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The Effect of Fermentation (Retting) Time and Harvest Time on Kudzu *(Pueraria lobata)* Fiber Strength

SIBEL ULUDAG,[1] VEARA LOHA,[2] ALES PROKOP,[2] AND ROBERT D. TANNER*,[2]

[1]*Civil and Environmental Engineering Department; and* [2]*Chemical Engineering Department, Vanderbilt University, Nashville, TN 37235*

ABSTRACT

The noncommercial kudzu plant has been growing wild in the southern United States since the 1930s. In this article, the kudzu fibrous vine is investigated for possible economic applications. The feasibility of removing the fibers by microbial retting is investigated as a low-cost method for recovery of these fibers. The harvest season, vine diameter, and the natural retting time are the three main variables investigated to determine the optimal fiber tensile strength. To extract these light yellow, unidirectional, and multicellular kudzu fibers, retting using a culture screened from a naturally occurring mixed culture was investigated. Late fall, winter, and spring retted fibers were subjected to tensile strength tests. The kudzu fibers were harvested from the wild in both Nashville, TN and Muscle Shoals, AL.

Index Entries: Kudzu; retting; natural fibers; fiber strength; tensile strength.

INTRODUCTION

Although kudzu *(Pueraria lobata)* was deliberately grown in the southern United States by the US Soil Conservation Service in 1930s and 1940s *(1)*, today it is considered to be an "escaped plant" *(2)*. Kudzu can reach a growth rate of up to 0.3 m (1 ft) in a day in late spring/early summer, and its vines can grow up to 18–30 m (60–100 ft) in a single season. The vines can climb upward and cover nearly everything in their path (such as fields and trees). Hence, it is considered to be an "unwanted plant" particularly by farmers, foresters, and park naturalists.

Kudzu provides herbal medicines that are used in China and Japan. For example, such medicines have proven to be effective in relaxing tight and painful muscles in the neck, and pain in the shoulders and back caused by "wind-heat" injuries *(3)*. The kudzu root is also very rich in starch, and the kudzu vine has a

*Author to whom all correspondence and reprint requests should be addressed.

fibrous structure. Although natural fiber production from kudzu vines has largely been replaced by synthetic fibers, other traditional natural fibers, such as cotton, flax, hemp, silk, and wool, continue to retain their popularity owing to their unique physical properties. In China, kudzu fiber is still being woven into cloth and is occasionally used to make baskets, packing materials, and suspension bridges *(4)*. The most famous area of handicraft cloth production is located near the headwaters of the Yangtze River. On the other hand, one of the last industrial-scale weaving plants located in Japan using twisted kudzu filaments closed in 1975 because of competitive pressures from synthetic fibers *(4)*. Today, coarse kudzu vine fibers are imported to the United States from Korea, where the kudzu plants are cultivated for use as "grass-cloth" wall coverings in interior design.

Kudzu fibers extracted from the woody stem (vines) of the plant have a multiple cellular and unidirectional structure. Kudzu fibers are classified as bast fibers (fibers extracted from the interior part of the plant sheath) *(5)*. When chemically treated, such fibers can be converted to long staple fibers (yarns).

The remarkable combination of properties—durability, strength, natural light yellow color, and purity, and the absence of noncellulosic foreign material (except in the winter fibers)—makes the kudzu fibers attractive and desirable. Natural fibers are obtained from the retting process as ready yarn, but of variable widths, rather than individual fibers. These natural fibers can be easily spun into bulky yarns in large-scale production.

METHODS

Retting Procedure

Kudzu vines of various diameters were harvested locally in both Tennessee (Nashville area) and Alabama (Muscle Shoals area). These cut vines were then classified according to diameter size into groups: seven groups of varying diameters for the late fall vines, four groups for the winter vines, and three groups for the early spring vines. The largest diameter vine tested was 0.008 m (0.32 in.). Afterward, vines of approx 0.15 m (6 in.) in length were submerged in tap water (ca. pH = 5.9) along with the microbial culture. They were kept submerged with the aid of weights on the top of container. This retting process then degraded the vine at room temperature (ca. 21°C) in the water solution (i.e., the fibers underlying the vine sheath were exposed for later recovery by the action of sheath degradation enzymes, which were contributed by the growing culture). After the fibers were removed, the underlying straw stalk was then recovered. Vine samples were taken from the water chamber until this solid-state (with respect to the "solid" vines) fermentation process was terminated. The stopping point was reached when the outer sheath was easily removed from the vine under flowing tap water without mechanical assistance. Mechanical assistance in the laboratory was provided by a spatula, used as needed in the retting process both to remove the outer sheath and extract the fibers. Retting action was followed in all of these experiments by the fiber recovery step. In that step, the separated fibers were washed with tap water and then dried at room temperature. In addition to all of the physical measurements related with the fiber itself, the pH profile of the developed microbial culture was observed using a Chemcadet pH meter to determine the optimal retting time.

Preparation of Fibers for the Tensile Strength Test

The thickness of each weighed fiber was measured by a micrometer with ±2.54 × 10^{-6} m (±0.0001 in.) tolerance, whereas the width and length were measured using an ordinary ruler. To measure the thickness of a fiber, the fiber was placed between two microscopic slides, each of which were 0.001 m (0.04 in.) thick. Since the kudzu fibers come from the retting process as flat strips, these measurements were easily carried out. To make a fiber thickness measurement, a flat kudzu fiber strip was placed between two glass microscope slides to create a "fiber sandwich." The flat side of one of the glass slides of the "fiber sandwich" was then placed against the anvil of the micrometer, and the micrometer handle was rotated clockwise until contact was made with the flat side of the other glass slide. The handle was turned until it could turn no more (the instrument prevented glass breakage with an internal "slip gear"). The final contact measurement of the "fiber sandwich" was easily replicated for each measurement, because the micrometer contained a ratchet that provided a replicable limit to the force applied on the glass plate (the "slip gear"). The flat strips, incidentally, came sectioned from the retting process (like narrow peel-off labels on the same page). This multisectioned kudzu strip of fibers was generally clear, soft, and nearly uniform in appearance, although comprised of fibers of apparently random widths. These textural properties of the fibers make them similar to today's modern fibers. The tensile strengths reported here are expressed in several different forms to fit the common units used in the textile industry, such as denier and texture. Denier is a direct numbering system for expressing linear density of a fiber, equal to mass in grams (g_f) per 9000 m of yarn or filament *(6)*. Although denier is used widely, the texture (tex) system has been adopted by the ASTM as the standard unit of linear density of textile fibers, and it is accepted as a part of the SI unit system. The texture is the "mass" of a fiber in grams force (g_f) per length of 1000 m (1 denier = 0.1111 tex) *(7)*.

Tensile Strength Test

Tensile force effects were tested using a D-Dillon Weigh-Tronix Inc. (Fairmont, MN) Tensile Testing Machine Model DTM and a Model P-3500 Instruments Division Strain Indicator. Since the expected strength was near the lowest detection limit of the machine, the experiments were run with the specified strain gage factor for low-load applications of +0.252. Fibers of approx 0.06 m (2.36 in.) in length were used in this breaking test. The tensile strength measurements were replicated in approximately one-third of the total fiber samples. The total number of fiber tests was around 130.

RESULTS

Our focus here was to determine for a given year three effects on the tensile strength of the fiber:

1. The season in the southeastern US in which the vine was harvested;
2. The effect of vine size; and
3. The effect of retting time.

The literature indicated that in temperate Japan, the optimal strength of the fibers came from vines harvested in early June to late July *(4)*.

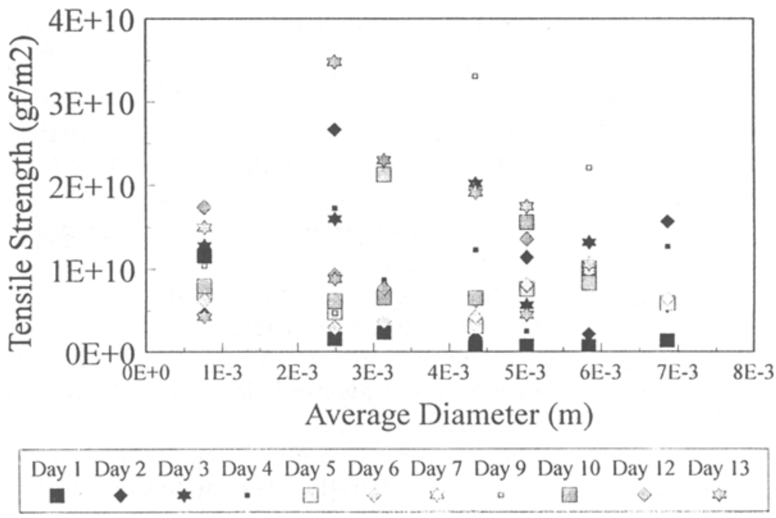

Fig. 1. The effect of kudzu vine diameter on the tensile strength (late fall, 1994).

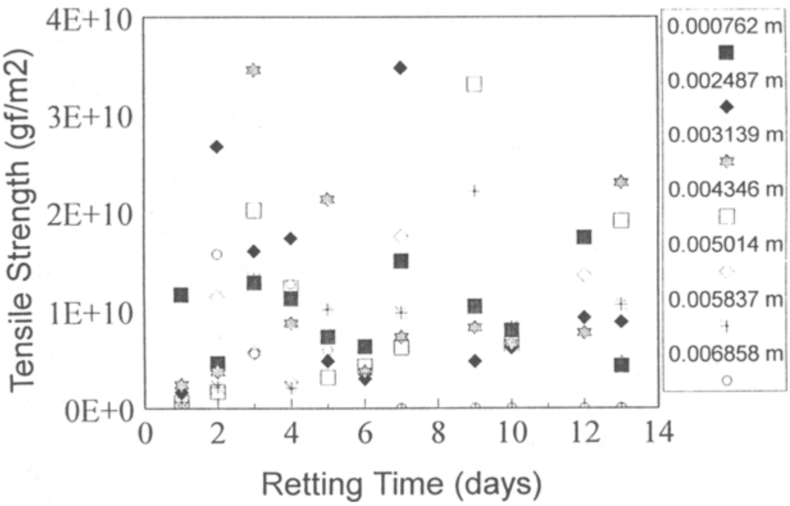

Fig. 2. Late fall kudzu fiber's tensile strength change with retting time.

Late Fall Harvest (November 19, 1994)

The effects of vine diameter and retting time on fiber tensile strength are shown in Figs. 1 and 2. The fiber strength reaches a maximum for a vine diameter of 0.002487, 0.003139, and 0.004346 m (0.0979, 0.1236, and 0.1711 in.) for d 7, 3, and 9, respectively (retting times). The kudzu fiber tensile strength reached a maximum limit around 3.5×10^{10} g_f/m^2 (50,000 lb_f/in^2), for the late fall, as shown in Fig. 1. Fibers extracted from vines between 0.002487 and 0.004346 m (0.0979 and 0.1711 in.) in diameter seem to be stronger than the others. The optimum retting time for the late fall harvest seems to fall within the range of the three highest values shown in Fig. 2 (3–9 d, with 6 d being the average).

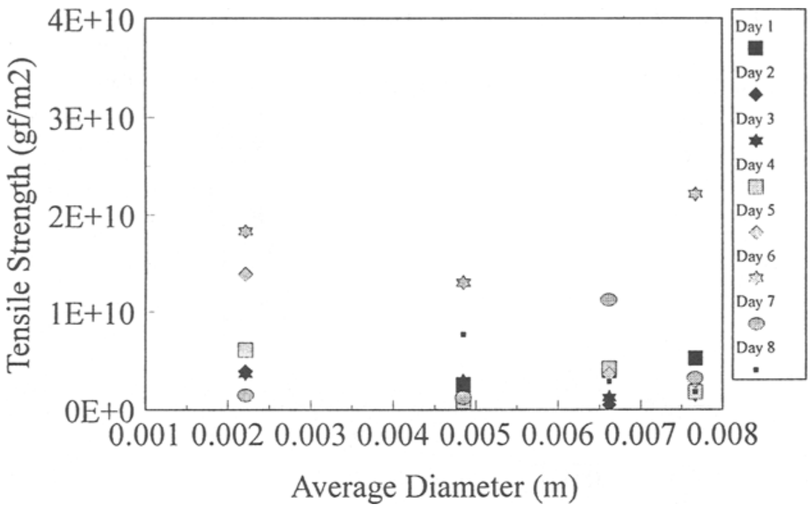

Fig. 3. The effect of kudzu vine diameter on the tensile strength (winter, 1995).

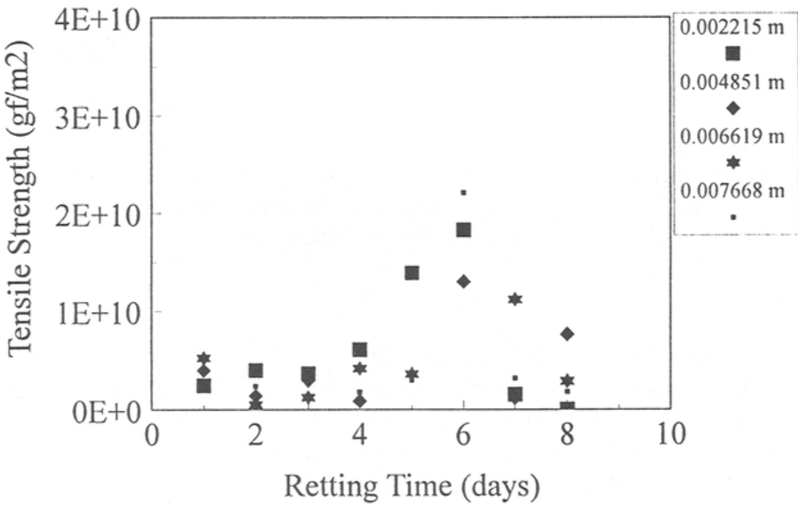

Fig. 4. Winter kudzu fiber's tensile strength change with retting time.

Winter Harvest (January 26, 1995)

The major result obtained from the fibers that were exposed to cold weather is that they are not as strong as late fall fibers. The fibers tested in this set all have a value below 2.0×10^{10} g_f/m^2 (28,421 lb_f/in^2), as shown in Fig. 3. The strongest fibers are the fibers of 0.002215 m (0.0872 in.) diameter vines. The optimum retting time, based on the maximum value obtained, is determined as 6 d in winter from the tensile strength vs retting time data (Fig. 4). Most of the kudzu fibers from the winter vines were gray in color (vs clear or light brown from the late fall vines), possibly because of fungal or bacterial contamination in the winter.

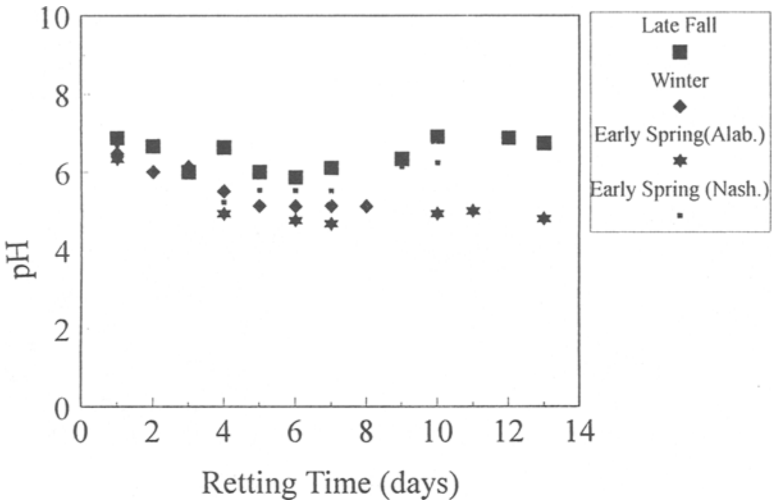

Fig. 5. pH change of retting solution with time.

pH During the Retting Process

In all seasons studied, the pH of the uncontrolled retting solution decreased with time up to 5–6 d and then usually increased (Fig. 5). The global pH value of the retting solutions changed between 4.8 and 7.0, when all of the seasons were considered. The reason for this change in pH may have been the dominance of acid-producing bacteria in the solution during the 5–6 d retting time.

DISCUSSION

In this section, we will compare the quality of the kudzu vine fiber between seasons and with other natural fibers. The averages of our experimental results are graphed in Figs. 6 and 7 and summarized in Table 1. In this project, the number of samples of early spring kudzu vine fibers were limited, since there were very few new-growth kudzu vines available at the harvesting location in Nashville. The kudzu vines available for harvest in Alabama in the early spring were thicker than those previously studied for late fall and winter, again because of the limited number of new-growth vines. Therefore, the discussion part of this article emphasizes mainly the late fall and winter fiber test results.

Late fall kudzu fibers are stronger than the winter kudzu fibers as shown in Figs. 6 and 7 and in Table 1. The early spring fibers from Alabama (harvested on March 20, 1995) were about the same strength as the late fall fibers, but the early spring fibers from Tennessee (harvested on May 8, 1995) were about twice as strong, as shown in Table 1. It is interesting that although late fall fibers are 1.6 times stronger in g_f/m^2 U than the winter fibers, this ratio rises to 2.4 in terms of g_f/denier and g_f/tex U. This follows primarily because of linear density differences between late fall and winter fibers. In winter, the fiber weight per unit length was different owing to the noncellulosic (contaminating) material, such as fungus, as previously mentioned. It appears that the absolute strength remains about constant, whereas the weight increases owing to the contaminants. This contaminating material might also lead to

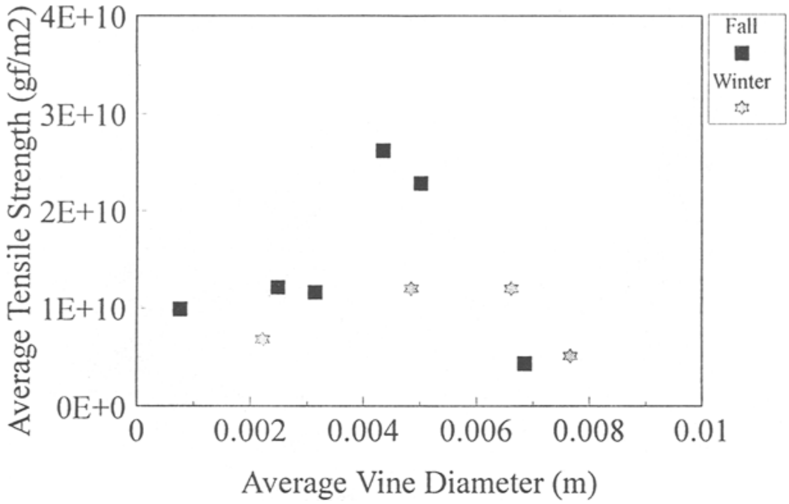

Fig. 6. Average tensile strength change based on average vine diameter in late fall and winter.

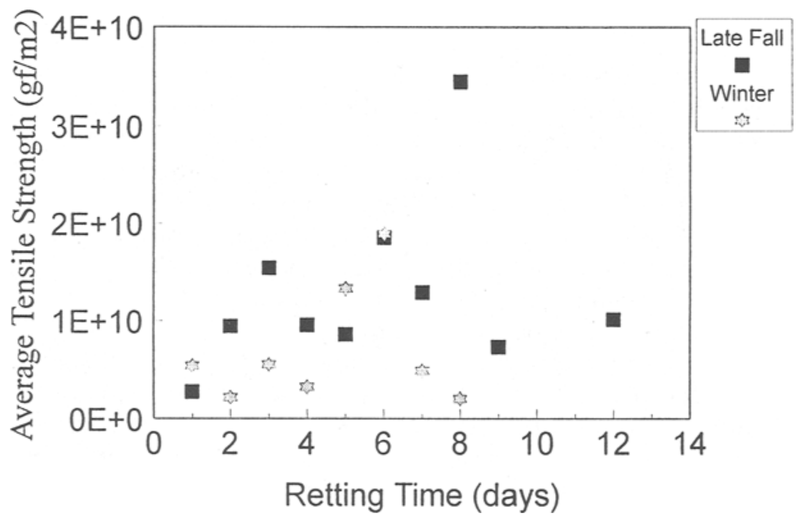

Fig. 7. Average tensile strength change based on retting time in late fall and winter.

greater or lesser measurements of the fiber thickness, leading to false thickness readings. In addition, since the kudzu vines harvested in Nashville, TN came from a public park the plant might have been exposed to an eradicating herbicide. If so, this exposure might have adversely affected the nature of the kudzu vine and its fiber.

The optimum harvest season for collecting strong kudzu fibers is from early June to late July in Japan *(4)*. Only 1-yr-old vines were reported to have been used to produce fibers in Japan. Here, the 0.002-m vines appear to be 1 yr old, the 0.004-m vines 2 yr old, and so on. Since the spring comes earlier to the southern United States than to Japan, the optimum harvesting time seems to be earlier in this study than the June or July optimum previously observed in Japan. There are no known reported

Table 1
Average Seasonal Tensile Strength Values of Kudzu Fiber
for the Given Dimensions of Tested Fiber

	Season			
	Late fall	Winter	Early spring	
Property	Nashville, TN	Nashville, TN	Muscle Shoals, AL	Nashville, TN
Average thickness, m	0.0002	0.0001	0.00006	0.000046
Average width, m	0.002	0.002	0.002	0.002
Average length, m	0.06	0.06	0.06	0.06
Diameter of vines, m	0.00076–0.00584	0.00220–0.00767	0.00726–0.00779	0.00254–0.00559
Average linear density, g_f/m	0.128	0.182	0.145	0.075
Average tensile strength				
g_f/m^2	2.07×10^{10}	1.30×10^{10}	1.88×10^{10}	4.27×10^{10}
g_f/denier	2.400	0.995	2.654	4.395
g_f/tex	21.384	8.965	23.890	39.556

tensile strength measurements for kudzu fibers in the literature to compare with our results. However, we can compare our findings with other natural fibers. It is interesting that even kudzu fibers harvested out of the expected optimum season (which is spring or early summer), as summarized in Table 1, are comparable with wool fibers, as summarized in Tables 2 and 3. Sunhemp seems to be the most comparable natural fiber with kudzu fiber. This may be the case because they are both bast fibers, and retting methods used for their fiber extraction are similar. Sunhemp fibers retted in pond water for 7 d can reach a value as high as 76 g_f/tex tensile strength *(8)*, which is several times higher than our kudzu fibers.

The tensile strength specification of an ideal textile fiber has been set at 5–8 g_f/denier *(9)* in order to meet standard fiber spinning and weaving conditions. Therefore, wild kudzu fiber quality of late fall and winter seasons determined in this study fall well below the strength desired for use by the textile industry, but the early spring Nashville untreated fibers do approach that standard. Building on the results determined here, with the aid of enormous versatility of fiber-manufacturing processes (e.g., a mixture of natural and synthetic fibers, twisting techniques, coating the fibers with oil, and so forth), kudzu fibers appear to be viable for commercial use by the textile industry.

The type of retting employed to process the vines to fibers may be just as an important variable as the retting time to obtain good-quality fibers. Microbial retting with a given cultural strain can be used as a baseline case to reference other retting methods. Improvements in retting processes can be achieved using techniques, such as the controlled warm-water procedure, and microbial retting by a specific group of bacteria *(10)*. The techniques of retting can affect both the fiber quality and the retting time.

The optimum retting time is defined in terms of the desired objectives. It is usually defined as the shortest time required to recover the strongest fibers. Indirect indicators for monitoring the retting appear to be the pH of the solution used in

Table 2
Tensile Strength (g_f/denier) of Various Natural Fibers and Kudzu Vine Fiber

Natural fiber	Description	Tensile strength, g_f/denier	Reference
Cotton	Wet	3.3-6.4	*7*
Wool	Wet	0.76-1.6	*7*
Abaca	Not twisted	6.710	*5*
Abaca	Oiled, combed	6.900	*5*
Sisal	Oiled, combed	4.400	*5*
Henequen	Oiled, combed	3.300	*5*
Kudzu vine fiber	Unprocessed		
	Late fall	2.400	This study
	Winter	0.995	This study
	Early spring		
	Muscle Shoals	2.654	This study
	Nashville	4.395	This study

Table 3
Tensile Strength (g_f/tex) of Sunhemp and Kudzu Vine Fiber

Natural fiber	Description	Tensile strength, g_f/tex	Reference
Sunhemp	Retted in village (6–8 wk)	18	*8*
	Sample retted in pond water (7 d)	76	*8*
Kudzu vine fiber	Unprocessed		
	Late fall	21.384	This study
	Winter	8.965	This study
	Early spring		
	Muscle Shoals	23.890	This study
	Nashville	39.556	This study

retting and the color change of the vine, usually from a yellow-brown to a gray-blue. The pH of the retting solution typically decreases until a lower pH plateau of 4.6–4.9 is reached, and then it rises. This increase appears to indicate the start of overretting, which is the deterioration of the fiber strength *(11)*. The optimum retting time of kudzu fiber in late fall, winter, and early spring seems to be indicated by the minimum plateau value in the relationship between pH and retting time, shown in Fig. 5.

It is noted that the kudzu vine fibers extracted from the early spring vines were the highest in quality in terms of tensile strength. As summarized in Tables 1, 2, and 3, the tensile strength of the kudzu vine fiber increased significantly in the early spring such that it may fit the specifications for direct use in the textile industry.

CONCLUSIONS

It is concluded from this study that kudzu, a wild plant endemic to the south-eastern part of the United States, can provide quality fibrous materials to the textile industry. Average tensile strength of the kudzu vine fiber was measured as 2.07×10^{10} g_f/m^2, and 1.3×10^{10} g_f/m^2 in the late fall and winter, respectively, in Nashville, TN. In the early spring it rose to 1.88×10^{10} g_f/m^2 and 4.27×10^{10} g_f/m^2 from samples obtained at Muscle Shoals, AL and Nashville, TN, respectively. Based on this study, but without tests between June and November, the optimum kudzu harvest time of the year in the southeastern United States for the extraction of strong fibers appears to be in the spring. Kudzu fiber tensile strength was found to be of sufficiently high quality for the plant fibers to compete with other natural fibers that are presently used in the textile industry. The optimum retting time of approx 6 d also appeared to be marked by the 6-d minimum in the pH vs time curve describing the kudzu retting solution. The tensile strength was a weak function of the vine diameter of kudzu.

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