Investigation of the Extraction Processes and Performance Properties of Kudzu Fibers

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Kudzu was first introduced in different regions in the USA for the purposes of improvement and preservation of soil since it can prevent soil erosion and also improve the fertility of lands (Gigon, Pron, & Buholzer, 2014; Li, Dong, Albright, & Guo, 2011; Tanner, Hussain, Hamilton, & Wolf, 1979). It has amazing ability to grow without any care in very infertile land. Since coarse and fragile kudzu fibers are not usually modified and weaving processes are traditionally hand weaving, its uses are now limited to making wallpapers, surface coverings (e.g. table coverings and mats) with some very expensive yardage for Japanese traditional ritual garments by a few craftsmen (Murai & Murai, 2014). Thus research on kudzu fiber production is crucial to find ways to utilize this plant and to increase its viability for textile production to support increasing global demands.

Cellulosic content in kudzu vine is in a very small quantity as compared with other plants used for bast fiber production. Since plenty of the raw material, namely running vines, are easily available with very little or without any cost, the small percentage yield is not a large problem; rather it can offer an economic gain where the kudzu vines are wasted. Components of kudzu vine can vary by different factors, such as geographic location, the season of the year, weather condition, maturity level, and age.

While few studies have been reported on kudzu fiber production, it was deducible from different studies that kudzu could be extracted as long fibers from the interior sheath by chemical treatments, microbial retting or enzymatic processes. While some studies have harvested in the fall, fresh kudzu vines were collected from Cherokee Bend, Moundville, Alabama in May 2016 and August 2016. Extraction of kudzu fibers processes was designed based on a study of previously reported research. Four major techniques were applied to separate fibers from vines: retting, boiling, enzymatic and mild chemical processing.

Boiling process: Selected samples were boiled (90-100 ^{0}C) in tap water in a beaker with lid for 100 minutes while other samples were boiled for 120 minutes for better separation. Then, all the samples were washed with cold water. Fibers were separated by hands in water. The 120-minute samples were easier for fiber separation. Two types of fibers were found in the vines-outermost soft fibrous part and stem with the compact woody part. *Retting/fermentation process:* A set of 90-minute boiled samples and an untreated sample set were dipped in water for 12 days. Separation of the fibers was very easy for boiled-retted fibers. However, samples that were only dipped in water without any pretreatment were also good in fiber separation. *Enzymatic process*: To accelerate the extraction process, selected samples were boiled (90-100 ^{0}C) in water for 50 minutes. These pre-boiled samples were treated with the combination of three enzymes: hemicellulase, xylanase, and pectinase. Six different combinations of the enzymes (hemicellulase = 2-4 g/L, xylanase = 1-2 g/L, pectinase = 1-2 mL/L) in buffer (pH = 4.6) solution (deionized water) were employed in launderometer at 50-55 ^{0}C for 90 minutes. Material to liquor ratio was maintained 1 to 10. Then, the temperature was raised to 90 ^{0}C for 50 minutes to kill the enzymes. Samples were washed in tap water and fibers were separated. Separation of the fibers was not very easy. *Mild chemical process*: Samples were directly treated with either only NaOH or a combination of NaOH and Na_2CO_3. For NaOH treatment, 2-4 % NaOH and for combined treatment, 2-4% NaOH and 3-4% Na_2CO_3 were used in the material to liquor ratio of 1 : 10 to 1 : 20. In hot plate and launder-o-meter cases, a temperature of 90-95 ^{0}C for 60-70 minutes was maintained. For the higher amount of NaOH, fibers were slightly damaged. However, in all the cases, fiber separation was very easy. The best condition was found to be 2% NaOH and 4 % Na_2CO_3 at 90-95 ^{0}C for an hour.

Fibers were assessed by visual appearances, measuring fiber lengths and tensile strengths, and microscopic analysis in SEM. An elemental analysis using EDAX SEM identified the presence of different elements. From the spectrum elemental analysis, it was observed that all the fibers were mainly composed of more than 96 weight % and 97 atomic % of combined carbon (C) and oxygen (O) when analyzed by K-shell X-ray peaks. Presence of other elements includes some metals, such as- calcium (Ca), aluminium (Al) and sodium (Na). Some of the K-shell peaks found of metal elements may be from processing attributes, for example-water, processing chemicals, enzymes, and salts. Microscopic analysis shows that boiling and mild chemical processes produced cleaner fibers while chemical process produced stronger fibers (breaking load 19.89 kg/tex) and softer fibers.

Since fibers were in bundle form and more than 8 inches long in all cases, they were directly used in a tensile tester (MTS Qtest 25) for respective fiber counts. Tensile properties of the produced eight different kudzu fibers were determined for a specific diameter of each group of fibers. Breaking elongation (BE%) of both soft and woody fibers was very high (22-38%) as compared with elongation of cotton fibers 4-8% (Fiori, Sands, Little, & Grant, 1956; Yang & Gordon, 2016). Reasonably, BE% of chemically extracted soft and woody fibers were the highest (37.94% and 35.69% respectively) because NaOH works as a scouring agent to improve fiber strength for most of the natural cellulose-based fibers. However, all kinds of kudzu fibers had fairly consistent BE% values. Breaking load in kg per tex for the soft fibers (5-20 kg/tex) in all cases was higher than the woody fibers. However, even the lowest breaking strength (3.7 kg/tex) for any of the Kudzu fibers extracted were higher as compared with traditional other long fibers, such as- hemp, jute, and flax. Chemical processes improved the strength of soft fiber to a very high degree, averaging 19.89 kg/tex. Except for the breaking stresses of the soft fibers extracted by retting and enzymatic processes (47.02 and 72.54 psi respectively), all other fibers showed breaking stresses of above 100 psi which is very high and suitable for many of applications besides textiles.

In all extraction cases, the amount of extracted woody kudzu fibers was more than 2-5 times that of soft fibers. Soft fibers were in bundle form but in a very thin semi-transparent layer and were easily modifiable. These fibers were very strong, silky, pliable, flexible and not too stiff to spin or weave for textile uses. The woody fibers were thick and densely arranged in coarse bundle-form, were slightly brittle and not as pliable as soft fibers, suitable for basketry.

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