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Study on the Strength Retention of Technical Cord Yarn

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Abstract: This research studies the factors which influence the tensile strength of tire cords. Five yarn samples are made by changing the spinning conditions and viscosity to get various physical properties. Different twisting methods are introduced and the yarns are twisted under different processing conditions for each twisting process. With the experimental results, various analyses are performed to find the important factors in retaining strength after the twisting process. SEM and optical microscopic photographs are taken along with some measurements to assist the analysis.

Keywords: Strength retention, Cord, Direct ring twister, Direct cabler

Introduction

Not all filaments have the properties required in various applications. For this reason, a post-processing such as twisting is frequently adopted to improve the properties of yarn. The process of twisting filaments is generally indispensable means to improve the yarn property, which cannot be obtained by a single yarn. For the industrial reinforcement materials such as tire-cord yarns, twisting is an essential process to obtain required properties such as high tensile strength. For example, hybrid cord of Aramid/nylon obtained through twisting process gives high performance that is fundamental in a tire application.

Among many synthetic yarns, polyethylene terephthalate (PET) has many advantages as cord and its consumption as tire cord has increased much recently. The advantages of PET as tire cord are high strength, good durability, high modulus and low creep. On the other hand, polyethylene naphthalate (PEN) possesses better mechanical properties as tire cord. However PEN yarn loses lots of strength by twisting process, therefore it restricts PEN to be used as tire cords. This problem is well known in the tire industry and we confirmed it by measuring the strength of yarn before and after the process. Figure 1 shows the result that the strength of PEN yarn decreases after twisting and recovers slightly after being dipped with a resin (dip-cord) that is used to improve binding force between the PEN cord and rubber. To improve this problem, there have been some studies on retaining the strength of PEN yarn by twisting process through modifying polymerization and/or spinning process [1,2].

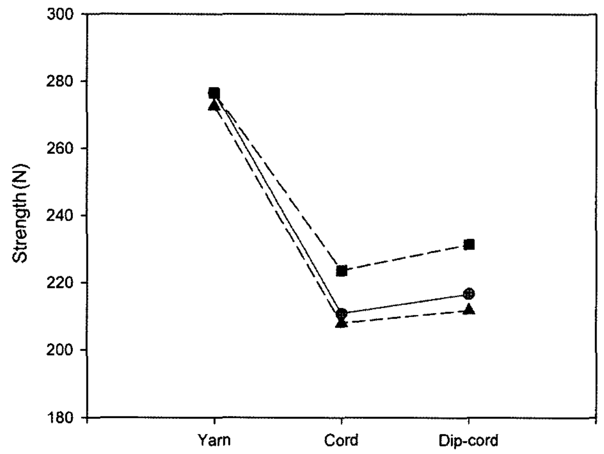

Figure 1. Strength changes of yarns by twisting where dip-cord means the cord is coated with a resin after twisting.

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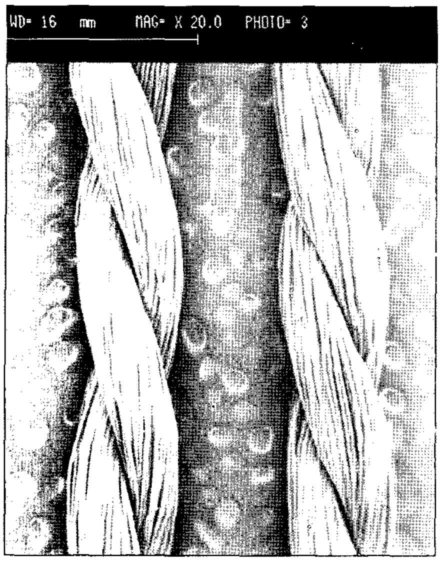
The methods of making cord yarn could be classified into direct ring twisting and direct cabling. Direct ring twisting (DRT) consists of two steps in which two single yarns are first twisted individually (ply twisting in the 'Z' direction), then the plied yarns are twisted counter clockwise together (cable twisting in the 'S' direction) to form a cabled cord [3]. The levels (turns per meter (TPM)) of ply and cable twisting are very important factors in achieving the optimum tire cord properties. In the cord formation process to merge two single yarns into a cord, the same amount of twisting (TPM) as the ply twisting is generally imposed to the cable twisting although the twisting is in the opposite direction. On the other hand, direct cabling process (DC) converts two twistless single yarns (false ply twisting) into a folded structure through a strand-twisting (cable twisting) and the resultant shape of the cabled cord is equivalent to one of the DRT process. Figure 2 shows two cords made by direct cabling (DC) and direct ring twisting (DRT) respectively in which the filaments and balanced twist of cords are shown clearly and the linear density of plied yarns is 166.7 tex.

There have been some researches to understand the basic mechanics of twisting operation for the last fifty years [4]. Fuchino *et al.* derived a formula for calculating ideal contractive force of multi-filaments with circular section and compared the calculated value with the observed one of the corresponding monofilament twisted at a fixed length [5]. Furthermore researches on the mechanics relating the geometry



By DC **By DRT**

Figure 2. Images of cords made by a direct cabler (DC) and a direct ring twister (DRT).

of twisted yarn to twisting torque and dynamic analysis on yarn twisting system have been performed [6-8]. Vinzanexar *et al.* studied on the behavior of rotor-spun doubled yarns that differs from that of ring-spun doubled yarns. They founded that rotor-spun yarns had higher snarling twist than the ring-spun ones [9]. Rhodes *et al.* studied on the effect of blend ratio of Kevlar and cotton on the processing efficiency, the physical properties of the blends and the possibility of using them as fabric [10]. Barron *et al.* studied on hybrid tire cords made of Aramid and low modulus yarns such as nylon and polyester to obtain better physical properties. They reported on the preparation method and characteristics of three-ply hybrid cords consisted of two Aramid plies and one nylon or polyester ply [11]. Also a patent on hybrid tire cord was registered by Fritsch *et al.* [12].

In this study, we are to investigate the factors which influence the strength retention after twisting process. To do this, we designed our experiment through combining material property like viscosity and processing conditions such as spinning speed, quenching pressure, draw ratio, twisting method, and so forth.

Experimental

Preparation of Yarn Samples

Five PEN yarns were made under several conditions given by the combination material property and processing conditions. The yarns were produced with a spin-draw machine and their conditions were as the following: winding speed: 3,000 m/min., Draw ratio (DR): 6.46, and Intrinsic viscosity (IV): 0.90. By giving a little change on these conditions, five samples were prepared and coded in YS series. Table 1 shows physical properties of the manufactured yarns and processing conditions. Increasing of intrinsic viscosity was done through solid polymerization. YS1 sample was made of this polymer and expected to have higher toughness. YS2 was made to have better uniformity of linear density by increasing quenching air pressure and YS3 was manufactured under higher spinning speed that was measured at the first godet roller. YS4 was designed to have lower modulus by increasing the number of filaments. It is expected that lower modulus yarn is less damaged during twisting process. For YS5, the draw ratio was increased to impart higher strength to the yarn. Table 2 shows the physical properties of these

Table 1. Yarn spinning conditions

Processing parameters \ Sample code	YS 1	YS 2	YS 3	YS 4	YS 5	Remarks
Intrinsic viscosity	0.93	0.9	0.9	0.9	0.9	
Quenching air pressure	50	80	50	50	50	mmAQ*
Spinning speed	470	470	580	470	470	m/min
No of filaments	249	249	249	384	249	
Draw ratio	6.60	6.60	6.60	6.60	6.46	

*1 atm = 10.332 mmAq (H_2O).

Table 2. The physical properties of yarn samples and cords prepared by DRT process

Processing parameters \ Sample code		YS 1	YS 2	YS 3	YS 4	YS 5	Remarks
Yarn properties	Linear density	169.6	170	169.9	168.4	168	tex
	Strength at break	138.1	141.8	141.0	147.9	144.2	N
	Elongation at break	9.1	9.6	9.3	7.8	7.9	%
Cord properties	Strength at break	21.22	21.58	22.32	21.40	19.89	kgf
	Elongation at break	12.9	12.4	11.7	10.2	10.4	%

Table 3. Cord samples made of YS3 by DRT process under different tensions and their physical properties

	Items	CS 1	CS 2	CS 3	CS 4	CS 5	CS 6	Remarks
Tension conditions of DRT	Tension in ply twisting	78.5	78.5	78.5	98.1	98.1	98.1	cN
	Tension in cable twisting	343.2	397.2	794.4	343.2	397.2	794.4	cN
Cord properties	Strength	215.8	219.5	209.8	207.0	218.9	205.4	N
	Elongation at break	11.6	11.8	10.8	11.4	11.7	10.4	%

Table 4. The physical properties of cord samples made of YS3 by different twisting methods

Items		CS 2	CS 7	Remarks
Yarn samples		YS 3	YS 3	–
Twisting method		DRT	DC	–
Cord properties	Strength at break	219.5	220.6	N
	Elongation at break	11.8	11.2	%
Strength retention		77.8	81.2	%

yarn samples.

After manufacturing these yarns, they were put into the direct draw twisting process (DRT) to make them into cords. The processing conditions of DRT were as follows; twisting level: 390 TPM, tension of ply twisting: 100 gf, and tension of cable twisting: 405 gf. The cord strength after DRT process was measured to calculate strength retention. The measured values are shown in Table 2 and the formula for strength retention is defined as following:

$$\textit{Tensile strength retention}\ (\%) = \frac{\textit{Strength of a cord}}{\textit{Strength of a yarn} \times 2} \times 100(\%)$$

Twisting Process and Its Conditions

We manufactured more cables with YS3 yarn under various tensions of DRT because the cord yarn retains the largest strength after twisting that will be presented later. During manufacturing the cables, some changes on the tension of the twisting machine were given to see the effect of processing parameters on the strength retention. The tension were controlled at two places as shown in Table 3, that is, ply twisting and cable twisting. With combination of tension levels, six cord samples (CS) were manufactured. At the ply twisting, the used tension levels were from 78.5 cN and 98.1 cN, and at the cable twisting the levels were 343.2 N, 397.2 N, and 794.4 N.

To compare the effect of twisting method on the strength retention, YS3 sample was made into cable cord with DC process that makes a cable in one step. The physical properties of the cable made with DC process are presented in Table 4, where comparisons could be made with the CS2 values in Table 3.

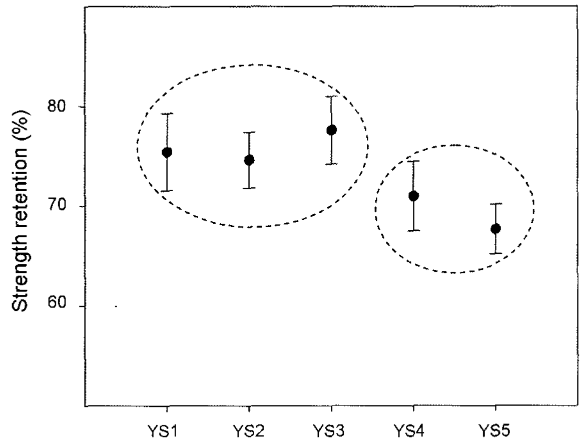


Figure 3. Strength retention after twisting the yarn samples by DRT method.

Results and Discussion

Figure 3 shows that significant loss of strength occurs for all the yarns after twisting by DRT process. Comparing Table 2 and the trend in Figure 3, it is shown that the yarn group of higher breaking extension (YS1, YS2, YS3) posses superior strength retention to the yarn group of lower breaking extension (YS4, YS5). This implies that the amount of strength retention could be influenced by the mechanical property of yarn.

To analyze the change of strength retention, the yarns were twisted by DRT method under some combination of tensions. The tensions of ply twisting and cable twisting were combined as shown in Table 3. Figure 4 shows the effect of tension on the strength retention where data are marked into two groups. The left side group corresponds to the result of strength retention caused by changing the tension of ply twisting and the right side group shows the result by changing the tension of cable twisting. As we see, it is difficult to say that there is a difference between two groups. However, there exist a common thing between two groups, that is, both groups have maximum strength retention in the middle tension of cable twisting. These results imply that the strength retention can be controlled by the tension and an optimum tension of cable twisting exists. To understand the role of twisting tension that influenced strength retention, we need to study on it further in the future.

We designed a experimental plan to see the effect of twisting

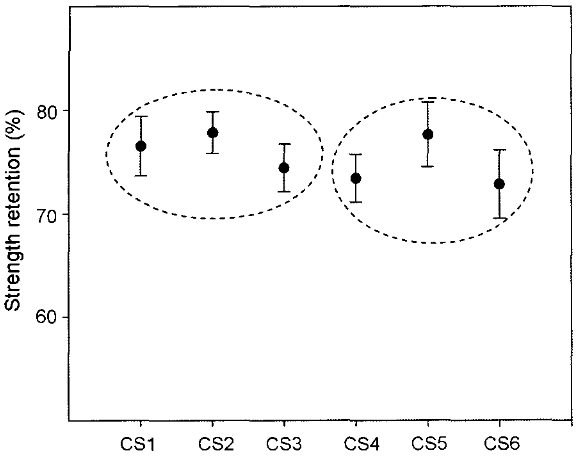


Figure 4. Strength retention of cords yarn made of YS3 by DRT process under different tensions.

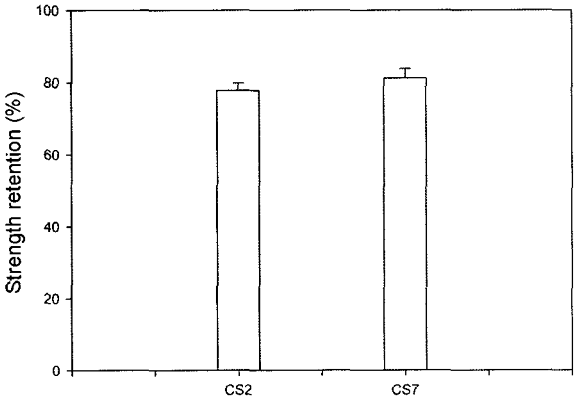


Figure 5. Comparison of strength retention between cords made by DRT and DC processes.

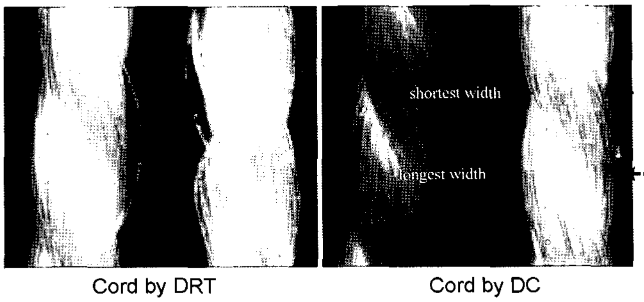


Figure 6. Surface images of the cords made by DRT and DC methods.

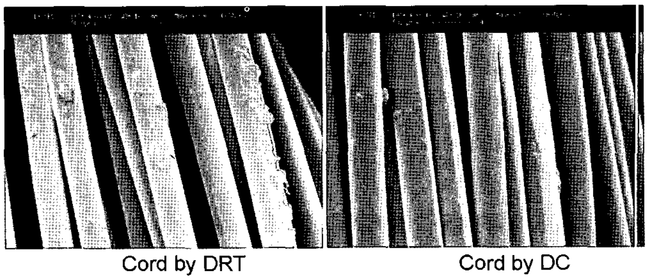


Figure 7. SEM images of the cords made by DRT and DC processes.

Table 5. The average of longest and shortest widths of cords made by the two twisting methods (the number of measured data = 30)

Items	DRT		DC	
	Longest width	Shortest width	Longest width	Shortest width
Avg. length (mm)	0.83	0.66	0.79	0.61
CV% of length	3.74	2.98	3.21	2.91

methods on the strength retention. Figure 5 and Table 4 show that the result of strength retentions after DC and DRT process where the values are an average of 10 measurements and their standard variations are marked on together. As it is shown, the level of strength retention by DC is higher than by DRT method. To understand this difference, we investigated the morphology of the cables with an optical microscope and scanning electron microscope. Figures 6 and 7 show the images taken by the optical microscope and SEM, respectively, which enable us to visually distinguish the cords made by DRT and DC methods. As we see in Figure 6, there is a separated filament from the body of DRT yarn, which implies the compactness of DRT yarn may be lower than that of DC yarn. To confirm this assumption, we measured yarn widths along yarn axis. Table 5 displays the measured values which indicates that the width of DRT yarn is larger than that of DC yarn. We predict that this result reflects the difference of compactness between two yarns. If we consider the fact that much higher tension is generally applied during DC process, the result seems reasonable.

The SEM images of cord's surface in Figure 7 show the damage caused by twisting process. The DRP process caused some damages on the filament surface which seems to be due to a scratch. On the other hand, the cord by DC method does not show any damage. DRT process consists of two steps, that is, ply twisting and cable twisting whose direction are opposite to each other. So, there is a possibility that the filaments get more stress compared to one step twisting of DC. Also, the friction by traverse guide which moves up and down along the filament length may be a reason for the scratch. It is much interesting that no scratch was observed on the surface of DC yarn despite of much higher tension and speed.

The cords were untwisted into filaments to measure the change of physical properties. The measurements and comparison are shown in Table 6. Looking into the results, the strength of untwisted yarn is lower than one of raw yarns (before twist), which may be due to the surface scratch and straining imposed by twisting process. Especially, the DRT

Table 6. Comparison of strength losses between yarns before twisting and cords twisted by DRT and DC processes

Process type	Items	Yarn status			Comparisons of strength losses		
		Yarn (①)	Cord (②)	Untwisted single yarn (③)	Total strength loss ratio (①~②)	Physical loss ratio (①~③)	Twisting structure loss ratio (③~②)
DRT	Strength at break (N)	137.6 (×2)	214.6	122.4 (×2)	22.02 %	11.05 %	10.97 %
	Strength retention (%)	–	77.98	88.95			
DC	Strength at break (N)	137.6 (×2)	224.3	126.1 (×2)	18.50 %	8.34 %	10.13 %
	Strength retention (%)	–	81.50	91.66			

process imposes torsional straining twice by ply (twisting) and cable (untwisting) process. Also, the strength of untwisted yarns was higher than one of cords, which can be explained with the increased stress acting to the vertical direction of the yarn axis. The stress increases proportionally with twist angle.

In addition, Table 6 shows the difference between the twisting methods where the data were obtained from the cords made of YS3 but different twisting process. As we see, the cause of strength loss by twisting is divided into two parts. One is corresponding to the structure change by twisting and the other to the damage by scratch and torsional straining. The relative importance is dependent on the twisting method.

Conclusions

The factors which influence the strength retention of PEN cord were analyzed through experimental design whose variables were the physical property of filament and twisting method. The yarn of higher breaking extension retained more strength after twisting. Additionally, to study the effects of processing variables, we introduced two twisting method, DRT and DC processes which were run under several tensions. For DRT process, the strength retention was lower than DC because of damage due to scratch and torsional straining despite that the tension and speed were much higher in DC process. These results were obtained through SEM and optical microscope images, untwisting of cable and measurement of cord width. Based on these results, we can say that the DC method is more effective in the view of strength retention.

Acknowledgements

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