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Impact of the Level of Yarn Twist on Sized Yarn Properties

Abstract
The impact of the level of yarn twist on the size pick-up, abrasion resistance and breaking force of yarn was analyzed. A cotton yarn differing only in twist level was used for testing. The sizing process was carried out on a laboratory sizing machine. Sizing conditions were varied, namely the squeezing force and size recipe. According to the results obtained, the level of twist affects the size pick-up, abrasion resistance and breaking force. Based on the coefficient of correlation, it can be claimed that the level of twist in relation to the size pick-up and breaking force is very high, confirming that a very close correlation is systematically proved.

Key words: *yarn twist level, size pick-up, braking force, sizing, sized yarn properties, yarn abrasion resistance.*

■ Introduction

The number of end breakages in the weaving process mostly depends on the size pick-up and sizing agents as well as on the share of individual components in the size. By qualitative sizing, the warp yarns are protected from the weaving process, resulting in the efficiency of looms and fabric quality planned. To achieve qualitative sizing, size is applied on the yarn so as to protect it and strengthen weak places. Dynamic forces arising during weaving assume maximum values at the moment of beat-up action, possibly exceeding the breaking force of weak places. In this case, if the weak place has not been strengthened enough during the sizing process, there will be a yarn break in the weaving. By sizing, fibers are fixed together in the position in which they were before sizing, during which a surface film is formed on the yarn, whereby the yarn receives abrasion resistance.

So far the quantity of size pick-up on yarn has been determined by the lab measuring of samples of sized yarn. Recently, there has been a continuous control and regulation of size pick-up during the weaving process, which makes it possible to keep the size pick-up constant. The parameters, on which the size pick-up depends, are continuously monitored, and using a special modular system, they are regulated and kept constant. In the sizing process the controlling parameters of the warp are the following: raw material composition of the warp, the moisture absorption and desorption capability, and physical properties such as linear densitylinear density, warp density in the size box etc. The absorptive capacity of the size on the yarn does not only depend on the yarn structure and yarn tension in the size box but also on the type of sizing agents, size viscosity, temperature and concentration. The penetration of size particles into the interstices of the yarn causes saturation and reduces the absorptive capacity. Therefore, it is possible that the thread inside remains unsized. It is essential that the size creates a surface layer whose strength will take up and withstand stresses in the weaving process, and the fibers within the yarn should remain in the position assumed before sizing. Surface sizing is preferred, and today producers of sizing agents are researching it intensively, as well as sizing machine manufacturers of size boxes, by pre-impregnation of the warp with water - the yarn inside is saturated with water so that the size and size pick-up,

respectively, remain applied only on the surface. The condition for this kind of sizing is new sizing agent properties with a higher capability of adhesiveness and elasticity. One of the problems still unresolved in the sizing process is that water vaporises during the sizing process, resulting in an increase in size concentration in the size box. The consequence is that the yarn is sized with increasing size concentration, and the size penetrates the yarn increasingly harder. Thus, the yarn will be sized with a higher size pick-up. A constant size pick-up on the warp yarn is achieved by regulating the squeezing force on the last pair of rollers. During the sizing process, the squeezing force is changed by altering the passage speed. The box entry speed is higher than the box exit speed in order to obtain as low a tension as possible in a wet condition and thereby a better penetration of the size into the interstices of the yarn [1 - 6].

Size pick-up does not only depend on sizing conditions, but also on yarn properties. The fact is that yarn of the same count, raw material composition and fiber quality sometimes differs in the level of twist, resulting from the purchase of yarn from different spinning mills, or even from the same spinning mill. Differences in twist level do not only exist in production batches but can also occur in the same yarn package. The level of yarn twist affects the size pick-up, because yarn with a lower level of twist is an „opener", enabling a higher absorptive capacity of the size than yarn with a higher level of twist. This is the reason why the size pick-up will be different, resulting in a different sizing effect. The influence of the twist level on the size pick-up and physical mechanical properties of sized yarn is investigated in this work [7 - 11].

■ Theoretical part

The sizing process is a complex and exceptionally significant task in the preparation of warp yarn. In the production phases of a textile surface fabric, sizing is a key process. The sizing should be matched with the phases before and after sizing.

The necessary strength, elasticity, smoothness and resistance to static electricity are imparted to warp yarns by sizing. The aim of sizing is to protect weak places in warp yarns against breaking in the weaving process. Likewise, it is essential that surface fibers are clung to the yarn by sizing, enhancing the uniformity and decreasing yarn hairiness, which will decrease friction and strengthen the yarn. Quality properties of yarn are yarn regularity, strength, hairiness, the frequency of weak places, twist level etc. To maintain some of these parameters during the weaving process, for a single cotton yarn or cotton blend, it is necessary to size.

Size is the main component of size liquor, and auxiliary agents provide better adhesiveness and penetration into intermediate capillaries. In order that the warp maintains elasticity and flexibility, lubricants and wax are added. These additions should produce a film around the thread [6].

Sizing agents should meet the following requirements:
good adhesiveness between fibers
- low loss of elasticity and elongation as well as an increase in yarn tensile strength
- they should be colorless and should not remove the dye from the warp
- warp threads should separate easily from one another after drying
- they should be resistant and not mouldy
- they should not contain substances harmful to health
- they should be able to prevent static electricity
- their preparation should be simple
- they should be easily removed in desizing
- they should be recyclable and biologically degradable

After production in a weaving mill, each yarn has, to a lesser or greater extent, various physical mechanical properties. It is necessary to know these properties before introduction into the downstream process because of the influence on the downstream process. These are linear densitylinear density, irregularity, hairiness, twist level and breaking force as well as other specific features affecting the concrete downstream process. The yarn properties are adapted to the application, which is the reason why yarns are manufactured as weaving yarns (warp and weft), knitting yarns, plied yarns etc.

Linear density - Fiber fineness is particularly important for the linear density. The best and most uniform yarn is obtained when fibers are distributed in a random arrangement, and the number of fibers in the yarn cross section is larger. For a given linear density, the average number of fibers in the cross section depends on the fiber fineness, meaning that the finer the fibers, the larger their number and the more uniform the yarn is. Linear density is expressed by the length mass. In principle the mass of a specific yarn length is determined when testing the linear density. The testing of linear density determines how high the mass is in a specific yarn length.

Twist level - Yarn is an assembly of pre-parallelised textile fibers which are then twisted around the joint axis. Contact between individual fibers is achieved by twisting. In the final spinning, the roving is attenuated to the necessary linear density and is further twisted, whereby the necessary strength is achieved. The level of twist is adapted to its application. Several fiber properties (in particular length, fineness and strength) are to be taken into consideration. Therefore, the level of yarn twist is one of the most important properties, which especially affects a se-
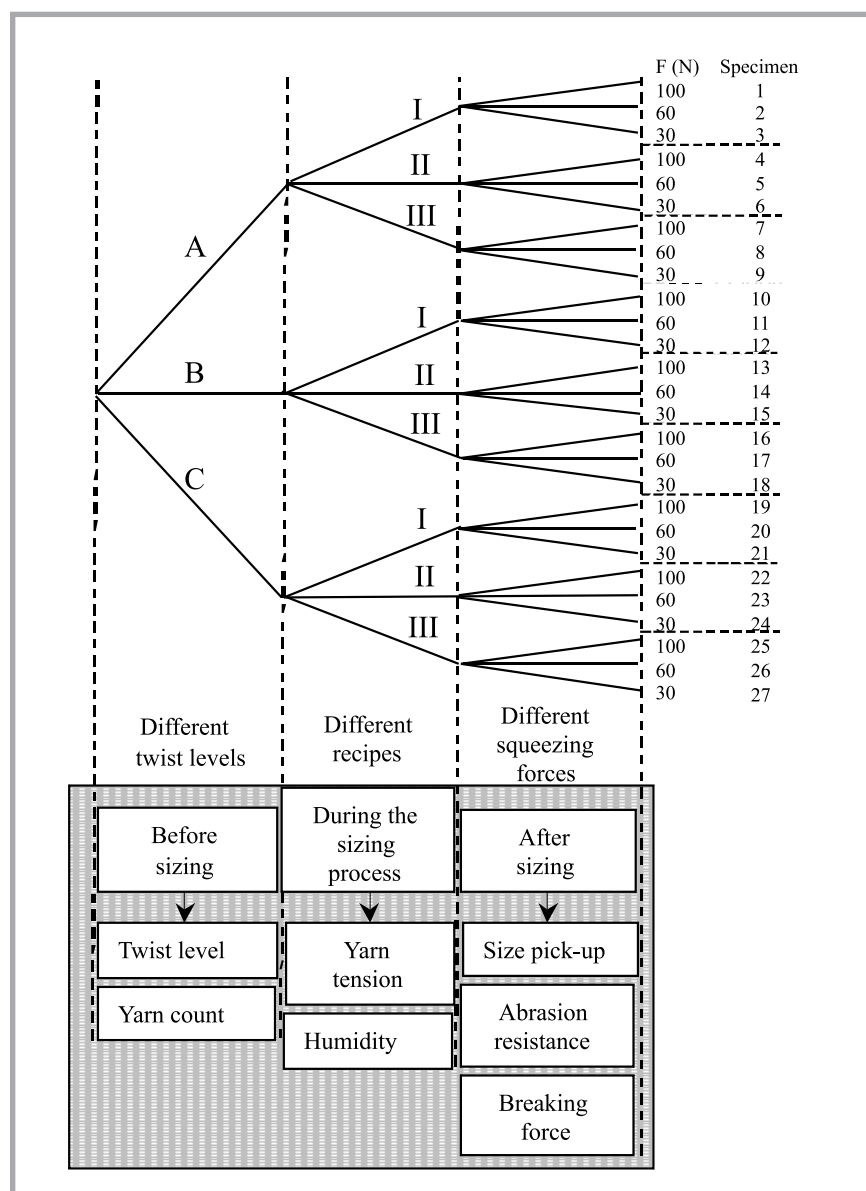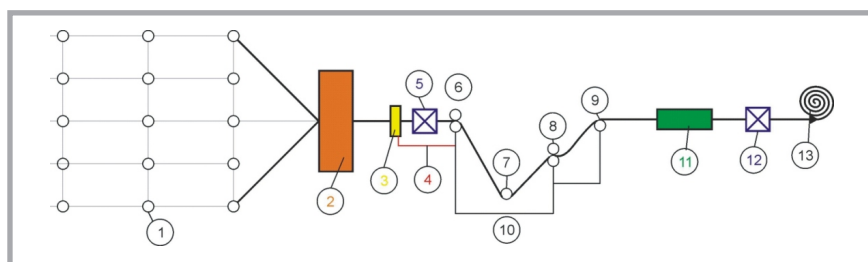

Figure 1. *Representation of the test procedure; F - Squeezing force (N).*

Types of testing		Yarn twist			Yarn count			Twist coefficient		
		T, t.p.m.	S	CV, %	Tt, tex	S	CV, %	α_m, $g^{1/2}$ $m^{-3/2}$	S	CV (%)
Yarn samples according to yarn twist	A	423.9	10.1	2.4	59.3	3.09	5.2	103.23	6.9	6.7
	B	467.4	13.4	2.9	61.3	2.88	4.7	115.72	6.4	5.5
	C	628.8	9.8	1.6	61.1	3.48	5.7	155.43	7.1	4.6

Figure 2. *Schematic representation of the sizing device; 1 - creel for yarn packages, 2 - reed, 3 - comb, 4 - size pre-box, 5- yarn tension measuring device, 6 - feed rollers, 7 - immersion rollers, 8 - squeezing rollers, 9 - delivery rollers, 10 - size box, 11 - dryer, 12 - device for the contact measurement of moisture, 13 - reel for winding sized yarn.*

ries of properties, in particular strength, elasticity, appearance etc. It is wholly defined by the direction of twisting and twist level. Before twisting, the fibers are parallel to the yarn axis, whereas during twisting they assume a helicoidal shape, whereby a change in length occurs. Twist intensity (twist level per unit of length) is determined according to the linear density, fiber properties (length, fineness, structure etc.) and also according to the yarn application. The level of twist is calculated per 1 m of fibre length. The value expressed in this way is designated by *T* and is called twist level.

Yarn breaking force and elongation at break - The reaction of yarn to external forces is referred to as mechanical yarn. This is probably the most important yarn property because it determines the processing methods and is responsible for the service life of the finished product, i.e. its performance. Due to the extended yarn shape, techniques of mechanical yarn processing are primarily directed at the exploitation of tensile properties. Thus, this is the most important mechanical property and at the same time the most investigated one. The quality of finished products depends, to a great extent, on the mechanical properties of the yarn since they are the prerequisite for the further use of the product, particularly in relation to the action of mechanical influences.

Yarn abrasion resistance - During various processing methods (winding, weaving, knitting), when passing through various guides, reeds, healds and similar machine elements, yarns are subjected to friction when passing over surfaces made from different materials of various smoothness, or when they rub against each other. Depending on its own frictional properties and abrasion resistance as well as on the surface characteristics of rubbing elements, the yarn, to a greater or lesser degree, wears out, deforms, and changes its surface, causing difficulties and standstills during production, respectively. When testing the abrasion resistance, the number of yarns passing over the abrading element is used as a measure of the resistance, whereby the yarn is broken. Sizing effects can also be investigated by determining the abrasion resistance.

■ **Experimental part**

Course of the test procedure

To represent the course of the test procedure for yarn as clearly as possible, a scheme was formed with the sequence and type of testing. The process is presented in several phases: yarn testing before sizing, testing during sizing and testing after sizing (***Figure 1,*** (see page 45)).

Material testing

Raw cotton yarn (100% CO) made at a spinning mill of the company „Oroteks"

d.d., Oroslavlje was used for testing. The linear density of the yarn tested ranged from 59 tex to 62 tex. The yarn came from the same batch, the only difference being in the level of twist : 400 t.p.m. (designated by A), 500 t.p.m. (designated by B) and 600 t.p.m. (designated by C) (***Table 1***).

Methods of yarn testing

Testing based on individual methods was performed in conditions of strictly defined humidity and temperature both of the material tested and the room where the tests were conducted. In the standard atmosphere in which the tests were performed, the humidity $HR = 65 \pm 2\%$ and the temperature $T = 20 \pm 2$ °C. The determination of yarn twist (HRN ISO/DIS 17202) was made using a hand-held torsiometer, model Twist T made by Medsan. The determination of linear density (HRN ISO 2060) was made by the skein method (***Table 2***), in which the yarn was weighed according to the Metler Toledo AB analytical balance model. Determination of the single-end breaking force and elongation at break (HRN ISO 2062) was made on a Statimat M type tensile tester produced by Textechno. The measuring length of the specimen was 0.5 m with a preload of 0.5 cN/tex. The elongation at break is not presented in this paper. Determination of the yarn abrasion resistance was made on a Zweigle yarn abrasion tester. Since there is no standard for determination of yarn abrasion resistance, the manufacturer's instructions were used. Each thread was clamped and tensioned by a weight of 20 g. 20 threads were simultaneously abraded, each specimen up to breaking point. The number of abrading roller strokes was read by a counter. The roller was coated with emery with a fineness of 600 P, moving over a length of 7 cm.

Sizing process

Figure 2 displays a simulation of the sizing machine and sizing apparatus, respectively, in which the yarn was sized under different conditions. This device simulates the sizing process, consisting of sizing - drying – winding, which was used for wet sizing.

The size box - ***Figure 2*** (***10***) - consists of a pump for size circulation from the pre-box into the size box, immersion rollers and rollers for size squeezing. In the bottom section of the pre-box there is an electrical heater to heat the size. The

Table 2. *Recipes, squeeze forces and size concentrations in the sizing process*

Sizing conditions		
Recipe	I	1 dm³ water + 41 g Tuboflex BC 3C + 4 g fat
	II	1 dm³ water + 82 g Tuboflex BC 3C + 8 g fat
	III	1 dm³ water + 123 g Tuboflex BC3C + 12 g fat
Squeeze force, N	1	100
	2	60
	3	30
Concentrations, %	1	4.20
	2	8.67
	3	11.44

heater is connected to a thermostat and a temperature sensor at the bottom of the box. In this way a constant temperature of the size is ensured. The upper part of the roller is equipped with an additional device regulating the squeezing force of the size surplus. The size pick-up was measured under three different pressures of the roller in order to squeeze the size (100, 60 and 30 N).

The warp moisture was measured before sizing and after drying using an Aqua-Boy hygrometer made by K.P., Mundinger GmbH, Germany, which was adapted to measure continuously and store data on a computer. The entry moisture corresponded to a moisture regain of 8.5%. The exit moisture was kept constant by regulating the sizing speed, ranging from 6 to 8%. A ETM tensiometer made by Schmidt was used to measure the yarn tension, which was also adapted to measure continuously and to store data on a computer. The moisture and tension values measured were processed by an A/D converter and registered on a data processing computer. During sizing, a constant sizing temperature of 80 ± 3 °C was maintained. The size concentration was measured using a Carl Zeiss Jena refractometer (**Table 2**). The sizing speed ranged from 4 to 6 m/min. The squeezing force varied from 100, 60 to 30 N (**Table 2**).

The yarn was desized according to the acid procedure based on Standard ASTM-D334-GOT [12]. To test the treatment's effect, a sized sample of 5 g was dried until it was completely dry and then

weighed. It was treated for 30 minutes in 200 ml 0.1 M of an HCl solution; afterwards it is rinsed with 400 ml of distilled water, then squeezed and neutralised with 200 ml 1% of a NH_4OH aqueous solution [12].

■ Discussion

During spinning, the following yarn twist was set on the machine: sample A – 400 t.p.m., B – 500 t.p.m. and C – 600 t.p.m. (**Table 1**). Some deviations were found in the tests and are given in **Table 1**. The linear density tested fluctuated between 59.3 and 61.3 tex in relation to the one indicated, which is 60 tex (**Table 1**).

All three yarn samples were sized on the apparatus (**Figure 2**) with three different recipes. In each recipe the squeeze force varied from 100 to 60 and 30 N, which also caused a variation in the size-pick up. 27 different sized yarn samples were obtained (**Figure 1** (see page 45)**, Tables 2** and **3**). The size concentration was varied by changing the recipe, ranging from 4.20% for recipe I to 11.44% for recipe III (T**able 2**). Since the size

Table 3. *Test results of yarn abrasion resistance, breaking force before and after sizing and size-pick up.*

| Samples		Abrasion of sized yarn till breakage (H)			Breaking strength of yarn before sizing (F1)			Breaking strength of yarn after sizing (F2)			Size-pick up (Sp)		
		x, n	S	CV, %	x, cN	S	CV, %	x, cN	S	CV, %	x, %	S	CV, %
A	I – 1	163.1	30.0	18.4	676.2	37.9	5.6	680.3	46.26	6.8	8.0	0.8	10.0
	I – 2	165.6	31.8	19.2	676.2	37.9	5.6	683.3	43.73	6.4	8.8	0.8	8.8
	I – 3	274.3	47.7	17.4	676.2	37.9	5.6	716.7	47.30	6.6	9.9	1.0	10.1
	II – 4	172.8	33.5	19.4	676.2	37.9	5.6	771.9	48.63	6.3	6.1	1.1	18.2
	II – 5	190.3	39.4	20.7	676.2	37.9	5.6	783.1	54.03	6.9	6.2	1.1	18.0
	II – 6	303.1	64.9	21.4	676.2	37.9	5.6	834.9	66.79	8.0	7.1	1.1	15.6
	III – 7	199.5	54.1	27.1	676.2	37.9	5.6	705.2	46.54	6.6	5.0	0.7	14.4
	III – 8	187.5	47.8	25.5	676.2	37.9	5.6	768.0	54.53	7.1	5.2	0.9	16.8
	III – 9	321.7	86.2	26.8	676.2	37.9	5.6	844.7	57.44	6.8	5.6	1.0	17.9
B	I – 10	166.3	33.6	20.2	685.2	47.3	6.9	711.7	38.43	5.4	8.9	1.3	14.7
	I – 11	170.4	31.9	18.7	685.2	47.3	6.9	728.8	41.54	5.7	9.4	1.5	16.3
	I – 12	277.9	62.2	22.4	685.2	47.3	6.9	747.1	41.84	5.6	10.9	1.9	17.4
	II – 13	176.2	41.4	23.5	685.2	47.3	6.9	773.3	55.68	7.2	7.4	1.4	19.4
	II – 14	240.2	54.5	22.7	685.2	47.3	6.9	798.6	47.92	6.0	7.7	0.9	12.5
	II – 15	296.1	77.9	26.3	685.2	47.3	6.9	849.9	59.50	7.0	8.5	1.5	17.8
	III – 16	195.5	43.8	22.4	682	47.3	6.9	742.8	44.57	6.0	6.3	1.0	15.4
	III – 17	196.5	49.9	25.4	685.2	47.3	6.9	777.1	46.63	6.0	6. 3	1.0	15.5
	III – 18	304.1	70.9	23.3	685.2	47.3	6.9	876.0	68.32	7.8	7.1	1.3	18.9
C	I – 19	152.1	31.5	20.7	720.6	60.5	8.4	722.8	34.69	4.8	10.0	1.6	16.0
	I – 20	176.1	36.8	20.9	720.6	60.5	8.4	773.1	47.93	6.2	10.5	1.8	16.7
	I – 21	330.4	81.6	24.7	720.6	60.5	8.4	791.9	41.97	5.3	11.5	1.7	15.2
	II – 22	262.5	62.0	23.6	720.6	60.5	8.4	793.1	42.03	5.3	7.6	1.1	14.9
	II – 23	323.0	75.9	23.5	720.6	60.5	8.4	835.1	50.11	6.0	7.8	1.4	18.6
	II – 24	367.8	83.5	22.7	720.6	60.5	8.4	871.8	49.69	5.7	8.8	1.7	19.7
	III – 25	174.2	43.0	24.7	720.6	60.5	8.4	771.9	47.86	6.2	6.7	1.2	17.4
	III – 26	161.4	40.4	25.0	720.6	60.5	8.4	783. 2	57.99	7.4	7.0	1.2	17.5
	III – 27	317.3	88.2	27.8	720.6	60.5	8.4	883.3	66.25	7.5	7.5	1.5	19.6
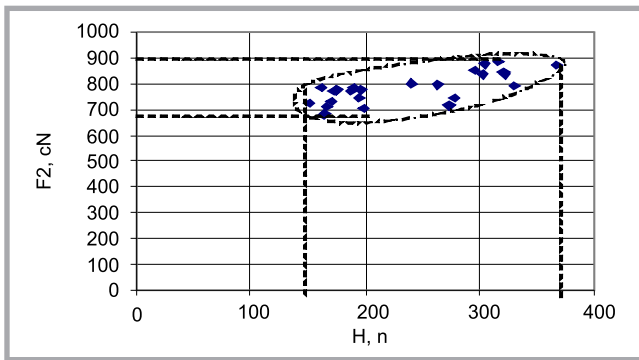
Figure 3. *Relationship between the abrasion and breaking force of sized yarn.*
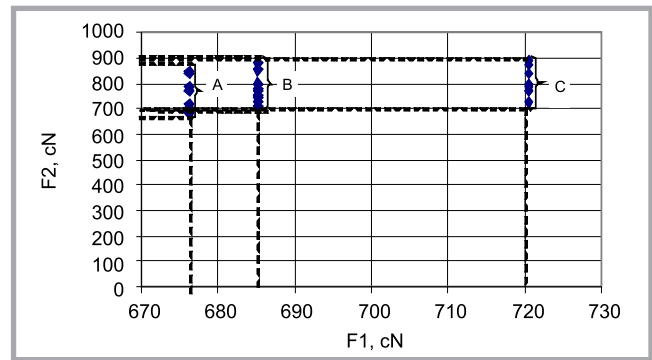

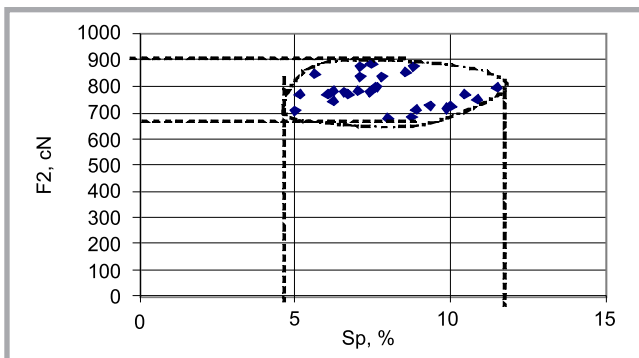**Figure 4.** *Relationship between yarn breaking forces before and after sizing.*

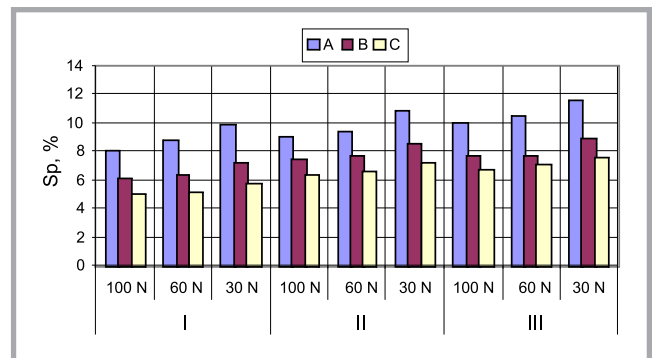**Figure 5.** *Relationship between yarn breaking forces after sizing and size-pick up.*

Figure 6. *Size-pick up in relation to sizing conditions and yarn type.*

consumption was relatively low, due to the compact design of the size box, with minimum evaporation no differences in the size concentration were expected at the beginning end of sizing.

The test results for yarn abrasion resistance vary depending on the yarn type, recipe and squeeze force. Yarn with a higher abrasion resistance mostly had a higher breaking force. The breaking force of all the samples ranges from 680.29 cN to 883.29 cN, while the yarn abrasion resistance ranges from 152.1 to 367.8 roller strokes till breaking on the abrasion apparatus (*Table 3* (see page 47), *Figure 3*).

The values of breaking forces before sizing are sorted by the direction of yarn twist (samples A, B and C). The values of breaking forces of the sized yarn are

divided into 27 samples (*Table 3* (see page 47), *Figure 4*). By placing the values of yarn breaking forces before and after sizing into a coordinate system, the scatter of values can be observed (denoted as A, B and C). A homogenous scatter of the values of breaking forces of the sized yarn, denoted as A, B and C, can be observed. This means that by yarn sizing under the same conditions (concentration and squeeze force) and with a different yarn twist, the same scatter of the breaking force in the coordinate system may be expected.

The breaking force of the sized yarn with a different size pick-up is different (*Table 3* (see page 47), *Figure 5*). The higher size pick-up, higher twist and lower squeeze force on the yarn caused a higher yarn breaking force and the scattering of

values obtained from the relationship between the breaking force after sizing (F2) and the size pick-up (Sp) cover a specific surface limited at the ordinates F2 = 680.3 and 883.3 cN and on the abscissa value at Sp = 5.01 and 11.51%.

To make a specific decision regarding the relationship between level of twist and size pick-up, it is necessary to consider each condition separately (*Table 3* (see page 47), *Figure 6*). Based on the results obtained, a specific linearity of the dependence of twist level and size pick-up may be observed. According to the histogram (*Figure 6*), it is observable that the size pick-up is highest in the case of the lowest twist level, and the lowest in the case of the highest twist level under all sizing conditions. Likewise, the size pick-up decreased by increasing the squeeze force and increased by reducing the squeeze force, respectively. In addition, it can be observed that the size pick-up is higher in the case of a recipe with a higher concentration than one with a lower concentration.

To prove that these assertions as true and not accidental, the correlation coefficient between the twist level and size pick-up, and that between the twist level

Table 4. *Correlation coefficient (R) between yarn twist and size-pick up and breaking force after sizing.*

Yarn twist	Recipes						R	
	I		II		III			
	Sp	F2	Sp	F2	Sp	F2	Sp	F2
A	0.9995	0.9492	0.9920	0.9983	0.9862	0.9982	0.9926	0.9822
B	0.8885	0.9165	0.8757	0.9841	0.9144	0.9984	0.8930	0.9670
C	0.9553	0.9923	0.9334	0.9893	0.9313	0.9233	0.9401	0.9688
R	0.9489	0.9532	0.9349	0.9906	0.9445	0.9739	0.9428	0.9727

and breaking force of the sized yarn are shown as regression straight lines (*Table 4*). According to the results obtained, correlation coefficient R is mostly higher than 0.9. The yarn samples with a twist level under designation B have the lowest average correlation coefficient - R = 0.8930, resulting in the weakest correlation between twist level and size pick-up. This may be the consequence of the highest variation coefficient when calculating the average twist level, fineness and size pick-up. The average correlation coefficient for sample A is the highest, amounting to R = 0.9926. The average correlation coefficient for all three yarn samples is R = 0.9428, which may indicate that the size pick-up depends on the yarn twist level, and on whether a relatively firm correlation is statistically proved.

The correlation coefficient between the twist level and breaking force is very high and homogenous in all the yarn samples and sizing conditions (*Table 4*). The lowest correlation coefficient is the same as in the relationship between the level of twist and size pick-up, namely in yarn sample B - R = 0.9670, the highest being for sample A, which is R = 0.9822. The total average correlation coefficient between the twist level and breaking force is very high - R = 0.9727, meaning that these two yarn parameters depend upon each other, for which a very high correlation is statistically proved.

■ Conclusion

Based on the investigations performed, the data processed and the discussion made, the following may be concluded:

By testing it was found that the 3 yarn samples differed from each other in the level of twist , while the other parameters are identical or very similar.

By yarn sizing a conclusion was reached that variations in the level of yarn twist influence the yarn abrasion resistance, breaking force and size pick-up. Yarn abrasion resistance is higher in sized yarn with a higher twist level, lower squeeze force and higher size pick-up.

The yarn breaking force depends on the level of yarn twist, thus a higher twist level causes a higher breaking force. The yarn breaking force becomes higher during sizing and is higher in the case of a

higher size pick-up but lower when the twist level is lower.

The correlation coefficient between the twist level and size pick-up is relatively high - R = 0.9428, as well as that between the twist level and breaking force of the sized yarn - R = 0.9727.

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