Analysis of non-conventional (dry) sizing methods

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Abstract. The method of "dry" sizing has long been known, but has not received widespread industrial application due to the high cost of the sizing ingredients. A classification of the variants of this method is presented and the differences, advantages and disadvantages of each of them are revealed. An experiment was performed for sizing of threads by two of the variants of the method, determining some of their main characteristics and comparing them with those of threads sizing in the classical way.

1. Introduction
In the process of making the fabric, the warp threads are subjected to increased mechanical impact. When they pass through the working parts of the machine (the bars, the lease rods, the lamellas of the main brake, the heald eyes of the healds, the reed and the weft thread) intense friction occurs. In addition, at the moment of opening the shed and plugging the weft towards the end of the fabric, the tensile forces in them increase significantly. This makes it possible for the fibers to slip against each other, which leads to additional thinning of the yarn. When forming the shed, the threads are subjected to bending and as a result of the fatigue of the material the fibers are "broken". The total result is a decrease in the strength of the yarn and an increase in the number of yarn breakage in the weaving process, which is undesirable for the technological process. In order to carry out a normal weaving process, the warp threads are subjected to additional processing - sizing.

Sizing is a technological process in which the application of additional substances on the warp thread improves its physical and mechanical properties. [1, 2] There are different sizing methods according to different criteria [3]. The search for new, energy-saving and environmentally friendly ways that at the same time provide the desired characteristics of the threads is a topical issue, especially in recent years. Depending on the type and condition of the size substance, the main methods of sizing are two:
- wet (classic) – sizing liquor of sizing substances is used, as the size is prepared in advance. It is applied to the warp threads on the sizing machine, where they are also dried;
- dry - easily soluble synthetic substances are used, which are solid at room temperature, have a low melting point and can be applied as a melt to the warp threads and hardened on them by cooling. These substances are usually soluble in water, which allows them to be easily removed from the fabrics, and some of them even act as detergents in the finishing treatment. [4]
2. Methods for "dry" starching

2.1. Nature of the methods for "dry" sizing
These methods use synthetic composite materials that do not contain water and other solvents as size substances. They are easily melted and can be applied to the fibers, and at room temperature they harden. In general, they are soluble in water and can be washed after weaving. The process of "dry" sizing is carried out through technological operations:

- application of size in solid or liquid form,
- melting of the size on the warp threads (when applied in the solid state),
- cooling the warp threads with air at room temperature.

2.2. Size substances
For "dry" sizing, a solid size agent based on polyglycol is used, the hardness of which is regulated by the addition of fatty alcohol or fatty acid products. The disadvantage of this combination is that the polyglycol of a certain molecular weight has insufficient adhesion to the fibrous materials, which leads to unfavorable mechanical abrasion during the processing of the yarns. There are other substances which, in addition to polyalkylene oxides, contain a C16-C20 saturated fatty acid ester and a polyalkylene oxide. In some cases, an alkyd resin is added, and water is used to reduce the melting point of the size.

2.3. Methods and machines for dry sizing

2.3.1. Method by dipping the warp threads in melted sizing substances
The oldest patent for a dry sizing machine dates back to 1953. Its author is the Austrian Alfred Hettwer. The size in the molten state is placed in two boxes, the warp threads being immersed in the size by a system of shafts. Through a system of guide shafts in one box, they move from left to right and back in the other. This is how they are sized at the top and bottom. The warp threads are then blown with air until the size has hardened and wound on a cross. The machine developed by the Swiss company Rüti Textil is similar. There is a patent for a machine with one box [5]. With it, the immersion shaft is equipped with deep grooves, each of which has a thread. The channels are filled with size and the thread remains wrapped around it on all sides.

2.3.2. Method by applying molten size to the warp threads
Another variant of the sizing machine was patented by SUCKER GMBH GEB in 1959 [6]. It was developed by Hans Kabelitz. In this method, the molten size is fed into hollow perforated shafts covered with layered fabric. Thus the shafts are always soaked with size. To improve the process, the threads are divided into two groups through one, the first group passing for example under the 1st and above the 2nd shaft, and the second group respectively above the 3-rd and below the 4-th shaft. This is how sizing takes place on both sides. In order not to harden the size on the shafts, they are additionally heated.

2.3.3. Aerosol sizing method
In 1965, Czech specialists patented a sizing method by spraying a moving warp with molten size substance. After unwinding from the warp beam, the base moves vertically into a chamber, where it is sprayed with the melted size from special nozzles. It is then cooled by the surrounding air and wound on the weaver beam. Electric heaters are installed in the chamber, which maintain a suitable temperature.

2.3.4. Method by applying hard size with subsequent melting
There are methods for "dry" sizing, in which the size is applied in a solid state on the warp threads. This is done by rubbing the warp into one or more blocks of starch (similar to waxing yarn in knitting). Then the warp pass between electric heaters, which melt the size. After cooling with the ambient air, the threads are wound on the beam again.
A common disadvantage of these methods is that the sizing substance is heated for a long time or is repeatedly heated and cooled, which leads to its destructive changes.

2.3.5. Method for electrostatic application of size
The method is new and was proposed by R. Roussev [7]. The method consists in passing an electrified textile thread through a pseudo-fluidized layer of a sizing substance electrified with the opposite type of static electricity. The adhered size is then melted, smoothed, cooled and made. In this method, only the size stuck to the thread is melted once. The disadvantages of the methods listed above are avoided, the process parameters are easily adjusted, accurately and in a wide range.

3. Experimental determination of some characteristics of sized yarns
The following sizing methods were chosen for comparison: classical, dry sizing by dipping and dry sizing by grinding and subsequent melting. For this purpose, laboratory samples of yarns were prepared, sized by the three selected methods. Dry sizing was not done by production technology, because no such was found. The comparison of the methods was performed according to the following characteristics of the sized yarns: tensile strength to break; extensibility, amount of size deposit and coefficient of friction.

3.1. Materials
The yarn for the three experiments was taken from one batch. It has the following characteristics before sizing: material - 100% cotton, linear density 20tex, tensile strength to rupture - 215g, elongation to rupture - 5.4%. For dry sizing experiments, short sections (about 10 m) of 20 different yarns from the same batch were taken.

3.2. Yarn sizing

3.2.1. Experiment 1
The yarn is sized in the classical way under real production conditions in a company for which a certificate has been issued. The information and materials provided are for internal company use, so the company name is not mentioned.

3.2.2. Experiment 2
Sizing was performed by the method of "dry sizing by immersion". For this purpose, a laboratory installation was created (Fig. 1). The yarn 1 is unwound from the spool 2 and through the guide shaft 3 is immersed by the wedge 4 in the molten size 6, which is located in the size trough 5. Excess size is removed by rubbing around the shafts 7. Pulling the thread is performed by the cylinder 9, which is mounted on the gear motor shaft (not shown in the diagram). To make continuous contact of the yarn 1
with it, a compression shaft 10 with an elastic coating (rubber) is used. In the area between the shafts 7 and the cylinder 9, the thread is cooled by a fan. Sizing is performed in sections of about 10 m (therefore a winding device is not provided), with the following parameters: thread speed 18 m / min; size temperature 58 ± 2°C and cooling temperature 20 °C.

3.2.3. Experiment 3
Sizing was performed by the method of "dry sizing by rubbing with subsequent melting". The laboratory installation is shown in Fig. 2. The yarn 1 is unwound from the spool 2 and is guided by the guide shafts 3 and 5. In the area between them are placed blocks of unmelted size 4. Passing through them, by rubbing the thread size sticks. It is then heated by the hot air fan 6 whereby the size melts. Cooling is performed by the ambient air. The yarn is pulled from the cylinder 7, which is attached to the gear motor shaft (not shown). A pressure shaft 8 with an elastic coating is used to make continuous contact. Sizing is performed in sections of about 10 m, with the following parameters: speed of movement of the thread 18 m / min; hot air temperature 140°C and cooling temperature 20 °C.

3.3. Laboratory testing of yarns
Laboratory tests were performed on sized yarns by the three selected methods. The following statistical characteristics have been determined: arithmetic mean $\bar{X}$; standard deviation $S$; coefficient of variation $V$ [%]; confidence interval $q$ and relative width of the confidence interval $p$. The statistical processing is made by specialized software – PROJECT, developed and provided to the authors by R. Roussev, at a Student's coefficient $t = 2.090$ and significance level $r=0.05$. For Experiment 1, the data were taken from the laboratory test certificate of the company that provided the materials. For Experiment 2 and Experiment 3, 20 measurements were performed.

3.3.1. Tensile strength to rupture
Tensile strength to rupture is determined by a pendulum dynamometer at a distance between the jaws of 500 mm. The device also makes it possible to take into account the stretch of the yarn until it breaks. The following results were obtained:

Experiment 1 - $\bar{X} = 269.25$ g (from the company's certificate). Experiment 2 and Experiment 3 - the results obtained are shown in Table 1.

### Table 1. The experiments results for tensile strength to rupture

|            | Tensile strength to rupture (g) |
|------------|---------------------------------|
| **Experiment 2** | 251 253 253 248 256 254 252 255 254 258 |
|            | 252 253 257 256 253 255 255 254 258 253 |
| **Experiment 3** | 246 248 245 246 244 245 244 247 244 248 |
|            | 245 247 248 245 246 244 247 245 246 246 |

3.3.2. Elongation
Elongation - as noted above, the pendulum dynamometer also measures the elongation of the sample to rupture. The extensibility is given in % and is determined by the formula:

$$\varepsilon_{\text{max}} = \frac{\Delta L}{L_0} \%$$

where,

$\varepsilon_{\text{max}}$ - maximum elongation

$L_0 = 500$ [mm] the initial length of yarn

$\Delta L$ – average elongation of the yarn at the time of rupture [mm].
Experiment 1 - $\varepsilon_{\text{max}} = 3.1\%$ (from the company certificate). Experiment 2 and Experiment 3 - the results obtained are shown in Table 2.

| Experiment 2 | Experiment 3 |
|--------------|--------------|
| Elongation of tensile to rupture (mm) | Elongation of tensile to rupture (mm) |
| 22           | 22           |
| 20           | 23           |
| 24           | 23           |
| 25           | 20           |
| 22           | 21           |
| 22           | 21           |
| 20           | 21           |
| 22           | 22           |
| 20           | 22           |

Table 2. The experiments results for elongation of tensile to rupture

The data obtained from the experiments were statistically processed and the results obtained are shown in Table 3.

Table 3. The experiments data for yarn sizing

| Experiment 2 | Experiment 3 |
|--------------|--------------|
| Elongation of tensile to rupture (mm) | Elongation of tensile to rupture (mm) |
| $\bar{X}$   | 254.0        |
| S            | 2.406        |
| V            | 0.947        |
| q            | 1.124        |
| p            | 0.443        |
|             | 245.8        |
|             | 1.361        |
|             | 0.554        |
|             | 0.636        |
|             | 0.259        |
|             | 22.1         |
|             | 1.294        |
|             | 5.854        |
|             | 0.605        |
|             | 2.736        |
|             | 23.2         |
|             | 1.056        |
|             | 4.553        |
|             | 0.404        |
|             | 2.128        |

3.3.3. Size coating
The amount of size on the threads is selected depending on the structure and type of fabric and is determined by the change in weight of the yarn after sizing. The weight of the yarn before sizing is calculated from the linear density equation. If the moisture content of the substrate before and after sizing is not taken into account, the apparent deposit $b$ is determined by the formula:

$$b = \frac{M_1 - M_0}{M_0} \cdot 100\%$$

where,

- $M_0$ - the mass of the yarn before sizing
- $M_1$ - mass of yarn threads after sizing.

Experiment 1 - $b = 13.1\%$ (from the company certificate). For Experiments 2 and 3 of the samples after sizing by the respective method, new ones with a length of 5 m were taken, and this was done from their middle. It is assumed that when sizing each sample at the beginning and end, the process is not stable and the results obtained would not be accurate. The total length of the sections is 100 m. The weight of 100 m of unsized warp thread is $M_0=2$ g. The following results were obtained: Experiment 2: $M_1 = 2.404$ g, $b = 20.2\%$; Experiment 3: $M_1 = 2.358$ g, $b = 17.9\%$.

4. Analysis of the obtained results
As noted above, the laboratory "dry" sizing is not industrial technology, so the results obtained in the experiments can be considered indicative. However, the following conclusions can be drawn:
- In dry sizing the starch is absorbed 100\%.
In dry sizing, the amount of size on the warp threads can be adjusted very precisely and in a wide range.

"Dry" sizing is done with much less investment than the classic way. "Dry" sizing machines occupy a very small production area compared to the classic ones.

There is a difference in energy consumption. In the case of "dry" sizing, it is only necessary to melt the size, and in the case of the classic sizing, energy is needed for the preparation of the size, for sizing and for drying the size base.

The management of the process of "dry" sizing is far more elementary than the classical way. The first requires control of the size temperature, the amount of size in the sizing box and the sizing velocity. In the classical way the parameters are much more - the ratio of different materials in the size, preparation of size temperature, time of addition of components, preparation mode, size temperature in the trough, size concentration, sizing velocity, drying speed in different zones, drying and cooling temperature in the separate zones, etc. All these factors affect the quality of the process and their exact setting is more than necessary. However, this requires the appropriate CAM system.

The tensile strength to rupture in the classical way is greater than in the "dry" sizing. This can be explained by the size materials used. In the classic way, a "hard" film is obtained, which does not allow the fibers to slip into the yarn, while in the "dry" sizing the film is "soft" and the bonding of the fibers is not so strong. For this reason, the extensibility is greater in the methods for "dry" sizing. This is the subject of an upcoming research.

The amount of coating in the classic way of sizing is optimal, determined after numerous studies. In the case of "dry" sizing, due to the lack of industrial technology, it is not possible to assess whether the deposit obtained in laboratory conditions is optimal. For this reason, a definite assessment of this indicator is not given.

The difference in the results obtained with the two methods of "dry" sizing is due to the fact that during "immersion" the starch penetrates to a greater depth in the volume of the thread, while in the other case it is on the surface and forms an uneven film.

As a result of the above, it can be concluded that "dry" sizing is a more progressive method. However, it is necessary to create an optimal production technology.

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