

## SOME NEW PERSPECTIVES ON IMPROVING WEAVING PROCESS OF COTTON YARNS

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### 1. Introduction and research background

Scientific research and technological developments in the weaving field worldwide have always followed the fundamental goals of providing improvements in the process and product qualities and producing efficiently a great variety of products for consumption. Weaving is the most predominant method of producing cotton textile materials. Approximately 80% of cotton produced worldwide is used in woven fabrics. In the weaving process, the warp yarns on a loom undergo extremely harsh mechanical actions of repeated stresses and strains as well as substantial abrasion due to friction. As a result, a virgin, greige yarn would develop a significant amount of hairiness (projecting fibers), which would hinder satisfactory fabric formation due to generation of lint, formation of balls in dense warps, inter fiber clinging and inter yarn entanglements, and, consequently, excessive yarn breakages, loom stoppages, and, hence, production and quality interruptions. To avoid these problems in weaving, the warp yarns, for centuries, have always been coated with a thin strong film of a suitable adhesive, generally any ordinary or modified starch. This process of coating the warp yarns on a slasher is called sizing or slashing. Basically, a sheet of warp yarns is impregnated with a special size formulation containing several chemical agents beside the main starch [1, 2]. However, the sizing chemical agents must be completely washed out and removed from the fabric, in order to achieve satisfactory fabric bleaching, dyeing, and/or any special finishing such as a flame-retardant treatment (FR) or a durable- pressed (DP) finish. In fact, fabric finishing starts with fabric desizing. The size mixture not only covers the yarn surface with a thin film, but it also is absorbed into the yarn core, thus gluing and cementing the projecting fibers to the yarn surface, increasing the yarn smoothness and strength, and, thereby, facilitating the weaving process.

The global need for sizing agents all over the world is estimated to be more than 3 million tons per year. Among the commonly used agents, the various starches make about 75% (potato and corn starch 60%; modified starch 15%; (poly) acrylates 12%; polyvinyl alcohol (PVA) 11%; and carboxymethylcellulose (CMC) and other substances 2%). According to the published data, the main size formulations include starches that are made of food raw materials [2, 3]. The demand of textile industry for starches in the CIS (Commonwealth of Independent States) countries alone is 80 – 85 thousand tons per year [4]. Due to scarcity of food raw materials, the importance of new research and technological developments to modify, conserve, and even eliminate starch applications in textile industry becomes obvious [5, 7].

During the past 20 – 25 years, with the objective of completely or partly eliminating starch applications in size mixtures, a number of new size compositions have been developed using synthetic polymers based on vinyl monomers and (poly) condensate high-molecular compounds [8, 11], as well as multi-component size formulations [12, 13]. However, these sizing materials are very costly, not easily available especially in CIS and East European countries, and are harmful for the environment when they are removed in the process of fabric desizing.

Although the textile chemists and technologists worldwide are continuously trying to develop new and improved size formulations and methods of size application, the classical or traditional size and sizing method, which were introduced in the industry more than 140 years ago, are still very much used without any substantial changes at more than 85 % of textile mills in the world today. The yarn immersion in the sizing mixture with the subsequent squeezing of the yarn still remains the main sizing procedure with all its technological weaknesses, drawbacks and difficulties. In several countries, however, progressive methods, such as warp yarn sizing with deposit rollers [14, 15]; sizing with porous sintering rolls [16, 17]; hot melt sizing [18, 19]; foam sizing [21–23]; pre-wet yarn sizing [24, 25]; and mechanical methods of starch splitting during size preparation [26–29], have been developed and applied. But these relatively new developments are still applied with caution and are not widely used by the industry.

Another significant operation in the process chain of manufacturing a woven cotton fabric, before actual finishing, is fabric desizing. As mentioned previously, desizing consists of completely washing out all of the sizing agents in order to achieve quality fabric finishing. Today, some effective methods involving continuous and simultaneous desizing, boiling and bleaching have been introduced in the mass production of certain cellulose textile materials [30, 31]. But, at this stage, they still remain somewhat sensitive to the environment and cause pollution (BOD), since large amounts of unsafe chemicals are released, without any wastewater treatment, into the sewage.

Summarizing all the facts mentioned above, we can state that the sizing and desizing processes deployed in the weaving industry today demand too much amount of heat and electric energy, human resources, water consumption, and sewage water treatment. In addition, the use of various chemical reagents (perhaps, toxins of complex compositions) that may be harmful to the environment is alarming. Therefore, a serious research focus on the development of improved, cost-effective, and environment-friendly process of warp sizing for cotton yarn weaving deserves a high priority. In fact, there is a comprehensive research program underway at the Southern Regional Research Center (SRRC), ARS, USDA, USA, to possibly eliminate the process of warp sizing for certain types of fibers, yarns and fabrics [32]. According to Dr. Sawhney, the sizeless weaving truly involves a development of a new, wholesome technology that includes almost all aspects of textile science and technology, viz., fiber selection and processing, yarn formation and quality, warp preparation and consistency, weaving machinery and conditions. Although it is well known that the plied, folded or cord yarns of cotton can be efficiently woven without the traditional sizing, the main reasons that hinder size-free weaving of singles cotton yarns are: 1) the unbalanced yarn twist torque (liveliness) that causes loss of twist and hence integrity of yarn structure during “repeated shedding” in high speed weaving; 2) the inherently non-uniform orientation of fibers in the cross section of any type of yarn structure; 3) presence of too many short fibers that are almost impossible to control during drafting, especially in spinning; 4) excessive hairiness of single’s yarn that causes formation of lint balls and beads in a dense warp for a densely woven fabric; and 5) excessive abrasion and torture of the warp yarn during weaving. An extensive literature search shows only a very limited work (attempts) relating to size-free weaving, which truly indicates the complexities of the problem of size-free weaving. The idea to eliminate the sizing process (and subsequent desizing) was also proposed, among others, by Dr. Richard A. Schutz at the 4<sup>th</sup> International Symposium on Sizing in Mulhouse (France) [33]. At any rate, considering the many complexities of size-free weaving, any progress in the field of size reduction and minimization is necessary and beneficial for the near future and especially for the developing countries of CIS and East Europe. One of the promising methods to achieve reduction of conventional starch sizes, while improving the warp sizing and weaving processes as well, is mechanical splitting of starch. We have developed a new method of starch splitting through an ultrasonic cavitation technology, which is described in this paper.

## 2. Cavitation Technology (a new approach to an improved starch size preparation and formulation)

Starch splitting based on the cavitation technology provides rapid and effective reduction of high-molecular natural chains without using chemical reagents. The results of this study were obtained by using ultrasound cavitation to split potato starch, in order to minimize the starch content in the size composition for cotton yarns. The main technological parameters, viz., the amplitude of ultrasound oscillations, the size temperature, and the average rate of splitting, were controlled. The size composition was characterized by such physio-chemical parameters as concentration, viscosity and adhesion. Starch sizes with concentrations  $K$  equal 3, 5, and 6% were obtained, using the laboratory ultrasound installation shown in Fig. 1, at the amplitudes of ultrasound oscillations  $\xi$  of 3, 6, 9, 12, and 15 m and the temperatures  $T$  of 70, 75, 80, and 85 °C.

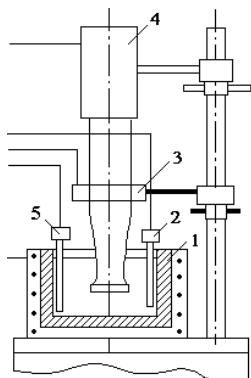


Fig. 1. Laboratory ultrasound installation for splitting starch: 1 – bath for size preparation; 2 – a transducer for ultrasonic cavitation registration; 3 – a transducer for registration of the oscillation amplitude; 4 – a converter; 5 – a transducer for temperature control and registration

The process of size preparation consisted of heating the water up to 30°C, starch loading and homogenization of the mixture in the cavitation field for 2 – 3 minutes, and then heating the size, while giving the cavitation treatment, until the specified (programmable) temperature and minimal relative constant viscosity were reached. The size viscosity was determined by the time (in seconds) of the size flow from the measuring funnel of 500 ml volume, with 5 mm diameter holes, and capillary length of 50 mm. The size adhesion was determined in percentage, as the ratio of the increasing mass of the sized yarn with respect to that of the sizeless yarn.

In Fig. 2, the viscosity curves show that viscosity values depend on the amplitude of ultrasound oscillations at various temperatures and concentrations. The change of the relatively constant minimal viscosity reached at the cavitation treatment can be explained/characterized as follows. It decreases with the temperature growth for all the concentrations and amplitudes of ultrasound oscillations. For example, when temperature increases from 70 to 85°C, viscosity decreases from 32.3 to 28.1 sec. (for  $K = 5\%$ ,  $\xi = 3 \mu\text{m}$ ) and from 30.8 to 26.6 sec. (for  $K = 5\%$ ,  $\xi = 15 \mu\text{m}$ ). Viscosity increases with the concentration growth for all temperatures and amplitudes of the ultrasound oscillations. For example, when concentration increases from 3 to 5%, minimal viscosity increases from 24.8 to 27.2 sec. at the amplitude of ultrasound vibrations  $\xi = 6 \mu\text{m}$  and temperature 85°C. Viscosity decreases with the increasing amplitude of ultrasound oscillations, but minimal viscosity values that are attainable do not differ dramatically. For example, when the amplitude of ultrasound oscillations increases from 3 to 15  $\mu\text{m}$ , the minimal viscosity decreases from 31 to 29 sec. for the concentration of 3% and temperature 70°C.

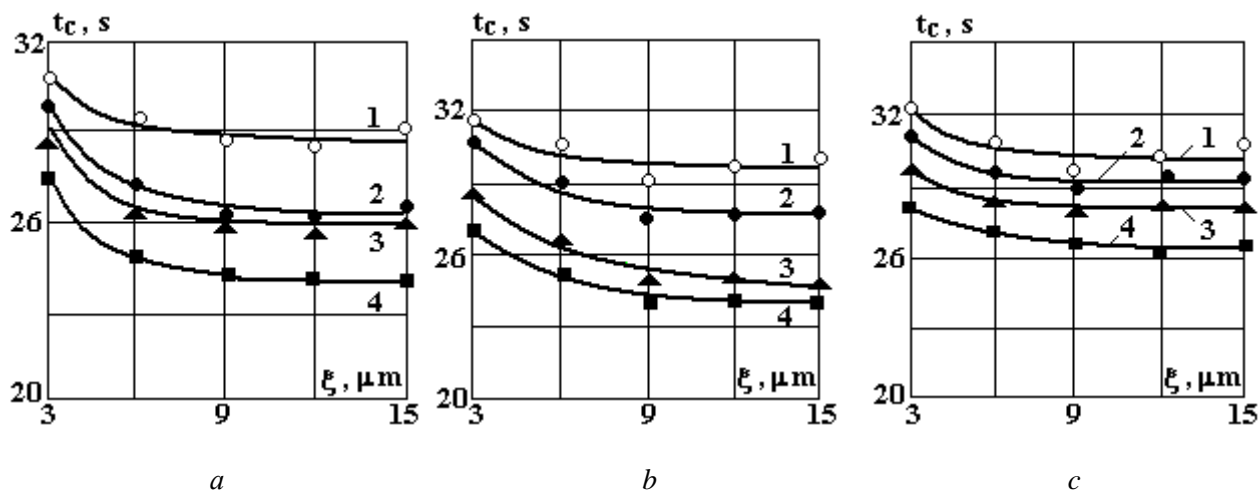


Fig. 2. Size viscosity vs oscillation amplitude. 1 – 4,  $T^{\circ}C = 70; 75; 80; 85$ . a – c  $K = 3; 4; 5\%$

The starch splitting (by the ultrasound cavitation) time that is needed to decrease the viscosity value to its minimum possible value is the other important technological parameter which can be used to state the duration of splitting and, hence, the duration of size preparation. In Fig. 3 the dependences are shown of the size processing duration needed to reach the minimal constant viscosity versus the amplitude of ultrasound oscillations, concentration and temperature. Those dependences can be characterized in the following way. The duration of treatment decreases when the amplitude of the ultrasound oscillations increases at all concentrations and temperatures. For example, the duration of ultrasound cavitation treatment decreases from 20 to 9 min. when the amplitude of ultrasound oscillations increases from 3 to 5  $\mu\text{m}$  at concentration of 3% and temperature 70°C. The duration of treatment increases with the concentration growth at all temperatures and amplitudes. For example, the duration of treatment increases from 9 to 14 min, when the concentration increases from 3 to 5% at the temperature 70°C and amplitude of ultrasound oscillations 15  $\mu\text{m}$ . The time of treatment decreases with growth of the size temperature for all concentrations and amplitudes of ultrasound oscillations. For example, the duration of treatment decreases from 20 to 16 min, when temperature increases from 70 to 85°C for size concentration 3% and amplitude of ultrasound oscillations 3  $\mu\text{m}$ .

The time and percentage of the starch splitting (by the ultrasound cavitation) allow to determine the average rate of splitting which also is an important technological parameter. The average rate of desizing, defined via the percentage of starch splitting per minute, was studied versus the amplitude of ultrasound oscillations for various concentrations and temperatures.

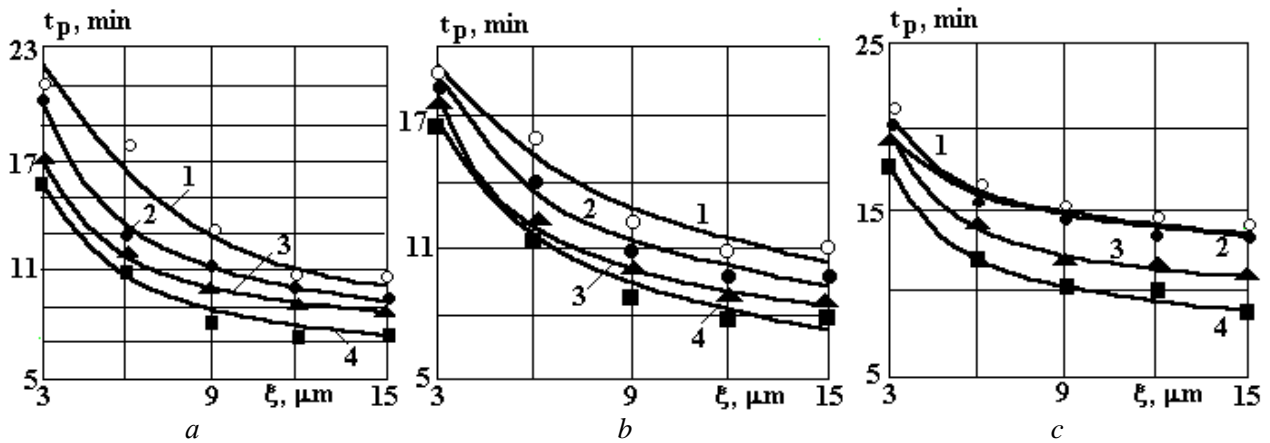


Fig. 3. Time of size treatment needed to reach the minimal constant viscosity.  
 1 – 4,  $T^{\circ}C = 70; 75; 80; 85$ . a – c  $K = 3; 4; 5\%$

Fig. 4 shows the influence of the amplitude of ultrasound oscillations on the starch splitting rate at various size concentrations and temperatures. The starch splitting rate is characterized in the following way. It increases when the amplitude of ultrasound oscillations increases for all the concentrations and temperatures studied. For example, the average rate of splitting increases from 3.7 to 10.2% per minute when the amplitude of oscillations increases from 3 to 15  $\mu\text{m}$  at concentration 3% and temperature 70°C. It decreases with the growth of starch concentration in the size for all temperatures and amplitudes of oscillations. For example, the average rate of splitting decreases from 10.2 to 5.3 % per minute when concentration increases from 3 to 6% at the temperature 70°C and the amplitude of oscillations 15  $\mu\text{m}$ . It also increases with the growth of size temperature for all concentrations and amplitudes. For example, the average starch splitting rate increases from 3.7 to 5.6 % per minute when temperature increases from 70 to 85°C for concentration 3% and amplitude of oscillations 3  $\mu\text{m}$ .

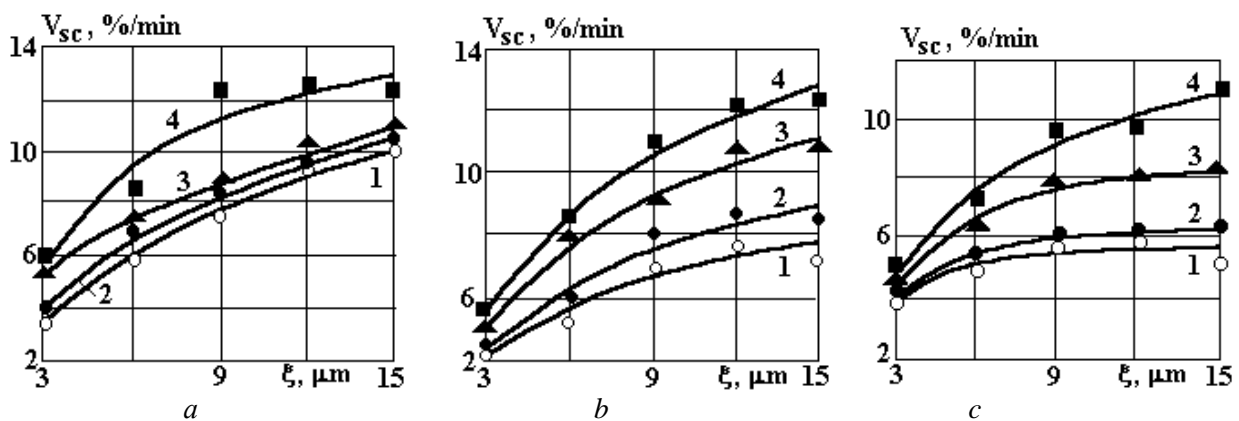


Fig. 4. Average rate of the starch splitting vs the amplitude of oscillations.  
 1 – 4,  $T^{\circ}C = 70; 75; 80; 85$ . a – c  $K = 3; 4; 5\%$

The size viscosity and, hence, the percentage of the starch splitting influences the size adhesion to the yarn. Therefore, technological parameters of the starch splitting by ultrasound cavitation can also influence the yarn size adhesion. In Fig. 5 the experimental data related to the yarn size adhesion versus the amplitude of ultrasound oscillations for various concentrations and temperatures are shown.

Analyzing those curves one can state that the adhesion can be characterized in the following way. Adhesion decreases with the growth of the amplitude of ultrasound oscillations due to increasing of the splitting percentage and size fluidity at all concentrations and temperatures. It decreases when the temperature increases due to fluidity increasing. It increases with concentration growth due to viscosity increasing at constant parameters of splitting (temperature, amplitude)

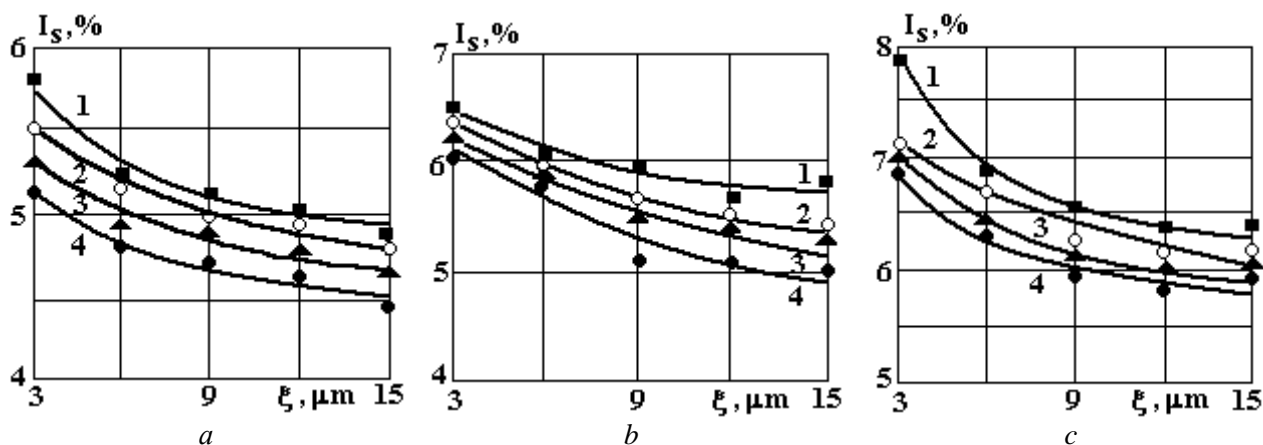


Fig. 5. Yarn size adhesion vs. the amplitude of ultrasound oscillations.  
 1 – 4,  $T^{\circ}C = 70; 75; 80; 85$ . a – c  $K = 3; 4; 5\%$

### Conclusions

Analysing the recent achievements in the reduction/minimization of the traditional size or sizing through starch splitting cavitation technology and even considering the possible elimination of sizing for weaving cotton warps, we can derive the following conclusions:

One of the main problems that needs to be resolved, especially for sizeless weaving, is the production of a yarn of the highest uniformity and evenness and the least amount of hairiness. In other words, a uniform, even packing of the fibers in the yarn cross section throughout the entire yarn length is very important. Obviously, this is a function of the fiber quality, yarn structure, and spinning machine or operation.

The current research results obtained from the starch splitting process conducted under the action of ultrasound cavitation indicate that it is possible to develop an effective and ecologically friendly size formulation by using the cavitation technology.

The cavitation method of preparing starch size may provide starch saving up to 30%, (depending on the fabric style), softening agent saving up to 50%, and 35% energy saving.

Weaving productivity may increase by up to 8%, mainly due to the improvement in the quality of the sized warp, which would lead to less yarn breakages during weaving. The modified size and sizing process would eliminate the use of harmful chemical reagents, which would make the sizing process ecologically friendly.

The weaving and fabric quality improvements resulting from the reduced starch concentration in the size composition would be further complimented by the decrease in the consumption of the chemical reagents.

Finally, it is safe to claim that the ultrasonic cavitation technology for the preparation of a starch size is a promising application for the cotton textile industry.

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### **Summary**

With the technological developments of high-speed, high performance weaving machines, the existing drawbacks of common warp sizing procedures and practices have become even more critical. Although warp sizing and fabric desizing are centuries-old processes and have undergone some significant improvements, they still remain expensive, complicated, and environmentally harmful. The optimal way to further improve significantly the cotton yarn weaving process and its ecological impact on the textile industry lies in the reduction and minimization of the size add-on and, eventually, in the elimination of the sizing process altogether. On the basis of the research presented here, it is proposed to use an ultrasonic cavitation technology in the starch splitting process. This technology offers a significant improvement in the physio-chemical properties of the starch-based sizing agents for preparation of high-quality cotton warps for efficient weaving. In addition, this technology reduces consumption of expensive food raw materials and renders the weaving process ecologically friendly.