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Effect of low-temperature oxygen plasma on the degumming of ramie fabric

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ABSTRACT

Ramie fiber is one of the most important materials for textile manufacturing. However, the conventional degumming processes for ramie involve numerous chemicals and water consumptions, resulting in a serious environmental concern. The purpose of this work is to investigate the effect of low-temperature oxygen plasma (LTP-O_2) treatment on ramie fabric degumming in combination with a subsequent mild wet chemical process. The oxygen plasma treatment variables such as oxygen gas pressure, discharge power and exposure time were investigated and optimized according to the indexes of fabric total impurity removal, whiteness, capillary rise height, tensile strength and elongation, etc. The results show that a notable effect of oxygen plasma on ramie degumming was observed in a subsequent mild wet chemical process. The fabric capillary rise height, whiteness, tensile strength and elongation of the pretreated ramie were improved with gas pressures from 20 Pa to 40 Pa, although accompying with a decrease tendency in impurity removal, as well as for the capillary rise height as pressures higher than 40 Pa. Furthermore, the fabric impurity removal, capillary rise height were enhanced with plasma discharge power from 30.0 W to 250.0 W, with less affects on fabric whiteness, tensile strength and elongation. Moreover, most of the degumming indexes were also improved as the exposure time from 1.0 min to 3.0 min, except for a worse deterioration of fabric tensile strength as an exposure time longer than 5.0 min. An optimized plasma process for ramie fabric degumming was at 40.0 Pa of oxygen gas and 250.0 W of glow discharge for 3.0 min. In comparison with a control and conventional degumming processes, higher degumming effects and mechanical properties of ramie fabric were achieved by the combination degumming process with more environmentally friendly due to less consumption of chemicals, water and energy. Moreover, the effect of oxygen plasma on ramie fiber was further confirmed and characterized by X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM).

1. Introduction

Ramie (Boehmeria nivea) is one of the oldest, green and natural fiber crops, namely China grass or Chinese plant, with a long history about over 6000 years in cultivation and for textile manufacturing in China according to archaeological data (Wei, 2007). Up to recent years, China still leads in the production and exports with a large share of about 90% in world ramie commercial market (Xie, 2008). Ramie has been paid worldwide attention again since the1980s, due to the increasing consumption of green and ecological textiles by customers from the world (Xie, 2008; Wei, 2007). Ramie is one of the longest, strongest and coolest natural fibers with numerous advantages as spinnable material, such as the well known ability of holding shape, less wrinkling, silky luster, special cooling feel, high absorbency, good air permeability, and feasibility to blend with other fibers, etc (Zheng et al., 2001; Liu, 1995). Furthermore, ramie is also a green and functional fiber with the characteristics of biodegradability, recyclability, very resistant to mildew, upstanding antibacterial and deodorization functions (Liu, 1995; Li et al., 2013). However, as a bast fiber, decorticated ramie is not only composed of cellulose, which is the main and useful component of ramie at about 60%~80%, but also involves various gummy materials like 14% ~16% of hemicelluloses, 4%~5% of pectins, 0.8%~1.5% of lignins, as well as other impurities, such as fat acids, waxes, inorganic compounds, etc (Jiang, 2011; Bruhlmann et al., 2000). Consequently, before the applications of ramie substrate in textile industry, the gummy materials, as well as other impurities, should be degummed or removed as fully as possible to improve the service

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properties of its products. Up to date, the conventional degumming processes with high consumptions of alkalis and/or acids, as well as other chemicals and energy, at high temperatures are still employed frequently in practice, which readily causing serious environmental pollution and even biological disorders by discharging toxic, non-biodegradable effluents (Zheng et al., 2001; Mukhopadhyay et al., 2013). Therefore, the development of clean, environmentally friendly, effective, water and energy conversation degumming or pretreatment processes for ramie is extremely necessary and urgent.

The available researches in literature show that Low-temperature plasma (LTP) could present effective and powerful effects on different textile substrates for pretreatments, with numerous advantages due to its waterless and dry surface modification for a cleaner production (Riccobono et al., 1973; Morent et al., 2008). Riccobono et al. (1973) developed the first application of plasma in the desizing of grey cotton and or its blends with polyester. Sando Iron Works Co. Ltd. (1995) built a low temperature plasma system for fabric desizing and scouring, as well as a continuous roll to roll system reported in 1995 (Sando Iron Works Co. Ltd., 1995; Tomasino et al., 1995). Cai et al. (2002, 2003) reported a positive effect of atmospheric pressure plasma of air/He, air/O_2/He on the removal of polyvinyl alcohol (PVA) size from cotton fabric. Bae et al. (2006) investigated the effects of oxygen low-pressure plasma pretreatment on the removal of different sizing agents, such as polyvinyl alcohol (PVA), polyacrylic acid ester (PA) and their mixture (MIX) on polyester fabrics. Long et al. (2008) developed an effective method for silk degumming by applying argon low-pressure plasma.

However, the above researches available in literature about plasma applications in textile pretreatments are mainly related to the removal of size agents and/or impurities on grey cotton, man-made fibers, and their blends, as well as for silk degumming. But very few works could be available in literature about the effect of low-temperature oxygen plasma on the degumming of ramie substrate, although it is very benefit to the cleaner production of ramie, and also is very desirable in ramie industry.

The purpose of present work is to investigate the effect of low-temperature oxygen plasma on the degumming of ramie fabric, in combination with a subsequent mild chemical process. The plasma parameters such as oxygen plasma pressure, discharge power and exposure time were investigated and optimized. The plasma treatment effect on ramie fabric degumming was also evaluated in comparison with a control and conventional processes, respectively. Moreover, the effect of oxygen plasma on ramie fiber was further confirmed and characterized by X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM).

2. Experimental section

2.1. Materials and chemicals

A commercial and raw ramie fabric (a woven, with a fabric weight of 127.2 g m^{-2}) was kindly supplied by Chongqing Fuling Kinde group Co., Ltd. (China) in this study. The raw ramie fabric was cut into a dimension of 30.0 cm × 15.0 cm, and used as received without any other previous treatment. All raw ramie fabric samples were conditioned at 20 °C ± 2 °C and 65% ± 3% relative humidity for 24 h before a measurement or testing.

All the chemicals used in mild wet-chemical pretreatment processes, such as sodium hydroxide, sulfuric acid, sodium hydrogen sulfite, sodium dodecyl benzene sulfonate, etc., were commercially available products. Pure oxygen gas (with a purity of 99.5% vol. %) employed in low-temperature plasma treatment was purchased from Suzhou Jinhong gas Co., Ltd. (Jiangsu province, China).

2.2. Apparatus and procedures

2.2.1. Low-temperature plasma treatment

The low-temperature plasma treatment for raw ramie fabric samples was carried out in the same batch plasma system (HD-1, Suzhou Hongda plasma technology company, China) as described elsewhere (Long et al., 2008). Before a low-temperature plasma treatment, the raw ramie fabric sample was dryed in an oven at 95 °C for 1 h, and then was hung vertically with a sample stand between the two parallel electrodes. The gas pressure for plasma treatment was ranged from 20.0 Pa to 100.0 Pa with an interval of 20.0 Pa, the glow discharge power input was varied from 30.0 W to 400.0 W at a step of 50.0 W or even 20.0 W, and the exposure time was also varied from 1.0 min to 15.0 min.

2.2.2. Wet-chemical degumming treatment

A conventional wet-chemical process was performed for the degumming of raw ramie fabric samples, and described in a flowchart as follows:

Soaked in an acidic solution → scouring in an → alkaline solution → washing with tap water

refining and bleaching treatment → washing with → acidic solution → washing with tap water

sample preparation for testing.

The soaking treatment for sample was carried out in an acidic solution involving 2% (o.m.f.) sulfuric acid with a material to liquor ratio of 1: 30 at 25 ± 1 °C for 20 min, in order to partly remove some unstable and soluble gummy materials from the raw ramie substrate in the acidic medium. The scouring procedure was performed in a hot alkaline solution containing 10.0 g L^{-1} of NaOH with a material to liquor ratio of 1: 30 at 90 ± 1°C for 80 min. Most of the gummy materials were degraded and removed from the ramie substrate, as well as for other impurities. The refining and bleaching treatment was carried out in an alkaline solution containing 15.0 g L^{-1} of Na_2CO_3, 2.0 g L^{-1} of $NaHSO_3$ and 1% (o.m.f.) of sodium dodecyl benzene sulfonate with a material to liquor ratio of 1: 20 at 100 ± 1 °C for 60 min, to further extract of the ramie fiber and improve the whiteness of the ramie substrate. Moreover, a washing procedure was followed by employing an acidic solution involving 3% (o.m.f.) sulfuric acid with a material to liquor ratio of 1: 20 at 25 ± 1°C for 5 min, for neutralizing the alkali and removing the adsorbed impurities on the ramie fabric. Finally, the samples were further washed with tap water before the sample preparation for testing.

However, the degumming of the ramie fabric samples after a previous treatment by oxygen plasma in this study, was carried out only in a mild condition and described in a flowchart as follows: