Size recipes for low-humidity weaving of cotton yarn

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The performance of starch and other sizing materials for cotton yarn has been investigated at different relative humidity by studying their film properties, adhesion to cotton and weaving performance. At low humidity, the poor weaving performance of cotton yarn sized with starch is due to the lower film extension and poor adhesion caused by low moisture regain. Hydroxyethyl starch (HES) gives excellent weaving performance of cotton yarn at 65% RH. Among the synthetic sizes, polyvinyl alcohol (PVA) gives excellent low RH weaving of cotton yarn even at low add-on. Polyacrylamide (PAM) is less effective but permits, at low add-on, satisfactory low RH cotton yarn weaving. Carboxymethyl cellulose (CMC) is useless for low RH weaving of cotton yarn. Among the blended size recipes studied, HES/Starch (50:50) and PAM/Starch (10:90) give excellent weaving performance at low RH and are most economical.

Keywords: Carboxymethyl cellulose, Cotton yarn, Hydroxyethyl starch, Polyacrylamide, Polyvinyl alcohol, Size recipes, Weaving

1 Introduction

Traditional starch-based sizing agents are not suitable for low-humidity weaving because they form brittle size films and have poor adhesion to cotton fibre. High humidity (≥80% RH) is required for satisfactory weaving of cotton yarn sized with starch-based size recipe which is not good for both man and machine. Also, the humidification cost to achieve 80-85% RH is 2-3 times the cost at 65-70% RH.

Synthetic binders like polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC), polyacrylamide (PAM) and chemically modified starch are not brittle because these are relatively more hygroscopic than starch. These materials enable weaving at lower RH but are uneconomical due to their high cost.

The present study was aimed at investigating the performance, at different relative humidity, of some sizing agents such as thick and thin boiling starches, hydroxyethyl starch (HES) and synthetic sizes in respect of their moisture regain, cohesion and adhesion properties, and their relative weaving performance. Finally, economical size recipes based on 90:10 blends of starch with each of other sizing agents were made. The weaving performance of cotton yarn sized with such recipes at different RH was evaluated to find a suitable economical and effective size recipe for low-humidity weaving of cotton yarn.

2 Materials and Methods

2.1 Materials

The following commercial sizing materials were used:

(i) Thick boiling corn starch (Maize starch): 2% concentration at 75°C having a viscosity of around 30 s (Red Wood No. 1 viscometer).

(ii) Thin boiling corn starch (Anilose A): 5% concentration at 75°C having a viscosity of 18 cSt (Ostwald viscometer).

(iii) Hydroxyethyl starch (HES): 0.05 molar substitution of hydroxyethyl to corn starch.

(iv) Polyvinyl alcohol (PVA, Cellacell 279): 4% concentration at 20°C having a viscosity of 20-30 cP (Brookfield viscometer).

(v) Carboxymethyl cellulose (CMC, Cellpro LVB): A low-viscosity type binder.

(vi) Polyacrylamide (PAM): A polymerized product of acrylamide monomer (mol. wt, around 4 lakhs).

2.2 Methods

2.2.1 Size Film Preparation

The solutions of above sizing materials were prepared and uniformly spread over acrylic sheets with the help of a doctor's knife and dried in atmosphere to get size films.

2.2.2 Determination of Film Properties

The moisture regain of size films was deter-
mined by conditioning them in desiccators for 48 h at 66, 75, 80 and 85% RH and then weighing. The breaking strength and breaking extension of size films (5 cm x 1 cm) were determined using an Instron tensile tester at 66, 75 and 85% RH. The adhesion power of different binders at 66, 75 and 85% RH was determined from the breaking strength of 10 cm long sized roving on the Instron tensile tester.

2.2.3 Weaving Performance

The weaving performance of sized cotton yarn was evaluated on the "Reutlinger Webtester (Sulzer-Ruti). This webtester simulates the most important stresses imposed on the yarn during weaving and the yarn undergoes cyclic elongation under a constant tension, abrasion and buckling. Each test was carried out with fifteen sized yarns (50 cm each) and the number of cycles up to the 10th break were noted. The test was repeated ten times for different sized yarns at 66, 70 and 78% RH.

3 Results and Discussion

3.1 Effect of RH on Moisture Regain of Size Films

The moisture regain values of different size films at 66, 75, 80 and 85% RH are given in Table 1. It is observed that the moisture regain of all the films increases with the increase in relative humidity. However, it may be observed that the synthetic size films are more sensitive to moisture than the starch size films including the modified starch (HES) size film. Among the starch size films, the moisture regain is lowest for maize starch (thick boiling) and highest for HES (starch ether); the thin boiling starch has higher moisture regain than the thick boiling starch. The moisture regain of any material depends on its molecular structure such as the packing of molecular chain and number of hydrophilic groups and their affinity towards water. The molecules in starch are held together by an extended micellar network and thus fewer hydroxyl groups are accessible for interaction with water. The fractionation in thin boiling starch increases the moisture regain by increasing the accessible hydroxyl groups. The packing of molecular chains in starch is reduced by the substitution of hydroxyethyl group and thus greater moisture regain is facilitated.

Among the synthetic sizes, CMC has the maximum moisture regain and is followed by PAM. The moisture regain of PVA is comparable to that of HES. High moisture regain of CMC is due to the presence of highly hygroscopic carboxylic group and that of PAM is due to the strong affinity of amide group towards water. In fact, both CMC and PAM films become tacky above 75% RH.

3.2 Effect of RH on Tensile Properties of Size Film

3.2.1 Breaking Strength

Table 2 shows that the breaking strength of PVA film is highest and is followed by those of unmodified and modified maize starch films. CMC and PAM films show negligible strength. The qualitative explanation for these results can be understood from the structures of these polymers. The strength of a polymer depends on its molecular structure such as crystallinity, orientation, degree of polymerization and interaction between polymer chains due to hydrogen bonding. Van der waals' forces, static attraction, etc. PVA constitutes a linear polymer chain with high cohesive energy density (4.2 kcal/Å chain length) due to good packing and extensive hydrogen bonding. Therefore, it gives high breaking strength. The strength of PVA film decreases with the increase in relative humidity. Ito³ observed that water absorbed by PVA molecules is bonded to the hydroxyl groups in the non-crystalline area and it breaks the hydrogen bond between the hydroxyl groups. The amount of bound water increases with the increase in relative humidity and remains as free water between the molecules. This plasticizes the PVA film.

| Table 1—Moisture regain of size films at different RH |
|----------------|----------------|----------------|----------------|----------------|----------------|
| RH, %          | Starch         | Anilose-A      | PVA            | CMC            | PAM            |
| 66             | 7.63           | 13.14          | 7.56           | 32.15          | 21.12          |
| 75             | 11.61          | 14.57          | 19.78          | 72.23          | 45.44          |
| 80             | 14.24          | 17.67          | 25.31          | 106.21         | 58.81          |
| 85             | 15.25          | 20.03          | 32.36          | 116.32         | 63.29          |

PVA—Polyvinyl alcohol; CMC—Carboxymethyl cellulose; PAM—Polyacrylamide; and HES—Hydroxyethyl starch.

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<th>Table 2—Breaking strength of size films</th>
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<td>Breaking strength, kg/cm²</td>
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*Size film becomes tacky at higher RH.*
Starch has pyranose ring in the main chain and side branching due to the amylopectin content. The total molecular packing being low gives lower breaking strength than that of PVA. The lower breaking strength of thin boiling starch and hydroxyethyl starch can be due to chain scission and lower molecular packing due to the substitution of hydroxyethyl group respectively.

The breaking strength of starch decreases at higher relative humidity. Initially, the absorption of moisture breaks few hydrogen bonds and the plasticization occurs to a limited extent which helps in uniform stress distribution. Further absorption of moisture breaks more hydrogen bonds and, therefore, reduces the breaking strength. The increase in breaking strength of thin boiling starch with increase in moisture is difficult to explain.

Presence of bulky carboxymethyl group in CMC and amide group in PAM prevents close molecular packing and absorbs excess water which plasticizes these polymers and reduces considerably the breaking strength.

3.2.2 Breaking Extension

Table 3 shows that the PVA film gives very high extension at all RH while the PAM film gives very high extension at 65% RH and becomes tacky at higher RH. The breaking extension of CMC is moderate and that of starch very low. The breaking extension of hydroxyethyl starch is much more than that of other starches.

The high breaking extension of PVA can be due to the chain folding⁴. Starches give very low breaking extension due to the rigid pyranose ring and branched amylopectin. CMC gives comparatively more breaking extension than starch due to the lower molecular packing caused by its bulky side group. The breaking extension of all size films increases with the increase in relative humidity due to the plasticizing effect of water.

3.3 Effect of RH on Adhesion

Table 4 shows that both PVA and PAM give better adhesion to cotton roving compared to starch-based sizing agents. In fact, the adhesion of PVA and PAM to cotton at 65% RH is comparable/better than that of starch at 85% RH. The adhesion of CMC and thin boiling starch is poor at low humidity. The adhesion of all sizing agents to cotton fibre increases with the increase in RH.

3.4 Performance of Pure Sizing Agents

The weavability cycles for cotton yarn sized with different sizing materials at different RH are shown in histogram (Fig. 1). The weavability cycles for the yarn sized with starch increase with the increase in RH and the difference between the performance of thin and thick boiling starches is statistically insignificant. Sizing with HES (chemically modified starch) gives excellent weaving performance at low RH. Among the synthetic sizing agents applied at low add-on, PVA gives the best weaving performance at low RH which is compar-

| Table 3—Breaking extension of size films |
|------------------|----------|----------|-----------|-----------|-----------|
| RH, %        | Starch  | Anilose-A | PVA       | CMC       | PAM       |
| 66           | 1.30    | 1.06     | 217.8     | 12.66     | 246       |
| 75           | 1.34    | 1.16     | 237.1     | 21.41     |           |
| 85           | 1.54    | 1.45     | 243.6     | 32.40     |           |

| Table 4—Breaking strength of sized cotton roving |
|------------------|----------|----------|-----------|-----------|-----------|
| RH, % | Size material | PVA (7.7) | PAM (8.9) | CMC (9.2) | Starch (7.6) | Anilose-A (7.0) |
| 66    | Virgin sizes | 6.3    | 6.03 | 5.07 | 5.73 | 5.2        |
| 75    | Virgin sizes | 6.7    | 6.5  | 5.91 | 5.73 | 5.5        |
| 85    | Virgin sizes | 6.8    | 7.02 | 6.8  | 6.2  | 5.7        |

*Values in parentheses indicate add-on %.

![Fig. 1—Weavability cycles of cotton yarn sized with different sizing materials at different RH](image-url)
able to that of HES sized yarn. Cotton yarn sized with PAM at low RH gives weaving performance comparable to that of the yarn sized with starch at high RH. The weaving performance of cotton yarn sized with CMC at low RH is poor and significantly lower than that of the starch sized yarn.

3.5 Performance of Blended Size Recipes

The weavability cycles for cotton yarn sized with economical blend size recipes (Fig. 1) show interesting results. Small addition of PVA or CMC to starch helps in attaining weaving performance of cotton yarn at low RH (70%) comparable to that of starch sized yarn at high RH. However, the addition of PAM to starch gives surprisingly the best performance at 65-70% RH which is comparable to that of the cotton yarn sized with PVA or HES and better than that of the yarn sized with PAM. HES blended with starch (50:50) gives better performance than starch/PVA or starch/CMC blend (90:10) size recipe at 70% RH.

These results suggest that PVA and CMC are not compatible with starch and their addition to starch helps mainly in plasticizing the film. However, better weaving performance by addition of PAM or HES to starch suggests compatibility between them in addition to the plasticization of the film.

3.6 Relationship Between Weaving Performance and Properties of Size Material

The weaving performance of sized yarn is dependent on the breaking strength and breaking extension of size film and adhesion. Linear multiple correlations of weavability cycles with film properties and adhesion were obtained and are as follows:

Multiple correlation of weavability cycles with:
- (i) breaking strength and extension of film and adhesion, 0.72;
- (ii) breaking extension of film and adhesion, 0.69;
- (iii) breaking strength of film and adhesion, 0.69; and
- (iv) breaking strength and extension of film, 0.57.

It may be seen that the correlation of weavability cycles with film properties and adhesion is good and not much affected by exclusion of either strength or elongation of the film. However, the correlation is reduced by excluding the effect of adhesion. This analysis shows that the weavability cycle for sized yarn is affected by the film properties and adhesion but the contribution of adhesion towards the weaving performance is significant.

4 Conclusions

Low add-on of PVA to starch gives good weaving performance of cotton yarn at low humidity (66% RH). HES, at higher add-on, gives weaving performance at 66% RH comparable to that of the PVA-sized yarn. Low-humidity (70% RH) economical size recipes are obtained by small addition (10%) of PVA, PAM or CMC to starch and by starch/HES (50:50) blend. PAM/starch blend size recipe gives excellent weaving performance at 65-70% RH which is better than that of the PAM-sized yarn.

References