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SMOULDERING IN DUSTS AND FIBROUS MATERIALS
PART III. FIBRE INSULATING BOARDS IN STILL AIR

by

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Summary

The rate of smouldering of three types of fibre insulating board has been investigated in still air; the boards were sawn into small strips and smouldering was initiated by a pilot flame. The linear rate of smouldering was found to depend upon the nature of the board, the size of the strip, and the angle to the vertical at which the strip was held. The relation between the dimensions of the strips and their smouldering times is discussed; a simple method is given for determining the approximate smouldering times of large strips from measurements taken upon smaller specimens.

Smouldering may be easily initiated in these boards by a small source of ignition at red heat.

Introduction

Previous notes in this series (1, 2) have been concerned with the propagation of smouldering in combustible dusts; in these experiments, which were carried out in still air, the dusts were formed into small trains and the rate of travel of the smouldering measured. The present note describes observations upon smouldering in several specimens of fibre insulating board of the type widely used as wall and ceiling linings. The determination of the rate of smouldering, and any variation of this with the size of the specimen, together with a measure of the ease of initiation of smouldering in these boards are therefore of practical interest.

The rates of propagation of smouldering in fibreboard strips held both horizontally and at other angles to the vertical were investigated. All experiments were carried out in still air.

Experimental

Materials

Three specimens of board were investigated: "board A" (manufactured from sugar cane fibre) and two boards composed of mixed woods (B and C). The latter samples differed markedly in appearance and probably also in composition; board C was darker in colour and much coarser than board B. The moisture contents and dry weight densities of the boards were determined by the normal method (3) (i.e. percentage weight loss per unit weight of undried board), and are given below.

Table 1

Board	Moisture content %	Dry weight density gm/ml
A	10·0	0·27
B	6·6	0·22
C	10·8	0·23

The moisture content of board B was low because the board had been stored in a warm dry room for a considerable time.

Experiments with board A

The main series of experiments was carried out with strips each 8 in. in length and 0·5 in. in thickness and with breadths of 0·5 in., 1 in., 1·4 in., 2 in., and 4 in. In addition, the smouldering of the same board (0·5 in. in thickness) in strips 12 in. and 46 in. in breadth was also investigated. In all these experiments, except those with 46 in. strips, the same procedure was followed: a strip was marked by lines drawn at centimetre intervals parallel to the breadth, over a total distance of 10 cm; the strip was then supported by a clamp so that the centimetre markings were either horizontal or vertical, these positions of the board are shown in Plates 1 and 2 respectively. Smouldering was then initiated across the whole width of the unsupported end of the strip by a small gas flame. The combustion zone was allowed to travel 2 - 3 cm along the strip before measurements were begun; the time of travel (smouldering time) of the centre of the zone was then taken at centimetre intervals over the total distance of 10 cm. The 46 in. strips were held so that smouldering either propagated horizontally, as in Plate 1, or vertically downwards as shown in Plate 3. In these experiments the boards were ignited across the total width by a hand gas blowpipe in order to obtain regular combustion zones.

In all the above experiments, except that shown in Plate 3, the smouldering zone progressed horizontally along the strip; the effect produced upon the smouldering time by variation of the direction of propagation was therefore investigated. The strips used were all 0·5 in. in breadth and one vertical face of each was marked at centimetre intervals as in the experiments described above; the strips were supported as shown in Plate 5. Investigations were carried out over the whole range of angles between the upward and downward verticals, and ignition was effected by a small gas flame as before.

Experiments with boards B and C

Both types of board were 0·5 in. in thickness and were sawn into strips 0·5 in., 1 in., 2 in., and 4 in. in breadth. The strips were then clamped in the position shown in Plate 2 and smouldering was initiated at the free end by a small gas flame as before. The smouldering of 0·5 in. strips held at various angles to the vertical was also investigated, but in less detail than with board A.

Results

Board A

The smouldering times of strips of this board held with the marked surface in the horizontal plane (as in Plate 1) or vertical plane (as in Plate 2) are given in Table 2.

Table 2

Smouldering times of strips from board A

Bread of strip in.	Smouldering time min/cm	
	Marked surface horizontal	Marked surface vertical
0·5	6·2	6·5
1	8·4	9·1
1·4	9·0	10·5
2	10·1	10·7
4	9·6	10·5
12	14·1	18·1
46	10·8	-

In most cases the combustion zone remained straight and passed along the strips at a uniform rate; however, the zone usually became curved in 12 in. strips since initially the edges smouldered more rapidly than the central part. A steady configuration of the combustion zone was eventually reached and measurements were then taken along the centre of the strip.

An attempt was also made to ignite a 12 in. square of the board, held horizontally, at its centre. The flame of a small gas/air blowpipe was applied to the board but neither sustained smouldering nor flaming could be initiated until a hole was burned through the board, sustained smouldering then commenced and spread out fairly uniformly at an average time of 16·9 min/cm.

The results of experiments upon 0·5 in. strips held at various angles to the vertical (as in Plate 5) are shown in Fig. 1 where the smouldering time is plotted on a logarithmic scale against the angle at which the strips were held from the vertical. It may be seen that the slowest propagation of the combustion zone (i.e. maximum smouldering time) was obtained when the strips were held horizontally. A similar effect occurred with the 46 in. strips: the smouldering time for combustion advancing vertically downwards (Plates 3 and 4) was only 7·3 min/cm compared to 10·8 min/cm in the horizontal position (Table 2).

Boards B and C

The results of experiments upon strips from these boards are given below in Table 3. All strips were held with marked surfaces in the vertical plane (as in Plate 2).

Table 3

Smouldering times of strips from boards B and C

Breadth of strip in.	Smouldering time min/cm	
	Board B	Board C
0·5	5·3	6·1
1	6·2	7·6
2	6·9	8·9
4	7·4	9·6

Further experiments were carried out with 0·5 in. strips held at various angles to the vertical, as in Plate 5; the smouldering times measured are given in Table 4. The values for the horizontal position (90° to the vertical) given in Table 3 are inserted in Table 4 for comparison.

Table 4

Smouldering times of 0·5 in. strips from boards B and C at angles to the vertical

Direction of propagation of smouldering	Angle to vertical °	Smouldering time min/cm	
		Board B	Board C
Downward	0	4·6	5·4
"	45	4·8	-
Horizontal	90	5·3	6·1
Upward	135	3·8	5·2
"	180	3·4	3·9

Flame spread and ignition tests

Attempts were made to measure the rate of flame spread along 0·5 in. strips of the three boards for comparison with the rate of propagation of smouldering. The strips were held in still air and ignition was by a small gas flame. The experiments were thus carried out with the strips at room temperature and there was no supporting radiation. It was found that strips from board A would not propagate flame either horizontally or vertically upwards; with strips from board B, however, flame spread horizontally at 25 sec/cm and vertically upwards at about 2 sec/cm. Board C would only propagate vertically upwards, at about 4 sec/cm. These times were measured over a distance of 10 cm. In no case could flame be induced to travel vertically downwards.

Tests with glowing cigarette ends showed that smouldering could easily be initiated in board B; the other boards normally carbonised to about 1 cm in depth near the source but sustained smouldering was not produced. The same tests were carried out on the dried boards to determine whether differences in moisture content could account for this differentiation. The results obtained, however, were similar to those with the undried boards. Smouldering could, however, be initiated in all three boards on applying a thin wire at dull red heat. Development of smouldering took place much more readily if the source were situated near an edge of the board than if it were on a wide face.

Discussion

In most of the experiments the combustion zones formed were linear and advanced at uniform rates. The chief exceptions to this behaviour occurred with the 12 in. strips of board A where the combustion zone maintained a constant curve; the smouldering times of these strips were anomalous, being greater than those of smaller strips and also greater than that of the 46 in. strip burning horizontally. The combustion zones of the 46 in. strips were linear across much of the breadth (as in Plate 4) but turned forwards near the edges of the specimen (as in Plate 3); this effect was presumably due to greater air access at the edges. In strips 4 in. and less in breadth the zone was straight from edge to edge. The 12 in. strips may therefore correspond to an intermediate case in which the bent portions of the combustion zone are of the same order in size as the width of the specimens.

The earlier experiments with wood dusts formed into small trains [1] showed that the smouldering times were independent of the train size; with the three specimens of fibre board, however, the smouldering time generally increased as the size of the strips was increased (Tables 2 and 3). If the rate at which smouldering is propagated in a given board is controlled solely by the rate of access of oxygen to the combustion zone, then the rate of access may be considered as a first approximation to be proportional to the perimeter of the combustion zone. This approximation is justifiable since the ash formed behind the zone will hinder air access parallel to the direction of propagation of smouldering. The smouldering time (min/cm), which is the reciprocal of the linear rate of smouldering (cm/min), will thus be inversely proportional to the perimeter of the combustion zone. Now with a given rate of supply of oxygen, i.e. in a steady state, the mass rate of consumption of combustible may be considered constant; if the density of the board is assumed constant, then the smouldering time (min/cm) will be proportional to the area of the combustion zone i.e. to the area of cross section of the strip. The smouldering time should therefore be proportional to the ratio $R = \frac{bd}{2(b + d)}$, where b is the breadth of the strip and d is its thickness. Values of b (cm) and the corresponding values of R (cm) are given below in Table 5; the value of d was constant at 1·3 cm (0·5 in.).

Table 5

Ratio area/perimeter for strips of various widths

Breadth of strip in.	Breadth of strip (=b) cm	$\frac{bd}{2(b+d)}$ cm (=R)
0·5	1·3	0·33
1	2·5	0·43
1·4	3·6	0·48
2	5·1	0·52
4	10·2	0·58
46	116·9	0·64

The relation between R and the smouldering time for the three types of board are shown in Figs. 2-4, omitting values for the 12 in. strips from board A. These graphs are fairly linear, the scatter of the results being much less with the strips from boards B and C. For large strips d is small compared to b, hence the value of R tends toward $d/2$ (i.e. 0·64); the smouldering times of the various boards for this limiting value of R (i.e. with large strips) may be obtained from the graphs by extrapolation, and range between 8 and 13 min/cm for horizontal propagation. In the case of board A the limiting smouldering time so calculated is within 10 per cent of that measured upon a 46 in. strip; the accuracy in the case of boards B and C should not be less since greater consistency was obtained in the experimental results. It is thus possible to obtain an approximate value for the smouldering time of large strips from measurements made upon smaller samples.

Different smouldering times were obtained with board A when the strips were held with the graduated face horizontal (as in Plate 1) than when they were held vertically (as in Plate 2); in both positions the smouldering propagated horizontally. The difference between the smouldering times of the two positions was less with the smaller strips but was still observed with strips of 0·5 in. square cross-section. Since the effect was produced in strips of square cross-section, it was presumably due to anisotropic properties of the board resulting from its laminated structure.

The results so far considered have been concerned with propagation of smouldering in a horizontal direction; propagation in other directions invariably produced a decrease in the smouldering time, this time varied approximately exponentially with the angle to the vertical (Fig. 1). Similar results were obtained with 0·5 in. strips of all three boards: the flow of smoke evolved when the strips were held at small angles to the vertical was noticeably more streamline than that formed by horizontal strips.

The propagation of smouldering in the fibre boards investigated differs considerably from the propagation of flame, without supporting radiation. Thus no 0·5 in. strips would burn with flame vertically downwards and the rate of propagation of flame in other directions was very much more rapid than with smouldering. Initiation of smouldering was easily achieved by a wire at dull red heat and could probably occur, under favourable conditions, with a glowing cigarette in all types of board investigated.

This note describes results obtained from the measurement of smouldering in still air; the effect of draught upon the smouldering, which is very marked with wood sawdust, and upon the ease of initiation of smouldering will be described in a later report.

Conclusion

The most important points arising from this investigation are:

1. Smouldering can be sustained in each of the three types of board and the general properties of the smouldering were similar in each board.

2. The smouldering time (min/cm), with a given board, depends upon the size of the specimen; however, it tends to a limiting value as the specimen size increases. This limiting value may be obtained approximately from observations upon small strips.

3. Propagation of smouldering in a horizontal direction is slower than at any other angle to the vertical. The relation between angle and smouldering time is approximately exponential.

4. Smouldering in these boards can be easily initiated by a red hot wire or, with one type of board, by a glowing cigarette; with the other boards this latter source produced extensive carbonisation and it is probable that initiation of sustained smouldering would occur under favourable conditions such as a slight draught. Decreasing the moisture content of the boards had little effect upon the ease of initiation of smouldering.

Acknowledgment

Mr. G. Skeet assisted with the experimental work.

References

1. F.R. Note No. 6/1952.
2. F.R. Note No. 11/1952.

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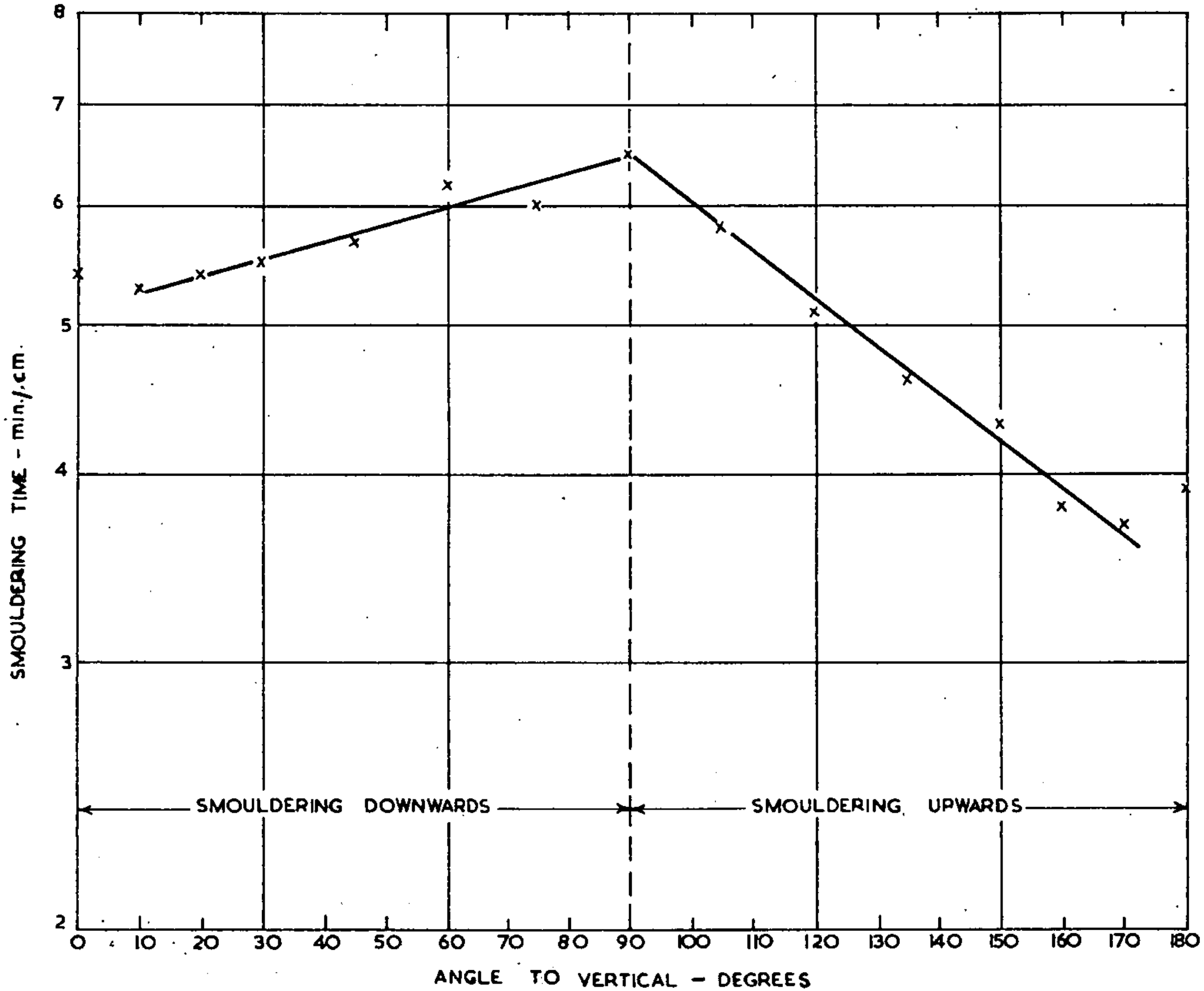

FIG.1. VARIATION OF SMOULDERING TIME WITH ANGLE TO THE VERTICAL FOR STRIPS FROM BOARD A.

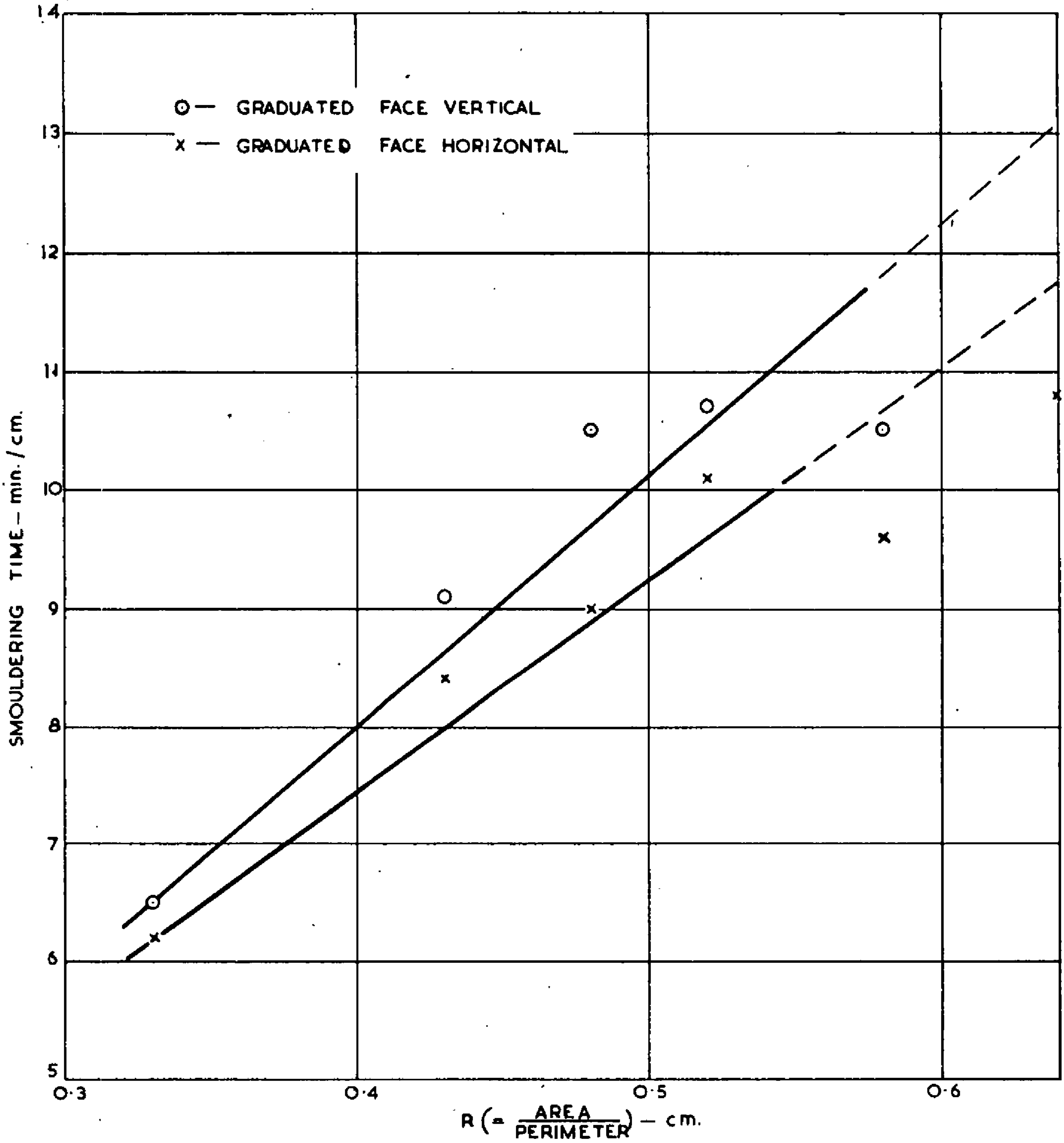

FIG. 2. VARIATION OF SMOULDERING TIME WITH AREA/PERIMETER RATIO OF STRIPS FROM BOARD A.

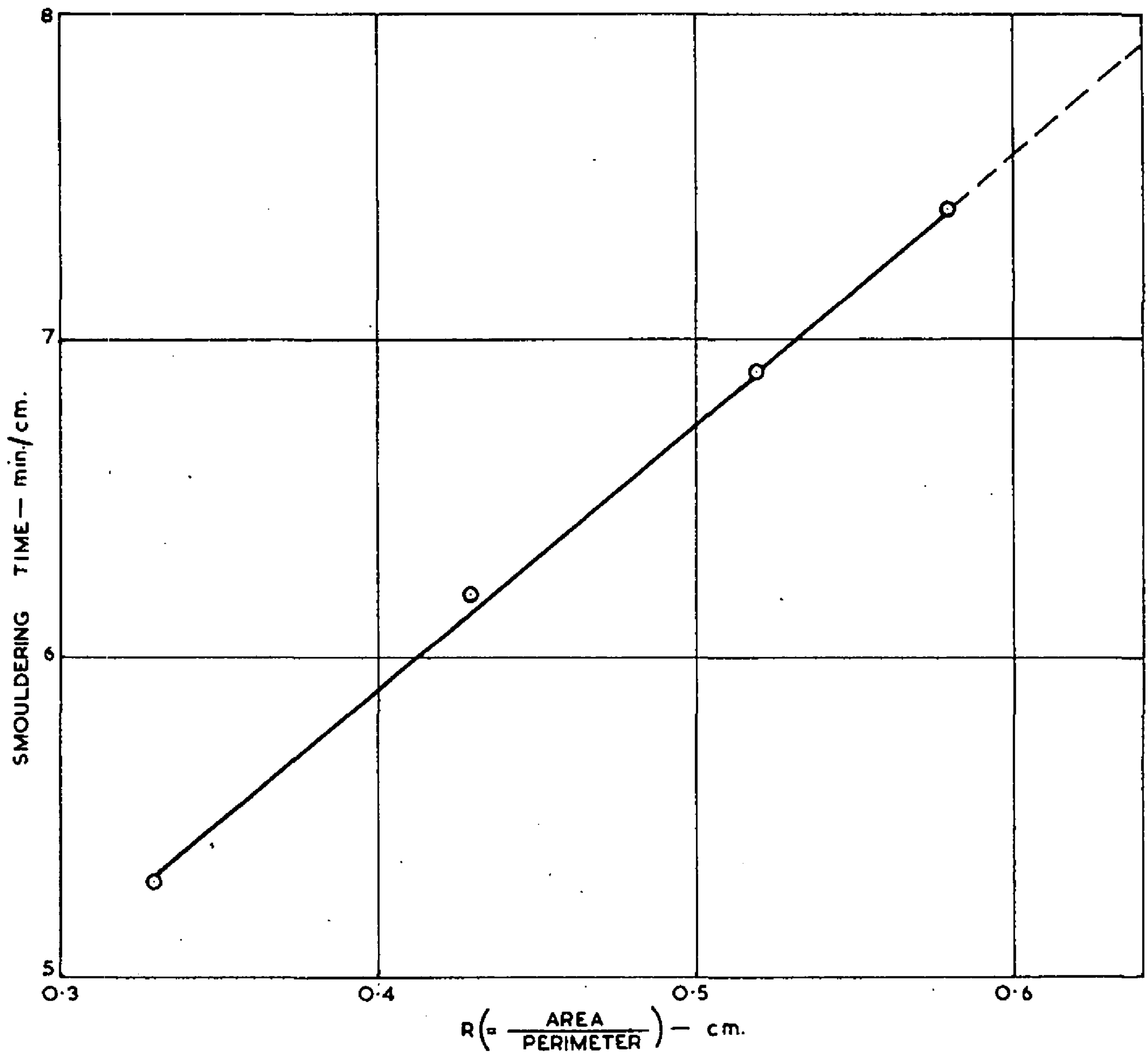

FIG. 3. VARIATION OF SMOULDERING TIME WITH AREA/PERIMETER RATIO OF STRIPS FROM BOARD B HELD WITH THE GRADUATED FACE VERTICAL.

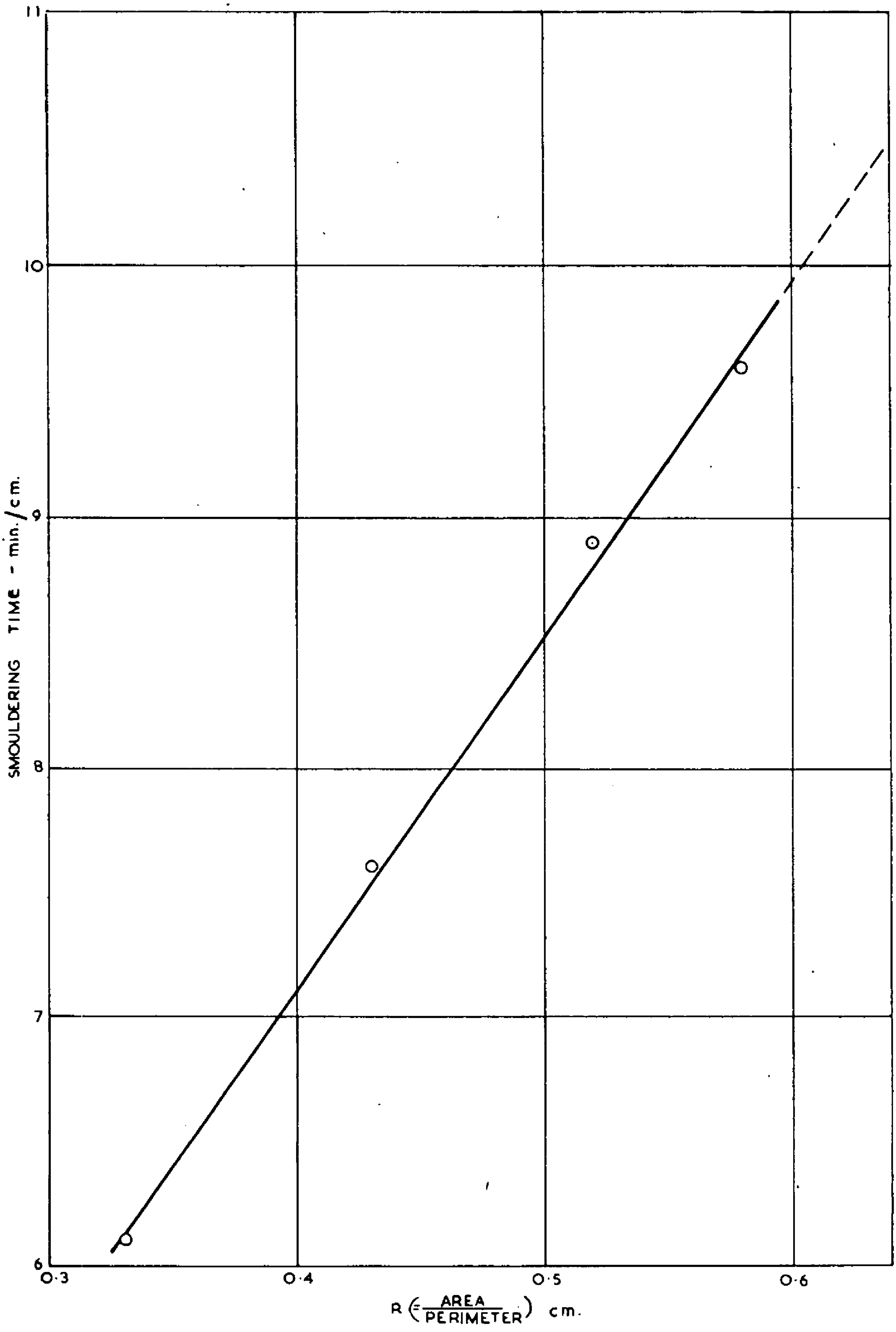

FIG. 4. VARIATION OF SMOULDERING TIME WITH AREA/PERIMETER RATIO OF STRIPS FROM BOARD C HELD WITH THE GRADUATED FACE VERTICAL.

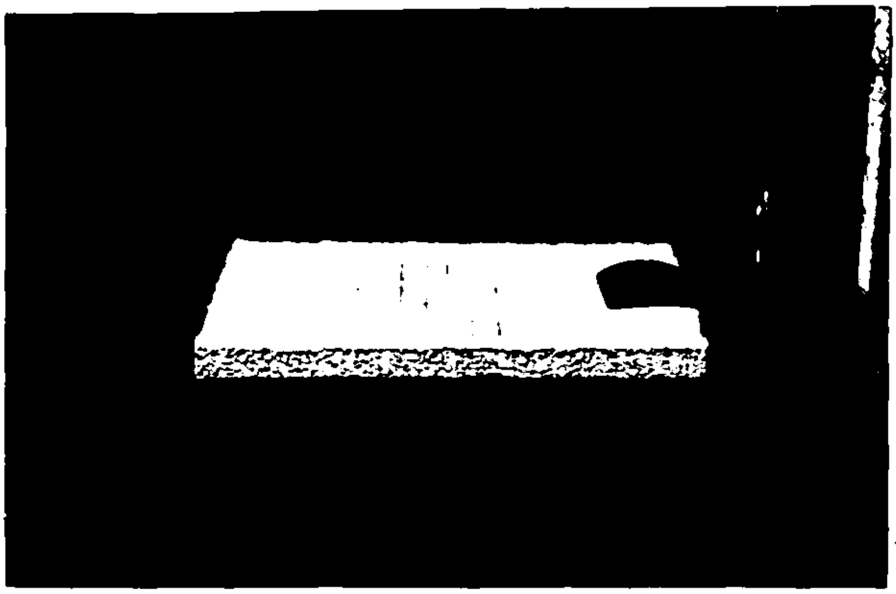

PLATE.1. POSITION OF STRIP HELD WITH GRADUATED FACE HORIZONTAL; SMOULDERING TO PROPAGATE HORIZONTALLY

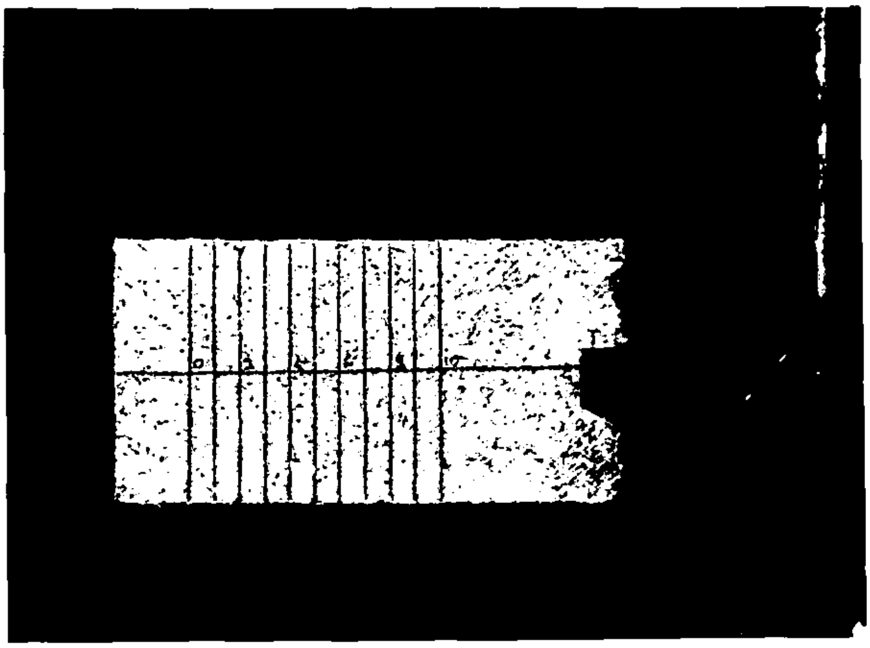

PLATE.2. POSITION OF STRIP HELD WITH GRADUATED FACE VERTICAL; SMOULDERING TO PROPAGATE HORIZONTALLY

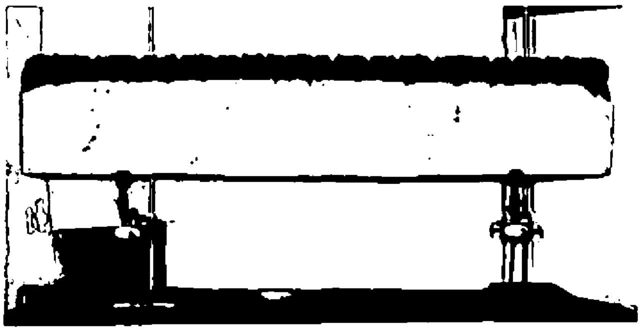

PLATE.3. SMOULDERING OF A 46 in STRIP OF BOARD A

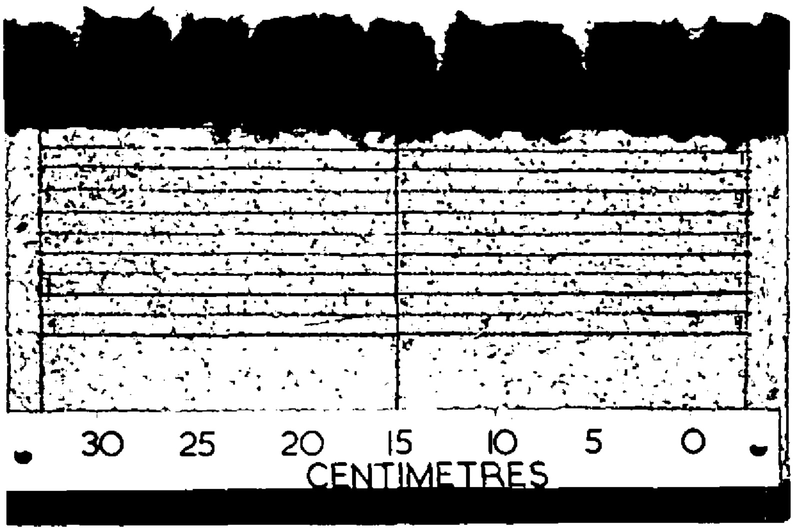

PLATE. 4. CENTRAL PORTION OF STRIP SHOWN IN PLATE 3

PLATE.5. POSITION OF STRIP HELD WITH GRADUATED FACE VERTICAL; SMOULDERING TO PROPAGATE AT AN ANGLE TO THE VERTICAL