Physical and Mechanical Properties of Henequen Fibers

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SYNOPSIS

A study of morphology, physical, and mechanical properties of henequen (Agave fourcroydes) fibers have been performed in this article. It has been concluded that properties of the fibers are more uniform in their middle section. As other natural hard fibers, henequen has a relative high tenacity, low elongation at break and a low modulus. These properties suggest that the fiber could be used as reinforcing agent in composite materials.

INTRODUCTION

For several decades, henequen (Agave fourcroydes) and other natural fibers have been used in different products ranging from cords to sacks and mats, among others. However, the entry of synthetic fibers in the market and their applications have substituted those of natural hard fibers; consequently, their application in several tasks have decreased. There are several fields where natural hard fibers could have a potential usage. One of these fields is the reinforcement of different matrices, such as polymeric thermoplastic or thermosetting materials for the preparation of composites. The possibility of using henequen fibers as such reinforcing material is hindered by the lack of practical knowledge about its physical and mechanical properties.

The characteristics of henequen fibers have been studied in a rough way by some authors.[1,2] Their studies centered on the structure and composition of henequen fibers and some other fibers. Chemical analysis of henequen fibers[3] indicates that their principal component is cellulose (59%), followed by hemicellulose (28%) and lignin (8%). The structural arrangement of these components inside the fiber, as in other natural hard fibers, is in such a way that lignin acts as a cementant matrix for the cellulosic fibers, which have their own separate structure. Also, cellulosic fibers are the rigid part of the fiber; then, the mechanical properties of henequen fibers, like stiffness and strength, appear as a consequence of such structural arrangement.

The aim of this article is to obtain some physical and mechanical properties of henequen fibers.

EXPERIMENTAL

Samples of henequen fibers were obtained from Cordemex, S.A. of Merida, Yucatan, Mexico, and were subjected to random sampling. The fiber samples were between 70 and 120 cm long and each fiber was divided in three equal sections that were labeled in the following way: tip to the free end of the fiber, medium to the middle part of the fiber, and butt to the section of the fiber that is close to the talus. A total of 25 fibers were tested.

The cross-section of the fiber was photographed using an Olympus B12-2 microscope, and the diameter of the fibers was measured with the aid of an optical microscope (American Optical Microscope, Model 120). Several precautions had to be taken to ensure an accurate measurement of the fiber diameter given the highly irregular cross-section shape. Measurements were taken at every centi-

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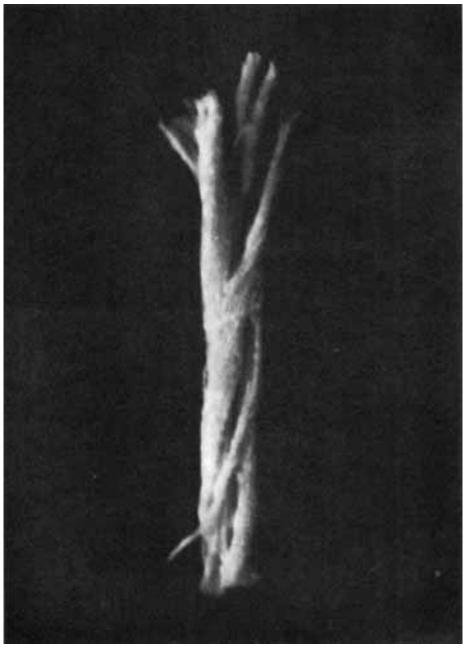

Figure 1 Photograph of Nitrated Cellulose in a Fiber Showing the Helical Orientation of the Ultimate Fibers.

meter along the fiber. At each location, two measurements were made along orthogonal directions by carefully rotating the fiber 90° about the longitudinal axis. To calculate the cross-section area, most fibers could be approximated as a circular cross-section and some, especially at the butt end, as a rectangular cross-section. Also, microtomed sections at several locations along the fiber were photographed to verify the accuracy of the fiber diameter measurements.

To obtain values of linear density (denier), segments one centimeter long whose diameters had previously been measured were weighted in a thermogravimetrical analyzer. These measurements were performed in five whole fibers.

Mechanical testing of each section of the fiber was carried out in an Instron 1125 universal testing machine equipped with a 50-kg tension load cell. Elongation and elastic modulus measurements were performed in samples 12 cm long using type 4C Instron cord grips. The tests were performed at a crosshead speed of 5 mm/min with chart speed of 100 mm/min and scale sensibility of 2 kg. Prior to testing, the samples were conditioned for 24 h at 25°C and 60% relative humidity.

RESULTS AND DISCUSSION

Physical Properties

Single henequen fibers are constructed by slim threadlike fibers known as ultimates, which are embedded in hemicellulose and lignin.[4]

It is known[5] that plant cells consist of several

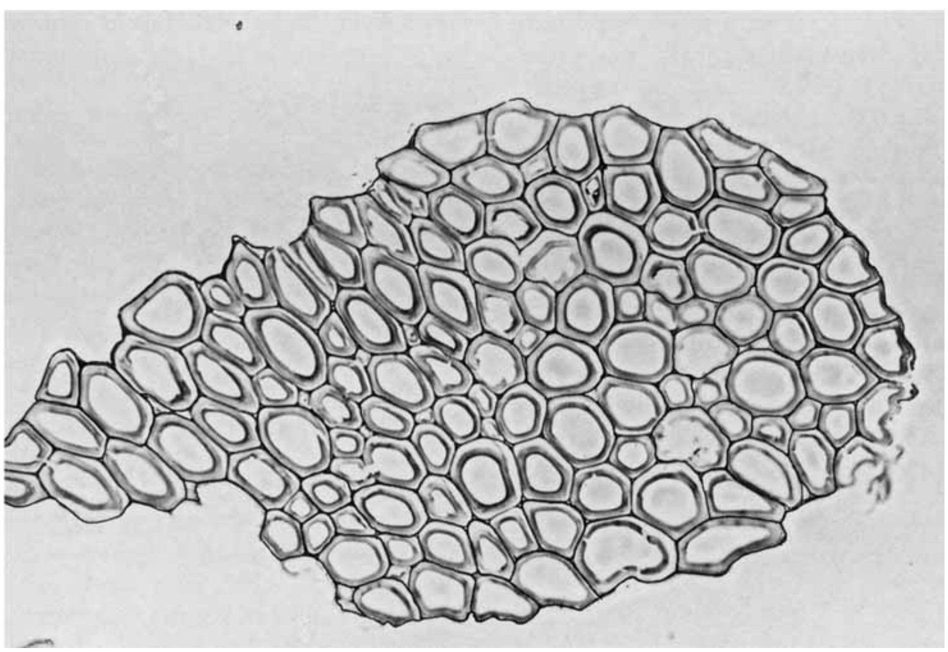

Figure 2 Cross-section of a Henequen Fiber (Agave Fourcroydes).

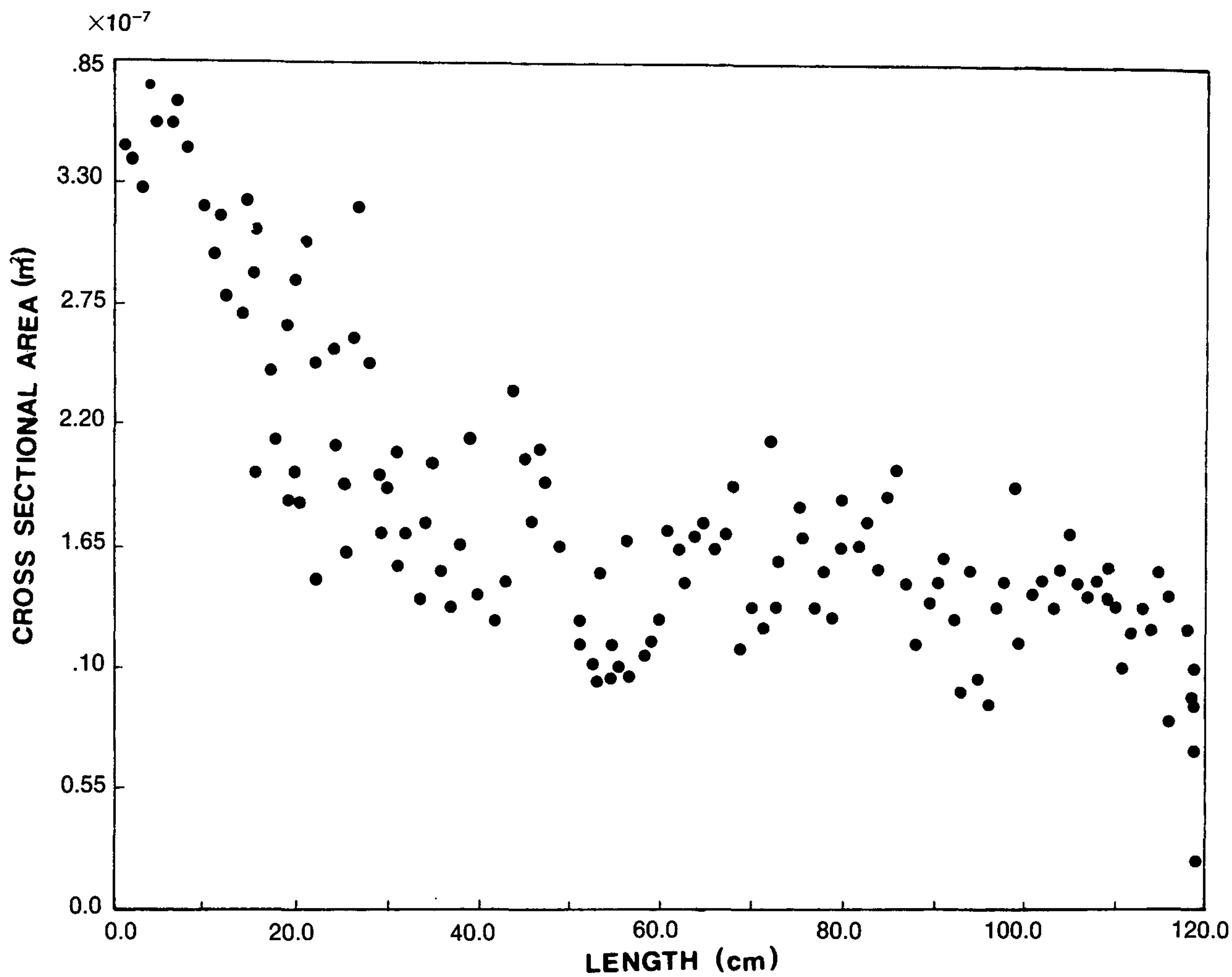

Figure 3 Distribution of Cross-sectional Area along a Henequen Fiber.

layers of cell walls and that the microfibrils in each layer are oriented in angular directions to form a flat helix in the transverse direction. The mayor structural material of the ultimates is cellulose. Figure 1 shows a photograph of nitrated native cellulose[6] in a fiber, and such helical orientation can be appreciated. Between the cells, there is a region called the compound middle lamella that contains mainly lignin and pectic substances. Figure 2 shows a photograph of the cross-section of a single henequen fiber. It is easy to distinguish the middle lamella and the cells that are polygonal in shape, mainly hexagonal and pentagonal; the lumen or cell cavity of each cell, which is between 3–12 μm, is roundish or has rounded corners, and the size of the lumen is large compared to the secondary wall, as reported by Lock and Barkakaty for sisal fibers (Agave sisalana).[7,8]

Henequen fibers have a slightly decreasing diameter and consequently cross-section area from butt end to tip end of the fiber, as seen in Figure 3. It can be noticed that the area of the cross-section in the medium section remains almost constant. At the butt end, the area of the cross-section decreases linearly toward the medium section, and at the tip end of the fiber it decreases very slightly. The values shown in Figure 3 are average of measurements on five different fibers of the same length. This behavior of fiber diameter and area of the cross-section is in agreement with the observation of Castro and Naaman for maguey fibers.[9] It can also be seen from the photograph in Figure 4 that the cross-section of the fiber changes in shape along its length. At the butt end, it resembles a beam or kidney shape [Fig. 4(a)]. Moving toward the medium section, it changes to an elliptical shape [Fig. 4(b)], and at the tip end it

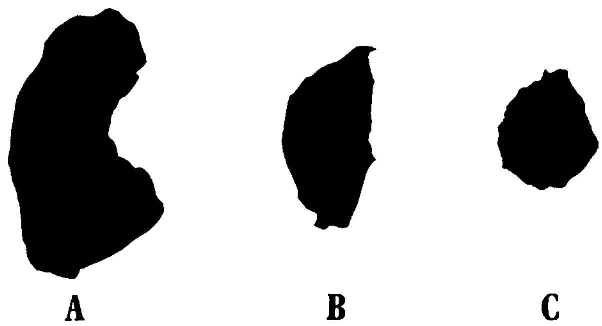

Figure 4 Photograph of Cross-section for Different Portions of a Henequen Fiber.

looks more like a circle [Fig. 4(c)]. The butt end has an average diameter of 0.47 mm with a standard deviation of 0.14 mm; the medium section of the fiber has an average value of 0.41 mm with a standard deviation of 0.11 mm; finally, the tip end of the fiber has an average diameter of 0.34 mm with a standard deviation of 0.11 mm. The ratio of large to small diameter in butt and medium sections varies between 1.48 and 2.00.

Figure 5 shows the variation of linear density (denier) along the fiber. It can be noticed that linear density remains fairly constant over the length of the fiber except at both ends. Also, comparing Figures 3 and 5, it is noticed that cross-section area and linear density remain fairly constant along the medium section of the fiber, but along the butt end the cross-section area varies linearly and linear density varies linearly only along half the length. At the tip end of the fiber, there is only a slight variation of the fiber cross-section area, but the linear density decreases rapidly toward the free end of the tip. This behavior at the ends of the fiber could be attributed to differences in the content of lignin and hemicellulose along the length of the fiber,[6] and also to small errors introduced by the approximations made in calculating the cross-sectional area and when measuring the fiber diameters, especially at the butt end. Average values of denier are 509 with a standard deviation of 93, 503 with a standard deviation of 86, and 439 with a standard deviation of 108 for the butt end, medium section, and tip end, respectively.

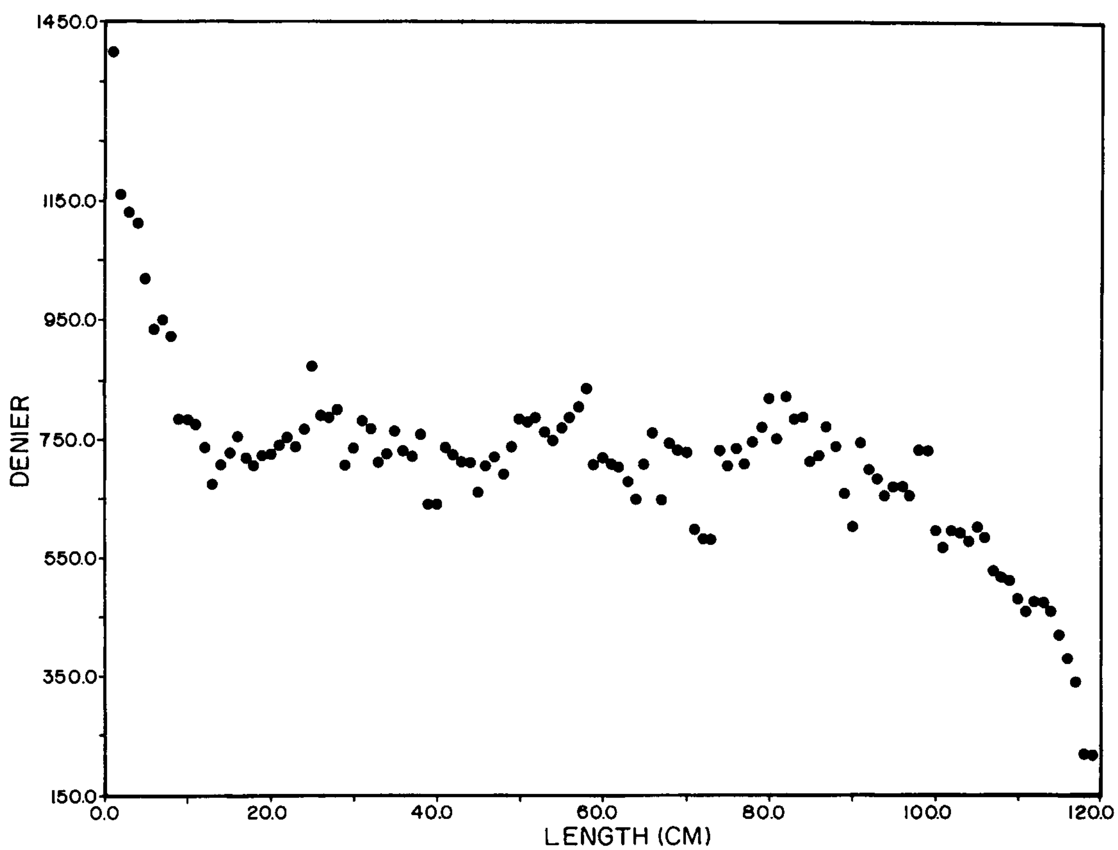

Figure 5 Distribution of Linear Density (Denier) along a Henequen Fiber.

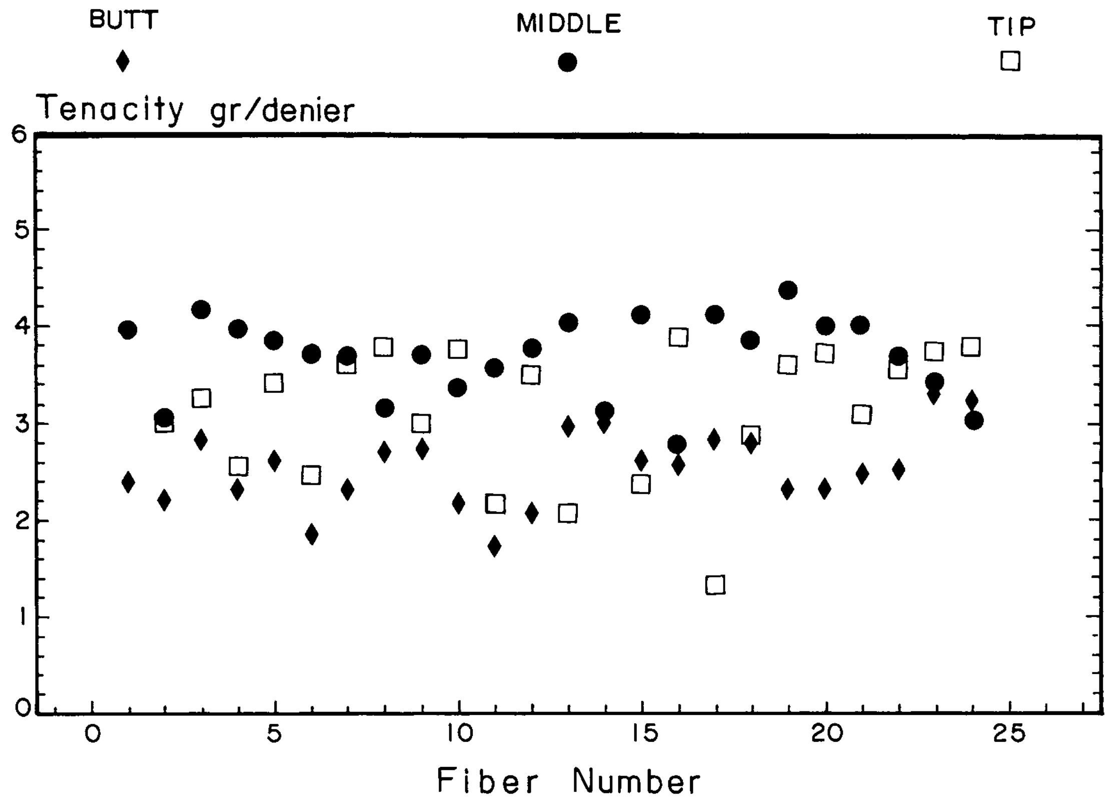

Figure 6 Values of Tenacity for Different Portions of Several Henequen Fibers.

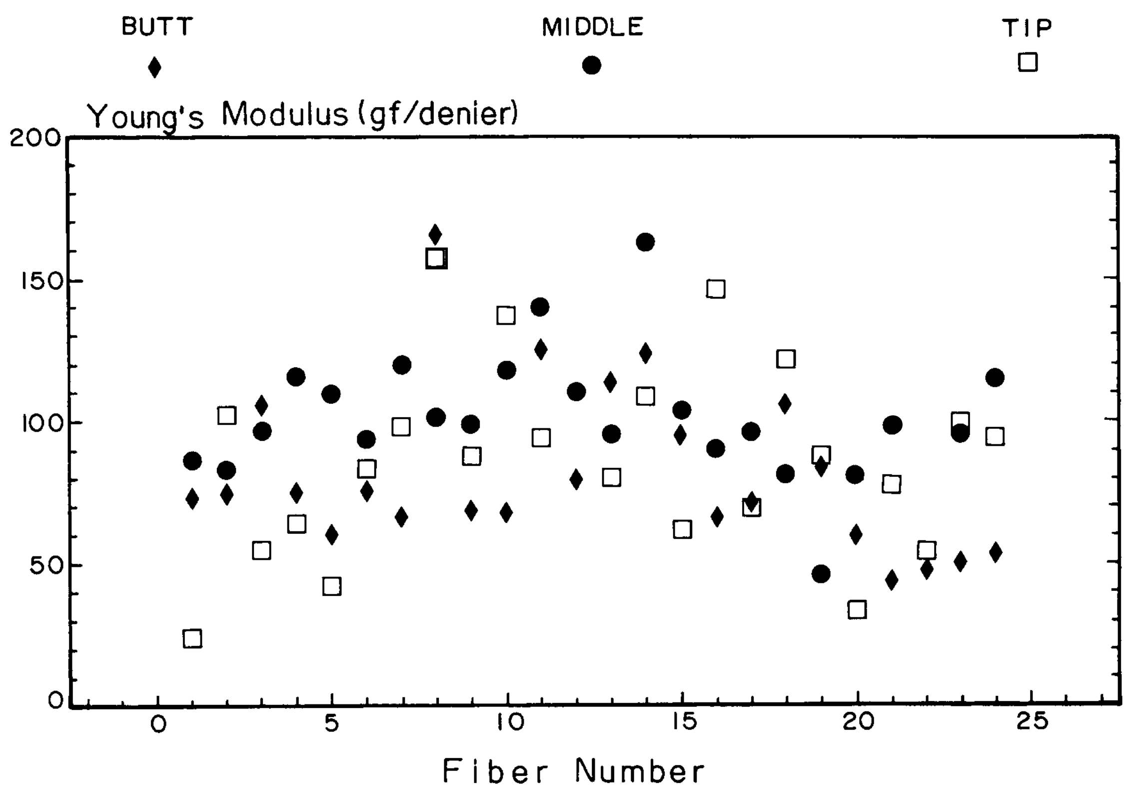

Figure 7 Values of Young's Modulus for Different Portions of Several Henequen Fibers.

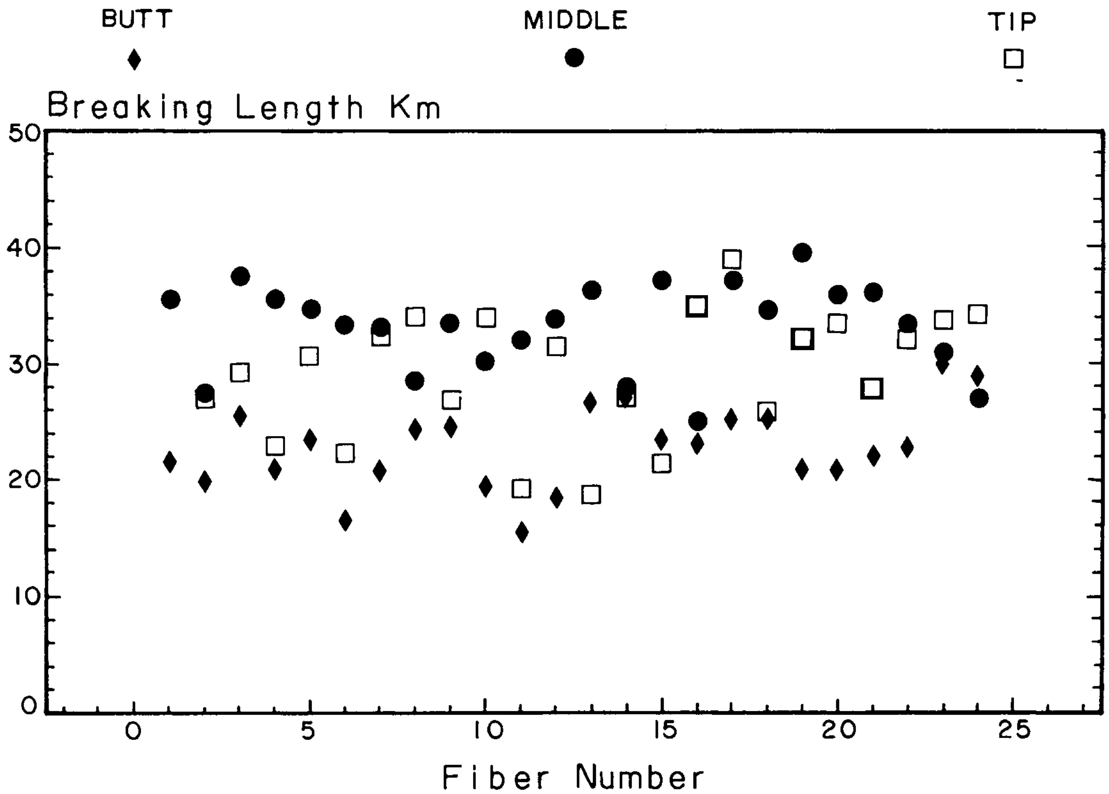

Figure 8 Values of Breaking Length for Different Portions of Several Henequen Fibers.

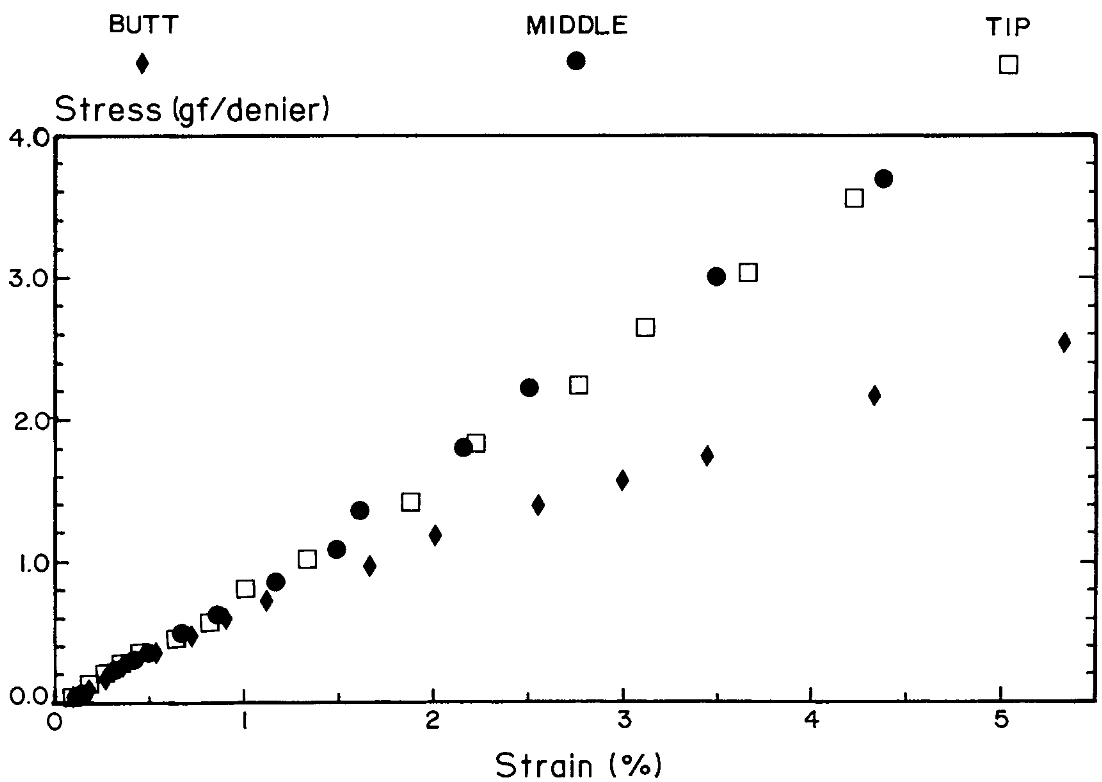

Figure 9 Typical Stress–Strain Curves for Different Portions of a Henequen Fiber.

Table I Mechanical Properites of Henequen Fibers

Fiber	Breaking Length (km)	Strain at Break (%)	Modulus of Elasticity (g/denier)	Tenacity (g/denier)
Jute	27–53	1.5	193	—
Sisal	30–45	2–3	135	4.1[a]
Henequen	25–37	4–6.6	99	3.72

[a] From Ref. 8.

Mechanical Properties

Mechanical testing of each of the three sections of henequen fibers shows that the values of tenacity, Young's modulus, and breaking length increase along the fiber from butt end to medium section. At the tip end, there seems to exist some scattering in the data (see Figs. 6–8).

Figure 9 shows typical stress–strain curves for different sections of the henequen fiber. It should be noticed that the curves for tip end and medium section are very close to each other, but the curve for the butt end shows lower values of stress even at large deformations. The tip end and medium section exhibit linear elastic behavior even at large strains, but the curve corresponding to the butt end exhibits a linear elastic behavior only at very small values of strain. This difference could be attributed to a difference in angular orientation of the ultimate fibers in each section with respect to the direction of the applied load. Barkakaty[8] concluded that, for sisal technical fibers, the smaller the spiral angle of the microfibrils in the secondary wall of the plant cells the greater the strength of the fiber.

Average values of breaking length, elongation, Young's modulus, and tenacity are shown in Table I. They are compared with jute and sisal (Agave sisalana),[10] which is a close relative of the henequen plant. From the table, it is concluded that the values obtained for henequen are in the same range as those obtained for other natural hard fibers.

CONCLUSIONS

The physical and mechanical properties of henequen fibers have been assessed in a systematic manner. The results show that henequen fibers have a variable diameter like similar natural fibers, being larger at the butt end and smaller at the tip end of the fiber. Also, the value of the diameter changes for different fibers at corresponding locations; this change is complicated by the nonuniform conformation of the fiber, whose cross-section changes from a beam-like shape at the butt end to a rounded form at the tip end of the fiber. The morphology of the fiber is similar to that of other natural hard fibers such as sisal, jute, abaca, etc.

It was noticed that the physical and mechanical properties of the fibers are more uniform for the medium section, and at the tip and butt ends there exists some scattering.

It has also been showed that all physical and mechanical parameters that depend on diameter change in the same fashion as the cross-sectional area and linear density of the fiber.

The mechanical properties of henequen fibers shown in this article indicate that it is possible to utilize them as a reinforcing agent in polymeric materials for the preparation of composite materials like other natural hard fibers, such as sisal fibers and palm fibers, etc.

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