Comparative analysis of size materials and their weaving potential

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The application of different varieties of natural starches, modified starches and synthetic size materials on cotton and P/C blend yarns has been studied followed by their evaluation with respect to retrogradation, cohesion, adhesion and solubility. It is observed that the size paste characteristics and film properties of modified starch are better than those of the natural starch. Yarns sized with modified starch perform better than those sized with natural starch and even some synthetic size materials. The use of starch ester is found to be beneficial as compared to other size materials, as the ester modification in starch gives better results and the yarn sized with it gives better weaving performance, close to that of PVA. Adhesion of size material with fibre substrate is found to have good correlation with weavability of sized yarns and it is an important parameter for selecting the size material for any application. The studies on the effect of lubricant show that the addition of lubricant into size solution helps to provide surface lubrication to the yarn which improves the abrasion resistance of the yarns and hence the weavability without affecting the essential properties.

Keywords: Adhesivity, Cohesivity, Cotton, Moisture regain, Polyester/cotton blend, Solubility, Viscosity, Weavability

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1 Introduction

Sizing is a process used for the application of a film forming polymer to provide temporary protection to the warp yarns from abrasive and other types of stresses generated on the weaving machines in order to reduce the warp breakages. The advent of very high speed shuttleless looms has increased the importance of sizing manifold in recent times, because the machine stoppages are more expensive due to significant loss of production. Yarn protection during the weaving operation is becoming more critical in order to obtain maximum weaving efficiency, and the largest possible return on investments has become top priority. Savings in energy due to sizing are achieved by lower humidity weaving in the loom shed, high pressure squeezing, foam sizing, solvent sizing, dry sizing and recycling of the exhaust energy.1,2

Sizing helps in forming a coating which encapsulates the yarn, embeds the protruding fibres and also causes some inter-fibre binding by penetration. The performance of the warp yarn largely depends on the nature of the protective coating and its interaction with the fibre substrate. The spun yarns being hairy usually require add-on exceeding 8-10%; depending on the fabric to be woven.3

More effective synthetic binders, like polyvinyl alcohol, carboxymethyl cellulose and polyacrylates, were developed as sizing agents for synthetic filament yarns. However, for the synthetic blend yarns, due to high add-on requirements, a blend of starch dominated synthetic binder has been an effective and economical size recipe. The small addition of synthetic binder to starch causes plasticization and increases the adhesion, but does not eliminate the drawbacks of starch. Hence, starch needs modification to overcome its drawbacks. Acid modified and oxidized starches have low viscosity compared to starch but other rheological properties are not improved.4-7

Major drawback of starch, brittleness of the film, can be reduced by providing internal plasticization. Chemically substituted starches, such as carboxymethyl starch, cationic starch and starch acetates, do not produce solution of stable viscosity due to the ionic nature of its substituted group; the viscosity of the solution is strongly affected by the electrolytes present in the solution. However, the substitution of non-ionic, hydrophilic hydroxyethyl group does not create the above problems. Many varieties of modified starches are available, like acid modified starch, oxidised starch, starch esters and starch ethers.8,9

The performance evaluation of size
material is very expensive and time consuming for industry. In the present work, a comparative analysis and performance evaluation of different size materials on cotton and polyester/cotton yarns for different applications have been carried out.

2 Materials and Methods

2.1 Materials

Different size materials, such as unmodified starches; cereal based (Sample A), acid modified starch (Sample B), oxidised starch (Sample C), starch ester (Sample D), hydroxyethyl starch (HES) (Sample E), sodium salt of carboxymethyl starch (CMS) (Sample F), polyvinyl alcohol (Sample G), polyacrylate 35% (Sample H) and polyester resin 30% (Sample I) were used for the study.

Two types of rovings, namely cotton roving (100%) and polyester/cotton (65/35) roving (polyester fibre of 1 denier fineness and 38 mm length) were used for testing the adhesion power of size materials. Two types of yarns, namely cotton ring-spun yarn (40s Ne) and polyester/cotton (65/35) ring-spun yarn (45s Ne) were used for sizing and evaluating the weaving potential of size materials.

2.2 Methods

2.2.1 Viscosity Test

Brookfield digital viscometer was used to measure the viscosity of size solutions. This instrument has spindles of various shapes and sizes meant for different viscosity levels. It has a rotational speed range of 5-100 rpm. The instrument gives torque applied to spindle for selected rotational speed and multiplying that torque value with constant of spindle and speed combination is the viscosity of the solution in centi-poise.

2.2.2 Retrogradation Test

Retrogradation is the change in viscosity with the change in temperature of the size solution. The viscosity of size solution at different temperatures was measured by above-explained method and a graph was plotted which gives the retrogradation property of the size solution. The same method was used for all the size samples.

2.2.3 Cohesion Test

The cohesivity of size materials is tested by measuring the tensile properties of size film. The prepared size solution was laid on a acrylic sheet uniformly and the film of the paste was made. Acrylic sheet was selected because size material does not stick to the sheet and can be easily stripped off. After drying in normal atmospheric condition, the film was kept inside the desiccator for conditioning. The desiccator uses super saturated solution of sodium nitrite which maintains 65% RH. After conditioning for 24 h, the film was cut into 15 cm × 1 cm strips and the thickness of each sample was measured by digital vernier calipers. The samples were again put into the desiccators for 24 h for conditioning. The conditioned samples were tested on Instron tester for tensile strength and elongation-at-break with gauge length of 10 cm and breaking time of 20 ± 3s. The thickness of the film should be constant and it needs to be taken into consideration. Film strength is the direct measure of cohesive power of size material.

2.2.4 Adhesion Test

For measuring the adhesive strength of size material, it was applied on different types of rovings assuming that the parent strength of roving is zero or negligible. The size was applied on rovings by the same method as is used in normal sizing of yarns. The conditions used for sizing are as follows:

- Size concentration: 6% by weight
- Sizing speed: 5 m/min
- Squeezing pressure: 2 bar/90 daN

The rovings were dried at room temperature and conditioned in desiccator for 24 h at 65% RH. Strength of roving was tested on Instron tester with the gauge length of 20 cm and breaking time of 20 ± 3s. The strength of the sized roving is only due to the strength of size or, in other words, it is the adhesive capacity of size material.

2.2.5 Moisture Regain of Size Films

The size films were conditioned in desiccator for 24 h at 65% RH. After weighing the films they were kept inside hotair oven for 30 min at 105 ± 3°C. The oven dry weight of the film was measured. Moisture regain of film was calculated by using the following formula:

\[
\text{Moisture regain} (\%) = \frac{W - D}{D} \times 100
\]

where \( W \) is the weight of size film at 65% RH; and \( D \), the oven dry weight of size film.
2.2.6 Solubility of Size Materials

For measuring the solubility of size materials, their films were prepared as described earlier. The film was cut into strips. A constant weight was suspended on each strip before putting it into water. The water level was kept constant for all tests. The size film when dipped into water swells and loses its strength. The time required to break the strip by known weight was noted down. The more the time required, the lower is the solubility of the film and vice versa.

2.2.7 Sizing of Yarn Samples

The size solution was prepared and cooked. Yarn samples were sized with cooked size solution on laboratory model Zell sizing machine with 6% size concentration, 15 m/min sizing speed, 90 daN squeezing load over warp sheet width of 12 inch.

2.2.8 Tensile Properties and Hairiness of Yarns

The sized yarn samples were conditioned and then tested on Instron tester for tensile properties using the ASTM D – 2256 standard test method with 250 mm gauge length and 20 ± 3s breaking time. The hairiness of yarn was tested on Zweigle hairiness tester following ASTM D – 5647 standard test method.

2.2.9 Weavability Test

In order to determine the relative weaving potential of yarns sized by different sizing materials, they were tested on Reutlinger Webtester (Fig. 1). The instrument simulates all major stresses occurring during weaving operation such as cyclic extension, axial abrasion, flexing and bending, excluding beat up and yarn entanglements. Like on a loom, above-mentioned weaving stresses are applied simultaneously on a sheet of parallel 15 threads held at a pre-selected constant tension.

The instrument records cycles required to break first 10 threads. The average numbers of weavability cycles of each sample can be found by taking the average of the number of cycles required for breaking first 10 threads on webtester. For every break, load is decreased by 1/15th of the initial preset load in order to maintain constant tension on each yarn throughout the test. During the test, if some yarns get elongated and become slack, they do not experience fatigue and abrasion. Since such slack ends do not have any serviceability on loom, they are called as pseudo-breaks. Therefore, they are manually removed at the cycles at which they become slack and a break is recorded on the instrument. The instrument also displays yarn elongation resulting due to fatigue and abrasive actions while maintaining constant tension per thread. Moreover, it is provided with a facility to alter individually various test conditions such as yarn tension, intensity of yarn-to-metal abrasion, yarn cyclic extension and cyclic speed. The test is carried out using the following parameters:

- Sample length: 50 cm
- Initial Tension: 3 g/tex
- Cyclic Extension: 0.5%
- Penetration of abrasion pin: 3 mm
- Speed: 400 cycles/min

3 Results and Discussion

3.1 Viscosity of Size Solution

The viscosity of size solutions tested on Brookfield digital viscometer at different temperatures is given in Table 1. It is observed that all the modified starches are of low viscosity than the original starch. Viscosity of some modified starch is close to that of PVA and displays yarn elongation resulting due to fatigue and abrasive actions while maintaining constant tension per thread. Moreover, it is provided with a facility to alter individually various test conditions such as yarn tension, intensity of yarn-to-metal abrasion, yarn cyclic extension and cyclic speed. The test is carried out using the following parameters:

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acrylic size material. However, the viscosity of natural starch is always high. This is because the thin boiling starch and oxidized starch will not swell but disintegrate or fragmentize on boiling. In case of starch derivatives, the re-association is reduced by substituted group and so they all show lower viscosity at the same concentration. Synthetic size material is dissolved in water at higher temperatures, thus giving lower viscosity. Lower viscosity of size paste is advantageous because less viscous paste will penetrate easily into the yarn and give a good cover with penetration which will not be removed easily during the abrasion of warp yarn on loom. Less viscosity also offers high concentration and hence the high add-on % is only possible with low viscosity paste. Thus, the low viscous solution is preferable over the highly viscous paste. The retrogradation behaviour of size materials is the change in viscosity with reducing temperature. The result obtained is shown in Table 1.

The change in viscosity with reducing temperature is high in case of natural starch while in case of modified starch the change is less and almost constant because of reduced re-association and disintegration as explained in the earlier section. This means that the natural starch is highly unstable, whereas modified starch has a stable viscosity over the temperature range from 100°C to 50°C. In case of synthetic size materials, once it is dissolved in water the viscosity is almost constant and it will not change with the change in temperature. All the synthetic size materials provide very slow change in their viscosity with decreasing temperature compared to starch. At the same time, some modified starches also give better performance. Lower change is preferable from the sizing point of view because as the size box is open, the atmospheric temperature will cause gel formation in case of rapid change in viscosity with reducing temperature. This effect will be more during the winter season if humidification plant is not used. Gel formation in the sow box will reduce the performance and quality of sizing because uniform sizing is not possible if gel formation occurs.

### 3.2 Cohesivity of Size Materials

Cohesivity is measured by checking the tensile properties of the film. The results are given in Table 2. It is observed that samples C and I cannot form films as they become very brittle and crack easily during drying. Cohesion or film strength depends on the force between the chains of molecules. One of the main factors contributing to the film strength is the chemical structure of polymer chain. The polymer structure influences the flexibility and magnitude of two forces between the chains which finally decide the strength and elongation of the film. The different polymeric chains are strongly attached to each other mainly by the Van der Waal’s forces between atoms and hydrogen bonding provided by the hydroxyl groups or substituents attached to the chains.

The strength of the sample G is less but the extensibility is very high as this material is forming a highly flexible film. Size film elongation is more important than film strength because extensibility is more important than strength from weaving point of view. The elongation is very high in case of sodium salt of substituted starch but other starch materials have moderate elongation-at-break. The synthetic size material gives very high extensibility because of its uniform and regular structure and very strong forces between two molecular chains.

### 3.3 Adhesivity of Size Materials

Adhesivity of size materials is evaluated so as to determine its utility as a sizing agent. The breaking strength and elongation of cotton and P/C roving sized with different size materials is shown in Fig. 2.

The adhesion of a paste depends upon the number of active hydroxyl groups available for hydrogen bonding with the substrate. The adhesive power of size paste deteriorates if less number of hydroxyl groups is available for bonding. The low gel formation and limited retrogradation of modified starch facilitate the release of active hydroxyl groups by the thermal and mechanical energy which can be

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**Table 2—Specific breaking strength and extension of size films at 65% RH**

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Specific strength kgf/mm</th>
<th>Elongation-at-break, %</th>
<th>CV % of breaking strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>24.86</td>
<td>2.20</td>
<td>9.93</td>
</tr>
<tr>
<td>B</td>
<td>36.43</td>
<td>3.19</td>
<td>8.65</td>
</tr>
<tr>
<td>C</td>
<td>Film not formed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>24.17</td>
<td>2.15</td>
<td>11.86</td>
</tr>
<tr>
<td>E</td>
<td>25.80</td>
<td>2.42</td>
<td>11.50</td>
</tr>
<tr>
<td>F</td>
<td>5.39</td>
<td>25.86</td>
<td>14.14</td>
</tr>
<tr>
<td>G</td>
<td>36.71</td>
<td>208.63</td>
<td>13.47</td>
</tr>
<tr>
<td>H</td>
<td>2.26</td>
<td>146.26</td>
<td>9.01</td>
</tr>
<tr>
<td>I</td>
<td>Film not formed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 2—Adhesive strength and elongation of sized cotton and P/C rovings

seen by the result presented in Table 2 and Fig. 2. The modified starches give higher adhesive strength than natural starches. It is interesting to note that the oxidized starch shows lower strength than all other materials. This is because the oxidation of starch helps to reduce the viscosity but after certain limit it causes damage to the starch granules to the extent that they lose their adhesion power with other materials. Starch ester shows better adhesion than unmodified starch and other modified starches.

The adhesive strength for P/C blend roving is higher than that for cotton roving (Fig. 2). This is because the strength of polyester fibre is higher than cotton fibre and proportion of polyester fibre is 65% which gives higher strength of roving. Fibre length of polyester is also higher than that of cotton which also contributes more towards the roving strength.

3.4 Moisture Regain

The moisture regain of different size materials is shown in Fig. 3. It is clearly observed that the moisture regains of modified starches are higher than the natural starch. It is well known that the moisture regain of any material depends on the chemical structure of the molecules, and the nature & extent of substituted groups. The basic unit of starch [anhydroglucose unit (AGU)] contains three hydroxyl groups for each glucose residue and the hydrogen bonds can be formed between water molecules and hydroxyl groups. The water sorption of natural starch is low due to the structural arrangement. The molecules of unmodified starch are held together by extended micellar network; as a result fewer hydrophilic hydroxyl groups are accessible. Thus, the lower moisture regain is observed.

3.5 Solubility of Size Films

The time required to dissolve samples A, D, F, G and H in water is 310s, 141s, 240s, 540s and 185s respectively. Samples B, C, E and I are not soluble in water. Solubility of substituted starch is better compared to natural starch while that of PVA is poor compared to starch. Solubility is dependent on accessibility of hydroxyl group at the chain end. Water molecule reacts with hydroxyl groups of the size molecule and breaks the bond between two chains which results in shortening of chain length and produces more functional end groups which accelerate the process further.

3.6 Evaluation of Sized Yarns Properties

3.6.1 Tensile Properties

Tensile properties of yarns after sizing is tested on Instron tensile tester by following ASTM D – 2256 standard method. The results for sized cotton and P/C yarns are shown in Fig. 4. It is observed that the strength of yarn is increasing after sizing and the elongation is decreasing with the increase in tensile strength of yarn. This is because, the size material penetrates into the yarn body and makes the yarn stiff. Adhesivity of size material with fibre improves the
strength, makes the yarn compact and reduces the yarn elongation. The increase in strength of yarn with PVA size material is higher than the other size material for cotton yarn.

3.6.2 Hairiness of Sized Yarns

The hairiness S3 value tested on Zweigle hairiness tester for cotton and P/C yarns is shown in Fig. 5. S3 value is the no. of hairs larger than 3 mm length present in 100 m of yarn. The hairiness of yarn decreases after sizing as protruding fibres on the surface of the yarn are bound to the yarn body and covered with size film. The hairiness of P/C blend yarn is less compared to cotton yarn initially but the reduction in both yarn is significant after sizing. The hairiness of yarn after sizing with PVA is very less as PVA gives very smooth and fine covering on the yarn. Hairiness is an indirect measure of continuity of size film.

3.6.3 Yarn Weavability

The number of cycles required to break cotton and P/C yarns (tested on Reutlinger Webtester) is shown in Fig. 6. The number of cycles required to break the yarn increases after sizing because of the application of size material. The hairiness is very low after sizing due to the covering of yarn with the size material. Abrasion resistance increases after sizing which ultimately gives better weavability. Overall, the weavability of modified starch sized yarn is better than that modified with natural starch but lower than with PVA. If the yarn breaking mechanism is observed, most of the times the yarn breaks after removal of fibre from yarn body due to abrasion. Size covering actually helps in improving the abrasion resistance of yarn but to withstand the abrasive stresses, the size material should have some penetration into the yarn body and for that a size solution with moderate viscosity is needed during application. From the above results of film properties, adhesion and yarn properties after sizing, it can be concluded that the modified starch performs better than the unmodified starch. Ester modification gives a lower viscosity at the same concentration level compared to ether modification. Still the performance of this modified starch is poor compared to PVA but if the cost and ecology factors are considered, the use of modified starch is beneficial compared to the use of PVA.
4 Conclusions

Paste characteristics and retrogradation behaviour of modified starch are better than that of natural starch. The weavability of sized yarn is greatly influenced by adhesion power of size material and is an important parameter for selecting the size material for any application. Modified starch performs better in terms of weavability than natural starch and some synthetic size materials; its performance is close to that of PVA. Solubility of modified starch is better as compared to natural starch. Ester modification proves better in terms of weavability among all the modified starches studied. Keeping cost and ecology in mind, the use of modified starch ester is preferable for cotton and P/C yarns compared to PVA or other synthetic size materials.

Industrial Importance: This study will provide the industrial sizing technologists, an insight into the properties of various natural and modified starch materials and the predictability of their weaving performance while deciding the size recipe.

References