*Du Pont method*[15]
Bulk factor	*Burnip's Method*[5,10]
Percent boiling water shrinkage	*BISFA method*[13]

III. RESULTS & DISCUSSION

Structural Characteristics:

Effect of raw material characteristics on the structure of the product yarns are studied by using microscopical views taken on Erma-scope at 100x magnification. The photographic views of the typical yarns, illustrating the visual surface characteristics of these textured yarns are given in figure 2(a-b). It is observed that textured yarns produced with finer filaments [Nylon sample-N_3, 44d/24fils., and polyester yarn sample-P_3, 70d/36fils.] possess higher small size curls as compared to coarser denier filament yarns in the respective group. This behaviour is mainly attributed to the larger helix angle formed by finer filaments with low bending and twisting rigidities at the optimum false-twist level[2], [16]. This has allowed the filaments to undergo higher bending deformation thereby acquire increased crimp frequency of small size curls [figure 2 (a)]. Higher differential in filament tension from core to sheath has boosted migration behaviour during false-twisting, and thus resulted in formation of more number of crossed curls[17-19]. It can also be noticed from the results that polyester yarns of different size but having identical filament fineness (2.08d) have behaved differently during texturising. Yarn with trilobal cross-sectional filaments [sample P_1; 150d/72fils.] has shown higher intensity of texturising over yarn with circular cross-section filaments [sample-P_2; 100d/48fils.]. This difference in the behaviour is mainly attributed to presence of brighter finish trilobal constituent filaments. Hence the rigidity of the trilobal filaments are lower compared to circular filaments, they can be bent easily during crimp formation[1-2, 17-20]. Higher filament deviation from yarn longitudinal axis and frequent movement of the flexible filaments (migration) during false-twisting has resulted in the formation of higher number of small crossed curls [figure 2(a)]. The effects of total yarn linear density at identical filament fineness (i.e. number of filaments) has been studied by folding two and three ends of 100d/ 48fils. polyester yarn to form 200d and 300 d yarns respectively. Optimum false-twist value (K) for mechanical crimp textured polyester yarn [equation 1] is higher for finer yarn (smaller value of D). So, it has undergone higher torsional bending[1- 4, 21-22]. Thereby textured yarn made up of finer feeder yarn has exhibited smaller curls with a higher frequency as compared to the coarser one [figure 2(b)].



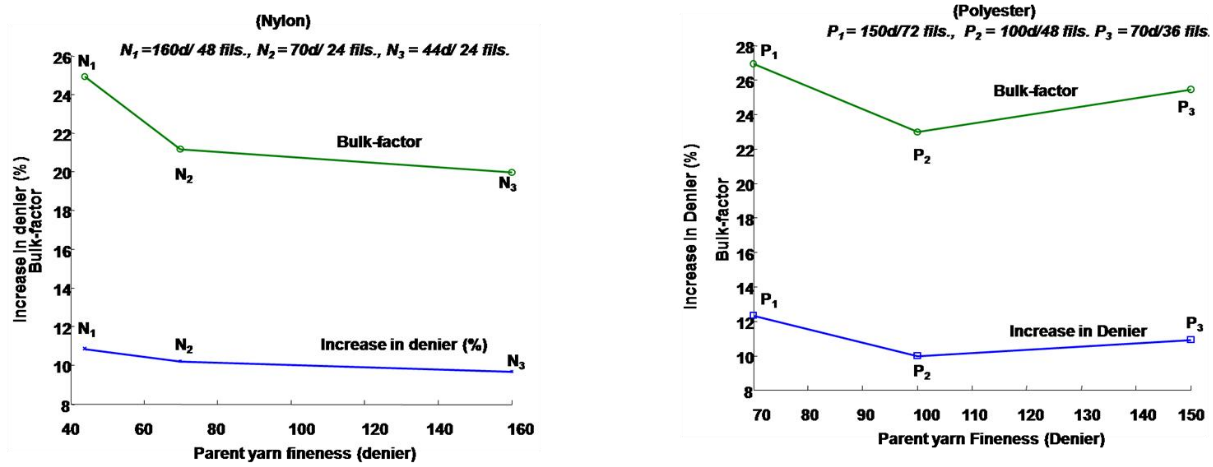
(a). Group A (b) Group B

Figure 2 Photographs of Microscopical Views of Textured Yarns

Change in Yarn Denier and Percent Bulk

(a) Effect of Type of Material

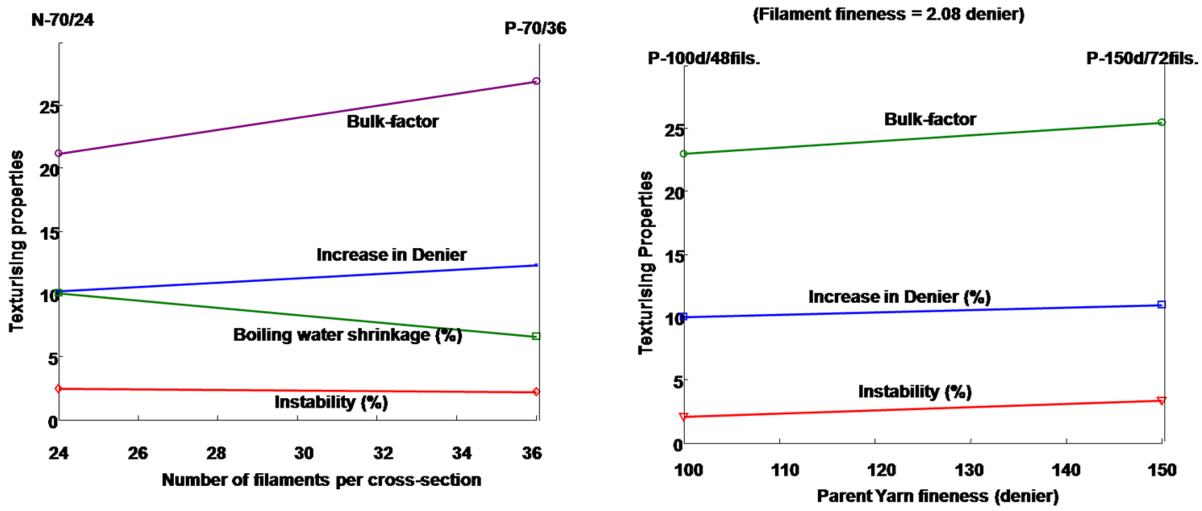
Higher values of bulk factor and increase in linear density values are reported for yarns consisting of finer filament for both the polymer yarns under consideration [figure 3].



(a) Nylon Group (b) Polyester Group

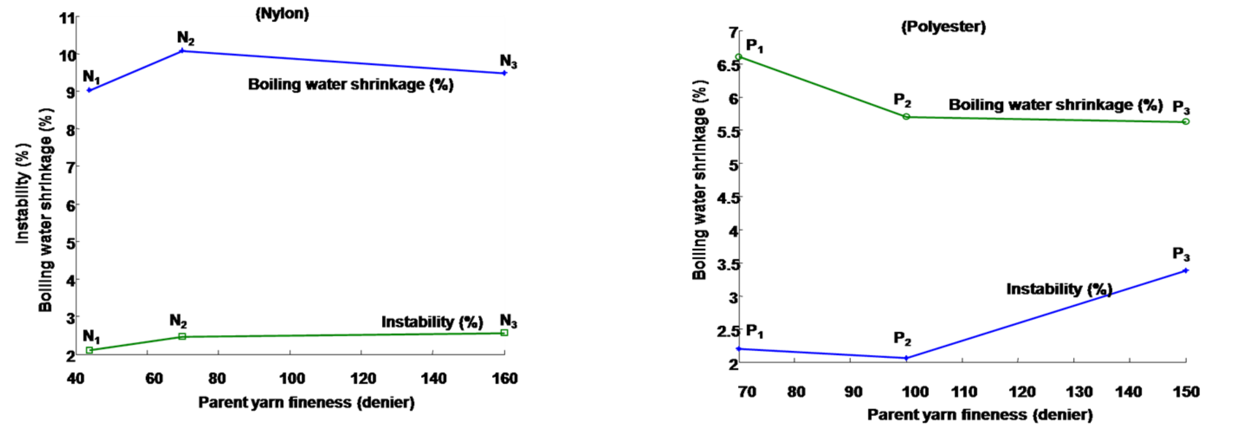
Figure 3 Effect of Type of Material on Denier and Bulk of Textured Yarn

Increased crimpiness has also allowed textured yarns to undergo more contraction, thereby more shortening in length, resulted in increased volume and linear density as compared to other samples under consideration. More increase in linear density and bulk has been reported on the account of coarser 150d yarn as compared to finer 100d yarn of polyester; although constituent filament fineness is same [figure 3(b) and figure 4(b)]. This inherent bulkiness of coarser yarn is due to less close packing of the trilobal filaments[22-23] . This has provoked presence of more air interstices in the structure and enhanced the bulk-factor of product yarn. Higher filament deviation from yarn longitudinal axis and frequent movement of the flexible filaments (migration) during false-twisting has resulted in the formation of higher number of small crossed curls [figure 2(a)], as mentioned earlier. This frequent migration along with higher crimpiness promoted increased contraction in the textured yarn linear length. It has been resulted in increased linear density along with the bulk of the product yarn, although it is coarser. In the absence of availability of such comparable samples for nylon group, practical significance of this theory remains unchecked for it.



(b) Comparison of Same fineness Nylon and Polyester Yarns

(a) Comparison of Same filament fineness Polyester Yarns



(c) Instability (%) and Boiling water shrinkage(%) of Nylon Yarns

(d) Instability (%) and Boiling water shrinkage(%) of Polyester Yarns

Figure 4 Effect of Type of Material on Texturising Properties

Tensile modulus of polyester (4.5 N/tex) is higher than nylon (1.7-3.3 N/tex)[1]. Higher bending and torsional stiffnesses, expectedly makes migration and bending more difficult for acquiring crimpy configuration for polyester as compared to nylon[1-4]. So, for the equivalent 70d supply yarn higher increase denier and bulk of the textured nylon yarn is expected. But against this theoretical prediction higher rise in linear density and bulk has been observed for textured 70d polyester yarn [figure 4(a)]. This contradiction from theoretical expectation is mainly arrived from the difference in the constituent filament fineness. Bending and torsional stiffness are directly proportional to the second moment of area about a diameter and to the polar second moment of area respectively. Therefore, the smaller the second moment of areas, the smaller the forces and torques required to bend and twist the filaments respectively[18, 24]. Thereby high tensile modulus, but fine constituent (1.9 denier) filaments polyester yarn has undergone more intensive bending deformation during texturising than flexible but coarse constituent (2.9 denier) filaments nylon yarn. Thus filament fineness has played a decisive role over total yarn fineness in confining texturising properties of mechanical crimp textured yarn.

(b) Effect of Yarn Fineness

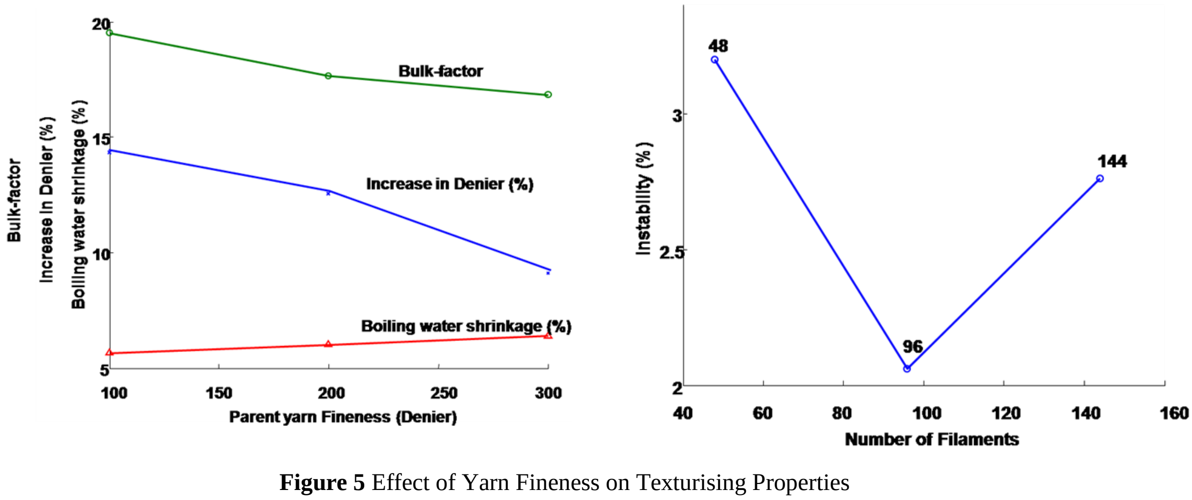


Figure 5 Effect of Yarn Fineness on Texturising Properties

The effect of yarn fineness on texturising properties is given graphically in figure 5(a-b). It can be observed from the results [figure 5(a)] that single-end yarn sample has executed highest linear density and bulk values. The possible explanation for this behaviour can be given with reference to false twist texturising. At optimum false-twist level finer yarn get twisted to a higher twist angle[1-2, 16]. Thereby textured yarn made up of finer feeder yarn likely to exhibit smaller curls with a higher frequency as compared to the coarse one. Photographs of microscopical views [figure 2(b)] represents surface characteristics of all product yarns under consideration substantiate this presumption. Pre-twist factor being constant, increased shortening of the length of flat filaments are mainly due to higher degree of crimping attained. More the contraction in length more will be the increase in denier. Thus yarn fineness has shown the similar trend to that of filament fineness in terms of bulk and linear density characteristics of the product yarn.

Percent Instability

Better texturised nylon yarn (sample N_3) has executed better stability [figure 5(c)]. The low instability value is mainly attributed to the enhanced interfilament friction due to increased mingling, holds the entangled curls together under the applied loads. As the filaments get coarser, the entanglement and curl formation deteriorate, producing yarns with fewer curls and poorly entangled cores resulting in an increase in yarn instability.

However, in case of polyester, compared to better textured 70denier/36 filaments yarn, 100denier/48fils. yarn has executed lower instability value[figure 5(d)]. This higher instability value of finer denier polyester yarn probably arises from the greater number of curls, increasing the likelihood of curl removal. So, it can't be interpreted as the degradation of texturising quality. It should be looked along with increase in linear density value [figure 3 (b)], which substantiate the argument. Similar behaviour is also observed for polyester yarns with identical filament fineness (2.08 denier). Although well-texturised, 150d/48fils. yarn has shown higher instability value as compared to 100d/48fils. yarn [figure 4(d)]. However instability values in both the cases are well within the acceptable limit[25]. Better stability is shown by 70d polyester yarn as compared to equivalent size nylon yarn under consideration [figure 4(a)]. Presence of more number of finer filaments during bulking has played a decisive role in this case. Enhanced degree of intermingling has resulted due to more number of participating finer filaments[18, 24]. Single-end yarn is found more unstable as compared to two-end or three-end yarns. It can also be seen that two fold yarn is more stable than single yarn, but further increase in the number of ends to three, the instability value again increases [figure 5]. This has attributed to the participation of number of filaments in the texturising zone. Inter-filament frictional get increases with number of filaments, adversely affects its mobility to acquire new configuration[26-27]. Moreover use of coarser yarn reduces area of contact per filament at false twist spindle during texturising[28-29]. Thus reduces bending torque per filament during texturising, resulted in reduced filament migration during false-twisting and thereby reduced potential of intermingling for three-fold yarn. Reduced mingling along with use of constant pre twist factor has reduced lateral binding forces for the crimpy configuration and enhanced instability. Reduction in bulk and denier values of coarse denier product yarn [figure 3(a-b)] also substantiates deterioration in the level of texturising.

Percent Boiling Water Shrinkage

Although, better textured and having identical boiling water shrinkage of parent yarn (Table 1), 44d/24fils. Nylon yarn, has executed comparatively lower shrinkage as compared to 70 d/24fils. [figure 4(c)]. This is attributed to less compact packing of trilobal cross-section coarser filaments of 70denier yarn resulted in more interstices for water to interact [22-23]. Well textured, finer 70d/36fils. polyester yarn having identical parent yarn boiling water shrinkage to the rest of samples in group, has exhibited highest boiling water shrinkage [figure 4(d)]. Thus shrinkage of textured yarn depends upon polymer characteristics on getting wet and degree of deformation attained during texturising process. However, percent boiling water shrinkage has shown rising trend along with increase in yarn fineness for identical filament characteristics [figure 5].

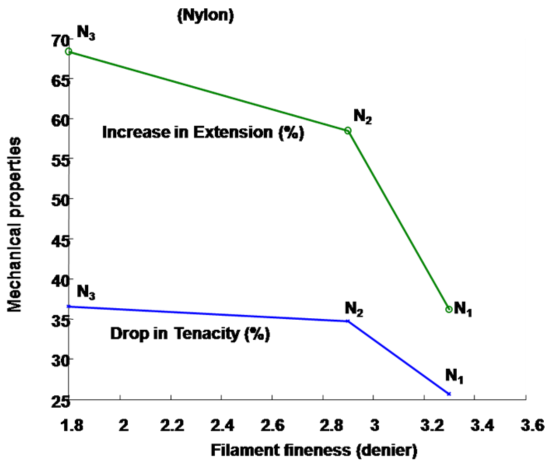
Mechanical Properties

It can be seen from table 3 that on mechanical crimp texturising better textured finer filaments nylon as well as polyester yarns [sample N_3 and sample P_3 respectively] have executed poor strength realization and highest percent extension compared to others. This is due to their more obliquity inside the yarn structure. Effect of filament fineness on the mechanical properties of the nylon yarn has been illustrated graphically in figure 6(a). It is apparent from that finer filaments have gone under more extensive texturising. Thereby higher drop in tenacity has been registered due to increased deviation from the longitudinal axis. Similarly enhanced percent extension of the product yarn is also attributed towards the opening of higher curls formed before rupture [figure 2(a)]. However, filament fineness is almost identical for all selected polyester yarns, so such comparison is not possible.

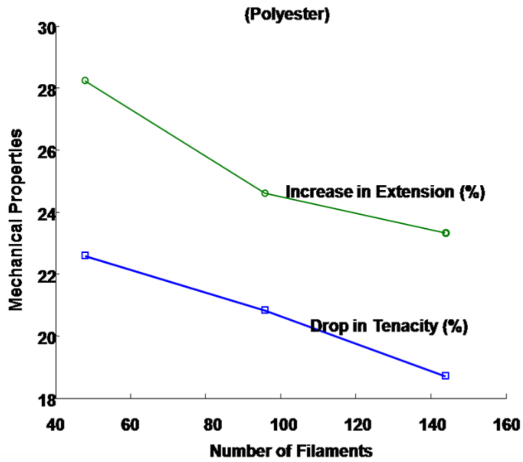
Table 3 Mechanical Properties

Property	Type of Yarn					
	Nylon			Polyester		
Sample code (Denier/fils.)	N_1 (160/48)	N_2 (70/24)	N_3 (44/24)	P_1 (150/72)	P_2 (100/48)	P_3 (70/36)
1. Drop in Tenacity (%)	25.61	34.71	36.54	29.14	25.21	35.55
2. Increase in Extension (%)	36.11	58.43	68.33	52.48	49.58	55.75

From the results it is clear that better textured single end yarn has exhibited highest drop in tenacity and increase in percent extension as compared to other samples [figure 6(b)]. Increased inter filament friction and deterioration in texturising quality, in the presence of more number of constituents has stopped further drop in tenacity and reduced extension of two-fold as well as for three-fold yarns.



(a) Effect of Filament Fineness



(b) Effect of Yarn Fineness

Figure 6 Mechanical Properties

Percent spin finish value of all the samples under study is almost identical (table 1). So, no profound difference in the behaviour for negligible difference in spin finish has been noticed for either group of yarn under study.

IV. CONCLUSION

Mechanical Crimp Texturising process offers an alternative route than spun yarn for bulking flat multifilament yarn. Versatility in terms of raw-material makes the process true for large domain of end users. Even simplicity of production process reduces burden of maintenance and storage also facilitates in declining the product cost. Two distinct groups of yarns, viz; Nylon and Polyester of different yarn denier, denier per filament, cross-sectional shape, type of finish and number of filaments within each group were used to study their effect on the structure and properties of mechanical crimp textured yarns. At comparable false twist level formation of uniform small size curls for finer filament yarns irrespective of type of material used in the form of closed or crossed curls have yield curls of higher frequency. Thereby they have exhibited higher bulk factor (ϴ) and increased linear density. Presence of more number of finer filaments during bulking has enhanced degree of intermingling; thereby 70d polyester yarn has exhibited better stability and bulk as compared to equivalent nylon yarn but with coarser constituent filaments. Nylon yarn with finer and trilobal cross section filaments has executed poor strength realization compared to others as they were more prone to drawing and twisting action resulted in more obliquity inside the yarn structure. As a consequence of this finer dpf and trilobal cross-section nylon yarn has executed highest extension at break. Percent spin finish value for all the samples under study were almost identical. No profound difference in the behaviour for either group of yarn has been noticed for negligible difference in spin finish. Thus limitations of availability of the sample has restricted in exploring response of some material variables like spin-finish, dull yarn etc towards new system. Finer single end yarn has exhibits smaller curls with a higher crimp frequency at a constant pre-twist level resulted in increased bulk, denier, extension, instability and reduction in tenacity. With the increase in number of filaments of same fineness, more efficient intermingling is observed, thereby yarn with two fold constituent filaments is found more stable than single yarn. But further increase in the number of ends from two-end to three-end, the yarn instability value has again increased. This has happened due to excessive increase in the filament frictional contact that has reduced its mobility. Also use of coarser yarn has reduces area of contact between filament and false twist spindle (magnetic-pin) during texturising, resulted in poor mingling as well as crimpiness.

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