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## Puntalama İşlemi Parametrelerinin Sentetik Filament İplik Mukavemetine Etkisi

## The Effect of Intermingling Process Parameters on the Synthetic Filament Yarn Strength


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***Araştırma Makalesi / Research Article***

# THE EFFECT OF INTERMINGLING PROCESS PARAMETERS ON THE SYNTHETIC FILAMENT YARN STRENGTH

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***ABSTRACT:*** Intermingling is one of the best alternative methods to make the filament yarns more resistant against high volume stress. This technique has started to replace conventional methods such as sizing and twisting. The intermingling process mixes multifilament yarns along with entanglement points and open parts by turns throughout the length of the yarns. This process makes tensile value of multifilament yarns entirely different from the component of separate filaments. Knot numbers and stability are generally mentioned to describe the intermingling quality in a multifilament yarn. In accordance with these parameters, statistical results demonstrated that machine speed and yarn type have a statistically significant effect on the knot number and tensile strength; however singly machine speed parameter has no considerable effect on the tensile strength. This study tries to define the effect of commingling on the filament yarn strength.

**Keywords:** Intermingling, tensile strength, air jet, filament yarn.

## PUNTALAMA İŞLEMİ PARAMETRELERİNİN SENTETİK FİLAMENT İPLİK MUKAVEMETİNE ETKİSİ

***ÖZET:*** Yüksek miktarlı gerilmelere karşı filament iplikleri daha dayanıklı hale getirmek amacıyla kullanılan en iyi yöntemlerden birisi puntalama işlemidir. Bu işlem ipliklere mukavemet kazandırma açısından haşıllama ve büküm gibi konvansiyonel metotların yerini almaya başlamıştır. Puntalama işlemi ipliklerin uzunluğu boyunca punta noktaları ve açık bölgeler şeklinde multifilament iplikleri birbirine dolamaktadır. Bu da multifilament ipliklerin mukavemet değerinin her bir filament ipliğin mukavemet değerinden tamamen farklılaşmasına neden olmaktadır. Bir multifilament ipliğin punta kalitesini ölçmek için genellikle punta sayısı ve sağlamlığı parametreleri kullanılmaktadır. Bu değişkenlere uygun olarak istatistiksel sonuçlar makine hızı ve iplik tipi değerlerinin punta sayısı ve mukavemet değeri üzerinde etkili olduğu, bununla birlikte tek başına makine hızı değerinin mukavemet üzerinde anlamlı bir etkisinin olmadığını göstermektedir. Bu çalışma filament iplik mukavemeti üzerindeki puntalama etkisini tanımlamaya çalışmaktadır.

**Anahtar Kelimeler:** Puntalama, çekme mukavemeti, hava jeti, filament iplik.

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## 1. INTRODUCTION

Friction force among the fibers is the only force holding the fibers together in staple fiber spun yarns. This friction force provides the staple fiber yarns to withstand tensions in the process of manufacturing yarns and fabrics. Random placement of staple fibers and twisting process make the friction force stronger and so staple fiber yarns can withstand different kinds of tensions in the production.

However, filament yarns do not have any important cohesion force like friction because of parallel settlement of fibers. Due to the lack of enough cohesion force between the filaments, many problems come out during the processes of yarn winding, unwinding, knitting, weaving, tufting, and similar fabric manufacturing processes. Filament yarns could not withstand tensions because of the parallel settlement of fibers. This settlement causes tension irregularities in the yarn structure. Depending on high textile manufacturing speeds, tension differences cause the yarn break and malfunction in the process.

In order to prevent yarn breakages, it is necessary to have a cohesion force among the synthetic filaments. In order to overcome this problem, intermingling is one of the way outs to make the filament yarns more resistant against high volume tensions. It is also accepted one of the relevant alternative technique in comparison with the conventional techniques such as sizing or twisting. Intermingling may also be called interlacing; commingling, splicing and entanglement point is also called fixed point, knot and nip in this study and other many researches [1].

In this article, polyester (PES) and polyamide (PA6) synthetic filament yarns with various linear densities are used to find out the effect of yarn count and yarn speed to the strength of intermingled yarns and intermingling uniformity. With this study, we aim to give an idea about intermingled yarn strength and compound to synthetic yarn manufacturers in especially hosiery and weaving sectors. In this way, the manufacturers may prevent yarn breakages and also machine stops choosing the best alternative yarn type according to the machine speeds.

## 2. REVIEW OF PAST WORKS

Alagirusamy et al. (2005) reported a study on effect of jet design to the intermingling and also described improvements of commingling nozzle design in the commingling process. This study found that knot frequency and interlacing degree of composite commingled yarns depend on the nozzle design. Air inlet number and inlet angle have an important effect on the structure of intermingled yarns. This study also mentioned about importance of air pressure. Because, air pressure enhancement gives an increase to the degree of interlacing of commingled yarns [2].

Ogale and Alagirusamy (2005) reported a study about tensile properties of commingled composites with a compound of glass fiber and filament yarns. This study indicated that composite modulus is ruled by glass compound while tenacity value is ruled by thermoplastic filament yarn compound. It is declared that a significant modulus decrease exists with an increase of air pressure in glass polyester and glass nylon commingled yarns. However, the air pressure does not affect the modulus to a large extent in the glass polypropylene commingled yarns. There is a decrease in tenacity value of all types of intermingled yarns as the volume fraction of thermoplastic fibres increases. It is also found that commingled yarns in knotted form would preserve almost 55% – 60% of the axial tensile strength [3].

Another work done by Webb et al. (2007), was carried out to optimize splicing parameters for splice uniformity in continuous filament yarns. This work demonstrated that the strongest splice does not in general comply with the best aesthetic appearance. Therefore, this work indicated that an overall optimum splicer configure is necessary which makes contact between splice strength and splice appearance. It is also described that due to the different chamber design and reduced blast duration, an optimum splice appearance can be obtained, but these modifications create a negative effect on the splice strength [4].

Golzar *et al.* (2007) reported a study about intermingled hybrid yarn ratio in continuous fiber reinforced thermoplastic composites. The study investigated fiber volume fraction and diameter of reinforced filaments and thermoplastic filaments in hybrid yarn. This study also explained that for improving the homogeneity in commingled hybrid yarn, combining the reinforcement and thermoplastic filaments during the production line is one of the best methods. It is claimed the method can decrease the fiber damage caused by air texturing and enhance the homogeneity of PP/GF composite [5].

Shiu-Wu Chau and Wen-Lin Liao (2008) studied on interlacing nozzle geometry to determine yarn interlacing frequency. They used a numerical approach to predict the yarn interlacing frequency of triangular interlacing nozzle. This study described that for air nozzles only differing in their inlet diameter, an optimal size of inlet diameter (i.e. critical inlet diameter) can be obtained for a given pressure, which delivers the largest yarn interlacing frequency. Insufficient or extreme size of inlet opening leads to a weak interaction of shock surface inside the expansion chamber, and results in less number of fixed points per unit length. An optimal inlet pressure ensures the largest yarn interlacing frequency per unit pressure. It is also mentioned that the critical inlet pressure is dependent on the nozzle geometry. When the inlet pressure is larger than the critical inlet pressure, only a small increase in the yarn interlacing frequency is expected because the upper-lower shock surface has been completely developed. It is concluded that both inlet angle and pressure affect the intermingling uniformity whereas no noticeable connection exists between these factors [6].

Boubaker *et al.* (2009) studied on a descriptive model for the longitudinal structure of wet pneumatic spliced yarn. It is found that elastic spliced yarns stand two more asymmetrical twisted zones in microscopic analysis although classical spliced yarns contain a symmetrical twisting zone. The study demonstrated that the wet pneumatic splice can be defined by six parameters which are zones of splice, length of each zone, splice length, number of twist turns on each zone, two elasthane filament ends and center x coordinates. It is claimed that the established model shows the main reason of the irregularity of the spliced elastic yarn appearance is yarn end coming from the cop [7].

Webb *et al.* (2009) performed a work about relationship between splicing performance and yarn count.The study reported that as yarn count was varied, industry-standard and experimental splicers with various configurationschanged in performance. This study concluded that when yarn counts increase sufficiently, it is needed to enhance three variables to acquire optimum splicing. These three variables are cross section of the splicing chamber, airflow, and the knife separation [8].

Özkan and Baykal (2012) performed a study on intermingling parameters and filament properties effect to the stability of knots. In order to achieve this aim, partially oriented yarn (POY) filaments were used as raw materials. Linear densities of POY, number of filaments in cross section, intermingling speed and intermingling pressure were taken as independent variables; and stability of the nips of intermingled yarns was evaluated as dependent variable. They found that a positive linear correlation exists between air pressure and knot stability. This correlation was also found statistically significant. This study also described that less yarn linear density values has positive linear relationship with knot stability and this relationship is statistically significant as well [9].

Kravaev *et al.* (2013) presented a new method to analyze the blending quality along the length of commingled yarns. It is claimed that this new method can be applied for the manufacturing process of thermoplastic composites. For yarn analyses, five different commingled yarn structures were specified which are twist, braid, wrap, entangle and non-interlaced. The blending quality and filament distribution in the cross section of GF/PA hybrid yarn used to manufacture thermoplastic composites were investigated. Due to the combination of the yarn analysis along the yarn axis and in its cross section, the new method allows for the first time a reliable comparison of the blending quality in commingled yarns used for the manufacturing of thermoplastic composites [10].

## 3. MATERIALS AND METHODS

In this study, PES texturized intermingled filament synthetic yarns with the linear densities of 50, 70, 100, 150 denier and PA6 texturized intermingled filament synthetic yarns with the linear densities of 40, 70, 100, 140 denier were used. Air covered elastic PES guipe (elastic yarn blended samples) yarns were also used with the compound of 50/20, 70/20, 100/20, 150/20 and air covered elastic PA6 guipe yarns with the compound of 40/20, 70/20, 100/20, 140/20. In these compounds, first parts symbolize PES and PA6 yarn counts, second part (20) symbolize elasthane yarn count in all samples. In this experiment, Creora® brand elasthane was used as elastic yarn inside of air covered guipe yarns. In this way, sixteen different yarns were used in the experimental part of this work. The elasthane yarn draft value is 2.8, which means the elasthane yarn stretches to the 280% value of its first length. All samples were produced in an air cover machine which has approximately 5 bars air pressure value. Three different machine speeds were used to separate the samples in three different groups, namely low intermingled, medium intermingled, and high intermingled. The machine speed values were 500, 600 and 700 meters per minute. It is claimed that while the yarn speed value increases, entanglement point number, which determines intermingling level, will decrease theoretically. According to the expert opinions and industrial experiments in related textile sectors, it is stated that there are 70 to 90 knots in a meter of the yarn depending on air pressure value and yarn speed. But, there were more than 100 knots in a meter of the yarn in our experimental study. It is thought that this case was a result of excessive air pressure application and variation of raw materials. In addition, experimental results generally demonstrated that high level intermingled yarns were produced in the speed of 500, medium level intermingled yarns were produced in the speed of 600 and lastly low level intermingled yarns were produced in the speed of 700 according to number of knots per meter.

The principle of intermingling process with knots and fluffy areas can be seen in Figure 1 [2]. Visual inspections indicate that knots are more visible and uniform in elastic blended (guipe) samples rather than plain samples in our experimental work.

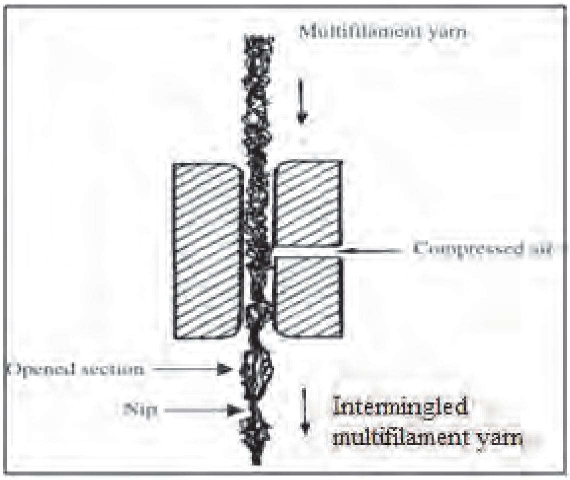


**Figure 1.** Principle of intermingling process [2]

All samples were tested on Uster Tensorapid 3. These tests were repeated twice and mean values were taken as the final tensile value. Test speed was 500 mm/min and pre tension value was 4.3 cN. Tensile test unit was taken as cN/tex in the test device. Before the tensile test, upper portion of the yarn bobbins were unwinded about 300 meters to prevent yarn unevenness. All yarns were acclimatized in the standard atmosphere conditions for 72 hours before testing as a standard testing procedure.

Figure 2 shows picture of the automatic tensile tester Uster Tensorapid 3 used in the experiment. Tensile tests can be soundly achieved in all types of filament yarns from 20 denier to 300 denier counts with this device. Mean value of two tests was taken as the final tensile value in this study.

**Figure 2.** Automatic multiple tensile test

Figure 3 shows test device's automatic control mechanism that can adjust test values and also device screen which test results can be obtained from. The device has also a printer which ensures to take outputs of test values.

**Figure 3.** Test device screen and printer

Table 1 shows the average tenacity values of intermingled PA6 composition yarns, which are aligned according to linear density (denier) values. It is considered that existing meaningless results could come out due to using different raw materials in the tensile tests. In 40/1 PA6 samples, meaningless tenacity results could occur owing to low linear density value and low strength value based on raw material. In 40/20 PA6 guipe samples, the tenacity results increase from the yarn speed of 700 m/min to 500 m/min as expected. Although there are exceptions, same expected results can be seen in 70/1 PA6 samples and 70/20 PA6 guipe yarns. Even though the values are close to each other, similar increases in tenacity with decreases in yarn speed can be observed in the other 100 and 140 denier PA6 samples. The interesting point is all tenacity results are around 40 cN/tex except 140/20 PA6 guipe yarns. These yarns have twofold strength value which is about 80 cN/tex compared to the other samples. It is thought that 20 denier elasthane yarns can enhance compact structure of the guipe yarn after a certain linear density threshold value. Thus, the strength value of the 140/20 PA6 guipe yarn could be higher. However, any tenacity increase cannot be identified with increase in yarn count from 40 to 140 deniers as expected. This means that the tenacity values do not vary linearly with the increase in thickness of the yarns.

Table 2 shows average tenacity values of intermingled PES composition yarns, which are aligned according to linear density (denier) values. In these yarns, 50/1 and 50/20 guipe samples' color are white, all the other samples are black. PES yarns have more pointless tenacity results compared to PA6 yarns. It is thought that these pointless results exist because of raw material variety and color difference. There is no tenacity increase in 150/20 PES guipe yarns as in the 140/20 PA6 guipe yarns. Insomuch that, 150/20 PES guipe samples include almost the lowest tenacity values.

**Table 1.** Mean tenacity and knot number values of PA6 yarns after intermingling process

| Yarn Compound | Sample 1- (cN/tex) | Sample 2- (cN/tex) | Average Tensile Strength (cN/tex) | Average Knot Numbers |
|---|---|---|---|---|
| 40/1 PA6 (700 mt/min) | 33.15 | 38.36 | 35.755 | 95 |
| 40/20 PA6 guipe (700 mt/min) | 33.96 | 33.50 | 33.73 | 110 |
| 40/1 PA6 (600 mt/min) | 30.64 | 34.85 | 32.745 | 130 |
| 40/20 PA6 guipe (600 mt/min) | 32.69 | 34.40 | 33.545 | 150 |
| 40/1 PA6 (500 mt/min) | 34.82 | 33.84 | 34.33 | 110 |
| 40/20 PA6 guipe (500 mt/min) | 37.99 | 36.17 | 37.08 | 170 |
| 70/1 PA6 (700 mt/min) | 41.60 | 34.05 | 37.825 | 85 |
| 70/20 PA6 guipe(700 mt/min) | 41.69 | 37.44 | 39.565 | 130 |
| 70/1 PA6 (600 mt/min) | 41.86 | 41.32 | 41.59 | 95 |
| 70/20 PA6 guipe(600 mt/min) | 39.46 | 39.11 | 39.285 | 135 |
| 70/1 PA6 (500 mt/min) | 23.88 | 41.86 | 32.87 | 105 |
| 70/20 PA6 guipe(500 mt/min) | 43.09 | 41.78 | 42.435 | 150 |
| 100/1 PA6 (700 mt/min) | 33.56 | 36.88 | 35.22 | 75 |
| 100/20 PA6 guipe (700 mt/min) | 38.66 | 37.69 | 38.175 | 135 |
| 100/1 PA6 (600 mt/min) | 40.42 | 39.12 | 39.77 | 80 |
| 100/20 PA6 guipe (600 mt/min) | 38,41 | 37.72 | 38.065 | 125 |
| 100/1 PA6 (500 mt/min) | 39.63 | 40.72 | 40.175 | 90 |
| 100/20 PA6 guipe (500 mt/min) | 37.42 | 34.69 | 36.055 | 120 |
| 140/1 PA6 (700 mt/min) | 42.94 | 39.97 | 41.455 | 110 |
| 140/20 PA6 guipe (700 mt/min) | 79.07 | 81.34 | 80.205 | 110 |
| 140/1 PA6 (600 mt/min) | 44.76 | 44.43 | 44.595 | 100 |
| 140/20 PA6 guipe (600 mt/min) | 77.86 | 79.91 | 78.885 | 110 |
| 140/1 PA6 (500 mt/min) | 44.42 | 44.78 | 44.6 | 100 |
| 140/20 PA6 guipe (500 mt/min) | 81.28 | 81.06 | 81.17 | 122 |

**Table 2.** Mean tenacity and knot number values of PES yarns after intermingling process

| Yarn Compound | Sample 1- (cN/tex) | Sample 2- (cN/tex) | Average Tensile Strength (cN/tex) | Average Knot Numbers |
|---|---|---|---|---|
| 50/1 PES (700 mt/min) | 32.98 | 35.19 | 34.085 | 100 |
| 50/20 PES guipe (700 mt/min) | 34.39 | 30.97 | 32.68 | 135 |
| 50/1 PES (600 mt/min) | 32.75 | 33.02 | 32.885 | 110 |
| 50/20 PES guipe (600 mt/min) | 29.56 | 28.86 | 29.21 | 160 |
| 50/1 PES (500 mt/min) | 30.51 | 31.94 | 31.225 | 115 |
| 50/20 PES guipe (500 mt/min) | 32.96 | 30.16 | 31.56 | 155 |
| 70/1 PES (700 mt/min) | 35.96 | 34.91 | 35.435 | 90 |
| 70/20 PES guipe(700 mt/min) | 34.44 | 36.01 | 35.225 | 105 |
| 70/1 PES (600 mt/min) | 41.36 | 33.31 | 37.335 | 100 |
| 70/20 PES guipe(600 mt/min) | 31.38 | 33.72 | 32.55 | 110 |
| 70/1 PES (500 mt/min) | 32.84 | 32.22 | 32.53 | 115 |
| 70/20 PES guipe(500 mt/min) | 34.43 | 34.24 | 34.335 | 115 |
| 100/1 PES (700 mt/min) | 33.53 | 32.30 | 32.915 | 100 |
| 100/20 PES guipe (700 mt/min) | 31.36 | 30.99 | 31.175 | 105 |
| 100/1 PES (600 mt/min) | 34.15 | 33.89 | 34.02 | 105 |
| 100/20 PES guipe (600 mt/min) | 32.11 | 33.23 | 32.67 | 105 |
| 100/1 PES (500 mt/min) | 31.37 | 31.97 | 31.67 | 100 |
| 100/20 PES guipe (500 mt/min) | 32.74 | 31.85 | 32.295 | 120 |
| 150/1 PES (700 mt/min) | 30.84 | 30.33 | 30.585 | 100 |
| 150/20 PES guipe (700 mt/min) | 29.91 | 30.08 | 29.995 | 110 |
| 150/1 PES (600 mt/min) | 29.25 | 30.28 | 29.765 | 100 |
| 150/20 PES guipe (600 mt/min) | 30.51 | 43.76 | 37.135 | 115 |
| 150/1 PES (500 mt/min) | 30.68 | 30.63 | 30.655 | 110 |
| 150/20 PES guipe (500 mt/min) | 30.48 | 29.06 | 29.77 | 120 |

## 4. RESULTS AND DISCUSSION

After completing the experimental part, the data were evaluated statistically with one way variance analysis (ANOVA). While the machine speed and yarn type values were selected as independent variables, tensile strength and knot number values were selected as dependent variables in the analysis of variance tests.

### 4.1. Machine Speed Effect on Knot Number

Analysis of variation results demonstrated that machine speed value had a significant effect on knot number value at 95% significance level (F = 3.644, p = 0.030, see Table 3). According to the results, knot number and machine speed values was negatively correlated which means as machine speed was increasing, number of knots was decreasing. Post Hoc test also showed that a significant difference existed between only 700 m/min and 500 m/min although there wasn't any statistically significant result between the machine speed values of 500 m/min, 600 m/min and 600 m/min, 700 m/min.

**Table 3.** Machine Speed Effect on Knot Number

| Unit: number/meter | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 3189.062 | 2 | 1594.531 | 3.644 | .030 |
| Within Groups | 40696.094 | 93 | 437.592 | | |
| Total | 43885.156 | 95 | | | |

### 4.2. Machine Speed Effect on Tensile Strength

The statistic results showed that machine speed value had not a statistically significant effect on tensile strength value (95% significance level F = 0.034, p = 0.967, see Table 4). Although the strength values were very close to each other, maximum strength value emerged in the speed of 600 m/min with respect to the results.

**Table 4.** Machine Speed Effect on Tensile Strength

| Unit : cN/tex | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 9.570 | 2 | 4.785 | .034 | .967 |
| Within Groups | 13186.719 | 93 | 141.793 | | |
| Total | 13196.289 | 95 | | | |

## 4.3. Yarn Type Effect on Knot Number

The ANOVA evaluation results indicated that yarn type had a statistically significant impact on knot number value (95% significance level F = 9.650, p = 0.000, see Table 5). In the case of especially elastic blended yarns, knot number was more depending on compact yarn structure. While 50/20 PES elastic yarn has the maximum knot number value, 100/1 PA6 plain intermingled yarn has the minimum knot number value with respect to the results. Post Hoc test also showed that there was a statistically significant difference between the yarn types of 40/1 PA6 and 40/20 PA6, 40/1 PA6 and 50/20 PES, 40/20 PA6 and 70/1 PA6, 40/20 PA6 and 100/1 PA6, 40/20 PA6 and 150/1 PES, 70/20 PA6 and 150/1 PES, 50/20 PES and 150/20 PES.

**Table 5.** Yarn Type Effect on Knot Number

| unit: number/meter | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 28264.323 | 15 | 1884.288 | 9.650 | .000 |
| Within Groups | 15620.833 | 80 | 195.260 | | |
| Total | 43885.156 | 95 | | | |

## 4.4. Yarn Type Effect on Tensile Strength

The ANOVA evaluation results demonstrated that yarn type had a statistically significant influence on tensile strength value (95% significance level F = 96.978, p = 0.000, see Table 6). Despite tensile strength values were close to each other, elastic blended and thicker yarns had relatively higher tensile strength values. Maximum strength value had come out in the elastic yarn type of 140/20 PA6 in accordance with the test results. Post Hoc test also showed that there was a statistically significant difference between the yarn types of 40/1 PA6 and 70/20 PA6, 140/1 PA6, 140/20 PA6; 40/20 PA6 and 140/1 PA6, 140/20 PA6; 70/1 PA6 and 140/1 PA6, 140/20 PA6, 150/1 PES; 100/1 PA6 and 140/20 PA6, 50/20 PES, 150/1 PES; 100/1 PES and 140/1 PA6, 140/20 PA6; 100/20 PES and 70/20 PA6.

**Table 6.** Yarn Type Effect on Tensile Strength

| Unit: cN/tex | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 12508.388 | 15 | 833.893 | 96.978 | .000 |
| Within Groups | 687.901 | 80 | 8.599 | | |
| Total | 13196.289 | 95 | | | |

## 5. CONCLUSION

It is accepted that the intermingling method is an innovative solution to make the filament yarns more durable against high volume tensions and yarn breakages in the manufacturing stages of multifilament yarns. Intermingling uniformity and stability can be affected from various factors like yarn count, air pressure, machine speed and raw material. In this study, PES and PA6 synthetic filament yarns with various linear densities are used to find out the effect of yarn count and yarn speed to the strength of intermingled yarns and intermingling uniformity. Furthermore, visual experiments are made to find out knot numbers in a meter of a yarn. The experimental observations and statistical results revealed that strong relationships exist between the variables of yarn type and machine speed with final yarn strength and knot numbers. It is also known that knot number directly affects the yarn strength in a positive way. It is seen that as machine speed increases, knot number will generally decrease due to less amount of air pressure apply with the yarn. In lower PA6 yarn densities, the tensile strength values are less compared to the higher yarn density samples. However, the tensile strength values in PES yarns are generally close to each other. In order to have the optimum intermingling parameters and yarn strength, raw material choice, various machine speed values and considering also the elastic blended synthetic yarns distinguish this work from other studies. It is obvious that further work is required in this area to examine carefully the intermingling process with more parameters to reach the aim of uniform and stable intermingling.

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