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Impact of Sizing on Physico-mechanical Properties of Yarn

Abstract
Breaking force, elongation at break and abrasion resistance before and after the sizing of yarns spun in five various spinning mills are examined. The measurement results for one yarn count spun in various spinning mills before and after sizing will be compared. An assessment of sizing effectiveness based on the difference in the values of breaking forces, elongation at break and abrasion resistance of yarn before and after sizing will be given. Yarn counts will be analysed on the basis of mutual deviation in spinning mills for each examined parameter separately, and a summary of the parameters before and after sizing will be given.

Key words: *cotton yarns, sizing, effectiveness, breaking force, elongation at break, abrasion resistance.*

Introduction

The warp threads running from the warp beam all the way to interlacing in a loom come into contact with the back rest roller, the drop wires, the healds and the reed, and also sometimes with the picking block and weft yarn, where yarn forces or stresses occur in the positions where the warp yarn passes from the right side to the left side and vice versa. These forces are effective in the warp and weft until counterbalanced. In addition to the above-mentioned stresses, the warp yarns are subjected to variable forces arising at shedding, then to the forces of weft yarn beat-up to the fabric fell; fabric let-off is actuated by the cloth regulator.

In order to protect weak places in the warp yarns from destruction, and not to classify them into the group of weak places in the yarn, the fibres within the thread should be bonded together; in this way their further destruction will be prevented. A thinner place in the yarn absorbs less size, and if it is a weak place, it requires more intensive sizing, demanding sizing agents of higher quality and requiring continuous control. If the frequency of weak places is higher and the yarn more uneven with a higher coefficient of variation, it is necessary to size it with a size coat of higher quality to meet the requirements of weaving.

By sizing, warp yarns are provided with necessary strength, elasticity, smoothness, and acquire resistance to abrasion and static charge. Quality sizing is deep sizing, where fibres are fixed in the position in which they were before sizing. Besides deep sizing, it is also important to apply size on the surface of the thread in the form of a film providing outer protection of the threads.

Modern sizing technology increases the efficiency of looms, brings savings of sizing agents and energy, and improves the quality of the sized warp. In spite of huge progress in sizing technology, there is a series of theoretical and practical problems concerning the optimisation of size coat. Since no standardised test methods yet exist, which could show to what extent end breakage rate would decrease on a loom after sizing, difficulties exist in planning the efficiency of looms and the quality of the end product. It is believed that size coat will enable a minimum end breakage rate on a loom. According to Figure 1, the optimum size coat is slightly higher than minimum size coat, because it is very difficult to attain its precision and uniformity throughout the yarn [1].

Due to an insufficient penetration of size into fibre interspaces, the central portion of the cross section remains unsized. The partly sized thread will not obtain the necessary strength, and by destruction of the inside fibre portion the fibres will be stretched, the protective size layer will break and be removed from the thread surface, and increasing friction will occur. The consequence of this occurrence is a decrease in productivity, the efficiency of the loom and the quality of the end product. One of the essential prerequisites for good and efficient sizing is that the size coat should be uniform from the beginning to the end of sizing of one lot. It is necessary to keep some of the influential parameters constant or within the function of the size coat, such as concentration, viscosity, the temperature of the size coat in the size box, the throughput speed of the warp through the box, the inlet moisture of the warp before sizing, the outlet moisture of the warp after sizing, and the squeezing force and yarn tension in the size box. To optimise the size coat quantitatively and qualitatively, it is necessary to apply the following parameters: the raw material composition of yarn and its properties such as yarn count, yarn twist, fibre length, spinning method, the type of weaving machine, the article, the seasonal and climatic conditions of processing natural fibres, and so on [2,3].

The yarn to be used as warp comes from a spinning mill with properties which, in most cases without sizing, do not guarantee satisfactory quality and productivity during weaving [4]. Due to its insufficient strength and surface hairiness, frequent end breakage rates and great yarn deformations occur [5,6]. The warp properties for optimum weaving are as follows [7-9]:

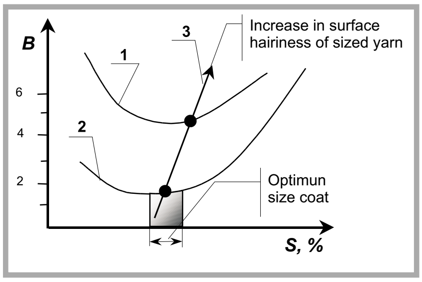

***Figure 1.** Optimum size coat for minimum end breakage rate at weaving: B - end breakage rate (for each machine and per hour), S - size coat (%), 1 - hairy yarn surface, 2 - smooth yarn surface, 3 - position of optimum height of size coat.*

- smoothness and evenness of the yarn surface, so that no high friction is generated upon mutual contact or contact with the elements of the loom,
- specific strength to withstand all dynamic stresses at shedding and beating up on the loom in the axial and radial direction of the yarn,
- elasticity, so that the shed and the fabric is formed properly taking into account the oscillating periodic stresses,
- synthetic fibres must contain an antistatic agent that is added to the size to prevent static charge.

If some of the properties of the warp yarns are sufficient enough to withstand all dynamic stresses at weaving, the insufficient properties are improved by changing the proportion of the sizing agents in the size.

Used Materials and Methods

The warp yarns, i.e. ply yarn, were chosen from among the available yarns. To carry out extensive and basic investigations, it was necessary to collect yarns from different spinning mills, and the result was a different quality of yarn derived from different cotton qualities and processing methods (Table 1).

Since most spinning mills are separated from the following processing stages, e.g. from weaving, yarn is frequently purchased from various spinning mills for the same fabric. As a result, yarn properties are mostly different, causing a divergent behaviour of yarns. Therefore a yarn with divergent properties was deliberately taken from different spinning mills. Table 1 shows a relatively large difference in twist level and yarn irregularity of the same fineness, so that a different performance of sizing could be expected.

The following agents were used for preparing the size:
- polyvinyl alcohol (PVA) type Vinerol STH tt. Hoechst (now Clariant),
- carboxymethyl cellulose (CMC) type Tylose C30 by Hoechst.

The size preparation recipe, the size parameters, and the sizing conditions were the same for all the samples:
- composition: 3.5 kg PVA + 3.5 kg CMC + 100 l water,
- concentration - 6.5%,
- sizing rate - 1.67 m/min, converted in such a way that the duration of immersing yarn in the size corresponds in terms of time to industrial process sizing at a rate of 50 m/min,
- temperature - 85-90°C.

Table 1. *Yarn count and marks.*

Spinning mill	Yarn code	Yarn count, tex	Yarn twist, twists/m	Yarn unevenness CV, %
Spinning mill I	I/A	20×2	544.0	4.03
	I/B	30×2	437.6	6.32
	I/C	50×2	343.7	2.18
Spinning mill II	II/A	20×2	539.5	9.02
	II/B	30×2	434.3	10.21
	II/C	50×2	349.2	8.06
Spinning mill III	III/A	20×2	604.4	12.17
	III/B	30×2	494.3	11.95
	III/C	50×2	463.1	10.37
Spinning mill IV	IV/A	20×2	599.5	6.27
	IV/B	30×2	443.9	8.48
	IV/C	50×2	431.5	4.78
Spinning mill V	V/A	20×2	744.8	18.02
	V/B	30×2	508.3	14.46
	V/C	50×2	600.8	9.92

Test Methods, Machinery and Testing Instruments

Before sizing, the following parameters were tested: the yarn twist (twists/m), unevenness (CV/%) and yarn count (linear density) in accordance with standards DIN 53 832 and HRN F.S2.050, the breaking force and elongation at break in accordance with standard HRN F.S2.052, and the abrasion resistance in accordance with the Zweigle abrasion tester instruction. The yarn was sized under constant conditions in an apparatus simulating the sizing machine. The yarn was unwound from the creel equipped with cross-wound bobbins with possible regulation of thread tension. Directly before entering the size box, a tensiometer is installed which measures yarn tension, and a comb for individual yarn guiding. The box is equipped with an immersing roller and a pair of squeezing rollers with possible regulation of squeezing pressure. The yarn was dried in a heating chamber with air streaming, and then wound on a reel. At the exit of the dryer, a humidity measuring unit is installed which measures yarn moisture, enabling the outlet yarn moisture to be maintained unchanged. The size was continuously circulated from the size box into the preinstalled box by overflowing, and back from the preinstalled box into the size box by a pump. The size was warmed up in the preinstalled box, and the temperature was maintained by a thermostat built into the box.

After sizing, the breaking force and abrasion resistance of yarns were tested as before. The yarn count was tested by the quantum method, 10 yarn samples of 10 m each were wound individually onto a reel, next weighed on Tehtnica model 2615 analytical scales, and the mean value was calculated.

The number of twists was measured by the method of untwisting ply yarn components to parallelisation with the Guida Hahn torsion meter. 50 test pieces were measured from each yarn, and the mean value was calculated.

The capacitive method was used to test yarn unevenness, with the Kiesokki device, Evennes Tester 80 model, type B, Osaka, Japan. The yarn speed through the condenser was 50 m/min, and 500 m yarn of each yarn sample was tested. Thin places were registered under -35%, thick places above +35% and neps above +140%.

The Textechno dynamometer, Statimat M model, was used to test breaking force and elongation at break. The preliminary tension of the yarn tested was 0.5 cN/tex, and the break took place within 20±3 seconds. 100 measurements for each kind of yarn were carried out. The yarn tested after sizing was wound manually on a tube beforehand, and the method of testing was identical to the testing of the yarn before sizing. 100 test specimens before sizing and 100 specimens after sizing were tested. The preliminary tension of the yarn tested was 0.5 cN/tex. The period of breaking the yarn was regulated by speed, and reached 20±3 seconds, in accordance with standard HRN F.S2.052.

Table 2. Relationship of breaking forces, elongation at break and abrasion resistance for each sized and unsized sample.

Yarn code	Ratio of:					
	Breaking force sized/unsized		Elongation at break sized/unsized		Number of abrasion cycles sized/unsized	
	minimum	maximum	minimum	maximum	minimum	maximum
I/A	1.01	1.35	0.92	1.23	1.04	2.80
I/B	1.02	1.28	0.00	1.29	1.24	3.39
I/C	0.99	1.02	0.72	1.10	0.97	5.40
II/A	1.02	1.34	0.80	1.07	1.47	2.69
II/B	1.03	1.25	1.06	1.23	1.27	4.26
II/C	1.00	1.19	1.01	1.21	0.76	3.77
III/A	0.99	1.72	0.72	1.10	0.97	2.39
III/B	1.27	1.58	0.71	0.90	1.00	4.72
III/C	1.03	1.31	0.93	1.23	0.77	3.54
IV/A	1.00	1.22	0.83	1.20	0.57	1.31
IV/B	1.06	1.31	1.11	1.15	1.12	4.56
IV/C	0.98	1.07	0.86	1.08	0.90	3.94
V/A	1.01	1.29	0.78	1.22	0.95	2.84
V/B	0.96	1.12	0.87	1.18	1.11	5.08
V/C	1.03	1.33	0.76	0.96	0.81	3.21

Yarn abrasion is of great importance for defining yarn quality. By testing abrasion resistance, the sizing effect can be found out, and the quality and uniformity of sizing can be tested. The testing of yarn abrasion was carried out on the Zweigle abrasion tester. As there is no standard for abrasion testing, the manufacturer's instructions were applied. 20 threads were abraded simultaneously all the way to breaking; the number of strokes of the roller used to abrade causing each yarn breakage was registered . Abrasion was carried out by a roller coated with emery paper with the fineness of 800 P, on the yarn section of 7 cm [4,7].

The yarn was tested in an air-conditioned room (65±5% rel. humidity and 20±2 °C), so that it contained conditioned moisture during testing.

Test Results

The test results, appropriately elaborated, are presented in Table 2 and in Figures 2-8.

Discussion of Results

Figures 2 through 4 show the average values of breaking forces and elongations at break of yarn before sizing, and the minimum and maximum values after sizing respectively. The higher the breaking force and elongation at break of yarn before sizing, the higher the difference in relation to the sized yarn (Figure 2). The breaking force of yarn before sizing is higher than the minimum and lower than the maximum breaking force after sizing, and these differences are greater between the minimally sized and unsized yarn than the maximally sized and unsized one. That leads to the conclusion that the yarn of 20×2 tex nearly from all spinning mills has the same sizing performance. The breaking force mostly increased, and the greatest difference is registered on yarn sample III/A, specifically from 2.92 to 300.08 cN. The elongation at break on average was not changed by sizing, and its deviation after sizing is somewhat higher in the negative direction in relation to the elongation at break of the unsized yarn. It may be concluded that a change of elongation at break by sizing the yarn of 20×2 tex from different spinning mills is very similar, and no greater differences in deviation are discernible. The yarn marked III/A has the greatest reduction of elongation at break by sizing, but this yarn had the greatest difference in breaking force. It may be concluded that this yarn was weakest, with the lowest elongation at break before sizing, and by sizing its breaking force increased the most, but the elongation at break is lower than average. This led to a high breaking force, but unfortunately the elongation at break was lowered, causing the yarn elasticity that is indispensable for weaving to be lost.

The breaking force of the unsized yarn of 30×2 tex is lower in all samples than in a minimally sized yarn, meaning that all the samples acquired a higher breaking force by sizing, specifically from 21.03 to 377.53 cN (Figure 3). The differences between the breaking forces of unsized and sized yarns are lower for all yarn samples of 20×2 tex. It may be concluded that under the same sizing conditions. a coarser yarn acquires a lower breaking force than a finer one. Thanks to sizing, the elongation at break of yarn mainly increased or remained unchanged, except for sample III/B which mostly had

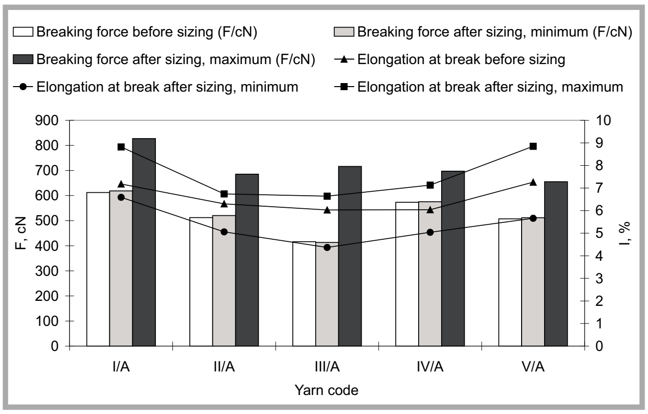

Figure 2. Average breaking forces and elongations at break of unsized yarn, and minimum and maximum values of the yarn of a count of 20×2 tex; I/A, II/A ... - yarns from different spinning mills, F - breaking force (cN), I - elongation at break (%).

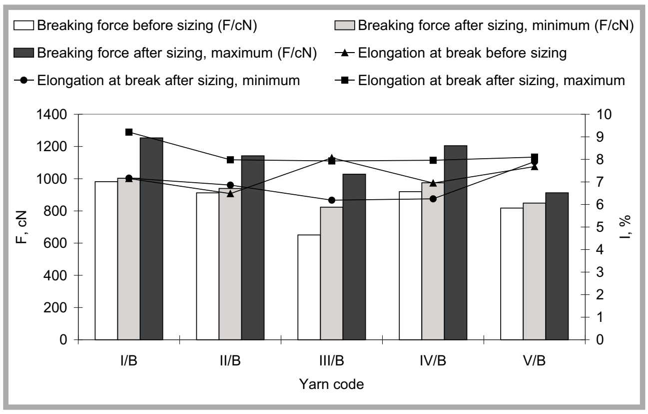

Figure 3. Average breaking forces and elongations at break of unsized yarn, and minimum and maximum values of the yarn of a count of 30×2 tex; I/B, II/B ... - yarns from different spinning mills, F - breaking force (cN), I - elongation at break (%).

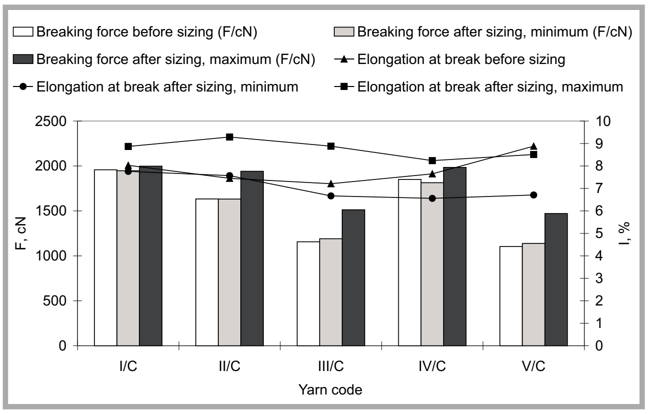

Figure 4. *Average breaking forces and elongations at break of unsized yarn, and minimum and maximum values of the yarn of a count of 50×2 tex; I/C, II/C ... - yarns from different spinning mills, F - breaking force (cN), I - elongation at break (%).*

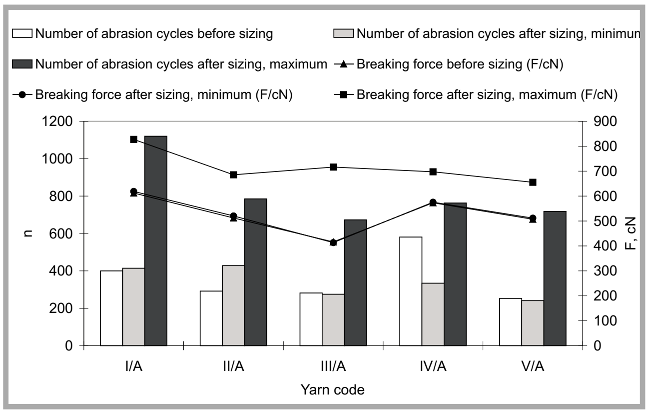

Figure 5. *Average breaking forces and number of abrasion cycles to the break of unsized yarn, and minimum and maximum values of the sized yarn of a count of 20×2 tex; I/A, II/A ... - yarns from different spinning mills, n - number of abrasion cycles to break, F - breaking force (cN).*

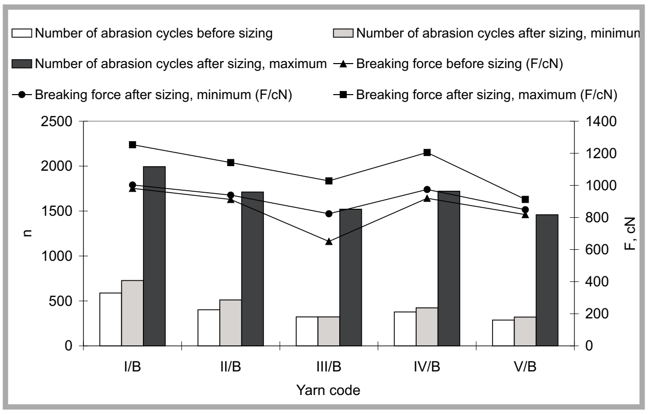

Figure 6. *Average breaking forces and number of abrasion cycles to the break of unsized yarn, and minimum and maximum values of the sized yarn of a count of 30×2 tex; I/B, II/B ... - yarns from different spinning mills, n - number of abrasion cycles to the break, F - breaking force (cN).*

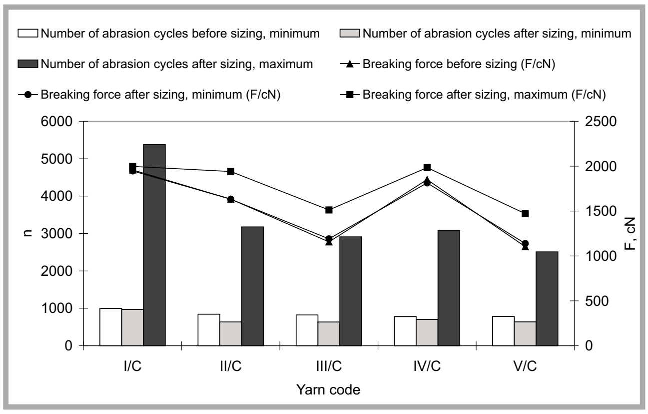

Figure 7. *Average breaking forces and number of abrasion cycles to the break of unsized yarn, and minimum and maximum values of the sized yarn of a count of 50×2 tex; I/C, II/C ... - yarns from different spinning mills, n - number of abrasion cycles to the break, F - breaking force (cN).*

a lower elongation at break in the sized yarn samples. The sizing effect is least visible in the V/B sample for breaking force and elongation at break, and the sample can be related to a relatively high twist level. It may be concluded that because of the sizing, the yarn of 30×2 tex from different spinning mills showed its difference in breaking forces and elongations at break, despite the same sizing conditions.

The breaking force of the yarn of 50×2 tex has the lowest difference before and after sizing, and there is practically no difference in sample I/C (Figure 4). But the elongation at break differs mostly between the samples before and after sizing, specifically between samples II/C and V/C. This difference is sought in different cotton fibres and spinning conditions. Figures 5 through 7 show the abrasion resistance of the yarn expressed by the number of abrasion cycles to break.

If the breaking force is compared before and after sizing to the abrasion resistance, a great similarity can be recognised (Figure 5). The breaking force of the yarn of a count of 20×2 tex is levelled out among the samples, and it has an increase and decrease identical to the number of abrasion cycles to break for each sample, meaning that by sizing the yarn, a comparable performance relative to breaking force and elongation at break is achieved irrespective of the yarns coming from different spinning mills or being produced from different cotton. The highest breaking force and largest number of abrasion cycles to break is noted in sample I/A. Deviations of the number of abrasion cycles to break between unsized and sized yarn are relatively great, and the minimum values of some samples are lower than the average values of the unsized yarn. It means that there are some places in the yarn of IV/A and V/A samples where abrasion resistance on the sized yarn is lower than on the unsized yarn, and that in these places the yarn was not protected, but was on the contrary weaker than before sizing. These places are prone to breaking when the yarn passes through drop wires, heald frames and the reed. It could be claimed that, in spite of a relatively high breaking force, the yarn cannot be satisfactory because of its weak abrasion resistance, i.e. the size recipe is inappropriate for the two aforementioned yarn samples. The abrasion resistance of other yarn samples increased by sizing, specifically over 100%.

The yarn of 30×2 tex acquired a multiple abrasion resistance by sizing, including all yarn samples (Figure 6). Abrasion resistance followed breaking force, meaning that at a higher breaking force abrasion resistance was higher. The minimum values of abrasion cycles to the break of sized yarn are nearly always higher

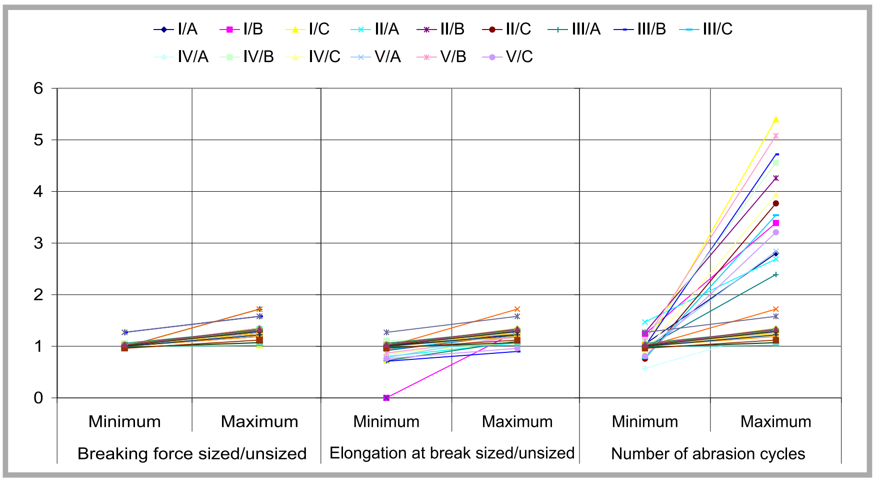

Figure 8. *Relationship of breaking forces, elongation at break and abrasion resistance for each sample (sized/unsized).*

than the average values of unsized yarn, meaning that the yarn increased abrasion resistance by sizing in all segments.

The yarn of 50×2 tex has the greatest abrasion resistance in sample I/C, including breaking force (Figure 7). The minimum number of abrasion cycles after sizing is mostly lower than for unsized yarns, meaning that there are places in the yarn after sizing that are weaker to abrasion resistance than the average abrasion resistance of the unsized yarn. However, the maximum values are many times higher than the ones before sizing for all the samples.

It may be concluded that yarn properties before sizing largely influences the properties after sizing. The difference in breaking forces is higher in finer yarn counts (20×2 tex), whereas the difference in elongation at break is higher in coarser yarns (50×2 tex). The sizing effect on abrasion resistance is mostly satisfactory. In coarser yarns (50×2 tex), there are places that are even less resistant to abrasion than average values before sizing.

The relationship of breaking forces in the samples (sized/unsized) ranges from 0.96 to 1.72, and there are no great differences among the samples (Figure 8). The relationship of elongations at break in the samples (sized/unsized) ranges from 0 to 1.23, and there is a slight difference among the samples, especially sample I/B.

The relationship of abrasion resistance in the samples (sized/unsized) ranges from 0.57 to 5.08, and there is a slight difference among the samples, especially sample IV/A, where this relationship is smaller, and the straight line has a different direction of inclination.

By this test it may be concluded that there is a certain difference in yarn properties among the samples after sizing, caused by different deviations of yarn properties before sizing, despite the same sizing conditions, the same raw material composition and yarn fineness. It emphasises the complexity of the matter where the optimisation of sizing should be regarded as a complex problem. Thus, optimum size coat can be defined by a long-term detailed analysis for each yarn, as well as by processing, sizing and weaving conditions.

Conclusion

- Yarn quality generally increases by sizing. A change in breaking force, elongation at break and abrasion resistance by sizing does not depend only on the sizing conditions, but also on the yarn properties before sizing. In addition to the breaking force, which is very important in the weaving process, it is necessary to emphasize that elongation at break, abrasion resistance etc. largely depend on the fibre and yarn properties, and on the conditions of processing the yarn for weaving.
- Greater fluctuations of some yarn properties before sizing affect yarn properties after sizing. The yarn of the same count and raw material composition, yet spun in different spinning mills and with different properties and fibre provenance, mainly possesses different properties. As a result this difference remains after sizing in all three parameters investigated, namely in breaking forces, elongation at break and abrasion resistance.
- The greatest increase in breaking force by sizing is registered in finer yarns, but also the most level increase considering the samples of the same count. Elongation at break of yarn by sizing deviates more in coarser yarns.
- Abrasion resistance of yarn by sizing has increased considerably, but with great deviations, so that places sometimes occur on coarser yarns which have a lower abrasion resistance than the yarns before sizing.
- This investigation aims to stress the importance of optimising size coat to achieve as high a production as possible in weaving and product quality. It is emphasised that significance and complexity towards the standardisation of sizing in order to produce high-grade yarns are very important.

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