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A New Pre-Wet Sizing Process – Yes or No?

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1. Introduction

As one of the most complex steps in fabric production, sizing plays a very important role in the weaving process. The primary purpose of the sizing process is to obtain the warp threads that can successfully be woven without major damages which occur during the yarn passage through sliding metal parts of the weaving machine (Lord, 2003). It applies to the improvement of physical and mechanical parameters of warp threads, primarily to increase strength and abrasion resistance and thus to reduce the number of warp breaks to a minimum in order to achieve the maximum efficiency of weaving machines and energy savings. Also, the goal of sizing is to keep the fibers in the yarn in a position where they were before sizing, with minimal yarn deformations during weaving. The success of the weaving process depends on the complexity of several factors including the characteristics of the desired material, the sizing process, the sizing ingredients and yarn properties, but also the extensive knowledge of a textile technologist (chemistry, rheology, electronics, mechanical engineering, physics, mechanics, mathematics, etc...), which makes this process more difficult and more important for the overall process of making woven fabric (Adanur, 2001). Today's achievements in all engineering branches enable an exceptional progress of the sizing processes to achieve a very high quality of sizing that meets the needs of today's modern weaving. However, the sizing costs, despite the complete automation of the regulation and control of the most important sizing process parameters, are still very high. Their reduction is possible by reducing the consumption of sizing agents and energy, as well as by modernization and development of machinery and technology, and all without consequence on the quality of the sized yarn. The choice of sizing agents plays the most important role in meeting all the requirements placed on the sizing process and sized yarn as well as optimizing and keeping the sizing process conditions and the size pick-up constant (Kovačević et al., 2006). Even today the optimization of the size pick-up applied to the yarn presents a major problem in the sizing process, despite the high degree of automation and high quality sizing agents. Influential parameters in the optimization of size pick-up are defined with the substance balance that enters and exits the size box (Equation 1). The requirement of keeping the size pick-up optimized and constant can be achieved by continuous measuring and keeping temperature and yarn moisture, size concentration in the size box constant, as well as automatic regulation of squeezing force and sizing speed (Pleva & Rieger, 1992; Soliman, 1995).

$$S_p = \frac{W_{Sp} - W_H}{\frac{100}{C} - 1 - \frac{W_{Sp}}{100}} \quad (\%) \quad (1)$$

Where: S_p - size pick-up, W_H - warp moisture at the box entry (%), W_{Sp} - warp moisture at the box exit (%), C - size concentration in the box (%)

Both, sizing conditions and yarn parameters affect yarn size pick-up. If the yarn is in some sections "more closed" with fewer interspaces among fibers or with more twists, the absorption of size in this section will be lower, resulting in a lower size pick-up on the yarn, despite constant sizing conditions. During the sizing process two types of forces are needed to be overcome: the forces of surface tension (wetting) and the forces of diffusion (Goswami, 2004). Penetration of the liquid (wetting) occurs in two phases:

1. penetration of the liquid into the capillary spaces between the fibers in the yarn (during which two forces have to be overcome - the difference between the pressure of enclosed air and surrounding liquid, and tension forces of the interface between fiber and water)
2. penetration of liquids into the fiber, i.e. extrusion of air bubbles and filling those spaces with a liquid.

Also a big unknown in size pick-up optimization is the sizing of wet warp, as well as the entire pre-wet sizing process. All previous knowledge of pre-wet sizing points to the obtainment of outstanding results, relevant physical-mechanical properties, reduction of consumption in sizing agents and energy, and an increase in weaving productivity (Hyrenbach, 2002; Rozelle, 1999, 2001; Sherrer, 2000). Therefore, this chapter aims to bring knowledge of the pre-wet sizing process by its analysis and by making a comparative analysis of the standard sizing process. The goal is to prove that there are a number of justified reasons for a new technological process, and to highlight the advantages and also disadvantages and possible improvements of better physical-mechanical properties of the yarn, reduction of size and energy consumption and increase in weaving productivity (Gudlin Schwarz et al. 2010, 2011).

2. Sizing machine

The pre-wet sizing process is still a rather unexplored area and not confirmed by scientific research. The most important reason why this research area has remained unexplored and with such a poor representation of this topic in scientific work is aggravated laboratory samples processing. Thanks to the laboratory sizing machine (Fig. 1) designed and constructed at the Faculty of Textile Technology, University of Zagreb, Croatia (whose segments are sizing box and dryer - which represents two consensual patents No.: PK20070247 and PK20070248, registered at the Croatian State Intellectual Property Office) both sizing processes - standard sizing process and pre-wet sizing process were able to be carried out. It consists of a creel for cross wound bobbins, with the possibility of tension regulation, two boxes - a box for pre-wetting with hot water and a size box, and a dryer. The pre-wetting box consists of a pair of immersion rollers and a pair of rollers for squeezing out excess water. The size box consists of a working box with two pairs of immersion rollers and two pairs of rollers for size squeezing, as well as a pre-box that allows to keep size levels in the working box constant, namely continuous size circulation from the working box to the pre-box with natural flow, and from the pre-box to the working box using a pump. During the sizing process it is possible to keep water temperature constant in

the pre-wetting box and size temperature in the size box with integrated heaters and thermostats, which indirectly warm up the water and size through the walls of the boxes. Thread tension was measured during the sizing process at the box entry, while warp moisture was measured at all important places: at the box entry, between two boxes - the pre-wetting box and size box, at the size box exit and after the dryer. Drying the sized yarn is preformed by contact, moving it across the two heated cylinders of the contact dryer. It is also possible to regulate and keep the sizing speed constant using the winder of the sized and dried yarn, as well as the speed regulator (Gudlin Schwarz et al. 2010, 2011).

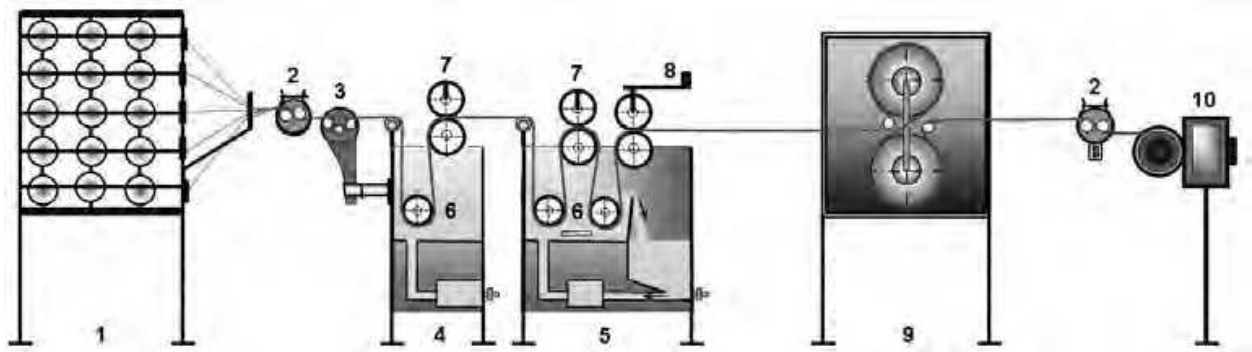


Fig. 1. Laboratory sizing machine (constructed on Faculty of Textile Technology, University of Zagreb, Croatia): 1 - creel for cross wound bobbins, 2 - moisture contact measuring device, 3 - thread tension measuring device, 4 - pre-wetting box, 5 - size box, 6 - rollers for immersing yarn into water and size, 7 - rollers for water and size squeezing, 8 - regulation of the pressure of the last squeezing roller, 9 - contact dryer, 10 - winder of the sized yarn

3. Testing methods and materials (yarn and size)

Sizing is a process which can be carried out on yarns of different raw material composition, and in this case it was 100% cotton carded ring spun yarn with a nominal count of 20 tex and with certain properties shown in Table 1.

Parameters		Yarn
Tt _n (tex)		20.00
Tt _r (tex)		18.55
Parameters of unevenness (400 m/min)	CV (%)	16.01
	Thin places	11.50
	Thick places	95.50
	Neps	208.00
T (twists/m)	\bar{x}	913.04
	CV	5.20
H (number of protruding fibers)	\bar{x}	20428.00
	CV	2.30
A (number of cycle)	\bar{x}	80.76
	CV	9.39
F (cN)	\bar{x}	281.69
	CV	6.78

Parameters		Yarn
E (%)	\bar{x}	3.83
	CV	7.26
W (cN×cm)	\bar{x}	292.75
	CV	13.08
σ (cN/tex)	\bar{x}	15.19
	CV	6.78

Table 1. Properties of unsized yarn; where : Tt_n - nominal count (tex), Tt_r - real count (tex), T - twist (twist/m), H - hairiness (No. of protruding fibers longer of 1mm from the yarn surface), A - abrasion resistance (No. of cycles), F - breaking force (cN), ϵ - elongation at break (%), W - work to rapture (cN×tex), σ - tenacity (cN/tex), CV - coefficient of variation, \bar{x} - mean value

As it was mentioned above, for a successful sizing process right choice of sizing agents and size preparation are of great importance, depending on yarn (fiber) type, origin of the sizing agent, different sizing auxiliaries, and the requirements of the sizing process itself. (Vassallo, 2005; Zhu, 2003). In the presented example and based on these needs, two different recipes with different concentrations were used in both sizing processes, as shown in Table 2.

Compounds	Recipe	Concentration
1. Water	Recipe 1 - R 1	7.5%
2. Sizing agent based on polyvinilalcohol (PVA)		
3. Sizing auxiliaries composed of natural fats and waxes with a specific emulsifier system	Recipe 2 - R 2	5.0%

Table 2. Characteristics of the sizing agents and auxiliaries, and size recipes

Sizing conditions are exactly defined and held constant during both sizing processes, and are shown in Table 3.

Sizing condition	
Thread tension between creel for cross wound bobbins and pre-wetting box	40 cN
Temperature of water in the pre-wetting box	65°C
Size temperature in the size box	75°C
Sizing speed	3 m/min
Pressure on the last pair of the rollers for squeezing excess size	19.1 N/cm ²
Temperature on the cylinders of the contact dryer	140°C
Output moisture	6 %

Table 3. Sizing conditions

To test the samples before and after sizing, standardized methods were used. Thus, the real count of yarn was tested according to HRN ISO 2060:2003, while yarn unevenness was tested on an Unevenness tester 80, type B, Keisokki Company. The breaking properties (breaking force, elongation at break, work to rupture and tenacity of yarns) were tested on a Statimat M made by Textechno according to ISO 2062. Yarn hairiness was tested before and after sizing by recording the fibers protruding from the yarn structure using a Zweigle G 565 hairiness meter according to ASTM D 5674-01, while the twists were tested by means of a MesdanLab Twist tester according to ISO 17202. Abrasion resistance tests were performed on a Zweigle G 551 abrasion tester before and after sizing, where each of 20 types of thread loaded with a weight of 20g was subjected to the abrasion process until thread breakage. The movement of the cylinder coated with emery paper (fineness 600): left - right and its rotation around its axis achieves certain abrasion intensity in the yarn and emery paper. During the process the yarn weakens, and at the moment when the mass of the weights hung on the yarn overcomes the yarn strength, a break occurs, and the number of roller movements until breaking the yarn is recorded.

The determination of the size pick-up can be performed in several ways, but for the purposes of this study the gravimetric method was used. The implementation process of this method is as follows: before sizing the samples were dried to absolutely dry, after which they were weighed, and then returned to climatic conditions and sized; after sizing the samples were again dried to absolutely dry and weighed (Kovačević et al., 2002). The amount of size pick-up is calculated using Equation 2:

$$Sp = \frac{G_S(g) - G_U(g)}{G_U(g)} \cdot 100 \quad (\%) \quad (2)$$

Where: Sp (%) - amount of size pick-up

G_S (g) - mass of absolutely dry sized yarn

G_U (g) - mass of absolutely dry unsized yarn

4. Testing methods and materials (yarn and size)

4.1 Yarn breaking properties

The most prominent mechanical properties of yarn are primarily breaking properties, which include: breaking force, elongation at break, work to rupture and tenacity. These parameters show us some of the most important yarn characteristics for the weaving process, and the positive impact of sizing to those properties is also one of the most relevant role of the sizing process. Sizing pursued to a greater increase in breaking force and at the same time in a less decrease in elongation at break, which in turn depends on the size pick-up and size distribution in the yarn (Gudlin Schwarz et al. 2011; Kovačević & Penava, 2004).

Figure 2 shows an F-E diagram of unsized yarn and yarns sized with two different size recipes R1 and R2, where the differences in force (F) and elongation (ϵ) between the yarns subjected to different processing methods can be clearly seen.

The values of breaking force of the tested samples are shown in Figure 3a, where a very small difference between the sized yarns occurs, with an average increase of almost 40%

compared to the unsized yarn. The only yarn that shows a deviation from the others in the form of a small increase in breaking force (of only 32%) is the yarn sized with R2 and the pre-wet sizing process.

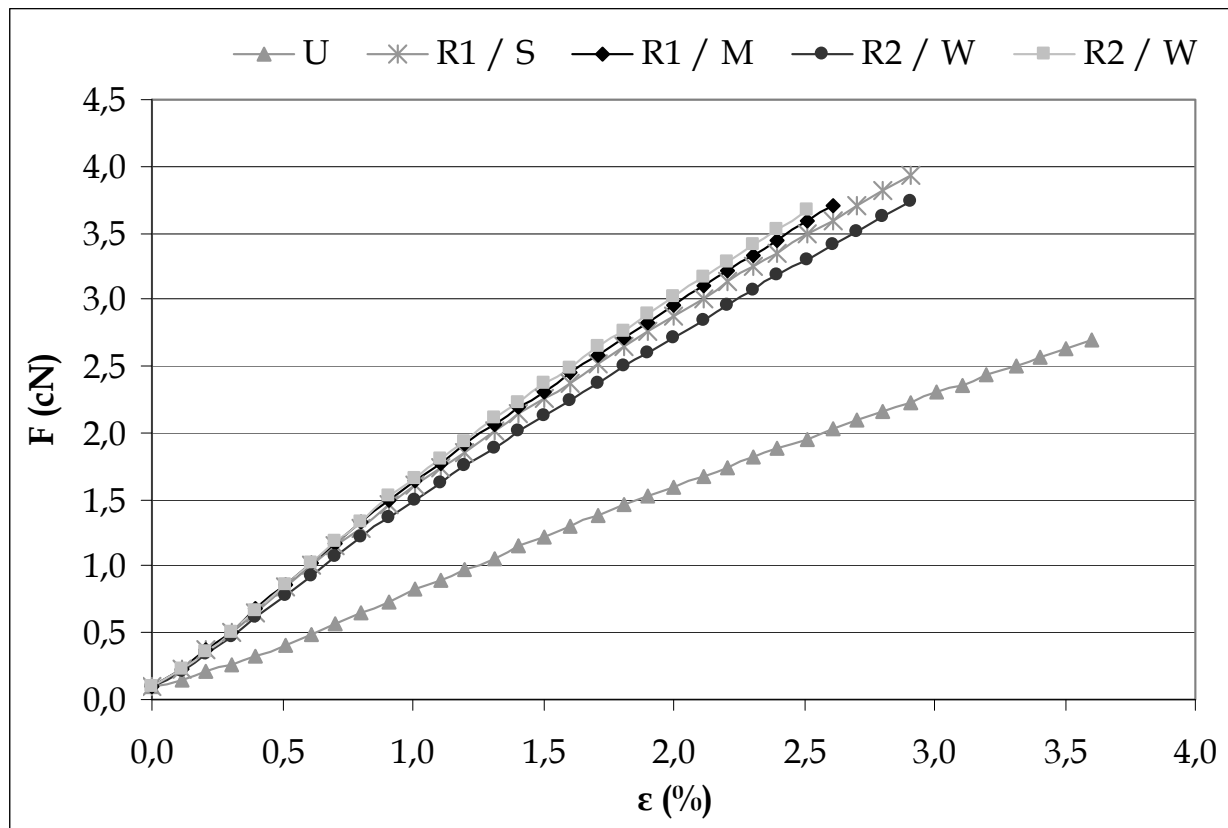


Fig. 2. F-E diagram of unsized yarn and yarns sized with recipes 1 and 2, by standard sizing process and pre-wetting sizing process; where: U - unsized yarn, R1 - yarn sized with recipe 1, R2 - yarn sized with recipe 2; S - standard sizing process, W - pre-wetting sizing process

Generally, by using the sizing process the elongation at break reduces and therefore represents the disadvantage of this process. The values of the elongation at break of the tested yarns are shown in Figure 3b, where the results are divided into two groups with almost identical values: the yarns sized with the standard process, which shows a decrease of almost 20%, and those sized with the pre-wet sizing process, with a decrease of almost 25%, compared to the unsized yarn.

In Figure 3c, which shows the results of work to rupture, are presented the uniform values within one sizing process, where a larger increase by 12% is recorded in the yarns sized with the standard process than in the yarns sized with the pre-wet sizing process, where the values increase by 4% for the yarn sized with R1, while the yarn sized with R2 records even a slight drop by only 3% compared to the unsized yarn.

Tenacity is a parameter that brings into relation yarn finesses and force, and the values obtained are shown in Figure 3d. The values of the sized yarns are quite consistent with an increase by nearly 33% for the yarn sized with the standard process, and by 31% for the yarn sized with the pre-wet sizing process.

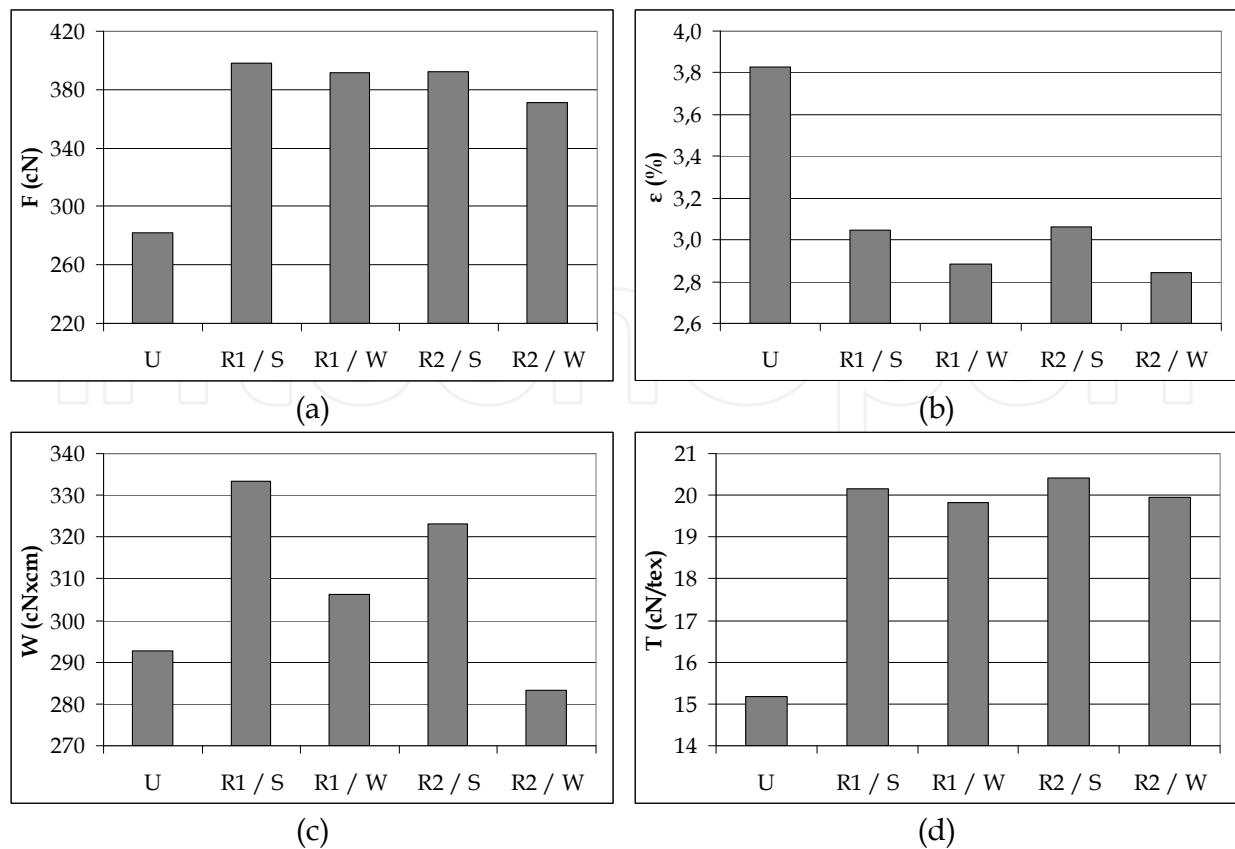


Fig. 3. Diagrams of breaking properties of the unsized yarn and the yarns sized with recipe 1 and 2 by the standard sizing process and the pre-wetting sizing process

4.2 Yarn hairiness and abrasion resistance

Yarn hairiness and abrasion resistance are parameters which are extremely important for the weaving process, which are greatly improved by a successful sizing process. Hairiness, i.e. the number of protruding fibers, is reduced by sizing, and the abrasion resistance is increased, which affects the reduction in friction resulting from the thread passing through the metal elements of the weaving machine and, therefore, the number of thread breaks in the weaving process (Gudlin Schwarz, 2011).

Figure 4a shows the values of the tested hairiness for the unsized yarn and the yarns sized with both processes and with both recipes. Yarn hairiness reduction sized with both processes is very similar, and amounts to 78% for the yarns sized with the standard process, and 81% for the yarns sized with the pre-wet sizing process compared to the unsized yarn.

The value diagram of the abrasion resistance of the unsized yarn and the yarn sized with both procedures and with both recipes is shown in Figure 4b. It is interesting that the yarns sized with both processes but with a higher concentration of size (R1) show good results in terms of increasing the abrasion resistance compared to the unsized yarn. The yarns sized with the standard process recorded an increase by even 68%, while the yarns sized with the pre-wet process showed almost half an increase by only 36%. Regarding the samples sized with a smaller size concentration (R2) with both processes, a notable decrease in abrasion resistance compared to the unsized yarn is recorded, namely by 4% for the yarns sized with the standard process, and by 14% for the yarn sized with pre-wet process. This phenomenon, in spite of the size pick-up which strengthens the yarn, is attributed to the

yarn extension that occurs during sizing, and it is greater in sizing with a lower size concentration (R2).

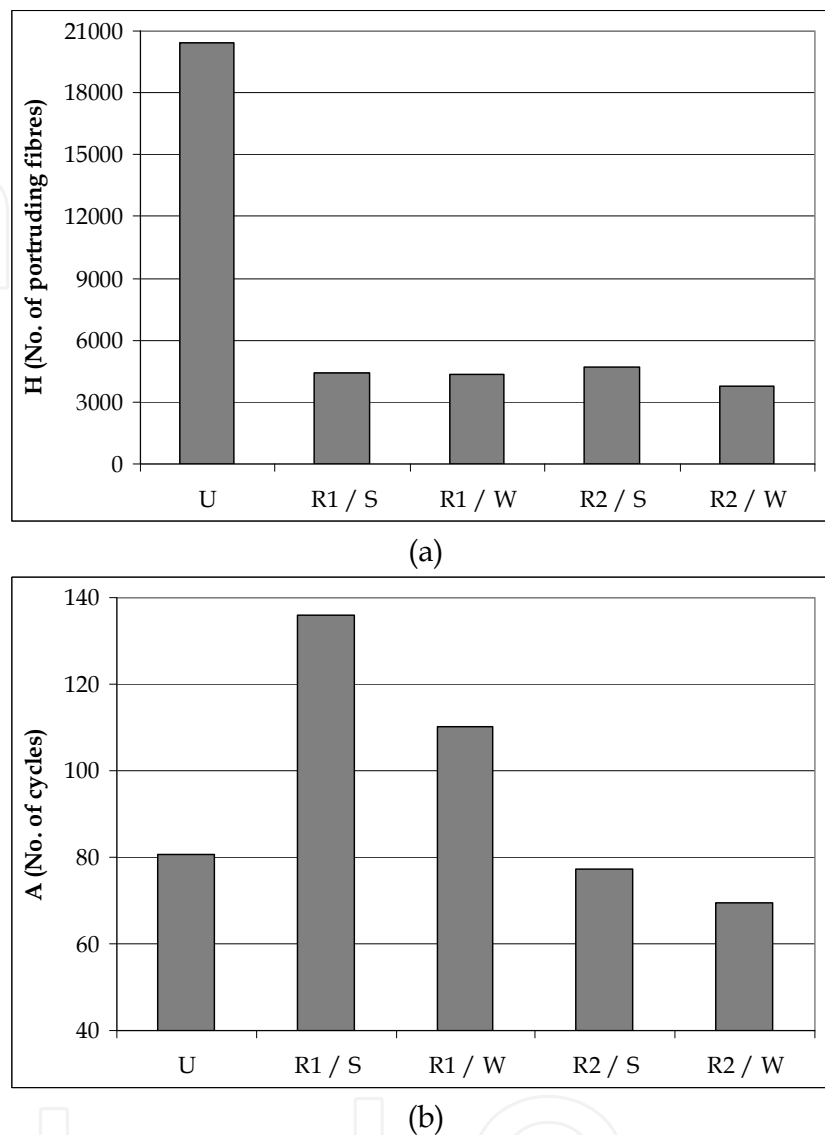


Fig. 4. Diagram of hairiness and abrasion resistance of the unsized yarn and the yarns sized with recipe 1 and 2 by the standard sizing process and pre-wet sizing process

4.3 Yarn extension

In the sizing process warp tension is a very important and unavoidable parameter, which in turn causes extension (visible even at a minimum tension) and thus the deformation shown by changes of mechanical properties. The appearance of yarn extension during the sizing process is unfortunately a reality that can not be avoided despite the minimum warp tension in segments when the warp is the most sensitive and that is in the wet state. The sensitivity of wet yarn begins with the entry into the size box and lasts until the exit from the dryer. The greater the yarn tension and its length in those segments, the higher is the yarn extension. During the pre-wet sizing process the yarn length in the wet state additionally increases between the pre-wetting box and the size box, which further increases tension

sensitivity, and thus susceptibility to extension and deformation. Yarn unevenness also affects extension properties to a great extent, where thin and thick places represent weaker yarn parts which are more sensitive to tension, especially in the wet state (Gudlin Schwarz, 2010). Similarly, the values shown in Figure 5 indicate that the elongation is higher during sizing with a lower size concentration (R2) in both sizing processes.

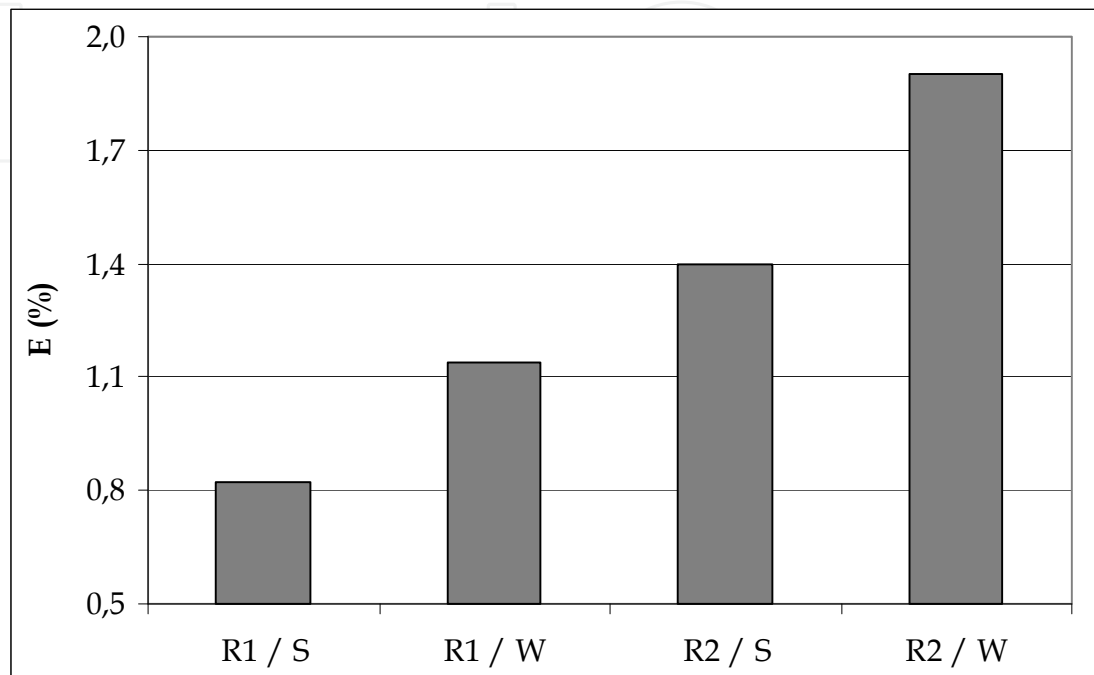


Fig. 5. Diagram of extension of yarns sized with recipe 1 and 2 by standard sizing process and pre-wet sizing process

4.4 Size pick-up of yarn

As stated in the introduction, optimizing the size pick-up to achieve the maximum utilization of the sizing process represent the biggest challenge in the whole process (Kovačević et al., 2002). The obtained results indicate that the amount of size pick-up and its distribution determine many features of sized yarn properties.

Figure 6 shows the value of the amount of size pick-up on the yarn. A small difference between the yarns sized with R1 by both sizing processes is easily observable. Significant differences are evident in the yarn sized with R2 in both processes, where an almost equal difference in reduced size pick-up (an average of 50%) between the standard sizing process (R2/S) and the pre-wet sizing process (R2/W) is maintained.

The yarn sized with lower size concentrations showed very good results in all important properties in terms of no significant deviations (in spite of a lower amount of size pick-up on the yarn) in relation to the yarn sized with a higher size concentration. This phenomenon is particularly interesting for the yarn sized with the pre-wet sizing process, where the amount of size pick-up on the yarn is considerably lower (due to water filling the interior of the yarn and the different distribution of the size pick-up on the yarn), than on the yarn sized with the standard process, indicating a reduced consumption of sizing agents and resulting in great savings (Sejri et al., 2008, 2011).

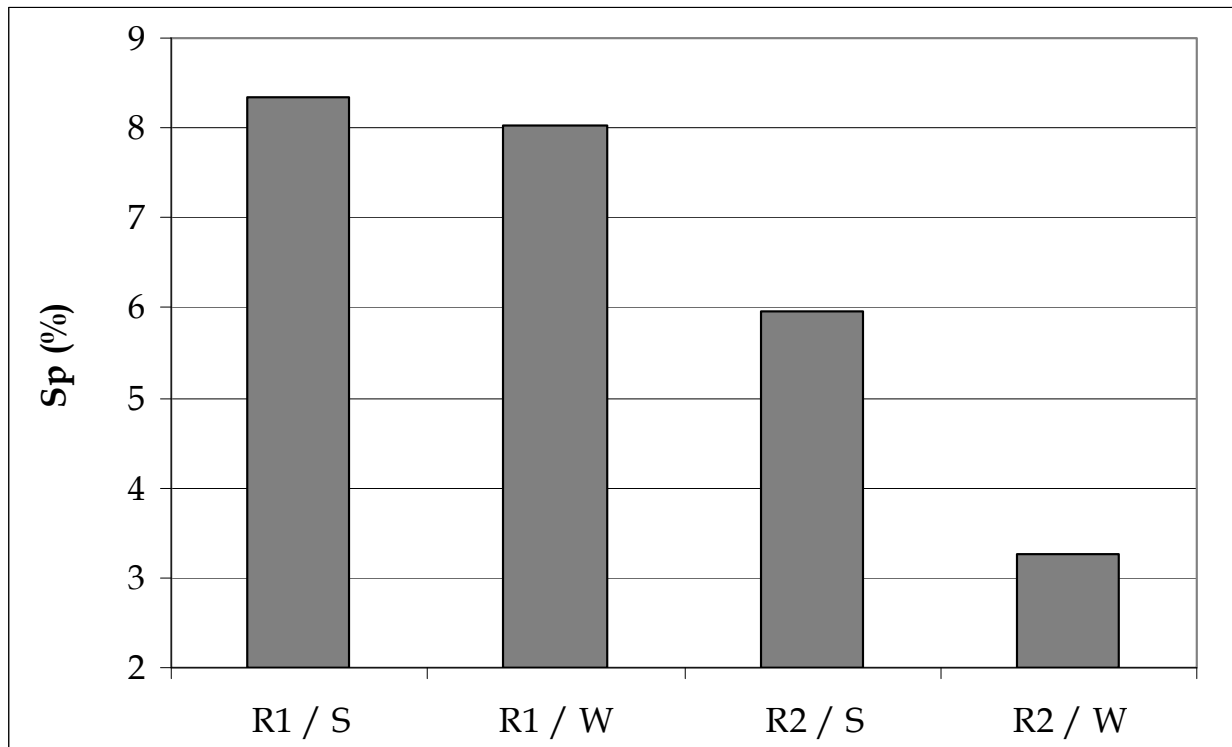


Fig. 6. Diagram of size pick-up (Sp) on the yarns sized with recipe 1 and 2 by the standard sizing process and the pre-wet sizing process

4.4.1 Distribution of size pick-up on yarn

As already mentioned, the pre-wetting sizing process differs from the standard sizing process in the construction of the sizing machine, where another pre-wet box with hot water is installed in the front of size box. The importance of the pre-wetting box is in soaking the yarn in hot water (60-70°C) before entering the size box, which enables the dissolving and removal of grease and other impurities and additives present in the raw yarn. Furthermore, in the phase of pre-wetting, it comes to wetting the yarn in water, i.e. to fill interstitial spaces in the interior of the yarn with water, and after squeezing the excess water the yarn remains wet and partially filled with water. As such, it enters the size box with much higher humidity than it is the case with the yarn in the standard sizing process where it enters the size box dry. Therefore, the contact of the retained water in the yarn with size leads to very rapid mutual bonding, allowing faster and easier penetration and diffusion of the size into the yarn. However, the size concentration in the interior of the yarn is lower than the size concentration in the size box, because the water remained in the interior of the yarn after wetting diluted it. Therefore, the greater part of the size remains on the surface of the yarn. When sizing the dry yarn, penetration of size into the interstitial yarn spaces is not as rapid as in the case of wet yarn, and thus the inner part remains almost unfilled with size, while around or on its periphery a solid size coat is formed, unlike the yarns sized with the pre-wetting sizing process, where the size pick-up on the yarn periphery does not form such an intensive solid size coat (Fig. 7-9) (Gudlin Schwarz, 2011; Johnen, 2005).

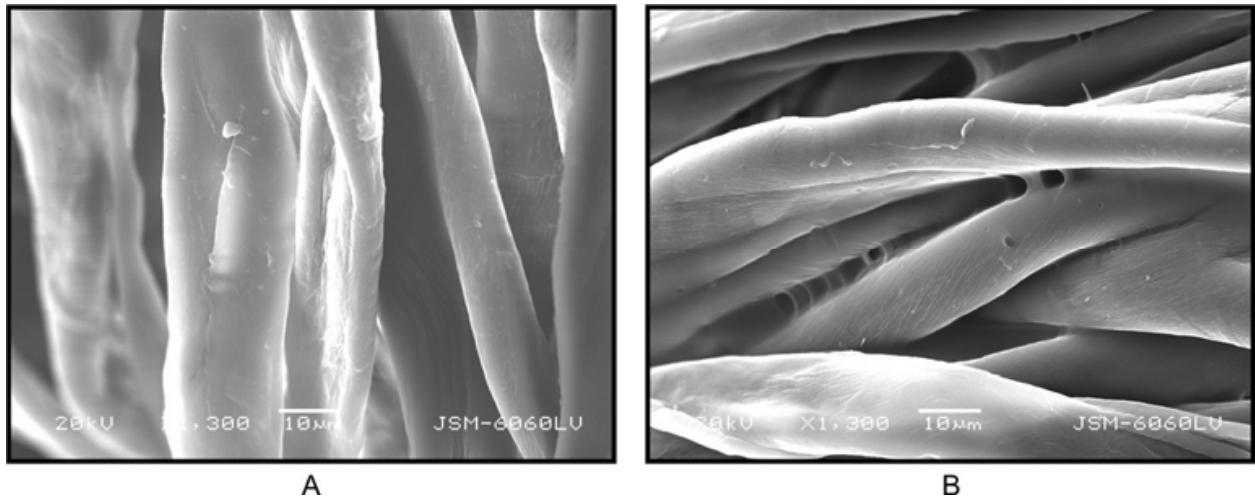


Fig. 7. Microscopic longitudinal-section image of the yarn sized with the standard sizing process (A) and with the pre-wetting sizing process (B); SEM microscopy JSM - 6060LV

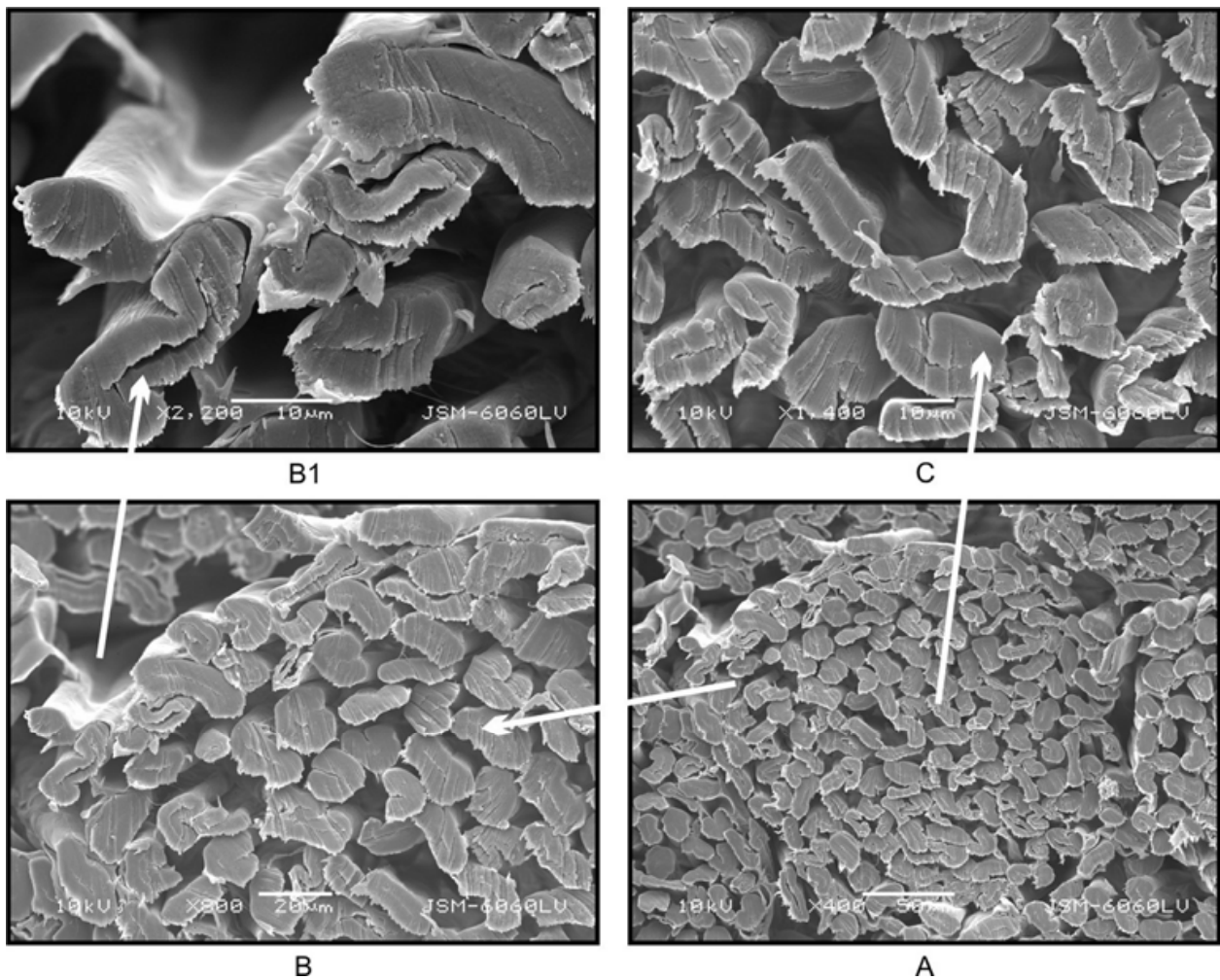


Fig. 8. Microscopic cross-sectional image of the yarn sized with the standard sizing process (A - view of the entire yarn, B, B1, - enlarged representation of the periphery of the yarn, C - enlarged representation of the centre of the yarn); SEM microscopy JSM - 6060LV

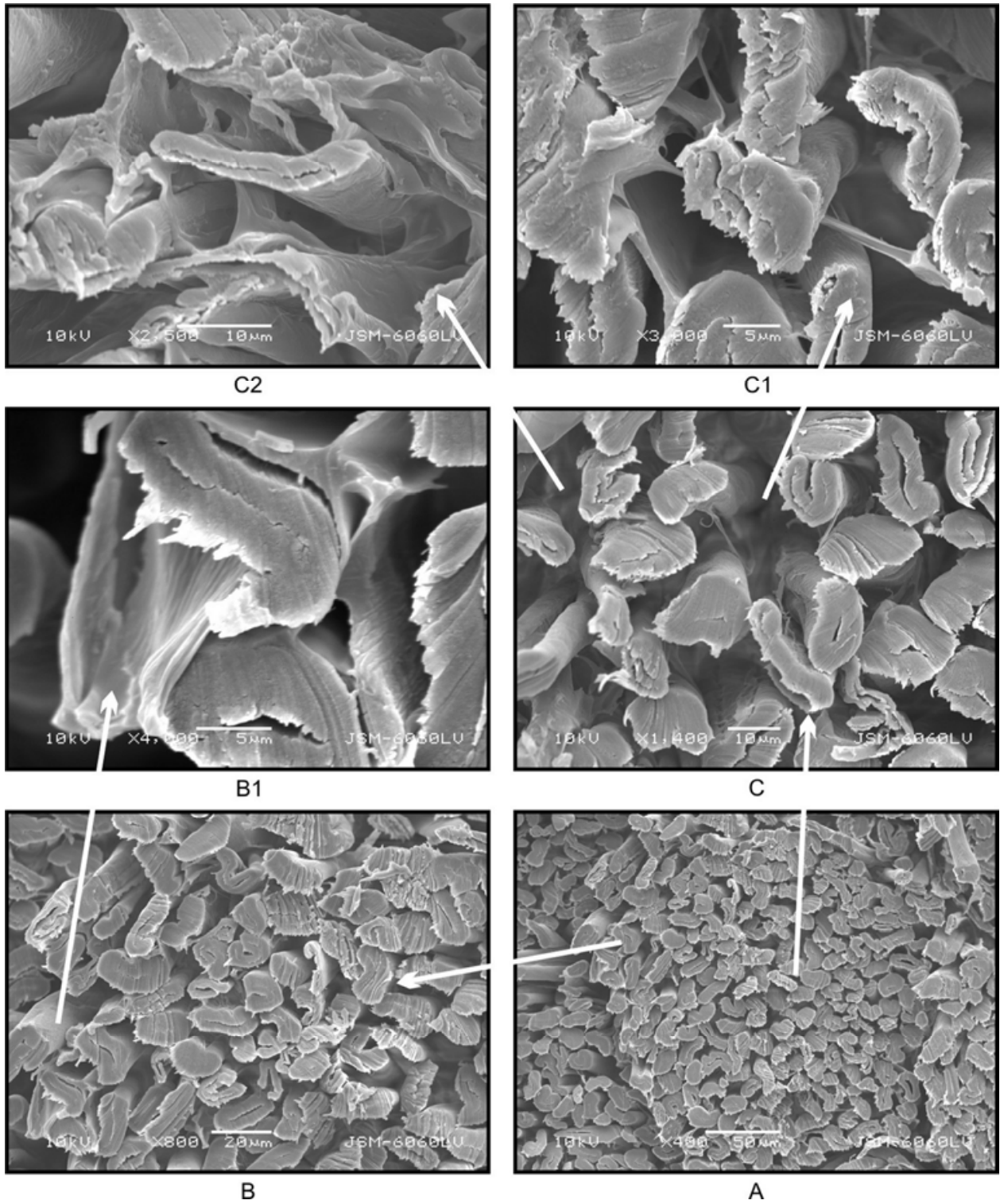


Fig. 9. Microscopic cross-sectional image of the yarn sized with the pre-wetting sizing process (A - view of the entire yarn, B, B1, - enlarged representation of the yarn periphery, C, C1, C2 - enlarged representation of the yarn centre); SEM microscopy JSM - 6060LV

5. Conclusion

Existing knowledge as well as the results of the conducted research shows that there is no big difference in the sized yarn properties obtained with the two processes, relevant for further process of making woven fabrics, while some properties of the yarn sized with the pre-wet sizing process are even noticeably better. Each of these processes brings certain advantages and disadvantages. The standard sizing process is a generally well-known, accepted and ubiquitous process in the textile industry. But of great significance is the fact that the replacement of the standard process in terms of upgrading and installing a part of the sizing range necessary for the implementation of the pre-wet sizing process does not require complex procedures or large financial expenditure. All these indicators are of great importance for the new sizing process, which give this process a priority over the standard sizing process in view of the possibility to reduce costs (size, water and energy costs - both for the sizing process and desizing process), with no negative impact on the properties of the sizing process nor on the quality of the sized yarn, including exceptional significance for the environmental aspect of the overall process.

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