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Original Article

Regenerated cellulose from high alpha cellulose pulp of steam-exploded sugarcane bagasse

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ABSTRACT

The need for biodegradable films for packaging, absorbents, and fibers has encouraged the development of novel biodegradable films made from natural sources, especially agricultural byproducts. The present investigation involved preparation of alpha cellulose and regenerated cellulose film, in view of the use of sugarcane bagasse, the cellulose-rich waste from the sugar industry. In order to prepare a cellulose pulp, the bagasse was exploded separately by saturated steam at temperatures of 195 °C and 205 °C for 5 min, washed, oven-dried, and submitted to an alkali pulping and bleaching process. The chemical compositions consisted of alpha cellulose, holocellulose, lignin, and the extractives of the bagasse and its pulp were analyzed. The results showed that the pulp contained high levels of alpha cellulose and low lignin. The cellulose pulp was being successfully regenerated as cellulosic films in an acid coagulation bath at different coagulation times. The characteristics of the steam exploded bagasse, cellulose pulp, and regenerated cellulose were investigated by SEM, XRD, FITR, TGA, tensile test, contact angle, and water retention measurement. The results of the XRD, FTIR and TGA all indicated that high alpha cellulose with low lignin pulp could successfully be made from steam-exploded sugarcane bagasse. The SEM images, contact angles, and water retention values also revealed that the regenerated films coagulated in an acid bath for 15 min were more hydrophilic than those that had coagulated for 30 min. The tensile test indicated that the regenerated cellulose films coagulated for 30 min were stronger than those coagulated for 15 min.

1. Introduction

The decreasing in non-renewable natural resources and the rapidly increasing in pollution problems motivate utilization of natural polymers to create interesting new materials [1,2]. Some of petroleum-based products, at present, are gradually being replaced by bio-based products made from cultivated plants or lignocellulosic materials such as agricultural residues. They are widely available, do not take long to substitute, and can rapidly decompose in nature. It has been estimated that the agricultural byproducts from major commodity crops such as sugarcane, rice, and soybean, created

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worldwide will reach over two thousand million tons or more per year [3]. This makes these byproducts ideal resources for natural cellulosic products. The use of the cellulose, the most abundant natural polymer compound found in various parts of plants, as a feedstock to replace petroleum-based products, such as plastic film, packaging, medical materials, membranes, absorbents, fibers, and in the future, more will be technically possible.

Sugarcane bagasse is cellulose-rich waste from the sugar industry, generally used as the main fuel source for sugar mills, a feed source for beef cattle, a fertilizer, and landfill materials. Sugarcane can be a potential feedstock because it can be grown and be harvested year round, and after the juice is removed, the bagasse itself can be stacked and stored for a long time [4]. Since the bagasse contains approximately 38–50% cellulose [4–6] and after a proper purification process the amount of lignin can be reduced from 1.62% to 0.68%, making it an ideal feedstock for the production of cellulose-based products such as cellulose pulp and its derivatives [7].

Regenerated cellulose is one of the end-uses of cellulose dissolving pulp, a chemical pulp with a high content of alpha cellulose and relatively low hemicelluloses and lignin content [8]. Regenerated cellulose materials have increasingly gained attention since they are biocompatible, biodegradable, thermal and chemical stable, and low cost. They can be prepared through three-step process, dissolution, shaping and regeneration, which will eventually transform cellulose to useful materials in various forms such as films, beads, fibers, etc. [9] To meet different type of demands, regenerated cellulose can be used to produce a variety of products, such as fibers for textiles and clothing, disposable medical materials and artificial membranes [10,11]. Recently, novel functional materials have been designed and fabricated via applied chemical and physical treatments during regeneration of cellulose solution such as cellulose/biopolymer composite hydrogels, porous membranes, and inorganic/cellulose hybrids [9,12]. Therefore, regenerated cellulosic material will become a promising candidate in utilization of cellulose.

In order to achieve high pulp quality the steam explosion should be introduced prior to the chemical pulping process [13,14]. This method is widely applied to any lignocellulosic biomass due to its potential for disrupting the crystallinity of cellulose, delignification [15,16] and easy hydrolysis of the hemicelluloses [15,17]. In other words, steam explosion can make it easier to separate the cellulose from the bagasse in the further stages, making use of fewer chemicals, less time, and less money in the terms of the overall processes.

This research intends to make high alpha cellulose pulp and regenerated cellulose film from agricultural waste from sugar mill industry. The bagasse is exploded with steam before it reacts with alkali and bleached to separate the cellulose from the lignin and hemicellulose. Steam explosion can effectively reduce the amount of hemicelluloses and acid-soluble lignin of bagasse fibers, while acid-insoluble lignin is removed throughout alkaline washing [18]. The cellulose is then made into the form of viscose and regenerated back to solid-formed cellulose using conventional viscose process. Finally, the regenerated cellulose should be analyzed for its strength, chemical and physical characteristic, and thermal stability.

2. Experimental

Sugarcane cultivar, K84-200, from the eastern region of Thailand, grown commercially for the sugar industry, was used in this study. The bagasse was cleaned, soaked in water for 24 h, dried, and kept in plastic bags to be used throughout the study. The chemical composition (%w/w) of the bagasse is α-cellulose 41.42%, holo-cellulose 69.53%, lignin 19.03%, and extractives 4.16% on a dry weight basis, shown in Table 1. All of the chemicals used were of analytical grade and used as received without any further purification. They all were obtained from either Sigma-Aldrich or local suppliers.

2.1. Steam explosion

A sugarcane bagasse sample (150 g dry weight basis), 2–3 cm in length, was loaded into a 3-L stainless steel reactor and treated by saturated steam at a temperature of 195 °C for 5 min. In due time, slurry was collected from the reactor. The steam exploded solid, hereinafter referred to as steam exploded bagasse, was separated by filtration, thoroughly washed with clean water, centrifuged to eliminate the fluid, then dried in an oven at 60 °C, and finally, the dry samples were stored in a plastic bag for the experimental reasons. The steam explosion treatment was repeated on another 150 g of the same sample using saturated steam temperature at 205 °C for 5 min. The dry weight of the steam exploded samples was calculated as the dry weight of the solid remaining after treatment referred to 100 g of the sugarcane bagasse introduced into the reactor. The chemical compositions, including alpha cellulose, holocellulose, lignin, and extractives of the steam exploded bagasse (solid remaining) were analyzed according toTAPPI-T203-om-93, Acid chlorite Method of Browning [19], TAPPI-T222-om-98, TAPPI-T204-om-97, TAPPI-T264-om-97 and TAPPI-T207-om-93.

2.2. Pulping and bleaching processes

The steam exploded bagasse was submitted to alkali pulping process. The sample was reacted with 20% (w/w) NaOH using a liquid to solid ratio of 20:1 at 80–90 °C for 2 h. At the end of the alkali process, the cellulose pulp, which was brown in color, was separated from the black liquor, rinsed through a sieve [mesh size number 50] with clean water until the water ran clear, oven dried at 60 °C, weighed to calculate percentage of the remaining solid (referred to 100 g of the steam exploded bagasse), and then exposed to the bleaching process. In the bleaching stage, the brown pulp underwent three cycles of bleaching. For the first cycle of bleaching, the pulp reacted with 4% (w/w) $NaClO_2$, adjusted to pH 3–4, using acetic acid. The liquor to dry fiber ratio, cooking temperature, and time were kept at 20:1, 80–90 °C, and two hours, respectively. The treated pulp was then washed until the pH of the washing water became neutral. After that, they were treated again with 2% (w/w) NaOH, using a liquid to solid ratio of 20:1 at 80–90 °C for 30 min. The bleached pulp was then washed

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