Effect of Starch Particle Size Reduction on the Performance of Sized Warp Yarns

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***Abstract*—The mechanical and physical properties of tapioca based starch are known to vary in relation to physical parameters including the particle size of the starch granules. In this study, ultra sonication was used to reduce the particle size of starch solution from 100µm to 8µm and the modified starch was applied on poly cotton warp yarns. The strength, extension, moisture regain and size add-on% was tested and compared with the properties of conventionally sized yarns. The results showed that better strength and extension properties can be obtained by the application of ultra sonicated size solution at lower drying temperatures and lower squeeze roller pressures with minimum size add-on%.**

Keywords— particle size reduction, ultra sonication, sizing, performance

I. INTRODUCTION

Sizing can be identified as the preparation process of warp yarn prior to weaving. The process is mainly employed to impart required mechanical properties of warp yarn to withstand the various stresses imposed during the process of weaving. Starches and their derivatives are majorly used as primary sizing agents of size formula due to their abundance, low cost and high adherence with cellulosic [*1*]. Poly Vinyl Alcohol is often blended with starch due to the high strength in PVA size film.

The performance of sizing materials plays an important role in the effective sizing process. The growing concern of the industry is to develop sizing agents which positively contribute to the quality, efficiency and cost of the weaving process.

The major problem in the conventional sizing process is the higher size add-on that is required to achieve the strength of sized yarns. However, the elongation of the yarn is reduced with the increase of size add-on. Also it is difficult to achieve an evenly sized film with a highly viscous size solution since it may lead to a reduction in the strength of the warp yarn, thereby increasing the number of yarn breakages during weaving. Despite these problems, sizing is a major concern in green concepts as the fabrics have to be desized after weaving and the waste water is disposed to the environment as effluent.

Starch is a polysaccharide which contains amylose and amylopectin. The reduction of starch particle size has attracted much attention during past few years due to their unique properties that are significantly different from the bulk materials [*2*].

Ultra sonication is one of the environmental friendly physical approaches which can be used for starch nano particle preparation [*3*]. In this method the ultra sound frequencies (>20kHz) are used to agitate particles in a suspension and with the increase of sonication time duration at lower temperature, the starch particle size can be reduced up to nano level.

The effect of ultra sonication on the physical properties of starch suspensions has been studied previously. According to the findings, an improvement of solubility, swelling power, water absorption capacity, a decrease of viscosity consistency index and enthalpy of gelatinization can be seen in ultra sonicated starch solution [*3*]. The lower viscosity is a benefit as controlled size penetration into warp yarns and effective slashing can be achieved with high solid content and high fluidity of the size solution [*1*].

Only a limited number of studies has been carried out to date to enhance the performance of sized yarns through the reduction of particle sizes and they are mainly based on adding external particles such as SiO_2 nano particles [*4*]. The studies on reducing starch particle sizes were basically focused on food and drug industries. There are no records in efforts of using particle size reduction for the size solutions which are employed in the textile sizing process.

In this study, the performance of warp yarns sized with conventional size solution was compared with the performance of warp yarns sized with solution prepared by ultra sonication. The objective of this research was to find out the effect of particle size reduction on the performance of sized warp yarns.

978-1-4799-1740-2/15/$31.00 ©2015 IEEE

II. Materials And Methods

A. Materials

The 65/35 poly/cotton yarn (45 Ne) was selected to be subjected to the sizing process. The required un-sized yarn, sized yarn, sizing materials, size solution, desizing chemicals were obtained from Prabha Textiles in Pilliyandala.

B. Preparation of ultra sonicated solution

The process was carried out with the size solution used in the industry for poly /cotton yarn sizing. The size recipe is as follows: 350 liters of water, 50kg of starch, 3kg of gum, 4kg of tallow and 8kg of PVA.

The solutions were sonicated using Hielscher UP400S probe sonicator at 60% amplitude for 15 minutes.

C. Starch particle size analysis

The Fritsch particle size analyzer was used to identify the particle size distribution of the ultra sonicated solution. The average particle size was determined with the results obtained.

D. Application of sonicated solution

The conventional size solution was used as the control sample and the sonicated solution was used as the test sample throughout the process.

The viscosity of both solutions at 70°C was tested using Brookfield viscometer prior to the sizing process. LV spindle 4 was used for conventional size solution at 100rpm and the viscosity was 1752cp. LV spindle 2 was used for the sonicated sample at 100rpm and the monitored viscosity was 137cp.

For the size application on poly cotton yarn, a single-yarn sizing machine was used. The solution temperature was always kept constant at 70°C to maintain a constant viscosity. The immersion depth was kept at its maximum level throughout the sizing period. The selected winding speed was 25.5 Hz (170m/min) and the subsequent reeling speed was 30 Hz (200m/min). The processes were carried out at constant speeds.

The squeeze roller pressures of 5, 12.5, 20 and 27.5 Kgf were used in the process. The sized yarns were dried at three different drying temperatures 75°C, 85°C and 95°C.

E. Testing of sized yarns

The performance evaluation of sized yarns treated in conventional and sonicated solutions were tested for strength, elongation, moisture regain and the size add-on%.

The strength and elongation tests were carried out according to the ISO 2062 standard using Instron Universal Tensile Testing machine.

The moisture regain tests were carried out according to the ASTM D 1909 standard. The moisture regain and size add-on percentage were obtained using following equations.

$$moisture\ regain(\%) = \frac{Ws - DWs}{DWs} * 100 \quad (1)$$

$$size\ add_{on(\%)} = \frac{DWs - DWus}{DWus} * 100 \quad (2)$$

Where,

Ws – Weight of sized yarn
DWs – Dry weight of sized yarn
DWus – Dry weight of unsized yarn

III. Results And Discussion

A. Particle size analysis

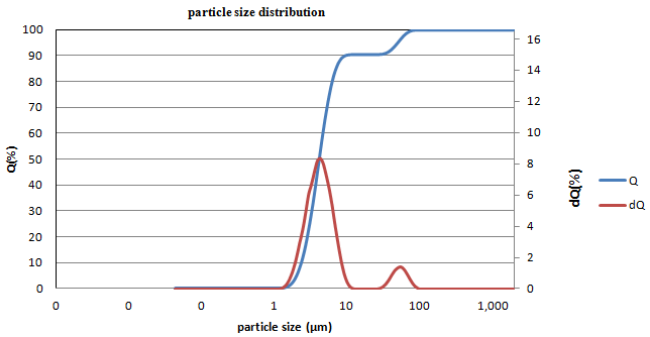

Fig. 1. Particle size distribution of ultra sonicated solution

In Fig.1, Q represents the cumulative particle distribution and dQ represents the relative quantity of the particles with a given diameter. Initially, the particle size of conventional size solution was 100µm. After ultra sonication, the size of the majority of starch particles fell within the range of 1 to 10µm. According to the calculations, the average particle size of starch was 8.46µm. Therefore the particle size of the size solution was reduced by 92%.

B. The viscosity of sonicated size solution

Since the size add-on amount is affected by the viscosity of the size solution, an optimum viscosity is needed for better size encapsulation and ease of size application.

The viscosity of the conventional size solution was reduced by 13 times through the ultra sonication process. Size solution with lower viscosity is expected to have high solid concentrate and increased fluidity.

TABLE I. The Size Add-On % At Different Squeeze Roller Pressures

Squeeze roller pressure (kgf)	Size add-on%	
	Conventional	Sonicated
5		6.68
12.5	6.67	7.66
20	7.70	11.95
27.5	9.82	9.53

The size add-on% of conventionally sized yarns was increased with the increase of squeeze roller pressure [*1*]. In the sonication method, the behavior was different. At 20kgf, the size add-on% was comparatively higher than other size add-on values and the size add-on% at 27.5kgf was lower than the size

add-on at 20kgf. However most of the times, it seems that the size add-on% of yarns sized with sonicated solution tends to be higher than the conventionally sized yarns.

Also it was shown that an almost equal size add-on% to conventionally sized yarns can be achieved at reduced squeeze roller pressures when sizing with sonicated solution. For example, for the conventionally sized yarn, the size add-on% at 20kgf was 7.70% and the similar size add-on% 7.66% was achieved at 12.5kgf when sizing with ultra sonicated solution. However this pattern was broken at squeeze roller pressure 20kgf for the sonication method.

C. *Effect on elongation of sized yarn*

TABLE II. THE EXTENSION VALUES AT DIFFERENT DRYING TEMPERATURES

Drying temperature(°C)	Extension (%)	
	Conventional	Sonicated
75	7.23	7.74
85	6.75	7.68
95	6.63	6.65

The elongation of a sized yarn normally reduces with the increase of drying temperature [*5*]. Although the same effect was shown in the yarn sized with sonicated solution, they tended to give better elongation properties in comparison to conventionally sized yarns at different drying temperatures (Table II).

The size add-on affects the elongation property of sized yarn [*6*]. Therefore the elongation of yarns sized at different squeeze roller pressures should be varied.

TABLE III. THE EXTENSION VALUES AT DIFFERENT SQUEEZE ROLLER PRESSURES

Squeeze roller pressure (kgf)	Extension (%)	
	Conventional	Sonicated
5.0		6.52
12.5	7.35	7.22
20.0	6.80	7.32
27.5	6.47	7.53

As the squeeze roller pressure was increased, the elongation of the yarn sized with conventional size solution was decreased. However the yarns sized with the sonicated solution acted oppositely. Better elongation properties of sized yarns were obtained at lower squeeze roller pressures.

D. *Effect on strength of sized yarn*

The squeeze roller pressure has a direct impact on the strength of the sized yarn. The average strength of yarns under applied pressures can be summarized as follows:

TABLE IV. STRENGTH VALUES OF YARNS AT DIFFERENT SQUEEZE ROLLER PRESSURES

Squeeze roller pressure (kgf)	Strength (N)	
	Conventional	Sonicated
5.0		2.9732
12.5	2.9188	3.0139
20.0	3.0748	3.0458
27.5	2.9334	3.0684

The comparison of data shows that the strength of the yarn sized with sonicated solution had better strength properties at 12.5kgf and 27.5kgf. Though it had a slight strength reduction at 20kgf, the sonicated yarn always had almost constant strength at different squeeze roller pressures (Table IV) in sonication method.

Also in the sonication method, an increase of yarn strength could be seen when increasing the squeeze roller pressure. This is because with the reduction of particles, starch material diffuses more into the yarn bundle, increasing its modulus.

E. *Effect on moisture regain*

TABLE V. MOISTURE REGAIN VALUES AT DIFFERENT DRYING TEMPERATURES

Drying temperature(°C)	Moisture regain (%)	
	Conventional	Sonicated
75	6.72	5.02
85	5.49	4.98
95	4.41	4.81

When the drying temperature increased, the moisture regain of yarns sized with both conventional and sonicated solutions decreased. The amount of moisture in the sized yarn is an important parameter that affects the quality of warp yarns [*1*]. However according to the obtained results, the moisture regain of yarns sized with sonicated solution was lower than the moisture regain of conventionally sized yarns.

The experimental results for yarns sized with sonicated solution shows that improved extension and moisture regain properties can be achieved at the drying temperature 75°C.

On the other hand, both the extension and strength properties were increased with the increase of squeeze roller pressure. Similarly, the size add-on% was increased with the increase of squeeze roller pressures.

Considering all squeeze roller pressure values and the results on tested properties, the sized warp yarn performance was highest at 12.5kgf than at the other pressure values.

IV. Conclusion

With the increase of size percentage yarn strength is also increased. However, through sonication, required breaking strength of sized yarn could be achieved with a low size percentage. So the reduction of particle size in a conventional size solution has a positive impact on both the strength and elongation of the warp yarns. Due to high size percentage, residual elongation is reduced. As the sonication method permits to deal with low size percentage, it also shows enhanced moisture regain and extension properties at lower drying temperatures.

With the reduction of particle sizes, the size add-on% was increased. In this study the sizing speed of the single end sizing machine was kept constant. Therefore required size add-on% for a sized yarn can be achieved at higher speeds of sizing. Owing to which production of the sizing machine is improved.

Furthermore, the required properties of the sized yarn for better weaveabilty can be enhanced with a lesser size add-on% by reducing the particle size of the size solution which in turn will reduce the sizing cost.

Acknowledgment

The authors wish to acknowledge the support of Mr. Hettiarachchi in providing required materials and the technical assistance given by Mr. H.M.R.P.B. Herath and Mr. R.P.U.S. Senarathne in warp yarn sizing and Mrs. D. M. D. S. Dissanayake and Mr. C. P. Malalanayake in testing of yarn properties.

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