Ivana Gudlin Schwarz,
Stana Kovacevic,
*Krste Dimitrovski

Comparative Analysis of the Standard and Pre-wet Sizing Process

University of Zagreb,
Faculty of Textile Technology,
Prilaz baruna Filipovica 28a, 10000 Zagreb, Croatia,
e-mail: ivana.schwarz@ttf.hr,

*University of Ljubljana,
Faculty of Natural Sciences and Engineering,
Snezniska 5, 1000 Ljubljana, Slovenia

Abstract
The aim of this paper is to show, using comparative analysis, all the differences, as well as existing advantages and disadvantages of two different sizing procedures. Materials used in the implementation of this extensive research are ring-spun cotton yarns, sized with PVA size. Test parameters of the yarn were analyzed, subjected to statistical analysis and compared. All the knowledge obtained is supported by a detailed analysis of microscopic cross-sectional images of unsized yarns and those sized with both processes, where differences between the two sizing processes in the distribution of size pick-up on the yarn are distinctly observable. The whole research, which is based on proving the technological justification and optimisation of pre-wet sizing, lead to the conclusion that it is a really exceptional technological process, which greatly contributes to large savings of sizing agents, water, energy and environmental protection, without any consequences for the quality of sized yarn.

Key words: *pre-wet sizing, standard sizing, ring-spun cotton yarn, mechanical properties, size pick-up.*

Introduction

As one of the most complex steps in fabric production, sizing plays a very important role in the weaving process. It improves the physical-mechanical parameters of warp threads, thus reducing warp breakage to a minimum, and achieves the maximum degree of weaving machine efficiency and energy savings. In order to fulfill these requirements, the choice of sizing agents is extremely important, as well as optimising and maintaining sizing process conditions and the size pick-up constant. Even today the optimisation of size pick-up applied to yarn presents a major problem in the sizing process, despite the high degree of automation and high quality sizing agents. Influential parameters in the optimisation of size pick-up are defined by the substance balance that enters and exits the size box (***Equation 1***). Using continuous measurements and maintenance of the temperature and sizing concentration in the size box, as well as automatic regulation of the squeezing strength and sizing speed, it is possible to define and maintain the size pick-up constant. Size pick-up can be controlled by the regulation of warp moisture at the box exit, which can be affected by the pressure of the last squeezing rollers. The requirement of maintaining the size pick-up constant, except the substance balance, is to maintain the other parameters affecting the size pick-up constant, such as the size temperature, sizing speed, thread tension etc. [1 - 4].

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

where S_P is the size pick-up, W_H - warp moisture at the box entry in %, W_{Sp} - warp moisture at the box exit in %, and C is the size concentration in the box in %.

Uniform sizing guarantees very high weaving machine efficiency and reasonable costs of fabric manufacturing. To achieve this goal, it is necessary to control as many parameters as possible during sizing and to regulate them automatically. Besides the above-listed parameters for optimising and maintaining the size pick-up constant, the viscosity of size, levels and circulation of size in the box, sizing agents, conditions of size preparation and yarn properties are also important. It is believed that the optimal size pick-up is the one that will allow minimum warp thread breaks on the weaving machine as well as satisfactory efficiency of the weaving machine and fabric quality, respectively. According to ***Figure 1***, the optimal size pick-up is slightly higher than the minimum because the precision and uniformity of size pick-up is very hard to achieve, especially on single cotton yarn, which is mostly sized.

A big unknown in size pick-up optimisation is the sizing of wet warp, as well as the entire pre-wet sizing process, which differs from the standard sizing process in the construction of the sizing range, where another box for pre-wetting with hot water is added in front of the size box. The essence of the box with water is that before entering the size in the size box, the yarn is dipped in hot water (60 - 70 °C), which enables the dissolution and removal of grease as well as other impurities and additives that are left on the raw yarn. Wetting the yarn allows to fill the interspaces of the yarn with water, where after squeezing out excessive water, the yarn remains wet and partially filled with water. By immersing such wet yarn in size, the water retained in the yarn comes into contact with the size, which leads to a very quick mutual bonding, allowing faster and easier penetration of the size into the yarn compared to dry yarn, which is immersed directly into the size. However, the size concentration in the yarn is lower than the size concentration because of the water retained in the yarn after wetting, which dilutes it. Therefore, a larger part of the size pick-up is retained on the yarn surface. When sizing is carried out on dry yarn, the size also penetrates into interspaces in the yarn, but not with the same speed at which size penetrates during the sizing of wet yarn, hence the inner part of the yarn remains

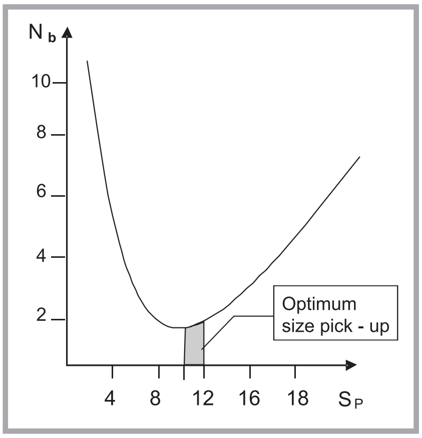


Figure 1. *Effect of size pick-up on the number of warp threads breaks on a weaving machine with optimum size pick-up; where N_b is the number of warp thread breaks per machine and per hour, and S_p is the size pick-up.*

almost size-free, while on the periphery a solid size mantle is created. All previous knowledge of pre-wet sizing points to the obtainment of outstanding results, relevant physical-mechanical properties, a consumption reduction in sizing agents and energy, and an increase in weaving productivity [5 - 9].

Different size recipes and size concentrations, respectively, are an important parameter in the optimisation of the standard sizing process and that with pre-wetting. This parameter reflects greater or smaller differences in the physical-mechanical properties of yarns sized by both processes, which is very important for this study in terms of highlighting the advantages of the pre-wet sizing process (possible additional size, water and energy cost reduction, as well as a lack of a negative impact on the sizing process and sized yarn).

The aim of this research was proving the technical, economic and environmental justification for the pre-wet sizing process, which is still a rather unexplored area and not confirmed by scientific research. The reason for such a poor representation of this topic in scientific work is that laboratory work and the preparation of samples is impossible, respectively, which is considered to be the most important reason why this research area has remained unexplored. With the optimisation of the sizing process, extensive planned research and a comparative study of standard sizing processes and the pre-wet sizing process, one can attempt to prove that there are many valid reasons for a non-standard technological process, emphasise a number of advantages and disadvantages, as well as possible improvements, and show the exceptional benefit for factories and producers [10 - 12].

Experimental

Sizing device

Both sizing processes (standard sizing and pre-wet sizing) were carried out on a laboratory sizing machine (***Figure 2***), constructed at the Faculty of Textile Technology, University of Zagreb. It consists of a creel for cross wound bobbins, with the possibility of tension regulation, and two boxes – a box for pre-wetting with hot water and a size box. 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 maintain constant size levels in the working box, 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 maintain constant water temperature in the pre-wetting box and size temperature in the size box with embedded heaters and thermostats, which indirectly warm 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 in all the important places: at the box entry, between two boxes – the pre-wetting box and sizing box, at the box exit and after contact 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 maintain the sizing speed constant using the winder of sized and dried yarn, as well as the speed regulator.

In the sizing process all the conditions mentioned, which are necessary to achieve maximum sizing results, were held constant, due to which it can be safely claimed that yarns were sized under the same conditions. Sizing was carried out using two recipes: the first recipe with a size concentration (R1) of 7.5%, and the second recipe (R2) with a concentration of 5%.The conditions of the sizing process were not varied by changing the recipe or size concentration. The water temperature in the pre-wetting box was 60 - 65 °C, and the size temperature was 75 - 85 °C. Thread tension was approx. 55 cN. The average moisture at the box entry was 6.0%, between the two boxes - 60.0%, at the box exit - 85.0% and after the contact dryer it was 5.5%. The sizing speed was 3 m/min, and the pressure on the last pair of rollers for

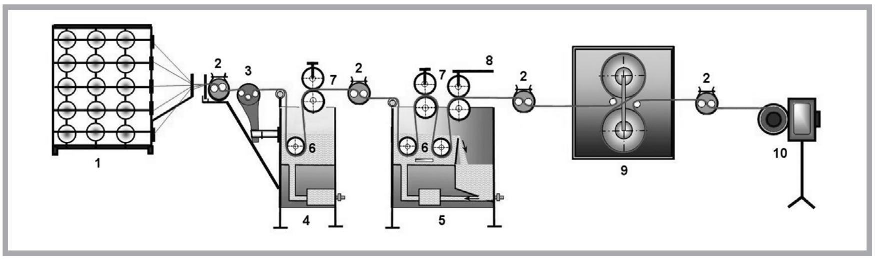


Figure 2. *Laboratory sizing machine: 1 - creel for cross wound bobbins, 2 – moisture measuring device, 3 - thread tension measuring device, 4 - pre-wetting box with hot water, 5 - size box, 6 - rollers for immersing yarn into size and water, 7 - rollers for size and squeezing out of water, 8 - regulation of the pressure of the last squeezing roller, 9 - contact dryer, 10 - winder of the sized yarn.*

Table 1. *Parameters of unsized yarns tested; CV - coefficient of variation in %.*

Parameters		Yarn 1	Yarn 2	Yarn 3
Nominal yarn count - Tt_n, tex		20.00	30.00	50.00
Actual yarn count - Tt_a, tex		18.55	29.57	46.20
Yarn twist - Tm, twist/m	average mean - x	913.04	707.44	537.60
	CV in %	5.20	5.93	2.61
Unevenness - U, CV in %		16.01	18.43	14.08

Table 2. *Characteristics of sizing agents and auxiliaries, and size recipes; * Brookfield, sp2, at 85 °C, 100 r.p.m., **at 85 °C, 10 s.*

Sizing agent and auxiliaries	Chemical nature	Viscosity*, mPa	Fluidity**, cm
TUBOFLEX PVA 80	Polyvinilalcohol	82.2	13
TUBOWAX 24	Natural fats and waxes with a specific emulsifier system	2.1	-

Recipe	Compounds and amounts	Concentration, %
Recipe 1 - R1	1 l water 100 g TUBOFLEX PVA 80 3.0 g TUBOWAX 24	7.5
Recipe 2 - R2	1 l water 70 g TUBOFLEX PVA 80 2.1 g TUBOWAX 24	5.0

squeezing excess size was 19.1 N/cm². The temperature on the cylinders of the contact dryer was 140 °C.

Materials and test methods

The materials used for this investigation were three 100% ring-spun cotton yarns with a nominal count of 20, 30 and 50 tex, certain features of which are shown in ***Table 1***.

Moreover, to treat the samples and to carry out the sizing process, necessary sizing agents (made by Bezema Company) were used. Size preparation depends on the yarn (fibre) type, the sizing agent's origin, different sizing auxiliaries, and the requirements of the sizing process itself. Based on these needs, two different recipes with different concentrations were developed and then used in both sizing processes, as shown in ***Table 2***.

To test the samples before and after sizing, standardised methods were used. Thus the breaking force, elongation at break, work to rapture and strength of yarns, made by Textechno, Germany, were tested on a Statimat M tensile tester according to ISO 2062. Yarn hairiness was tested before and after sizing by recording the fibres protruding from the yarn structure using a Zweigle G 565 hairiness meter, according to ASTM D 5674-01; twists were tested by means of a MesdanLab Twist tester according to ISO 17202, while yarn unevenness wAS tested on an Unevenness tester 80, type B - tt. Keisokki. 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 20 g were 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 a 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, with the number of roller movements until the break having been recorded.

Results and discussion

The results of extensive tests are represented graphically (***Figure 3 - 5***) in order to clearly show the difference between

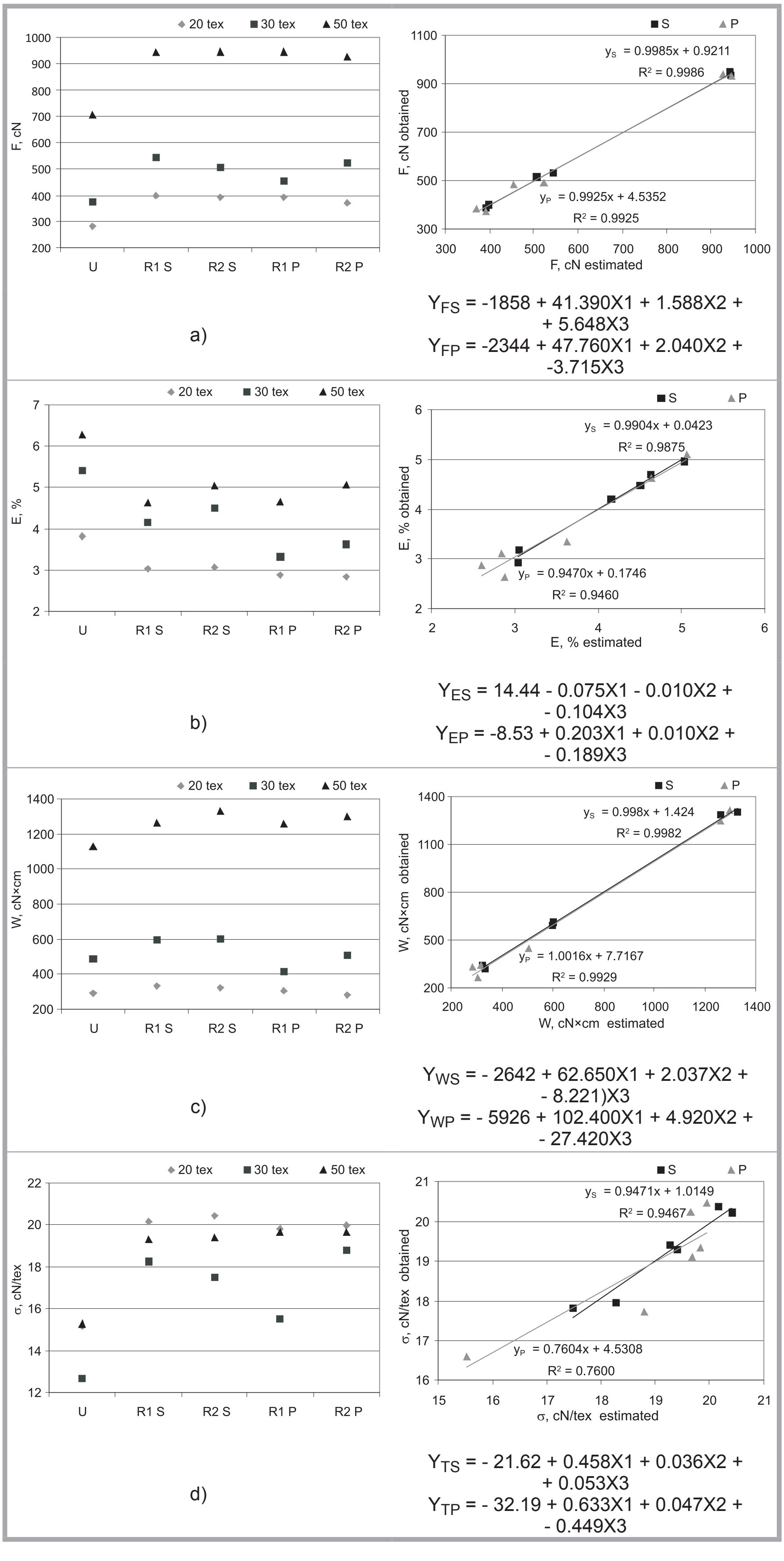


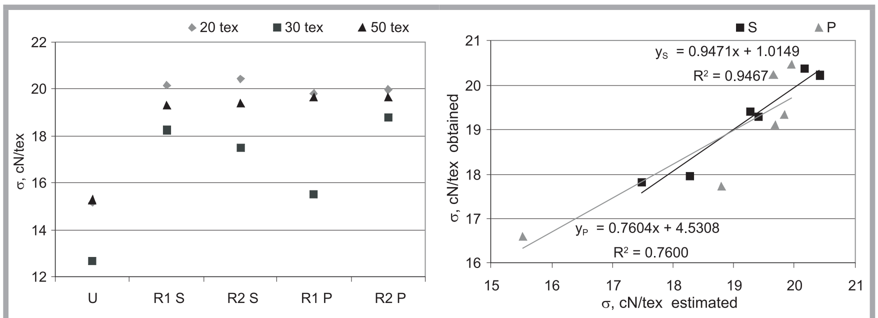
Figure 3. *Diagrams of the breaking properties of unsized yarns and yarns sized with recipes R1 and R2 with the standard sizing process and pre-wet sizing process: a) F in cN - breaking force, b) E in % - elongation at break, c) W in cN×cm - work to rupture, d) σ in cN/tex - strength (where: U - unsized yarn, R1S - yarn sized with the standard sizing process and recipe 1, R2S - yarn sized with the standard sizing process and recipe 2, R1P - yarn sized with the pre-wet sizing process and recipe 1, R2P - yarn sized with the pre-wet sizing process and recipe 2).*

yarns sized with the two recipes and two different sizing processes.

Using the results obtained and their multiple regression analysis, we arrive at the conclusion that there is a strong influence of the large number of existing independent variables (predictors) on the dependent variance (criterion), between which it is possible to achieve a high correlation. The goal of the regression analysis conducted is to determine the extent to which a linear combination of predictors explains variations in criteria, and what the contribution or importance of individual predictors is [13]. Predictors that are very important to achieve a maximum correlation with the criterion depend on the criterion (Y_S - a criterion for dry yarn in a standard sizing process, Y_P - criteria for wet yarn in a sizing procedure with pre-wetting), and in our case they are parameters: yarn count before sizing (X1), twists before sizing (X2), and the size concentration in recipes (X3).

Figure 3 (see page 137) shows a graphical representation of test results for the breaking properties - the breaking force, elongation at break, work to rupture and strength of unsized yarns and yarns sized with size recipes R1 and R2 using the standard sizing process and pre-wet sizing process. Moreover, graphical representations of the multiple regression analysis of the results obtained are given, with corresponding multiple regression equations, as well as the high correlation between criteria obtained through testing and statistical estimation.

Figure 3.a shows the breaking force of all the samples tested. The values of sized yarn samples of counts of 20 and 50 tex, which were sized with both processes and recipes, are almost the same, with an average increase, compared to unsized yarns, of almost 38% for 20 tex yarn and 33% for 50 tex yarn. For 30 tex yarn, differences in sized yarns are more visible, the best results of which were achieved for yarn sized with the standard process and R1, and yarn sized with recipe R2 using the pre-wet sizing process. Multiple regression equations are also shown in ***Figure 3.a*** for the standard sizing process and pre-wet sizing process separately, as well as linear regression equations and the correlation between the values of breaking force obtained by testing and those of the breaking force estimated by analysis.



$$YSpS = - 35.65 + 0.440X1 + 0.033X2 + 0.668X3$$

$$YSpP = - 39.29 + 0.387X1 + 0.031X2 + 1.539X3$$

Figure 4. *Diagram of the size pick-up (Sp in %) of yarn sized with recipes R1 and R2 using the standard and pre-wet sizing processes.*

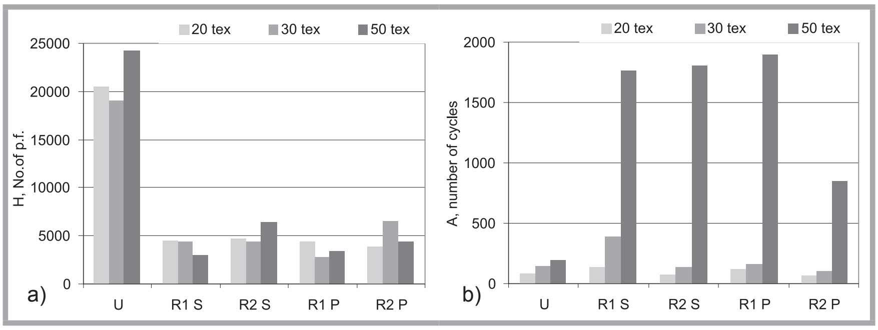


Figure 5. *Diagram of a) hairiness b) abrasion resistance of yarn sized with recipes R1 and R2 using the standard sizing and pre-wet sizing processes.*

Values of the elongation at break of the yarns tested are shown in ***Figure 3.b***. For 20 tex yarn the results are divided into two groups with almost identical values: the yarn sized with the standard process, and those sized with the pre-wet sizing process, with a difference between the groups of almost 7% in favour of yarn sized with the standard process. A similar situation is with 50 tex yarn, where one group represents yarn sized with both processes and R1, and the second group - yarn sized with R2, with a difference between the groups of almost 9% in favour of yarn sized with R2. As in the case of the breaking force, the values for a yarn count of 30 tex are different, where the smallest decrease in elongation at break was recorded for yarn sized with R2 and R1 using the standard process. Furthermore, the diagram shows multiple regression equations, linear regression equations, and correlations between the values obtained by testing and those of the elongation at break estimated by analysis.

In ***Figure 3.c*** the uniform values of 20 tex sized yarn can be observed; they vary within 15% without major deviations from those of unsized yarn, which is also the case for the values of 50 tex sized yarn, varying within 6% only, with an average increase in sizing yarn of 14% compared to unsized yarns. In the case of 30 tex yarn, case differences are discernible, where the maximum deviation, as in case of the breaking force and elongation at break, is observable in yarn sized with R1 using the pre-wet sizing process. By analysing the predictors that influence the criteria - work to rupture, multiple regression equations are obtained, and through the linear regression of the values obtained and by analysis of the values of work to rapture estimated, a high degree of correlation with the standard sizing and pre-wet sizing processes is obtained.

Breaking strength is a parameter that brings into relation yarn finesses and force, the values of which obtained are shown in ***Figure 3.d***. The values of 20 tex sized yarn are perfectly consistent with an increase of almost 33% compared to unsized yarn, as is the case with 50 tex yarn, where the average value of equal values of the samples increased by 28% compared to unsized yarn. 30 tex yarn shows differences among the values, where once again the maximum deviation is observable in yarn sized with

R1 using the pre-wet sizing process. The coefficient of the correlation between the values obtained by testing and those estimated by multiple regression analysis for the breaking strength for the pre-wet sizing process is quite low (only 0.76), while it is very high for the standard sizing process.

What can be observed is that in all tests of breaking properties 30 tex yarn shows the greatest deviations between both sizing processes. These differences can be explained by the occurrence of high yarn stretch during pre-wet sizing, which occurs due to the higher yarn unevenness.

Figure 4 shows the value for the amount of size pick-up on yarns. Yarn size pick-up on yarns sized with the standard sizing process is higher than on those sized with the pre-wet process. According to the differences obtained, it can be noted that during standard sizing, size penetrates into the interspaces of fibres filled with air, becoming denser with the increasing concentration and more difficult to be squeezed out of the yarn passing between the squeezing rollers. A small difference between yarns sized with R1 in both sizing processes can be easily seen, which is present at all three yarn counts. Significant differences are observable in yarn sized with R2 using both processes at all three yarn counts, where an almost equal difference in reducing size pick-up (on average 50%) between the standard sizing process (R2S) and pre-wet process (R2P) is maintained. For size pick-up values as dependent variables, a multiple regression analysis was also conducted. On the basis of estimated values of the linear regression analysis together with the testing value obtained, a correlation value of 0.8153 is obtained for the standard sizing process, and even a higher correlation of 0.9141 for the pre-wet process.

Figure 5 shows diagrams of two 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 fibres, 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.

Figure 5.a shows values of tests on the hairiness of unsized yarns and yarns

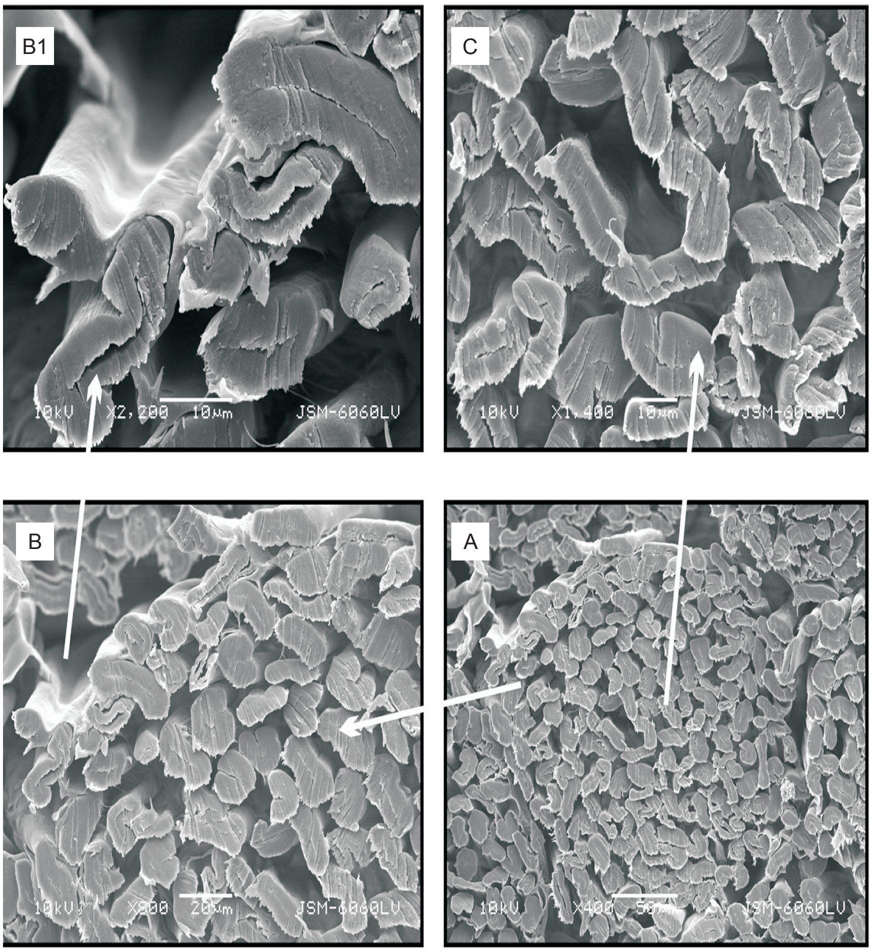


Figure 6. *Microscopic cross-sectional image of yarn sized with the standard process (A - view of the entire yarn, B & B1 - enlarged representation of the periphery of the yarn, C - enlarged representation of the centre of the yarn).*

sized with both recipes using both sizing processes. The largest hairiness reduction was recorded for yarn sized with R1 using the pre-wet process, by even 84%, followed by the yarn sized with R1 using the standard process - 82%. As for R1, the same is the case for R2, where a greater hairiness reduction was recorded for yarn sized with the pre-wet process (77%), compared to yarn sized with the standard process (76%).

A diagram of abrasion resistance values of the unsized yarns and yarns sized tested with both recipes using both processes is shown in ***Figure 5.b***. For more refined yarns (20 and 30 tex), there is an observable decrease in the abrasion resistance of yarns sized with R2 using both processes, compared to unsized yarn. The size pick-up strengthens and reinforces the yarn, which is attributed to the extension that occurs during the sizing process, which is larger in yarn sized with a lower size concentration. For 50 tex yarn, this phenomenon is not present, but the increase in abrasion resistance for all sized yarns is several times larger than for unsized yarn.

The procedure of distributing size pick-up over the yarn, which differs for yarn sized with the standard process and pre-wet process, is also very interesting (***Figures 6, 7***). For yarn sized with the pre-wet process, the process of wetting yarn in hot water allows to fill interspaces of yarn with water. Immersing the wet yarn in size leads to the diffusion of water retained in the yarn with size, as well as to very quick mutual coupling, which allows faster and easier penetration of size into the yarn, where it is visible (***Figure 7***). However, the concentration of size in the interior of the yarn is less than that of the size, because the water retained in the interior of the yarn dilutes it. Therefore, most of the size pick-up remains on the surface of the yarn. Using the standard process, the sizing penetrates through the dry yarn and thickens, passing with more and more difficultly and at a lower speed through dry yarn interspaces, and therefore inside the yarn it almost does

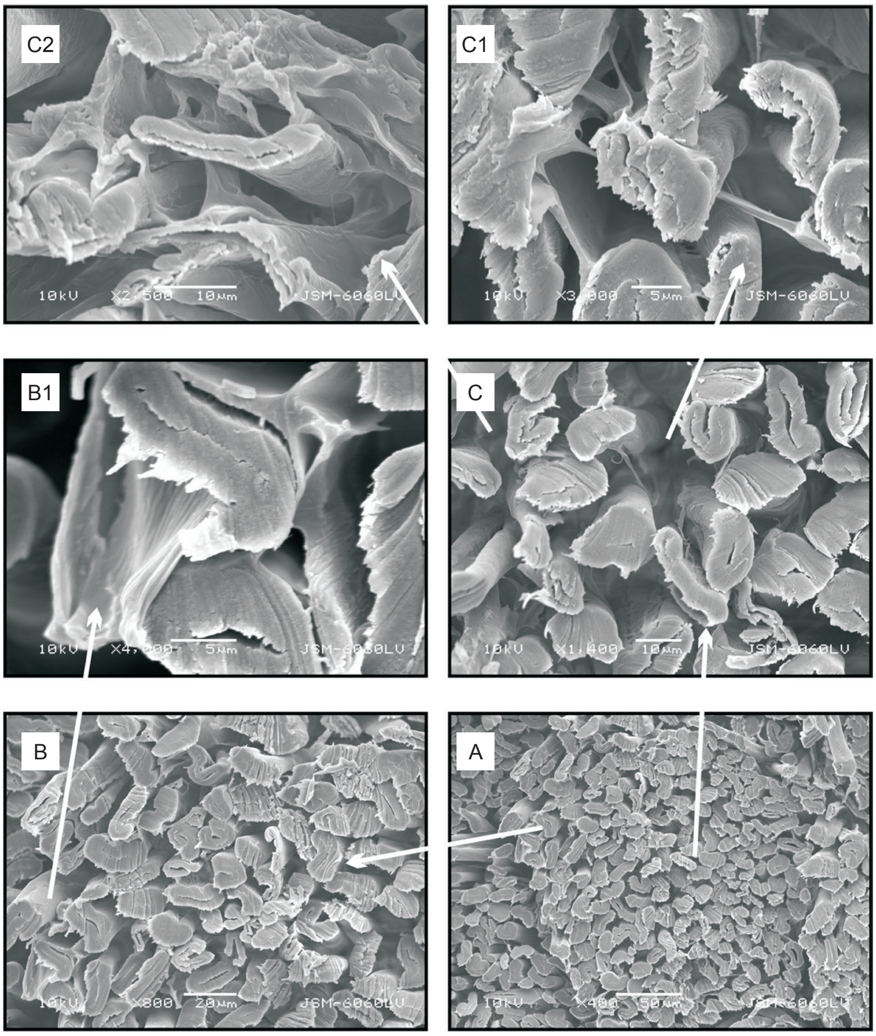


Figure 7. *Microscopic cross-sectional image of yarn sized with the pre-wet process (A - view of the entire yarn, B & B1 - enlarged representation of the periphery of the yarn, C, C1 & C2 - enlarged representation of the centre of the yarn).*

not exist (***Figure 6***). However, this is the reason why the size is mostly retained on the periphery of the yarn, where it creates a 'mantle', as opposed to yarn sized with the pre-wet process, where the size applied on the periphery of the yarn does not form such an intense and rigid layer. These assertions are easily observable in microscopic images. For example, an image of yarn with a count of 20 tex - unsized and sized with recipe 1using both processes, was taken with an SEM microscope JSM - 6060LV.

Conclusions

The processing of samples, the implementation of standardised testing methods and the analysis of the results obtained allow to make a comparative analysis of the standard sizing process and pre-wet sizing process. 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. On the other hand, based on the research conducted, it can be concluded that there is no drastic difference in the results obtained for the two processes, with only some properties of yarn sized with the pre-wet sizing process being noticeably better. This is the reason why this process is preferred due to the economical effects - the consumption of sizing agents and power is lower.

At the same time, thanks to processing with two different size recipes using both sizing processes, an insight into eventual differences in this parameter is provided. The properties of yarn sized with recipes of a lower size concentration (5%) showed very good results in terms of insignificant deviations (despite a much smaller amount of size pick-up on the yarn) as compared to the recipe with a higher size concentration (7.5%), especially in the pre-wet sizing process, in which some properties are even better. These indicators are of great importance for the pre-wet sizing process in view of the possibility to reduce additional 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.

Moreover, the important conclusion drawn from this study (concerning the pre-wet sizing process) is that yarn with a higher unevenness of fineness, due to a high sensitivity to stress in a wet state, which causes yarn stretching and deformation, is necessary to minimise yarn tension, not only in the pre-wetting and sizing part of the process, but also after exiting the dryer. This phenomenon is not so pronounced in case of the standard sizing of dry yarn.

This research was based on the processing, testing and comparison of two sizing processes for raw yarns; however, it is assumed that similar research of dyed warp i.e. yarns dyed with different colour shades, could lead to very interesting findings. These findings are expected in differences between the two sizing processes and differences in properties between the shades of dyed yarns, which also represents a great unknown and a problem for the sizing process.

All of the indicators mentioned above and the results obtained from the investigations conducted indicate the exceptional importance and justification of a non-standard technological process (pre-wet sizing process), which, with much lower costs (sizing agents, water and energy savings), gives excellent results, having a positive impact on reducing the number of yarn breaks, machine efficiency, and, thus, on the quality of finished fabrics.

The aim of the study was to prove the technical, economic and environmental justification for the pre-wet sizing process, which was achieved by extensive investigations.

Acknowledgments

The results shown in the paper came from investigations of the project "Advanced Technical Textiles and Processes", code: 117-0000000-1376, Faculty of Textile Technology, University of Zagreb, Croatia, conducted with the support of the Ministry of Science, Education and Sports of the Republic of Croatia.

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Received 19.04.2010 Reviewed 03.09.2010