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Note from the field

Partially gelatinized corn starch is a potential environmentally friendly warp-sizing agent

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ABSTRACT

Partially gelatinized corn starch (PGCS) was used for sizing cotton yarn in the search for potential sustainable and environmentally friendly warp-sizing agents as substitutes for poly vinyl alcohol. PGCS was prepared by a constant temperature method (CTM). The viscosity stability of PGCS was investigated and characterized by wide-angle X-ray diffraction, differential scanning calorimetry, polarized light microscopy and laser diffraction particle size analyzer. The results indicated that the viscosity of CTM_{65} (starch milk held in a water bath shaker at 65 °C for 30 min) was stable. The cotton yarn was sized by PGCS (CTM_{65}) on a cylinder slasher sizing machine. Scanning electron microscopy indicated that starch granules on the surface of the yarn had completely gelatinized and formed a film when the yarn was treated via the No. 2 drying cylinder (to reduce yarn hairiness). This research supports the idea that PGCS could improve the viscosity stability of native starch paste and have potential as an environmentally friendly warp-sizing agent.

1. Introduction

Warp sizing and desizing consumes large amounts of water and chemicals, and mostly responsible for the toxic effluents released into the environment from textile plants (Reddy et al., 2014). It is well known that the properties of native starches (NSs) do not cope with the sizing process (e.g. NS needs to be esterified or etherified to improve viscosity stability and ensure the sizing percentage; the viscosity of NS is too high and needs to be reduced by acid degradation or oxidization to suit the widely used warp sizing method 'high-temperature, high-pressure and low-viscosity'). Although starch derivatives provide good sizing performance, textile plants have to deal with rising costs of starch derivatives compared with NS. Therefore, the economic cost of warp sizing encourages research to find ways to lower costs (Hasanbeigi and Price, 2015) and to develop green textiles (Moreira et al., 2015).

Partial gelatinization sizing technology (PGST) is a corn starch sizing technique by controlling the degree of starch gelatinization at temperatures above the gelatinization temperature in an irreversible granule swelling. Once the yarn with the partially gelatinized starch dries, the sizing agent will gelatinize completely and form a starch film (Fig. 1) which enhances the strength and wear resistance of sizing (Wu et al., 2014). Previous literature (Wu et al., 2014) indicated that partially gelatinized corn starch (PGCS) was prepared by steam heating method, however, the present research is expected to focus on the degree of starch gelatinization impact on warp-sizing.

Partial gelatinization of starch is frequently achieved by high pressure (Chang et al., 2014), oxidation (Fiedorowicz and Para, 2006), spray drying (Niazi et al., 2013) and ball milling (Liu et al., 2011). Reports on the viscosity and viscosity stability of PGCS, especially the warp-sizing performance of PGCS for cotton yarn are, however, unknown. Therefore, understanding the nature of the

Abbreviations: PGCS, Partially gelatinized corn starch; PGST, partial gelatinization sizing technology; GD, gelatinization degree; NS, native starch; CTM, constant temperature method; CTM_{63}, starch solution was held in a water bath shaker at 63 °C for 30 min; CTM_{64}, starch solution was held in a water bath shaker at 64 °C for 30 min; CTM_{65}, starch solution was held in a water bath shaker at 65 °C for 30 min; CTM_{66}, starch solution was held in a water bath shaker at 66 °C for 30 min; CTM_{67}, starch solution was held in a water bath shaker at 67 °C for 30 min; CTM_{68}, starch solution was held in a water bath shaker at 68 °C for 30 min; HPSEC-MALLS-RI, high-performance size-exclusion chromatography equipped with multi-angle laser-light scattering and refractive index detectors; Mw, weight molar mass; Mn, number molar mass; Mw/Mn, dispersity index.

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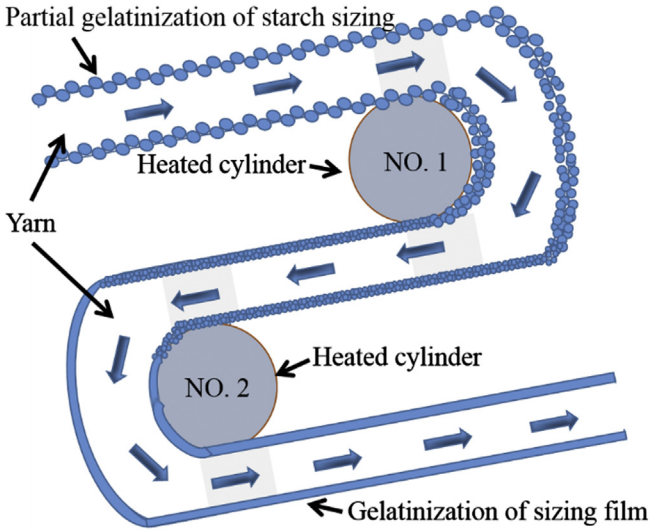

Fig. 1. Schematic of sizing mechanism of partial gelatinization sizing technology.

underlying PGCS is necessary. Hence, the experimental results of this study will provide relevant information for using PGCS as a sustainable and environmentally friendly warp-sizing agent.

2. Materials and methods

2.1. Materials

Commercial corn starch (apparent amylose content of 27.4%) was purchased from Tianmei Development Co. Ltd. (Shandong, China). Pure cotton roving (405 tex, twist factor of 105) was provided by Qingfeng Textile Co. Ltd (Wuxi, China). Fiber length and fineness were 29 mm and 1.67 dtex for pure cotton roving.

2.2. Partially gelatinized corn starch preparation

A constant temperature method (CTM) was used in the study. Briefly, corn starch (10 g on a dry weight basis) was dispersed in distilled water (90 mL) and the resulting starch solution was held in a water bath shaker at 63 °C (CTM_{63}) to allow partial gelatinization under gentle stirring for 30 min. Based on this method, CTM_{63}, CTM_{64}, CTM_{65}, CTM_{66}, CTM_{67} and CTM_{68} were prepared using the appropriate different temperatures (e.g. 63, 64, 65 °C …).

2.3. Viscosity determination and viscosity stability of partially gelatinized corn starch

Unless noted otherwise, viscosimetric measurements were carried out with a Brookfield DV-C portable rotating viscometer (Brookfield Engineering Lab. Inc., Stoughton, MA, USA) using spindle No. 61 at 25 °C. All measurements were performed three times. Apparent viscosity was expressed in mPa·s.

Effect of different starch concentrations on viscosity: for comparison purposes, samples (starch concentrations: 6, 8, 10, 12, 14, 16, 18 and 20%) were prepared using CTM_{65}.

Effect of different temperature on viscosity: the apparent viscosity of prepared samples (starch concentration 10%) were respectively measured at 60, 50, 40, 30, 20 and 4 °C.

Effect of different preservation times under refrigeration on viscosity: when the PGCS was prepared, the samples were cooled to 4 °C using an external ice bath within 10 min. After appropriate storage times at 4 °C (1, 2, 3, 4, 5, 6, 8, 10, 14, 18, 22, 26 and 30 d), the apparent viscosity of prepared samples was measured at 4 °C to collect data for analysis.

2.4. Wide-angle X-ray diffraction (WXRD) and differential scanning calorimetry (DSC) investigations of PGCS

WXRD patterns of the PGCS samples were observed on a Bruker D8-Advance XRD instrument (Bruker AXS Inc., Germany) using Cu radiation (2θ: 3–35°, 0.6°/min) (Xu et al., 2013). The extent of starch gelatinization was measured using the method of Fu et al. 2012. The final gelatinization degree (GD) of samples was calculated using Eq. (1):

$$GD = \{(\Delta H_{ns} - \Delta H_{PGCS})/\Delta H_{ns}\} \times 100\% \quad (1)$$

where ΔH_{ns} and ΔH_{PGCS} are the melting enthalpies of NS and PGCS, respectively.

2.5. Optical analysis of partially gelatinized corn starch and sized cotton yarns characterized by SEM

The 'Maltese cross' of PGCS samples was observed by Olympus BX41TF light microscope (Olympus Co., Tokyo, Japan) at 400 × magnification. The size of paste particles was assayed for samples by Microtrac S3500 laser particle size analyzer (Malvern Instruments Ltd., Worcestershire, UK.). The cotton yarn and sized cotton yarn [cotton yarn was sized by PGCS (CTM_{65}) on cylinder slasher sizing machine] were scanned using a SU1510 SEM (Hitachi, Japan) under 5.00 kV at 100 magnification.

2.6. Molecular weight distribution analysis and measurement on sized yarns

The molecular weight distribution of starches was determined by HPSEC-MALLS-RI according to the method described by Wu et al. (2013).

Tensile strength and breaking elongation of sized yarns were tested on a HD021N Tensile Tester (Nantong Hongda Instrument, China) under 65% relative humidity and 20 °C. For each yarn sample, 20 pairs of tensile strength and breaking elongation readings were measured and their mean values were used to calculate the increase in tensile strength (*Its* %) and loss in elongation (*Le* %) from Eqs. (2) and (3):

$$Its(\%) = \{(S - S_0)/S_0\} \times 100\% \quad (2)$$

$$Le(\%) = \{(E_0 - E)/E_0\} \times 100\% \quad (3)$$

Where S and S_0 were the mean values of tensile strength of sized and unsized yarns. E and E_0 were the mean values of breaking elongation of sized and unsized yarns, respectively.

3. Results and discussion

3.1. Characterization of partially gelatinized corn starch—WXRD and DSC

The lyophilized white PGCS powders (CTM_{63}, CTM_{64}, CTM_{65}, CTM_{66} and NS) are characteristic of the A-type polymorph pattern (2θ: 15, 17, 18 and 23°) (Fig. 2a). This suggested that these PGCSs maintained their native A-type crystallinity after the CTM. However, the peaks (2θ: 15, 17, 18 and 23°) of the lyophilized white PGCS powders, treated with CTM_{67} and CTM_{68}, became weaker or disappeared, suggesting that A-type crystallinity of NS was changed

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