STRUCTURE AND PROPERTIES OF A NATURAL CELULOSIC HOLLOW FIBER

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Abstract Measurements have been made of the length, diameter, moisture regain, density, refractive indices, luster, strength, breaking elongation, crystallinity and morphology of domestic milkweed fibers. These fibers have unique properties not found in other natural or man made fibers. The yarn processing of blends with cotton and polyester are discussed.

Key Words Fibre, Hollow Fibre, Milkweed, Luster, Physical Properties, Blend, Yarn, Spinning, Estabragh, Polyester, Cotton

چکیده برخی ویژگیهای فیزیکی مانند ابعاد، رطوبت بازیافتی، جرم مخصوص، ضریب شکست، جلا، خواص مکانیکی و تبلور یکی از الیاف بومی ایران از نوع شیرگیاه اندازه گیری شده است.آزمایشات انجام شده نشان می دهد این الیاف دارای خواص استثنائی می باشد که در دیگر الیاف مصنوعی و طبیعی معمول یافت نمی شود. قابلیت ریسندگی این الیاف و تولید نخ به صورت مخلوط با الیاف پنبه و پلی استر مورد بحث و توجه قرار گرفته است.

INTRODUCTION

In the southern regions of the central plateau of Iran, there grows an indigenous plant which belongs to the Aclepiadaceae family. This plant grows wild and produces silky, lustrous, needle-like seed fibers. Since the potential value of the plant for soil conservation on hillsides is known to be very great, it is now being cultivated in nurseries for transplanting onto open hillsides as a conservation technique. If the fibers could be harvested as a usable textile raw material, the economics of this form of soil conservation could possibly be improved. It is believed that the fibers were used for making lustrous yarn and fabrics many centuries ago during the Achaemenian period [1]. In order to distinguish this plant and its fibers from their counterparts, its local name, i.e. "Estabragh", is used throughout this report. This word also describes an ornamental silk garment embroidered with gold.

The plant, depending on age, may grow up to two meters in height. Figure 1 shows a wild plant. The fibers to which the seeds are attached are packed in a green bean-like seed pod that bursts open when ripe and dry. Fibers are very similar to milkweed fibers (Asclepia Syriace) [2] which grow in the united State of America and the Rux fibers (Calotropis Gigantea)

Figure 1. A wild Estabragh plant.

which grow in Southeast-Asia [3]. In recent years Estabragh fiber, like milkweed, has been used mainly for stuffing and insulation.

There are a limited number of reports on the use of milkweed as a textile fiber. Louis and Andrews [4] believed that the lack of cohesiveness of the milkweed fibers causes extreme difficulties in textile processing, and so milkweed fibers have to be processed in a blended form with other fibers. Investigating the response of the knitted-fabrics to scouring and bleaching and to subsequent durable press finishing, it was found that certain strength and moisture related advantages can be achieved by replacing part of the cotton in a fabric by milkweed fiber [4].

In another publication, Andrews, et al. [5] report the response of cotton and its blends with milkweed to selected swelling and cross linking treatments. It was found that not all properties of cotton/milkweed blends were influenced similarly by ammonia and sodium hydroxide mercerization. From their exploratory research they concluded that, if viable, milkweed could become a new marketable agricultural commodity.

Recently Drean et al. [6] reported the results of their investigation on some properties and spinning of milkweed fibers. Cotton/milkweed blended yarn was made using microspinning line. They used the 1988 crop fibers, Quebec Canada, from greenhouse transplants. Their fibers had 20.1mm mean length, 16.0 cN/tex Stelometer strength, 1.5% breaking elongation, 1.47 relative density, and 9.9% moisture regain.

We believe that Estabragh, like milkweed fiber, has unique properties not found in other man made or natural fibers. From these special properties its approapriate end uses can be determined. Hence the purpose of the present work was to study the structure and properties of Estabragh fibers. For the testing of spinnability, due to the lack of cohesion among fibers, blended yearns were also produced in conventional short staple spinning system.

EXPERIMENTAL WORK

Approximately two Kg of Estabragh fibers were collected from the hillsides of Shooshtar, a town in Khouzestan province, Iran. The cotton fibers used for blending were an Iranian domestic product, first grade white, 25mm staple length. Polyester fiber used were regular 30mm length, 3 dtex [7-10].

The lengths of individual fibers were measured by the oiled-plate method [11]. The diameter of the fibers was measured at the tip, centere and base of the fibers using a Zeiss projection microscope. The linear density (tex) was measured by the cutting and weighing method [11]. The Sheffield Micronair instrument was used for measuring the cotton fiber fineness according to ASTM D 1448-59. Because of the differences in cross-sectional shape and wall thickness between cotton and Estabragh, use of Micronaire instrument for estabragh is not practicable without a considerable amount of further evaluation. For the measurement of refractive indices an Interference microscope by Carl Zeiss Jena was used.

X-ray diffraction patterns were obtained using a Philips X-ray diffractometer. Cu K_α radiation with a wave length equal to 1.548Å filtered by nickel foil was used. Samples were scanned at 2 degrees per minute between $2\theta = 10$ to $2\theta = 36$ and the chart speed was set at two cm/min.

An Instron tensile tester was used for the measurement of load-elongation curves of both fibers and yarns. The fibers were mounted taut by adhesive across a square card frame and after inserting the sample between the jaws the card was cut.

Micrographs were made using both a JEOL scanning electron microscope (SEM) and a Zeiss optical microscope.

The luster of the fibers was measured using a d-10 Goniophotometer (Hunter Associate Laboratory Inc.

Reston VA., USA). Samples of fibers aligned by pulling through the fingers to make a parallel array were placed on a black card and taped on top and bottom. These samples were then mounted on the goniophotometer. The angle of the incident light was 45 degrees and the angle of reflection varied from 0 to 90 degrees. The fiber axis was parallel to the plane of incidence.

Moisture regain of the fibers was measured at 25°C and 65% relative humidity. First the sample of fibers as received was conditioned over saturated sodium nitrate for six days. Then one part of the sample was weighed and dried in an oven at 110°C and the other part was weighed and dried over phosphorous pentoxide (P_2O_5) in an evacuated desiccator for 9 days, after which the samples were weighed again. The density of the fibers was measured at room temperature (rh.= 42%, 25°C), by floating fragments of fiber in a mixture of benzene and chloroform. Before measurement, the fibers were cut into very small pieces, otherwise air bubbles remained inside the canal of the fibers would lead to very low results for the density measurement.

Seven samples of blended yarn (each approximately 100g) containing 100%, 75%, 65%, 50%, 25% cotton and 60% polyester were produced, designated 100C, 75C/25E, 65C/35E, 50C/50E, 60P/40E and 60P/40C respectively. In the production of these yarns, firstly, the cotton or polyester fibers were opened and cleaned in conventional opening equipment. The required amount of cotton or polyester and Estabragh fibers were then opened and mixed by hand. The mixture of fibers was spread over the feed tray of a revolving-flat card. The layer of mixed fibers was fed by hand into the feed rollers of the carding machine and the card web collected as usual. The relative humidity during carding was 75%; and in order to reduce the number of fibers flying into the air, water was sprayed over the fibers on the tray.

After carding, three passages of drawing were used to obtain 4g/m. slivers, after which roving and then yarn were produced on conventional roving and ring spinning frames.

RESULTS AND DISCUSSION

Fiber pods: Figure 2 shows a seed pod and flossy fibers. The fibers are arranged parallel to each other and protrude from the seeds. The pods are 6 to 8cm in length and 3 to 5cm mean diameter containing some 250 seeds and an average of 0.73g of fiber, (averaged over 10 pods). The fibers can be separated from the dried seeds very easily [7,10].

Fiber Length: Figure 3 shows the distribution of fiber length of a sample chosen at random from the 2 Kg stock. The mean length is 26.4mm and ranges from 5 to 42mm. The cumulative distribution shows 50% of fibers in the samples have a length more than 28mm [7].

Fiber diameter: The results of diameter measurements are shown in Table 1 and are the average of 140 measurements. This table indicates that the fibers are needle like. Typically, the base has a diameter 3 times greater than the tip. The average diameter is 25.3 micrometers. Similar measurments on a sample of domestic cotton fibers give an average

Figure 2. An opened seed pods.

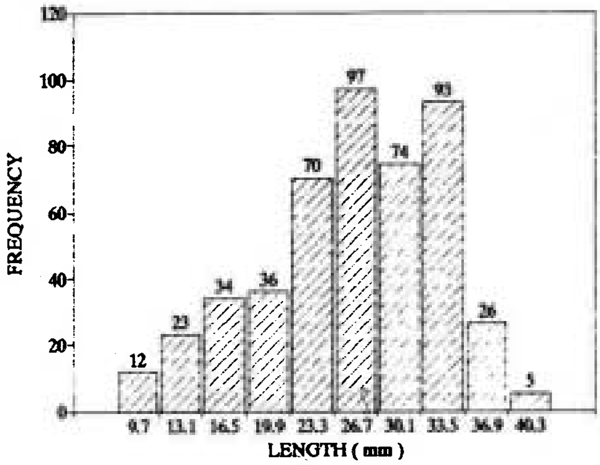

Figure 3. The distribution of Estabragh fiber length.

projected width of 18.5 micrometers ($\bar{x}$ =18.5, CV = 24.5%) [7].

Fiber Fineness: Due to the high air resistance of the Estabragh fibers in the Micronair cup and since the resistance to the airflow is related to the specific surface and the density of fibers [11], it was not possible to measure the linear density of Estabragh fibers using the Micronair instrument when calibrated for cotton fibers. Hence the fineness was measured by the cutting and weighing method. Measurements on 5 samples each containing 500 to 1000 fibers gave an average of 0.15 tex, while the corresponding figure for Micronair measurements of the cotton was 1.02 tex. It should be noted that because of the much thinner wall of the Estabragh fibers, they have a much smaller average tex value despite having a larger average cross-sectional measurement [7].

Strength and elongation: Table 2 shows breaking load, breaking elongation and Pressley Index for both the cotton and Estabragh fibers. At zero nominal gauge length, the Pressley Index for the cotton is much larger than it is for the Estabragh fibers, while strength and breaking load measured by the Instron with 15mm gauge length for cotton is lower than it is for the Estabragh fibers. This anomaly is probably due to the breakage of Estabragh fibers in the jaws of the pressley tester. In the Instron tests the fibers were glued to a card and theh tested, as described in the previous section [7].

TABLE 1. Fiber Diameter (Micrometers).

Base	Middle	Tip
x=36.3 CV%=13.8	x=28.6 CV%=12.8	x=11.1 CV%=62.8

TABLE 2. Comparative Properties of the Fibers.

Property	Estabragh	Cotton
Pressley Index Lb/in^2*	53.9±5.0	90.6 ± 0.4
Breaking Load g.*	5.7±0.6	4.2 ± 0.8
Breaking Elong. %*	2.6±1.0	6.3 ± 2.0
Tenacity g/tex.	38.3	32.5
Density g/cm^3.*	1.459 ± 0.001	1.508 ± 0.002
Refractive Index $n^{\perp\perp}$	1.597	1.582
Refractive Index $n^{\perp}$	1.538	1.528
Birefringence	0.059	0.054
X-ray crystallinity, %	57	75

* 95% Confidence Limits are indicated

Refractive Indices: Estabrageh fibers were found to be birefringent indicating molecular orientation. Comparative refractive indices are shown in Table 2. Both parallel and perpendicular refractive indices ($n^{\perp\perp}$ and $n^{\perp}$) of cotton fibers are lower than those of Estabragh fibers. The lower value of birefringence of cotton fibers is probably due to the twisted ribbon-like structure.

X-ray Diffraction: Curves relating the intensity of X-ray beams and diffraction angles (2θ) for de-waxed samples of cotton showed three sharp peaks at 2θ equal to 23, 10.5 and 15 degrees, corresponding to 3.98, 5.33, and 5.81 Å spacings, respectively. The peak at 23 was the sharpest. Estabragh fibers showed a sharp peak at 2θ = 22 and less sharp peaks at 2θ =16 corresponding to 4.04 and 5.6Å respectively, which indicates differences between the crystalline structures of cotton and Estabragh fibers. From the diffraction curve the percent crystallinity of cotton was calculated using the empirical equation of Segal et al. [12]. The results are presented in Table 2. If the crystallinity of Estabragh fibers can be calculated by the same empirical equation, then cotton fibers will show a much higher crystallinity than Estabragh fibers.

Fiber Density: The densities of dried samles of Estabragh and cotton fibers, shown in Table 2, indicate that the structure of Estabragh fibers is more open than that of cotton, confirming the results of the crystallinity measurements.

Moisture Regain: Moisture regains at 65% rh. and 25°C for samples of the two fibers are shown in Table 3. The regains of samples dried at 110°C are greater than those of being dried using P_2O_5 at room temperature. This could be due to the evaporation of volatile compounds. The moisture regain of Estabragh fibers is more than that of cotton fibers which indicates that there are more regions accessible to water molecules in Estabragh fibers than there are in cotton.

Fiber Morphology: Figure 4, is a photograph of a single Estabragh fiber by optical microscopy. Upon bending, the fibers buckle and collapse. Figure 5 shows the cross section of such a fiber. The fibers are found to be very smooth and thin walled. Figures 5 and 6 show the side and the hole (central canal) of a fiber in which three regions can be seen in the side; outer wall, inner wall and microfibrils packed in between. Boiling in water causes the fibers to collapse. Their cross sections change from round to flat or an irregularly collapsed tube.

TABLE 3. Moisture Reghain of Fibers.

Samples	drying methods	Regain %
Estabragh	P_2O_5	9.02
Estabragh	Oven 110°C	9.76
Cotton	P_2O_5	6.52
Cotton	Oven 110°C	7.53

Luster: A sample of Estabragh fibers weighing 0.25g was boiled with 100cc water and 0.2cc Triton x-100 for 5 minutes. Then the samples were rinsed, and dried in an oven at 110°C. Due to the lack of standard samples for the testing of luster, these wahsed samples along with samples of the as received fibers and samples of de-gummed silk fibers and 3 denier bright viscose rayon were tested by goniophotometer.

The curves represents the reflected light intensity verses the reflection angle are shown in Figure 7. The figure indicates that for the samples tested, the most lustrous fiber is rayon. The as-received sample of Estabragh fibers is more lustrous than cotton but less lustrous than silk. As expected, for the fibers tested the maximum reflection intensity is at 45 (mirror reflection) while for cotton fiber it is at 35. This is in agreement with previously reported results for cotton fibers [13], which is due to the convolutions of the cotton fibers. Generally, the reflection curves for silk and rayon have a sharp maximum, indicating a sharp luster. The curve for cotton is broad. As a result of boiling Estabragh fibers the intensity and the sharpness of the curves are reduced.

Yarn processing: Table 4 shows the count, twist, strength and breaking elongations of the samples of

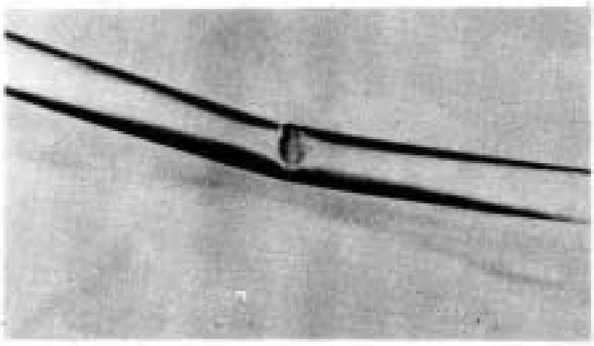

Figure 4. A bent Estabragh fiber under the light microscope; 400X.

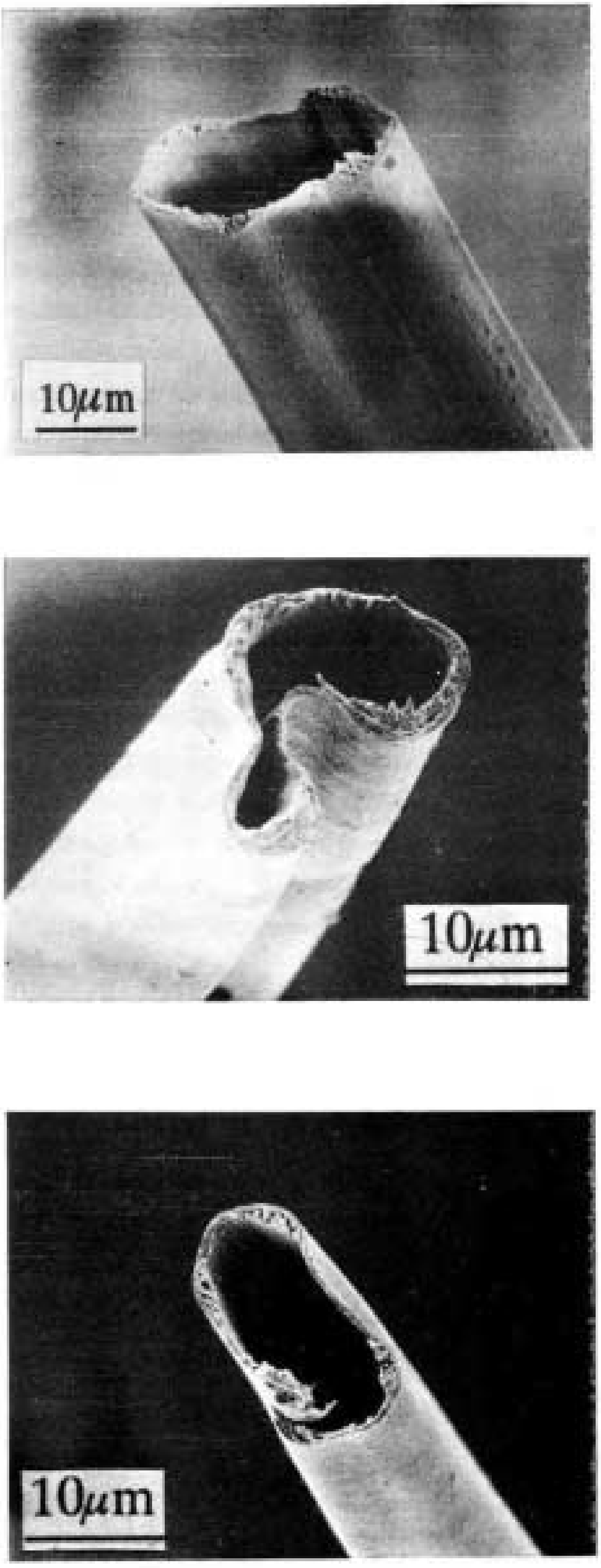

Figure 5. Sections of Estabragh fibers, SEM.

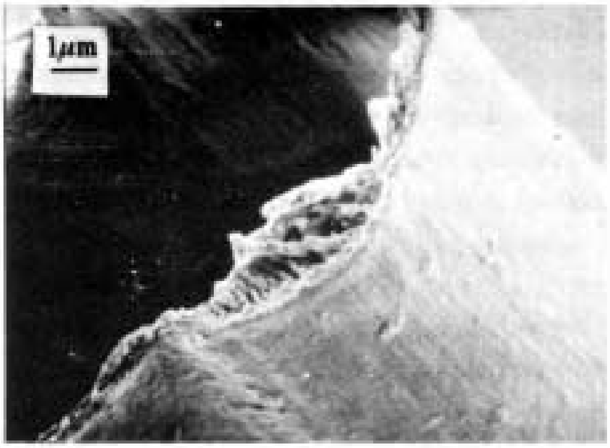

Figure 6. Portion of a section of Estabragh fiber, SEM

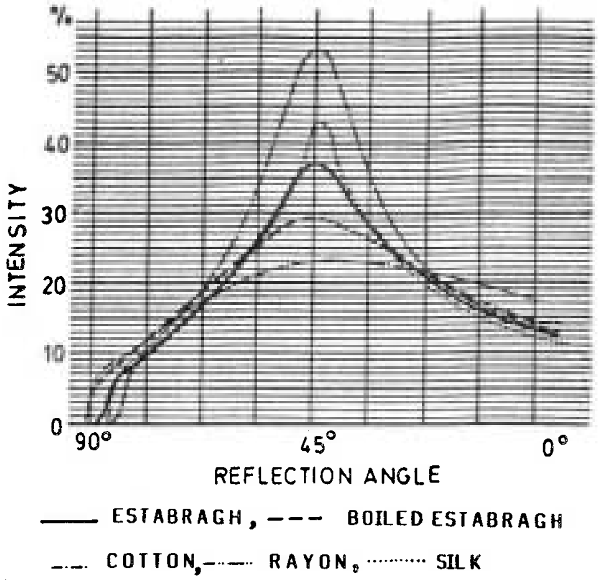

Figure 7. Goniophotometer curves; reflected light intensity vs. reflection angles. Incidence angle = 45°.

the yarn proudced. The 95% confidence limits are also indicated. The proportions of the blends as indicated in Table 4 are nominal. The actual amount of Estabragh fibers in the blend is not known since during the production it was observed that a large amount of the Estabragh fibers was lost as flywaste. The reduction in linear density of the blended yarns is partly due to the fact that some of the Estabragh fibers were lost during spinning.

TABLE 4. Characteristics of Yarn Samples.

Nominal Blend ratio	Count tex	Twist tpm.	Strength cN/tex	Breaking elong.%
100C	34.4 ± 2.5	703. ± 26	12.7 ± 0.8	6.2 ± 0.4
75C/25E	24.8 ± 2.1	674. ± 25	8.1 ± 0.7	4.0 ± 0.6
65C/35E	27.3 ± 0.8	683. ± 24	9.7 ± 0.8	4.6 ± 0.4
50C/50E	29.8 ± 1.9	696. ± 31	8.3 ± 0.7	4.9 ± 0.4
25C/75E	31.3 ± 1.3	696. ± 25	6.6 ± 0.5	4.0 ± 0.5
60P/40E	31.4 ± 2.0	686. ± 19	13.3 ± 0.6	18.3 ± 1.4
60P/40C	36.4 ± 1.1	715. ± 12	13.4 ± 0.5	14.0 ± 2.0

* 95% Confidence limits

In order to estimate the amount of Estabragh fiber loss during spinning, a mixture of 60% polyester staple fiber and 40% Estabragh fiber were used to produce blended yarn by the method described in the previous section and the amount of Estabragh fibers remained in the products were determined by a chemical method [10]. It was found that the amount of Estabragh fibers remained in card sliver, drawn sliver, roving and yarn were 23%, 22%, 21% and 18% respectively. These figures indicate that the maximum fiber loss was during carding operation. Determination of the actual amount of the Estabragh in the cotton/Estabragh blended yarn is not possible without a considerable amount of further evaluations. Both fibers are cellulosic and it is difficult to distinguish them from their cross sections in the blend.

The results of the tensile strength tests are also shown in Table 4. The results indicate that increasing the amount of Estabragh fibers in the blend, the strength and breaking elongation of the yarn is decreased. It is well known that the strength of blended yarn depends upon the stress/strain relationships of both component fibers. Since the breaking elongation of Estabragh fiber is smaller than that of cotton (Table 2), then it is to be expected that, for some blend proportions the strength and breaking elongation will be less than the strength and breaking elongation of yarn made from 100% of either component.

CONCLUSION

Structural features and some properties of a domestic cellulosic hollow fiber ie., Estabragh, which is very similar to milkweed is determined. This fiber has interesting properties. Mean fiber length is 26.4 mm, mean linear density is 0.15 tex, and mean diameter is 28.6 micrometers. The specific breaking stress of Estabragh fibers is greater than that of cotton. This could be due to the greater molecular orientation and lightness of Estabragh fibers. At standard relative humidity the regain of Estabragh fibers is more than that of cotton fibers, confirming the results from density and X-ray crystallinity measurements that it has fewer ordered regions. Based on the results of luster measurement, the luster of Estabragh fiber is much higher than that of cotton. It can be speculated that fabrics made from Estabragh fibers would have a soft luster.

Because of the lack of cohesiveness and crimp in Estabragh fibers, production of 100% Estabragh yarn by a conventional short staple production system is not possible. For production of yarns, equipment and techniques should be developed which would prevent the fibers from being lost as flywaste. Perhaps the fibers will have to be crimped by mechanical or chemical means. It is expected that the luster of fibers decrease by these processes.

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