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SMOULDERING IN DUSTS AND FIBROUS MATERIALS

Part IV Jute Cloth in Still Air

by

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Summary

An investigation of the smouldering of jute has been made with particular regard to the development of fires involving this material, such as storage fires. The rates of propagation of smouldering in several types of jute cloth have been measured and were found to depend chiefly upon the weave and condition of the material, direction of propagation, and number of layers of cloth undergoing combustion. It was also found that smouldering could easily be initiated by a glowing cigarette end or a similar small source of ignition.

Practical applications of these results are discussed.

Introduction

The importance of smouldering as an industrial fire hazard has already been discussed in earlier reports concerned with some common combustible dusts. (1,2) The results of experiments described in these reports showed that slow smouldering could occur even in very shallow layers of dust and that its initiation could be effected easily by a glowing cigarette end. Apart from dusts, however, there are other materials of general industrial use which are combustible and may, therefore, support smouldering. Among the most common of these latter materials is jute sacking; this is extensively used in both transportation and storage. The origin of fires in materials stored in jute sacks is often obscure; in many cases the source of such fires has been reported as spontaneous ignition of either the stored materials or of the sacking. As supporting evidence for this supposed cause was frequently scanty, or even non-existent, the origin of these fires was only occasionally established with any degree of certainty.

Recently the problem of storage fires in certain oilseeds (palm kernels) contained in jute sacks has been the subject of several investigations;(3,4) a considerable amount of experimental work was carried out upon both the seeds and the sacking in order to determine whether spontaneous heating and ignition were the probable causes of the fires. The experiments showed that, while spontaneous heating up to 80°C could occur in these materials, no evidence was obtained in the laboratory of the further heating necessary for spontaneous ignition under the conditions of storage in this country; in view of these conclusions the alternative suggestion was put forward (3) that the fires resulted from slow smouldering of the jute sacks, initiated by an external source of ignition. This was supported by the observations made upon actual stacks of bagged oilseeds which were not seriously damaged by the outbreaks of fire; these observations showed that charring tended to occur in small well-defined areas within the stack ("hot spots") whilst the remainder was comparatively unaffected. If the ignition had been spontaneous, widespread heating would be expected throughout much of the stack accompanied by charring near the centre. The actual behaviour of the stacks was therefore closer to that which would be expected if, for example, a small source of ignition were introduced into the stacks during the building operations; if smouldering were initiated in this manner it might continue for a long interval before it was transformed into flame. If the smouldering had proceeded unnoticed the production of flame would then appear to be spontaneous.

Furthermore, if spontaneous ignition does occur in materials stored in jute sacks, the production of smouldering will most probably be the first stage of the ignition. The subsequent developments will then be similar, irrespective of whether the fire was initiated spontaneously or by an external source of ignition.

If the occurrence of smouldering is to be considered as a possible initial stage in fires in bagged materials, it is necessary to know the approximate rate of propagation of smouldering in the jute cloth. The experiments described in this note were therefore chiefly concerned with the measurement of the rates of smouldering in several types of cloth in common use. The effect of the weave and weight of the cloth was investigated initially on the material as received from the manufacturers; attempts were also made to simulate wearing in the original cloth by both washing in boiling water, which expanded the threads and loosened the weave, and by rubbing the cloth with a wire brush, which mainly raised a nap on the material. Experiments were also carried out upon the clean cloth in both new and "worn" conditions to obtain a measure of the ease with which smouldering could be initiated.

Since, in practice, the continual use of sacks results not only in wearing but also in the soiling of the cloth, a study was made of the effect upon the smouldering rate of impregnation of the cloth with various combustible oils; the effect of the addition of water to the cloth was also investigated for comparison.

All the experiments described in this report were carried out under still air conditions.

Experimental

Materials Three specimens of new jute cloth differing considerably in weight and weave were obtained. Some characteristics of the cloth are given below in Table 1.

Table 1

Details of the jute cloths, in the condition as received.

Cloth	I	II	III
Weave	Twill	Twill	Scrim
Weight per unit area gm/cm^2	0.077	0.044	0.016
No. of warp threads (ends) per inch	38	27	10
No. of weft threads (picks) per inch	12	10	15
Thickness mm.	1.20	0.67	0.66
Moisture content %	9.4	8.8	9.5

Cloth I, the heaviest, was very closely woven but was not as thick as some of the coarsest types of sacking; cloth III, had a very open weave and was typical of the lightest material. Cloth II was of intermediate weight and weave.

The oils used in the experiments upon impregnated jute were: transformer oil (flash point 295°F), kerosine, and oleine (95% free fatty acid). Further experiments were carried out upon cloth impregnated with distilled water.

Procedure In the experiments upon the cloth in its original state, without treatment, the material was cut into rectangular pieces and fixed in a metal support; the number of layers of material was varied in a series of experiments and the cloth was arranged so that smouldering either propagated along the warp threads (i.e. parallel to the selvedge in the original roll of material) or along the weft. Three supports of various widths were used, values of which are given in Table 2. Support C empty is shown in Plate 1 and the same support with the cloth held in position is shown in Plate 2.

Table 2

Widths of the supports for the jute cloths

Support	A	B	C
Width cm.	4.5	7.7	13.5

Smouldering was initiated by standing the support upright and playing a small pilot gas flame on the upper free edge of the cloth specimen; this prevented flame travelling from the pilot light and singeing the projecting hairs on the cloth. When a uniform smouldering zone was formed the support was placed so that smouldering could propagate in the direction required in the particular experiment (i.e. horizontally or vertically upwards). The zone was allowed to travel a few centimetres to achieve steady propagation before timing was started; the time of travel was then measured at centimetre intervals over a total distance of 10 cm. If the smouldering had ceased, or if the combustion zone was consistently narrowing after this distance, then the cloth arrangement concerned was classified as "non-smouldering".

Some experiments were carried out upon cloth in which the weave had been loosened by washing, in order to simulate wearing. The washing procedure was as follows: strips of the cloth were boiled for 30 min. in water containing about 2 per cent synthetic detergent. The water was then decanted and the cloth rinsed several times in hot water; these operations were followed by rinses in cold water. The strips were then lightly wrung and left to drain and dry overnight; drying was finally completed by placing the cloth in an oven at 100°C for 30 min. The cloth was then cut into rectangular pieces, mounted in a support, and the experiments were carried out in the same manner as with the original material. During the washing the cloth darkened considerably and the water was also discoloured.

The alternative method of simulating wearing was to raise a nap by stroking the cloth with a small wire brush made from file carding. The cloth was cut into strips, parallel to the weft threads, and brushed on both sides along the length of the strips; care was taken not to disturb seriously the weave of the cloth. The material was then cut and mounted in the supports as before; smouldering was initiated by means of a wire heated electrically to a dull red. The gas pilot light could not be used as flame easily spread from it vertically downwards, being transmitted by the nap.

The experiments upon the jute impregnated with various oils or water were carried out upon cloth II, as received, only. The liquid was applied to the cloth by spraying or by dropping from a fine jet as evenly as possible; the cloth was then rolled and covered for periods up to 30 min. to allow the liquid to spread uniformly. The amount added to the cloth was then determined by weighing; following this the material was cut and six layers were mounted in support C so that smouldering could propagate parallel to the weft threads. Smouldering was then initiated by the pilot flame; propagation in both the horizontal and the vertically upward directions was investigated as before.

Results

Clean jute cloths The smouldering times of the clean cloths, as received, washed, and brushed, are given in Table 3 and Figs. 1 and 2. The values given are generally based upon single determinations only; but those shown in Fig 1 and 2 (for the cloth received) are usually the mean of two determinations. In any given experiment, if the smouldering were sustained, the combustion zone advanced at a uniform rate and the smouldering time was therefore independent of the distance travelled by the zone. If the number of layers of cloth were only just sufficient for sustained smouldering, the combustion zone did not extend completely across the cloth specimen. In these cases a margin of unburnt cloth up to 2 cm. in width was left at the sides of the support. In no instance did a single layer of cloth sustain smouldering.

Smouldering could be initiated in the three cloths by small sources of ignition such as a dull-red, hot wire or a glowing cigarette end. The ease of ignition varied with the nature and conditions of the cloths, but these igniting sources were invariably more effective when acting upon washed or brushed material.

Impregnated jute cloth The results of the experiments upon impregnated cloth II are shown in Figs. 3-6, where the smouldering time is plotted against the weight of liquid added to unit weight of cloth as received. During the smouldering it was again found that the combustion zones advanced at uniform rates, in both the horizontal and the vertical positions of the support. This was in spite of the visible transference of oil by distillation from near the hot combustion zone to the cool unburnt cloth. The oil so transferred, however, condensed in small globules upon projecting hairs of the cloth and did not spread uniformly throughout the layers mounted in the support.

The addition of more than a certain amount of liquid to the cloth prevented smouldering from being sustained. The amount of liquid per unit weight of cloth required for this depended upon both the nature of the liquid and the direction of propagation of smouldering (horizontal or vertical). Thus, with a weight ratio of liquid to cloth of 0.4, sustained smouldering in the vertical position occurred with water impregnation but not with transformer oil. Although detailed investigations were not undertaken it appeared that the changeover to non-smouldering in the cloth, with a given liquid, occurred abruptly when a certain critical amount of liquid had been added, although the cloth was still combustible.

Discussion

The experiments described above show that the three types of jute cloth investigated of widely differing weights and weaves, were capable of undergoing regular and sustained smouldering. The linear rate of propagation in clean material depended upon the characteristics of the cloth, upon whether propagation was along warp or weft threads and upon its direction (horizontal or vertical), and also varied with the condition of the material. Thus from Table 3 and Figs. 1 and 2 it may be seen that under similar conditions the rates of smouldering of cloth I, the heaviest material, were less than those of cloth II.

Table 3

The smouldering times of clean jute cloths

	Condition of cloth	Support	Smouldering parallel to	Minimum no. of layers for sustained smouldering (=n)	Smouldering time for n layers min/cm.	Remarks
Cloth I (smouldering upwards)	As received	A	weft	>4	-	-
	"	C	"	4	5.7	8.1 min/cm for 6 layers
	Washed	B	"	2	3.7	4.4 min/cm for 3 layers
	"	B	warp	2	3.6	4.5 min/cm for 3 layers
	Brushed	B	weft	2	3.1	3.5 min/cm for 3 layers
Cloth I (smouldering horizontally)	Washed	B	weft	>3	-	-
	"	B	warp	>3	-	-
	Brushed	B	weft	3	6.5	-
Cloth II (smouldering upwards)	As received	B	weft	2	see Fig 1	-
	"	B	warp	3	see Fig 2	-
	Washed	A	weft	2	2.5	3.0 min/cm for 3 layers 3.4 min/cm for 4 layers
	"	A	warp	2	2.5	2.5 min/cm for 3 layers 3.0 min/cm for 4 layers
	"	B	weft	2	see Fig 1	-
	"	B	warp	2	see Fig 2	-
	Brushed	B	weft	2	2.3	2.5 min/cm for 3 layers
Cloth II (Smouldering horizontally)	As received	B	weft	>4	-	-
	"	B	warp	>4	-	-
	Washed	A	weft	4	5.8	-
	"	A	warp	4	5.2	-
	"	B	weft	3	4.7	5.0 min/cm for 4 layers
	"	B	warp	4	4.5	-
	Brushed	B	weft	>3	-	-
Cloth III (smouldering upwards)	As received	B	weft	>8	-	-
	"	C	weft	10	2.6	-
	Washed	B	weft	6	2.6	inflamed, see below.
	Brushed	B	weft	>8	-	-
	"	C	weft	10	2.6	-
Cloth III (smouldering horizontally)	As received	C	weft	>10	-	-
	Washed	C	weft	>6	-	-
	Brushed	C	weft	>10	-	-

Note: In the experiment upon washed cloth III, smouldering vertically upwards, the cloth suddenly inflamed after the combustion zone had been timed over a distance of 9 cm. The experiment was repeated but, although the rates of smouldering were almost identical, the cloth did not inflame. No inflaming was observed with either cloth I or II under the still air conditions of all the experiments.

Direct comparison with cloth III is not possible on this point because sustained smouldering could not be obtained with a reasonable number of layers of cloth. The smouldering times obtained when propagation was along the weft threads were usually slightly greater, and never less, than those measured upon smouldering along warp threads, other conditions being identical. Since the difference in the smouldering times was small it was not investigated in detail; it was, however, to be expected since the warp and weft threads were not equal in number (Table 1) or diameter.

Increased rates of smouldering were obtained with both the washed and the brushed cloths; the increase was evident under all experimental conditions investigated. These results indicate that greater smouldering rates would be obtained with used clean sacking than with unused materials. It is noteworthy that very similar smouldering times were measured upon both washed and brushed cloths, under the same experimental conditions, although the former cloth was oven dried whereas the latter materials had moisture contents as given in Table 1.

The effect of impregnating the cloth with various oils, to simulate soiling of the material, was normally to decrease the rate of smouldering. The results, given in Figs. 4-6, show that the increase in smouldering time over that of clean cloth was approximately proportional to the amount of oil added. As a similar effect was obtained with distilled water (Fig.3) it may be inferred that the oils and water acted in similar manners upon the smouldering i.e. acted as coolants. It is therefore probable that wearing and soiling of jute sacking affect the smouldering time of the material in opposite senses. The amount of liquid required to be added to the cloth in order to prevent sustained smouldering may not depend solely upon the properties of the liquid but may also be affected by the characteristics of the cloth. Consequently it is probable that if the number of layers of cloth were increased or if the layers were of greater width, and a larger support were used, then more liquid would need to be added to the cloth to prevent smouldering.

With all the specimens of clean cloth it was noted that a minimum number of layers of material was necessary for sustained smouldering. This minimum number depended upon the weight and weave of the cloth, the size of the support, the direction of propagation of smouldering, and the condition of the cloth. With the cloths investigated, however, it was never less than two. The minimum number decreased as the breadth of the support was increased, i.e. with wider layers, probably because there would be less heat conducted away from the centre of the combustion zone; the minimum number was also markedly less with washed or brushed cloth than with cloth in a new condition. The latter effect is in agreement with the more rapid smouldering observed with the clean cloths subjected to the wearing processes. From the practical viewpoint, the fact that one layer only of the cloths investigated would not sustain smouldering may not be of great importance. Increased thickness of cloth is present in folds and seams and two layers of material must be in contact whenever bags are stacked.

The results also showed that, apart from a minimum number of layers being required for sustained smouldering, the smouldering time of a given cloth increased as the number of layers was increased (Figs. 1 and 2). There is, moreover, an approximately linear relationship between smouldering time and number of layers within the range tested; this may be compared with a linear relationship obtained with strips of fibre insulating board,[5] of constant thickness, between smouldering time and the ratio of area of cross section of the combustion zone to its perimeter. With the jute cloth the thickness of a cloth layer is negligibly small compared with its width (Tables 1 and 2 respectively) and it follows that with a larger number of cloth layers the area of combustion zone is increased but not its perimeter, which remains sensibly constant. The smouldering time should therefore be proportional to the cross sectional area of the combustion zone and, since the width of the zone is constant in a given support, should therefore be proportional to the number of layers of cloth. The results shown in Figs. 1 and 2 are in fair agreement with this.

In general, the ignition of all the cloths was remarkably easy; thus smouldering could be initiated without difficulty by glowing cigarette ends or wire heated to a dull red. The rapid surface spread of flame over the nap of brushed cloth has been previously observed with actual stacks of bagged materials (4) and there is thus a correlation between the laboratory processing and normal wearing.

The work described above was undertaken in order to ascertain whether smouldering could be an intermediate stage in the development of fires involving jute sacking, particularly storage fires. It has been shown that sustained smouldering can occur, and in fact may be easily initiated, but that its rate of propagation depends upon several factors involving not only the weave of the cloth but also its condition and the effect of the surroundings. It is therefore only possible to make certain broad generalisations with regard to the smouldering time of jute cloth, the precise value of this time in a particular incident will depend upon local conditions. Thus, from Table 3, the smouldering time of clean material similar to those studied will be 3-6 min/cm, depending mainly upon the direction of propagation of smouldering. This time range could, however, be affected by increases in the number of layers of cloth, the condition of the material (whether badly worn or soiled) and by the incidence of draught. In the interior of a stack of bagged material there may be negligible draught and the combustion may even be retarded by a self-produced deficiency of oxygen. If it be assumed that an average smouldering time is 5 min/cm, then in 1 hr the combustion zone would travel about 4.7 in. in still air. The total time of travel along a 4 ft. sack length, say, would thus be about 10 hr, assuming propagation along a straight line. Smouldering could therefore easily continue within a large stack of bagged materials for several days. The effect of draught upon the propagation of smouldering in jute cloth is still to be investigated; it seems probable that a marked increase in the rate will be caused. Draught may also affect the transition from glowing to flaming combustion; the bursting into flames of washed cloth III, during an experiment mentioned above, was probably due to exceptionally favourable convection currents and indicates that perhaps only slight airflows are necessary. This will be the subject of a further note.

Conclusions

The main points arising from this work are:

1. Sustained smouldering may be initiated easily in jute sacking by a small source of ignition, such as a glowing cigarette end.

2. The rate of propagation of smouldering depends upon several factors including the weight and weave of the cloth, the condition of the material (worn or soiled), the direction of propagation of combustion, and the number of layers of cloth undergoing smouldering.

3. It is concluded that smouldering of the jute cloth may easily continue for several days within a large stack of bagged materials.

Acknowledgment

Mr. D. W. White assisted with the experimental work.

References

1. F.R. Note No. 6/1952.
2. F.R. Note No. 11/1952.
3. F.C. Note No. 56/1951.
4. Burgoyne J. H. J. Soc. Food Agric. 1951 2 157.
5. F.R. Note No. 24/1952.

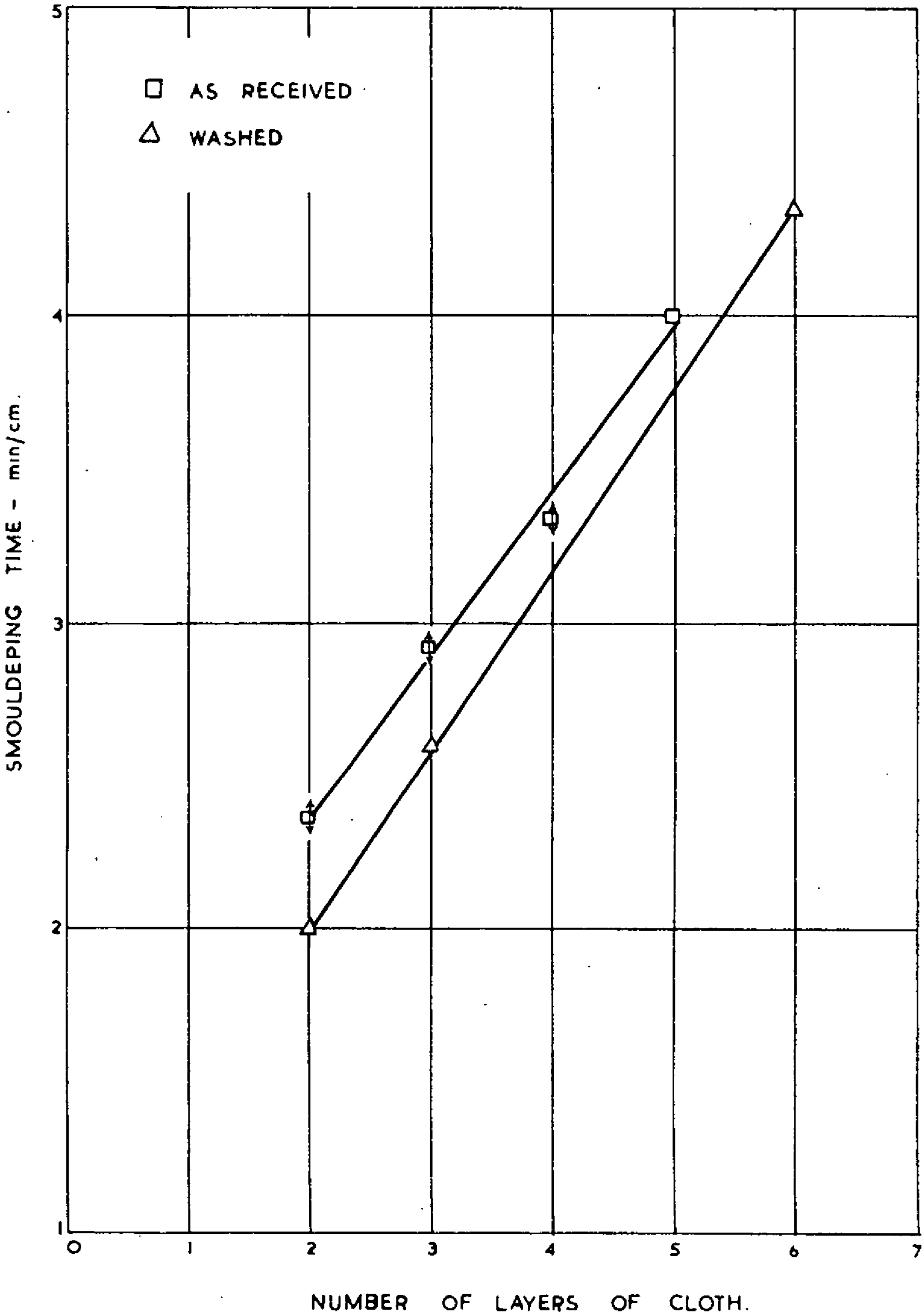


FIG. 1. SMOULDERING OF CLOTH II IN SUPPORT B; PROPAGATING ALONG WEFT, UPWARDS.

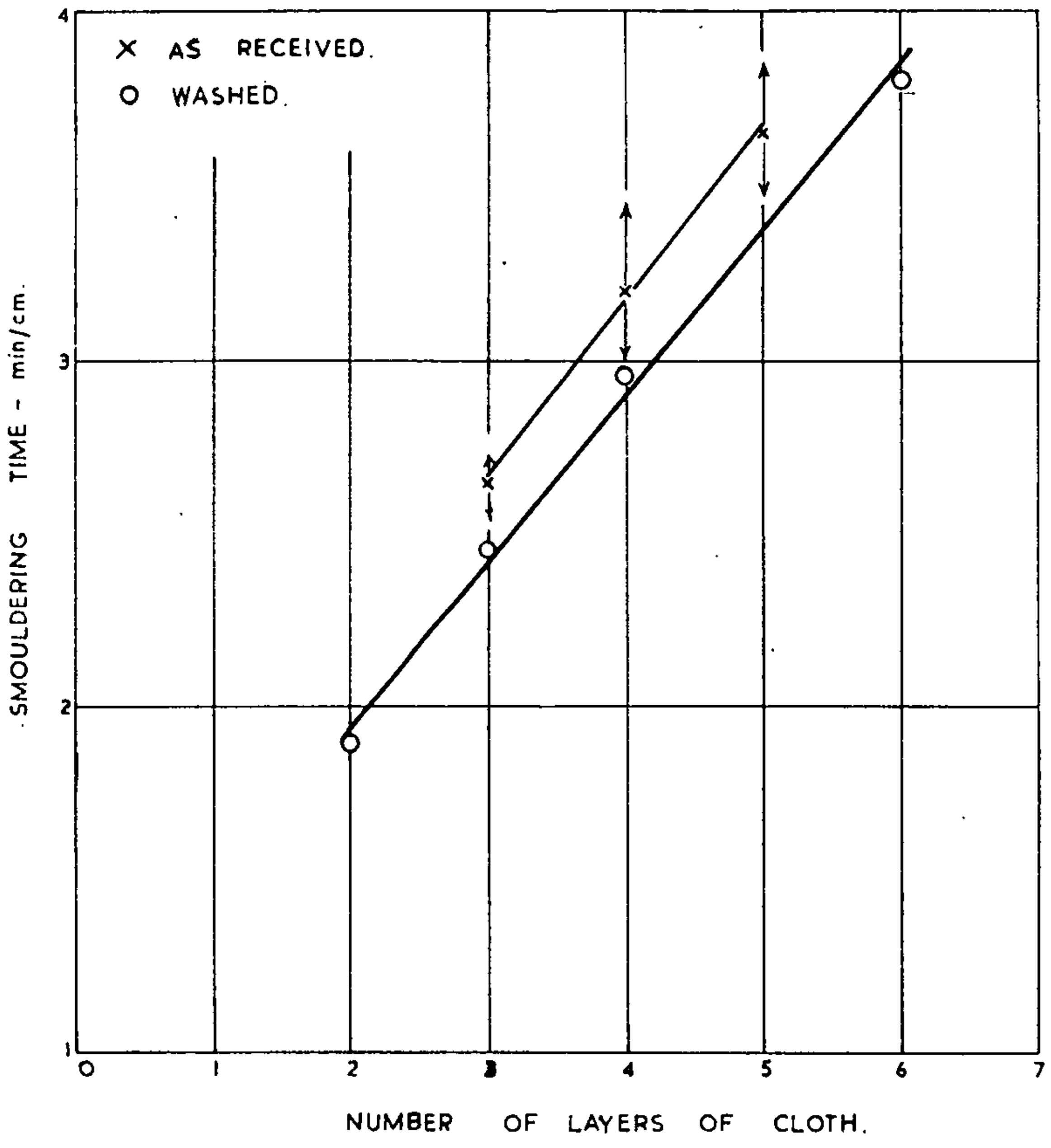


FIG. 2. SMOULDERING OF CLOTH II IN SUPPORT B; PROPAGATING ALONG WARP, UPWARDS.

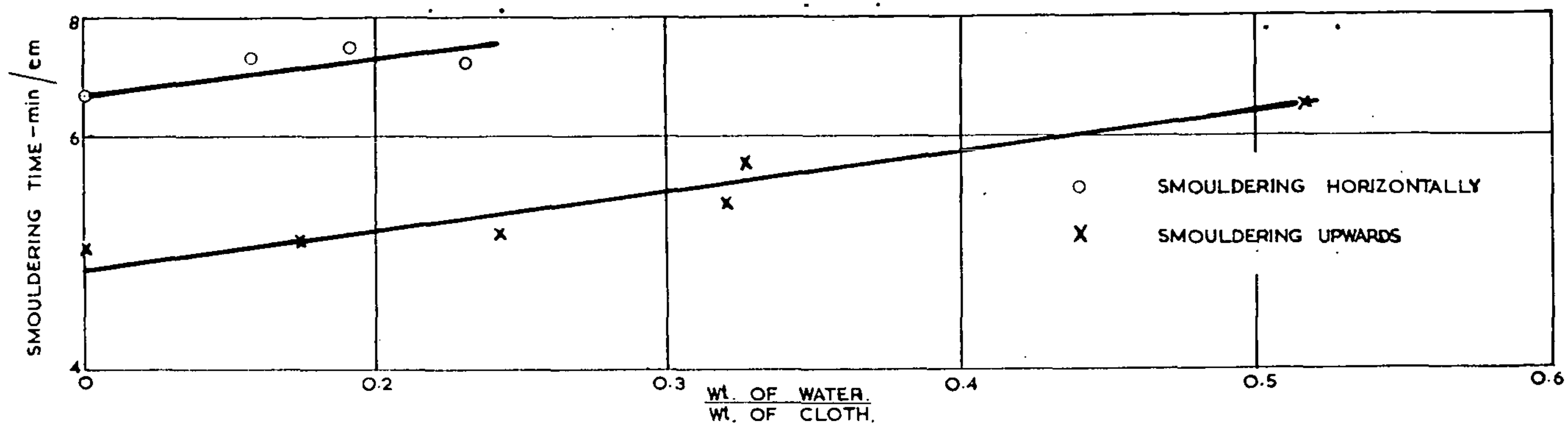


FIG. 3. SMOULDERING TIMES OF CLOTH IMPREGNATED WITH WATER.

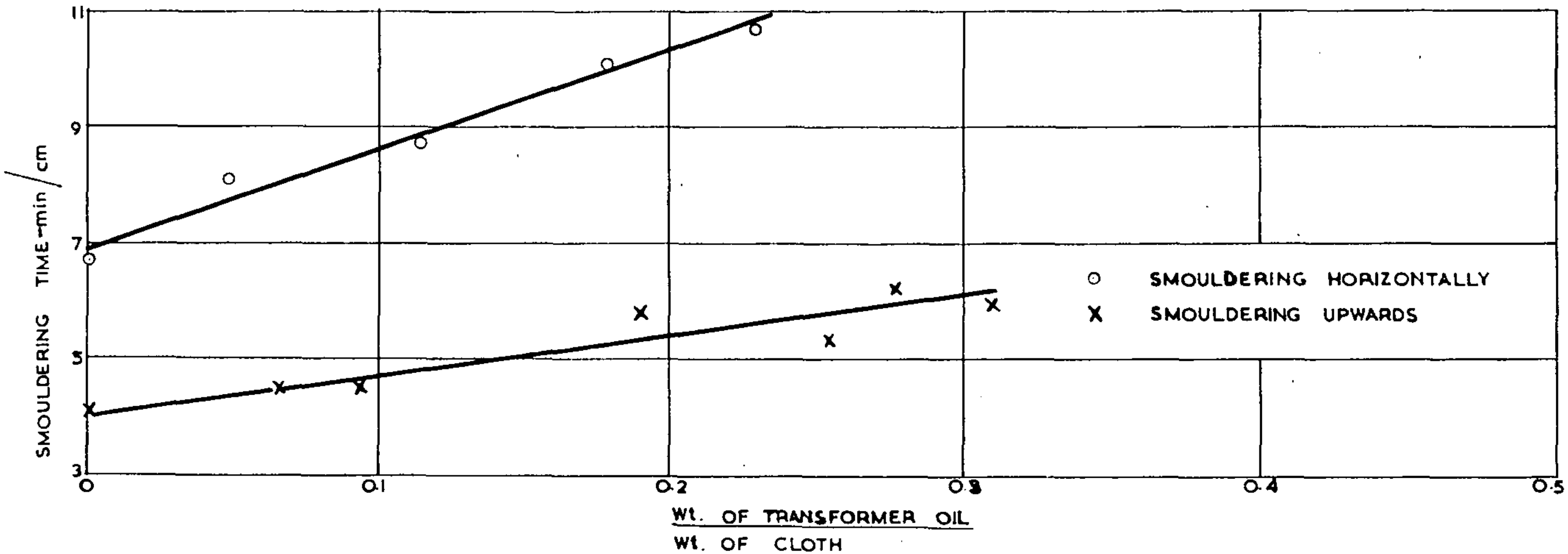


FIG. 4. SMOULDERING TIMES OF CLOTH IMPREGNATED WITH TRANSFORMER OIL

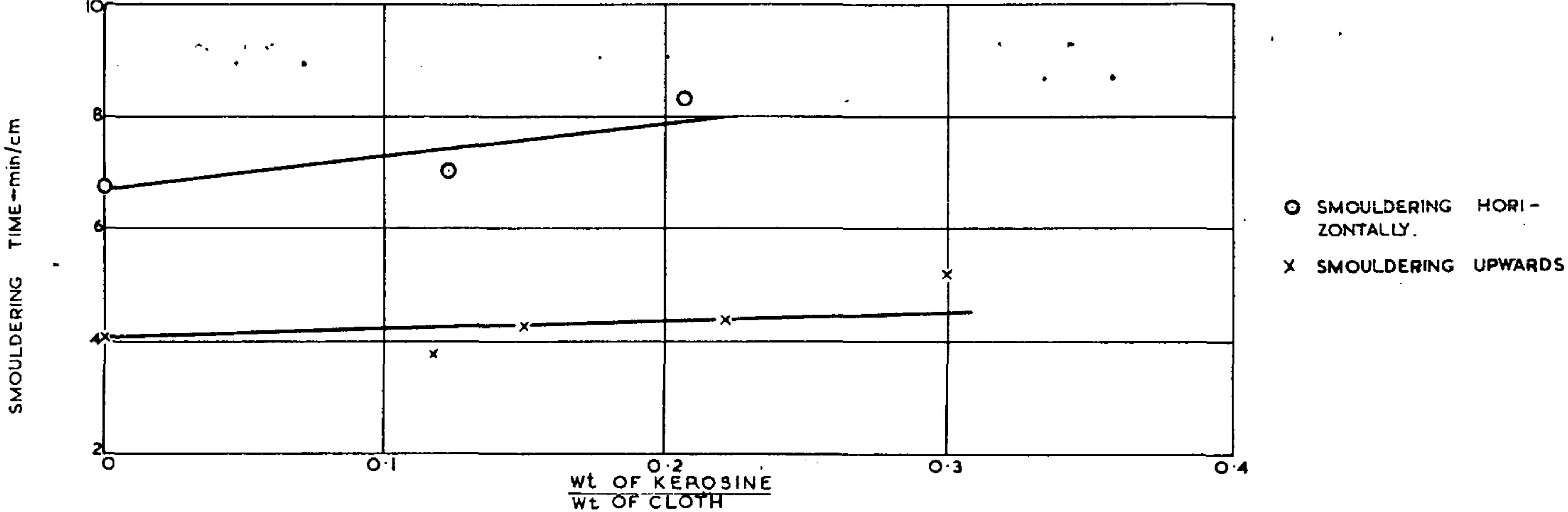


FIG. 5. SMOULDERING TIMES OF CLOTH IMPREGNATED WITH KEROSINE

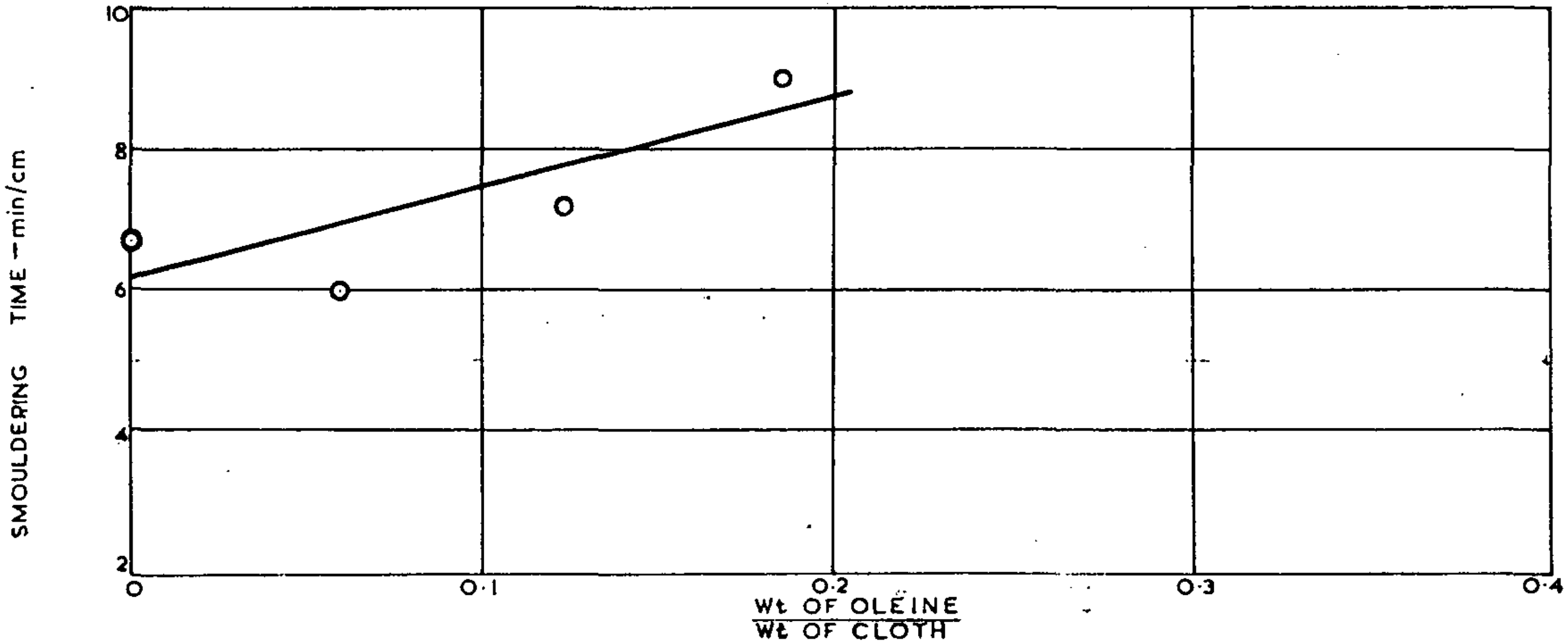
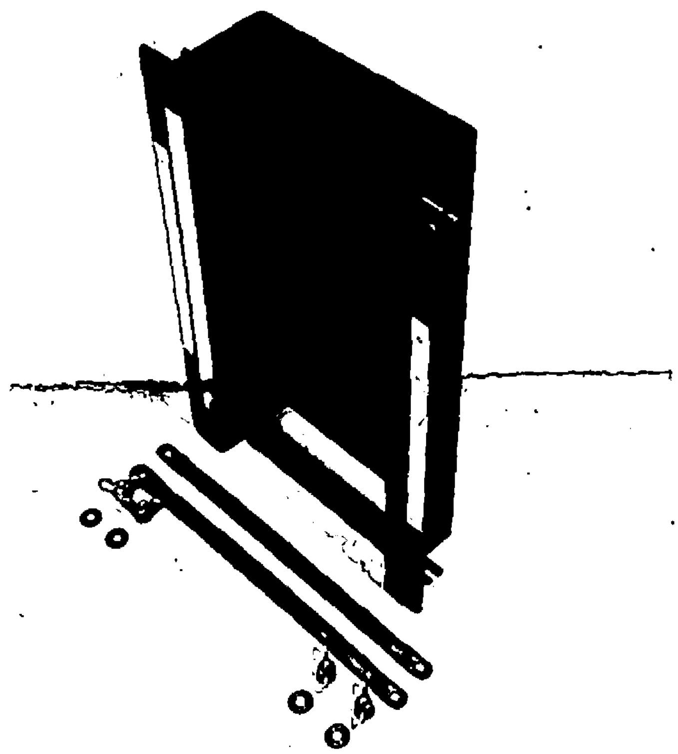
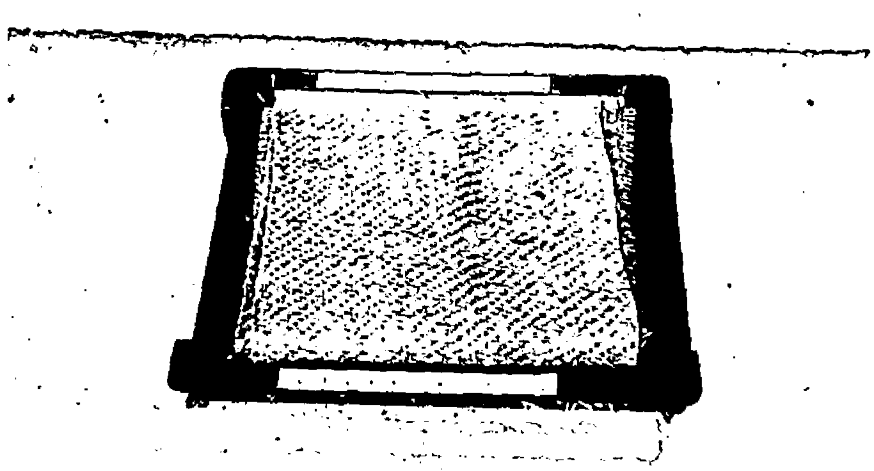


FIG. 6. SMOULDERING TIMES OF CLOTH IMPREGNATED WITH OLEINE, SMOULDERING HORIZONTALLY



SUPPORT FOR JUTE CLOTH SHOWING CLAMPING BARS



SUPPORT WITH CLOTH IN POSITION