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A STUDY OF PHYSICAL PROPERTIES OF INDIGENOUS SISAL FIBRES UNDER VARIOUS CONDITIONS

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Abstract. Breaking strength and percentage elongation of indigenous sisal fibres were determined after soaking them in distilled water, decinormal solutions of hydrochloric acid and sodium hydroxide and sea-water for a minimum period of 24 hr. The strength is significantly dependent on linear density and percentage elongation. The soaking appears to reduce the breaking load and the stress-at-break considerably but there appears to be no significant difference between the various treatments.

Preliminary investigations on sisal fibres were conducted previously and have been reported earlier.[1] Present studies were carried out with a view to investigate the effect of distilled water, alkali, acid and sea-water on the strength and elongation of sisal fibres: the main physical characteristics which ultimately determine its effective usefulness. Ropes made from sisal fibres could be used for navigational purposes in place of jute ropes which undergo many unfavourable seasonal and climatic variations. Accordingly, it was thought necessary to undertake such investigations to find out the effects resulting due to the above-mentioned treatments and thus help us in putting sisal fibres to practical uses.

Materials and Methods

Fibres were extracted from freshly cut sisal leaves by hand-beating, scraping and washing.[1] After brushing and drying, samples of sisal fibres were taken and kept immersed in distilled water, decinormal HCl solution, NaOH and sea-water for 24 hr. One extra sample was left in sea-water for seven days. The fibres were removed from the respective solutions and conditioned in an atmosphere of 65% R.H. and 21°C for 24 hr.

Breaking load and percentage elongation of the individual fibres were determined on Scott's tester IP-2, a single thread tester in which a fibre is held between its two jaws and progressively increasing load is exerted by means of a weight moving in an inclined plane till the fibre breaks. Fifty tests were performed for this experiment and the length under test was 10 in. The weight of each conditioned fibre was determined on a torsion balance before the stress-strain experiment and the linear density in μg/cm was calculated.[1] All the above tests were carried out under standard atmospheric conditions. (65% R.H., 21°C).

Results and Discussions

1. *Examination of the Stress–Strain Data for Fibres.* Results for individual fibres after soaking in distilled water are presented in Table 1. The mean values of various mechanical constants after various treatments are compared in Table 2 with those taken from a previous publication[1] for fibres tested at 65% R.H. without any soaking. Fibre strength in particular the stress-at-break (breaking load/linear density) decreased by more than 30% (Table 1), indicating a significant loss of strength after soaking in distilled water for 24 hr. Although upon drying the cellulosic substance, in close conformity with wool, contains more moisture at different R.H. than it would regain upon wetting up to a similar R.H. at a constant temperature, the loss of strength amounting to 30% cannot easily be reconciled. In the case of sisal the difference in absorbed water under the above-mentioned conditions is nearly 3% indicating that the loss of 30% in fibre tensile strength can only be attributed to some hidden factors not accountable in the present investigation.[2] The difference of 5.9% in elongation and that of 10.1% in the breaking load do not, however, appear to be significant in view of the scatter in their respective magnitudes (Table 1). Detailed examination (Table 1) of the breaking load, linear density, percentage elongation and stress-at-break, for the fibres tested after soaking in distilled water for 24 hr revealed that:

(*a*) The linear density of the fibres (62%) ranges from 200 to 400 μg/cm with two more distinct groups of fibres, 20% of which have linear density from 400 to 600 μg/cm and 12% from 650 to 800 μg/cm (Fig. 1a). The breaking load similarly shows three to four peaks (Fig. 1b), the maximum number of fibres (70%) having breaking loads from 1.40 to 2.60 lb and nearly 22% and 8% fibres exhibiting breaking loads of 0.80–1.39 lb and 2.80–3.12 lb respectively. This is a very interesting feature which clearly shows that the representative sample used for testing involved two distinct type of fibres with the possibility of a third but small group having comparatively higher values of the physical constants investigated.

The breaking load generally increases with the increase in linear density (Fig. 2), but the relationship is a complex one and appears to be curvilinear in-

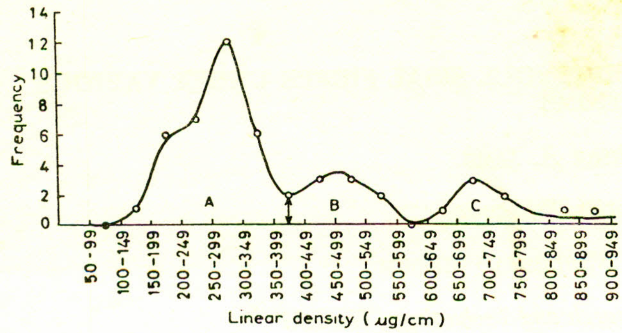

Fig. 1 (a). Frequency distribution of linear density.

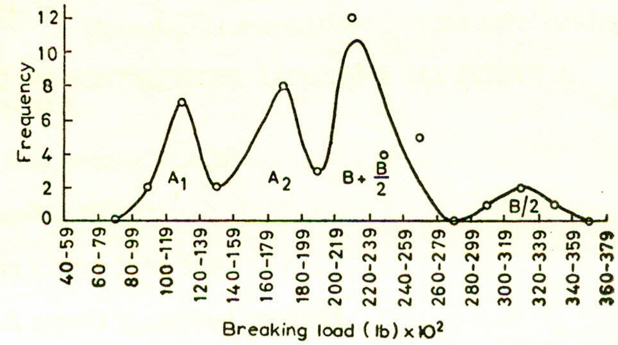

Fig. 1 (b). Frequency distribution of breaking load.

TABLE 1. RESULTS ON INDIVIDUAL SISAL FIBRES (24 HR SOAKING IN DISTILLED WATER).

Linear density (µg/cm)	Breaking load (lb)	Breaking stress (lb/µg/cm) $\times 10^3$	Elongation (%)	Liner density (µg/cm)	Breaking load (lb)	Breaking stress (lb/µg/cm) $\times 10^3$	Elongation (%)
462	2.40	5.195	2.5	571	1.70	2.977	2.5
884	2.15	2.432	5.0	335	2.40	7.164	3.0
797	2.21	2.773	5.8	541	2.95	5.453	3.0
923	2.11	2.286	4.9	295	2.52	8.542	2.8
709	3.30	4.654	3.8	374	2.06	5.508	2.5
748	3.01	4.024	3.5	465	2.32	4.989	2.6
683	3.12	4.568	2.5	252	1.01	4.008	3.5
535	2.10	3.925	3.0	333	1.44	4.324	2.1
738	2.00	2.710	2.7	388	2.23	5.747	3.5
783	1.43	1.826	8.0	230	1.62	7.043	5.2
372	1.80	4.839	1.5	207	1.66	8.019	4.8
331	1.78	5.378	2.2	409	2.41	5.892	2.2
262	1.29	4.924	2.0	282	2.03	7.199	5.0
305	1.15	3.770	1.2	313	1.66	5.303	2.1
510	2.17	4.255	3.3	348	1.62	4.655	5.2
236	1.50	6.356	2.0	319	1.43	4.483	2.0
390	2.12	5.436	2.7	244	1.62	6.639	4.9
551	2.38	4.319	4.6	276	1.89	6.848	2.2
321	1.11	3.458	1.6	305	1.12	3.672	5.0
256	1.02	3.984	3.6	207	1.68	8.116	3.2
245	1.12	4.571	2.5	476	2.42	5.084	2.4
163	0.92	5.644	2.6	364	2.07	5.687	2.0
335	2.07	6.179	3.6	340	0.80	2.353	2.0
404	2.03	5.025	5.1	301	1.16	3.854	1.0
352	2.17	6.165	4.1	262	1.25	4.771	3.0
				Mean 415	1.87	4.94	3.2

TABLE 2. MEAN VALUES OF VARIOUS CHARACTERISTICS OF SISAL.

	Dry	Distilled water (24 hr)	0.1N HCl (24 hr)	0.1N NaOH (24 hr)	Sea-water	
					(24 hr)	One week
Linear density (µg/cm)	307	415	295	437	366	459
C.V. (%)	30.9	40.6	24.0	28.0	30.0	27.1
Breaking load (lb)	2.08	1.87	1.37	1.92	1.78	1.91
C.V. (%)	23.5	29.7	28.8	29.3	26.6	27.9
Breaking stress (lb/µg/cm) $\times 10^3$	7.10	4.94	4.73	4.68	5.14	4.29
Elongation (%)	3.4	3.2	3.6	3.1	5.0	3.1
C.V. (%)	35.7	48.6	29.6	46.6	37.7	36.5

volving second power of the linear density. This is considered to happen due to the anomaly that some of the thicker fibres possess comparatively low breaking loads while a group of finer fibres is unusually more stiff. The cause of such discrepancy could be the difference of crystalline parts in the fibres tested, the state of their maturity and even the soil conditions.

The breaking load was then divided by the linear density in order to convert it to the stress-at-break in an endeavour to do away with the effect of linear density on the rheological behaviour of the fibres. The stress-at-break conforms with the two parameters studied earlier and clearly involves two distinct groups of fibres (Fig. 3a). Most of the fibres (about 80%), however, represent the main group having breaking stress ranging from 3.30×10^3 to 7.30×10^3 lb μg/cm. About 14% fibres are weaker and the remaining are slightly stronger.

The stress-at-break is inversely related to the linear density (Fig. 3b). It, therefore, follows that fine fibres are generally stronger and the thicker fibres tend to become comparatively weaker after certain stage in their growth, due, perhaps, to the development of the size of lumen at the centre incorporating collapsed cellulosic cells analogous to the medulla of a woollen fibre. This indicates that different groups possess unique fibre substance which is responsible in imparting different breaking stresses to them and the differences in rheological behaviour are not merely the outcome of linear density or area of cross-section.

The percentage extension also shows two peaks (Fig. 4a) about 70% of the fibres exhibit low values while 20% show higher percentage elongation-at-break. The fibres with lower percentage of extension generally break at lower loads (Fig. 4b). The relationship is again curvilinear and the breaking-load depends on the second and possibly on higher powers of percentage elongation-at-break. It is clear (Fig. 4b) that on the average, no fibre broke for elongation less than 1% and for loads less than 1.20 lb under the conditions of our test and for the fibres examined. It will, of course, be worthwhile to extend the fibres having approximately the same linear density to the same percentage extension and then determine if the breaking load or stress-at-break really differs between the fibres. A plot of the corresponding values showed that the percentage extension is, in no way, related to or dependent upon the linear density of the fibres examined.

2 (a). *Treatment Effects* (*General*). The effect of treating the fibres in 0.1N HCl, 0.1N NaOH and sea-water is broadly similar to that produced by immersion in distilled water. The breaking load decreased quite markedly (Table 2) but there does not appear to be any conspicuous change of strength between different treatments. The only noteworthy difference in breaking strength is shown by the fibres tested after soaking in decinormal HCl solution. This apparent effect together with other discrepancies of minor nature could well be attributed to the fibres of different linear densities employed for various treatments. Since it has been previously shown (section 1) that breaking load depends upon the linear density, the former was converted (Table 2) into breaking stress, i.e. the breaking load was divided by the linear density to make the comparison more meaningful. The magnitudes of the stress-at-break support the above conjecture that although the fibre strength decreased quite appreciably after treatment as compared to that of dry fibres, the values of breaking stress ranging from 5.14×10^3 to 4.29×10^3 lb/μg/cm are not significantly different between the treatments. The maximum variations from the value for distilled water are $+0.20\times10^3$ and -0.65×10^3 lbs/μg/cm which are within the limits of variations encountered (Table 1).

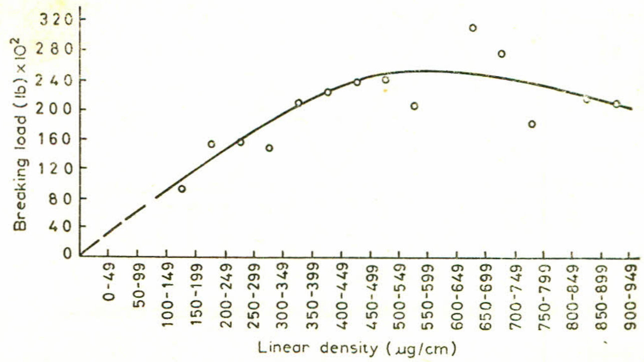

Fig. 2. Relationships between breaking load and linear density.

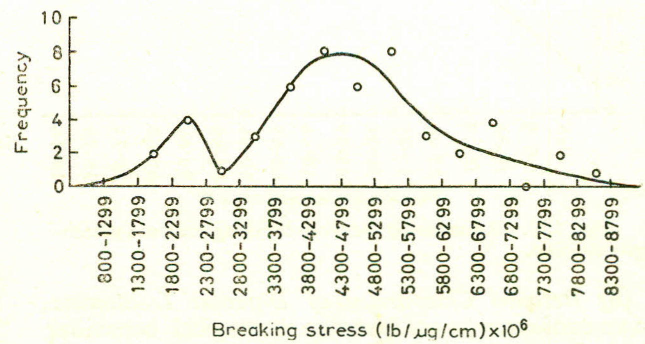

Fig. 3(a). Frequency distribution of breaking stress.

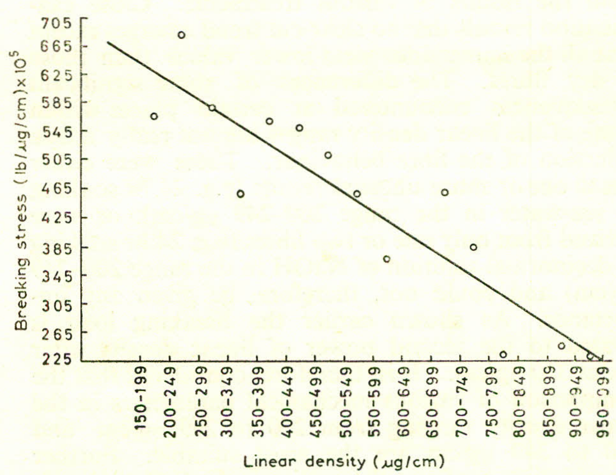

Fig. 3(b). Relationships between breaking stress and linear density.

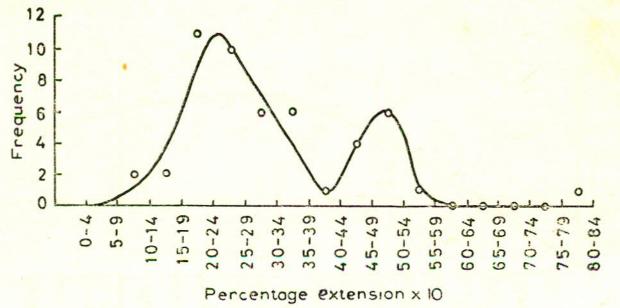

Fig. 4(a). Frequency distribution of perscentage extension.

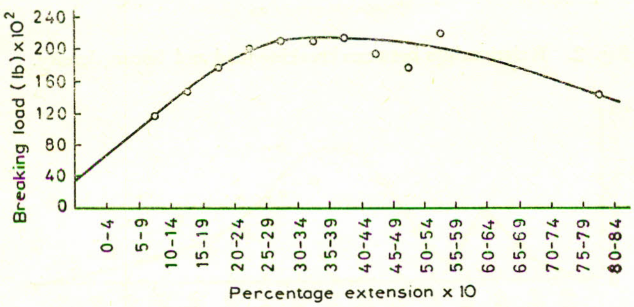

Fig. 4(b). Relationship between breaking load and percentage extension.

(b) *Detailed Comparison of Different Treatments.* In an endeavour to compare the rheological behaviour Table 3 was compiled where the fibres possessing the linear density within the same range were separated from the results of various treatments. Close examination reveals that no clear-cut trend emerges except that all the immersions yield lower values than those of dry fibres. The differences of some significant consequences encountered at certain places within some of the linear density ranges are not really a true reflection of the fibre behaviour. These were either due to one or more unusual results (e.g. 24 hr soaking in sea-water in the range 200–249 μg/cm), or were derived from only one or two fibres (e.g. 24 hr soaking in decinormal solution of NaOH in the range 200–249 μg/cm) and could not, therefore, be given any importance. As shown earlier the breaking load is related to the second power of linear density after about 350 μg/cm. It is, therefore, considered that the comparison of various mechanical parameters in the linear density ranging from 250 to 299 μg/cm and 300 to 349 μg/cm are the most suitable. Further examination confirms the earlier findings that significant differences in tensile strength do not occur between treatments of the fibres in solutions of various pH values. The reason for comparatively lower values of breaking stress in decinormal NaOH solution and that of one week's soaking in sea-water in particular, when compared with those soaked for 24 hr in distilled water and sea-water, lies in the fact that large percentage of the fibres used in the former group possessed higher linear density than the linear part of load-linear density relationship. This further confirmed that second power of the linear density was definitely involved. The breaking stress obviously decreased due to the comparative fall in breaking load after the linear density of 350–400 μg/cm. On the

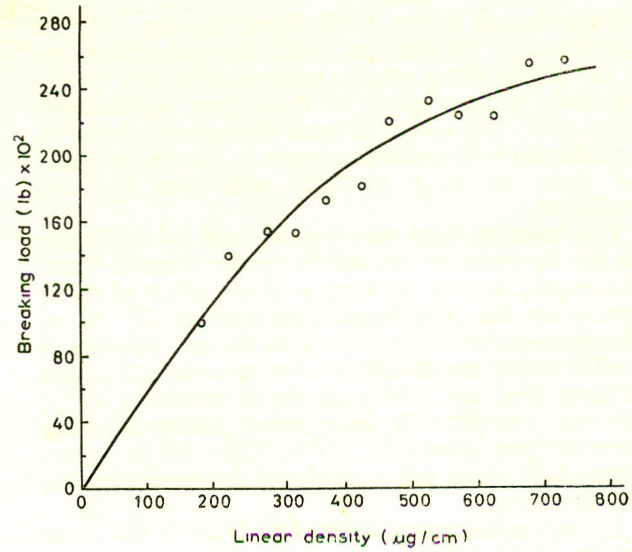

Fig. 5. Relationships between linear density and breaking load.

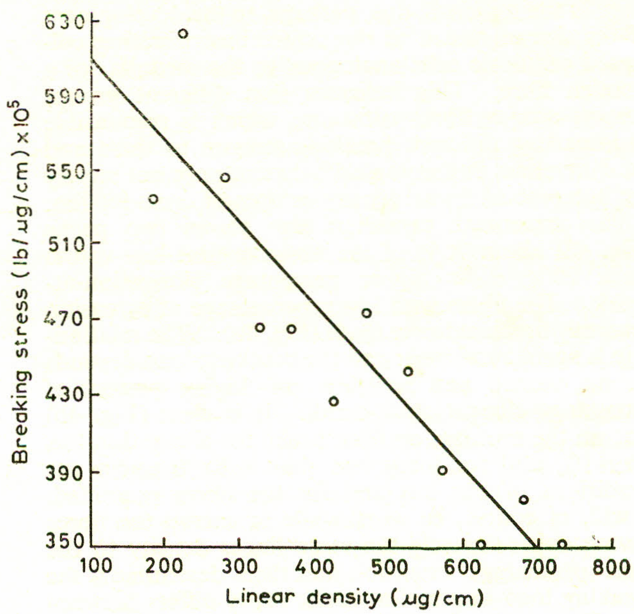

Fig. 6. Relationship between linear density and breaking stress.

other hand, in the treatment of decinormal HCl solution most of the fibres used were below 400 μg/cm and had comparatively lower breaking loads which could reconcile the slightly lower breaking stress in this case.

Since differences in the mechanical parameters were not considered significant, it was, therefore, decided to pool the results (excluding dry value) and examine if the conclusions drawn earlier and based on immersion in distilled water alone were correct. The breaking load, the breaking stress, the linear density and the percentage extension obtained after pooling their respective values exhibited normal distribution with an elongated tail on the high value side and most of the fibres corresponded to the main group. The

TABLE 3. MECHANICAL PARAMETERS UNDER DIFFERENT CONDITIONS AND VARIOUS RANGES OF LINEAR DENSITY.

Treatment	No. of fibres	Linear density (μg/cm)	Breaking load (lb)	Breaking stress (lb/μg/cm) ×10⁶	Extension (%)	Remarks
Range (150–199)μg/cm						
Dry	1	163	1.10	6748	2.0	
Distilled water	1	163	0.92	5644	2.6	
0.1N HCl	7	182	0.96	5219	3.7	
0.1N NaOH	2	197	1.05	5355	2.8	
Sea-water$_1$*	1	197	1.36	6903	4.5	Unusually high value
Sea-Water$_1$†	1	173	0.75	4335	3.0	
Grand mean**		184	0.99	5344	3.5	
Range (200–249)μg/cm						
Dry	14	227	1.78	7835	4.1	
Distilled water	6	228	1.53	6786	3.8	
0.1N HCl	10	225	1.26	5595	3.9	
0.1N NaOH	2	230	1.12	4837	3.4	
Sea water$_1$	8	218	1.52	7207	5.4	One value unusually high
Sea water$_2$	1	236	1.39	5254	3.0	
Grand mean		224	1.39	6228	4.3	
Range (250–299)μg/cm						
Dry	11	276	2.02	7302	3.7	
Distilled water	7	269	1.57	5754	3.2	
0.1N HCl	7	283	1.30	4626	4.2	Two values unusually low
0.1N NaOH	10	284	1.72	6005	2.4	Three values unusually high
Sea water$_1$	9	284	1.53	5366	4.8	One value unusually low
Sea water$_2$	6	291	1.55	5311	2.8	One value unusually low
Grand mean		282	1.54	5458	3.5	
Range (300–349) μg/cm						
Dry	7	315	2.11	6721	3.1	
Distilled	12	324	1.48	4549	2.6	
0.1N HCl	7	330	1.70	4961	2.8	
0.1N NaOH	6	322	1.66	5169	2.6	
Sea water$_1$	5	335	1.41	4208	5.3	
Sea water$_2$	3	322	1.30	4052	3.0	
Grand mean		326	1.53	4652	3.1	
Range (350–399)μg/cm						
Dry	8	371	2.54	6857	3.6	
Distilled water	6	373	2.07	5564	2.7	
0.1N HCl	11	370	1.44	3871	3.2	One value unusually low

*Sea- water$_1$, after 24 hr. soaking; †Sea- water$_2$, after soaking for one week; **Grand mean grand mean excluding dry fibre.

Table 3 (continued)

0.1N NaOH	5	370	1.92	5215	2.4	
Sea-water₁	14	367	1.82	4970	5.3	
Sea-water₂	5	373	1.51	4033	2.0	
Grand mean		370	1.73	4653	3.6	
Range (400–449)μg/cm						
Dry	3	417	2.13	5225	1.7	One value unusually low
Distilled water	2	406	2.22	5458	3.6	
0.1N HCl	5	427	1.76	4112	3.3	
0.1N NaOH	3	411	1.57	3802	2.9	One value unusually low
Sea-water₁	3	434	1.60	3702	4.8	
Sea-water₂	10	429	1.89	4421	3.5	
Grand mean		425	1.18	4269	3.6	
Range (450–499) μg/cm						
Dry	3	468	2.58	5506	2.7	
Distilled water	3	468	2.38	5089	2.5	
0.1N HCl	1	453	1.86	4133	5.3	
0.1N NaOH	5	471	2.07	4418	2.8	
Sea-water₁	1	453	2.07	4569	2.7	
Sea-water₂	6	471	2.33	4971	3.0	
Grand mean		468	2.21	4743	3.0	
Range (500–549)μg/cm						
Dry	2	521	2.47	4738	2.0	
Distilled water	3	529	2.41	4544	3.1	
0.1N HCl	Nil	Nil	Nil	Nil	Nil	
0.1N NaOH	2	530	2.24	4214	2.8	
Sea-water₁	4	521	2.56	4902	3.8	Two values unusually high
Sea-water₂	4	526	2.09	3977	2.7	
Grand mean		526	2.33	4429	3.2	
Range (550–599)μg/cm						
Dry	0	—	—	—	—	
Distilled water	2	561	2.04	3648	3.5	One value very low
0.1N HCl	0	—	—	—	—	
0.1N NaOH	2	586	2.58	4408	2.6	One value unusualy high
Sea-water¹	1	569	2.23	3919	10.0	
Sea-water₂	7	574	2.21	3864	3.2	
Grand mean		573	2.25	3925	3.7	
Range (600–649)μg/cm						
Dry	0	—	—	—	—	
Distilled water	0	—	—	—	—	
0.1N HCl	0	—	—	—	—	
0.1N NaOH	8	628	2.19	3485	4.2	One value very low
Sea-water₁	2	617	2.38	3880	3.3	
Sea-water₂	3	619	2.28	3695	2.9	
Grand mean		625	2.24	3517	3.8	

Table 3 (continued)

Range (650–699)μg/cm					
Dry	0	—	—	—	—
Distilled water	1	683	3.12	4568	2.5
0.1N HCl	0	—	—	—	—
0.1N NaOH	3	683	2.55	3726	3.8
Sea-water$_I$	2	672	2.57	3830	5.0
Sea-water$_2$	1	691	2.00	2894	2.7
Grand mean		681	2.56	3757	3.8
Range (700–749)μg/cm					
Dry	0	—	—	—	—
Distilled water	3	732	2.77	3796	3.3
0.1N HCf	0	—	—	—	—
0.1N NaOH	2	748	2.56	3422	5.2
Sea-water$_I$	0	—	—	—	—
Sea-water$_2$	3	724	2.40	3307	4.9
Grand mean		733	2.58	3519	4.4

grand mean values were, therefore, calculated but the values based on less than three fibres were left out of further analysis.

(c) *Study of Breaking Load and Percentage Elongation.* The breaking load and breaking stress are plotted against the linear density in Figs 5 and 6 respectively and the relationship between the breaking load and the percentage elongation is shown in Fig 7. The results are in general agreement with those for distilled water. The breaking load exhibited a curvilinear relationship with the linear density (Fig. 5) and the breaking stress decreased linearly (Fig. 6) with the increase in linear density. The linear po rtion in the former plot may be considered to extend from 100 to 300 μg/cm, in which range the breaking stress falls by only 15% of its maximum value (cf. Fig. 6). The linear density accounted for nearly 82% of the variation in the breaking stress (Fig. 6) and the result appears to have complete correspondence with that for distilled water, where approximately 83% of the variations were accounted for.

As mentioned in section 1, the percentage extension was independent of the linear density. On the average a single wet or soaked fibre can sustain a load of 1.82 $\pm$0.05 lb after which it breaks with a percentage extension varying from 3.00 to 8.00 (Fig. 7).

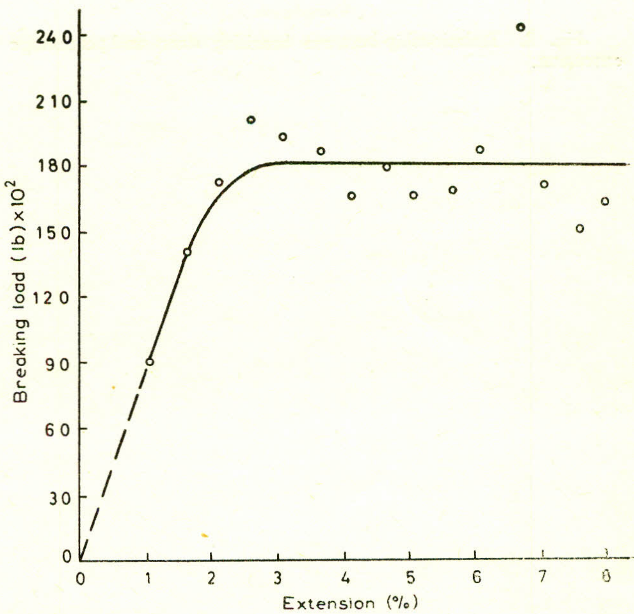

Fig. 7. Relationship between percentage extension and breaking load.

Breaking stress is significantly smaller for treated fibres as compared to dry fibres at all percentages of extension (Fig. 8). This result is in complete conformity to those discussed in section 2(b). The interesting feature is that the change in breaking stress at lower percentage of extension is small while it is strikingly large at higher percentage of extension. The decrease in stress-at-break from dry to treated fibres, for example, is about 33% at 2% extension as compared to nearly 50% at 6% extension. Moreover, the decrease in the breaking stress appears to increase linearly with the increase in percentage extension and this probably results from the unique fibre substance of the fibres concerned. It can, therefore, be concluded that the more elastic fibres (with higher percentage extension-at-break) become considerably weaker after soaking in various liquids as compared to those exhibiting lower perecentage extension under dry conditions.

The relationships in Figs. 5, 6, 7, and 8 could be further improved if the unusually low or high values of the rheological characteristics for some of the fibres, as indicated in Table 3, were dropped out. This change was, however, not attempted because it could have no significant effect on the general conclusions.

Conclusions

The decrease in breaking strength from dry to 24 hr soaking is of the order of 30.4, 33.4, 34.1 and 27.6% in case of distilled water, decinormal solutions of HCl and NaOH and sea-water respectively while the corresponding decrease after soaking in sea-water for one week is 39.6%. The results clearly indicate that

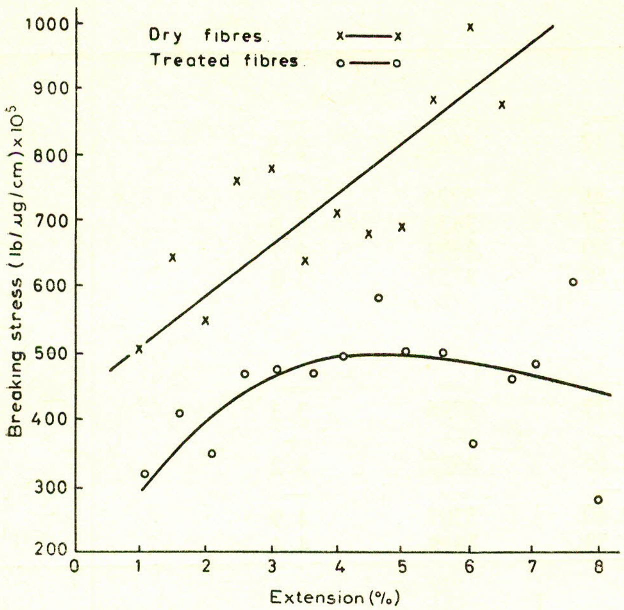

Fig. 8. Relationship between breaking stress and percentage extension.

the ropes and other products made from indigenous sisal fibres can be safely used under all circumstances. It, however, still remains to see how the strength of a standard rope manufactured from indigenous sisal, under similar conditions in a mill will compare with that made from the imported material. This and other aspects will form the subject of further research in this project.

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