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THE ESTIMATION OF VERTICAL FLAME SPEED OVER FABRICS BY FLAME PROPAGATION ALONG A 45° SLOPE AND ROUND A SEMICIRCLE

by

P. H. Thomas and H. Wraight

Summary

Two tests for the flammability of fabrics - the semi-circular test B.S. 476 : Part II : 1955 and a 45° test, a modification of the American Flammability Test - are compared with each other and with the speed at which flame spreads up a fabric hanging vertically. It is shown that the empirically derived correlation, between measured vertical flame speed and the performance of the semi-circular test can be used to correlate the two tests with each other.

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THE ESTIMATION OF VERTICAL FLAME SPEED OVER FABRICS BY FLAME PROPAGATION ALONG A 45° SLOPE AND ROUND A SEMICIRCLE

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Introduction

In the United States an apparatus for determining the flammability of fabrics to be used for clothing was accepted as a United States Commercial Standard in 1953 (1). This paper describes work done (2) to discover if any relation existed between the performance of materials on a modified form of this test and on the test developed by the Joint Fire Research Organization and published in B.S. 476 : Part II : 1955(3). Some of the fabrics which have a raised pile or nap may, under certain conditions exhibit a rapid surface flash on the pile or nap which can then ignite the base fabric. This aspect of flame spread can only be measured by the American Test which provides for a method of raising the pile and for testing 'oven dry'. It is not discussed further in this paper which is concerned with the relations between the vertical flame speed and the rates of spread of flame on the base fabric, unaffected by the pile or nap in the two tests. The igniting source is applied in the American Test for only 1 second and this is insufficient to ignite many materials which will spread flame. For the purpose of the tests described here the flame was applied until ignition occurred.

Description of American Flammability Test

The American Flammability Test is described in detail in the published Standard:(1) essentially the test consists in applying a butane flame $\frac{5}{8}$ in. long, for one second to the upper surface of a 2 in. x 6 in. specimen held in a frame at 45° in a ventilated box. The time taken for the flame to travel up the specimen and burn through a cotton thread 5 in. from the gas jet is recorded automatically.

For this programme of tests an apparatus was constructed similar to the American Flammability apparatus. The method of test was the same except that the flame was applied until ignition occurred and that a non-luminous coal gas flame of the same size was used instead of the standard butane flame for many of the experiments. This does not have any significant effect on the time of spread of flame.

Experimental procedure and results

The number of specimens in each sample tested was usually twelve. One half of the number were dried in an oven at 105°C for thirty minutes and left to cool in a desiccator for use on the modified American test and the others were conditioned to be in equilibrium with an atmosphere at 22°C and 57 per cent relative humidity for use on the semi-circular test.

Tests were made on a wide range of materials including cotton, viscose and acetate rayons, wool, and paper. Each material was tested on the 45° test and the semi-circular test and the vertical flame speed was measured by the method described by Lawson, Webster and Gregsten (4). The results are given in Table 1.

Relation between the two tests and vertical flame speed

From the results of the semi circular test it is possible to calculate (5) a vertical flame speed from the equation:

$$V = 0.315 \frac{D^{5/2}}{T_s} \qquad \ldots (1)$$

where D is the distance of spread in inches
T_s is the time of spread in seconds in the semi circular test
and V is the vertical flame speed in/sec.

In B.S. 476 : Part II : 1955 in which the semi circular test is described a Figure of Merit 'M' has been defined as 100 divided by the calculated vertical flame speed, i.e.

$$M = \frac{100}{V} = \frac{320\ T_s}{D^2/2} \qquad \ldots (2)$$

Calculated values of 'V' and M are also given in Table 1. Using equation 1 it is possible to derive a similar equation for the modified American test (Appendix). This is given by

$$V = \frac{47}{T_{45}} \qquad \ldots (3A)$$

where T_{45} is time of spread in seconds for the 45° test.

Hence since $M = \frac{100}{V}$ this gives

$$M = 2{\cdot}1\ T_{45} \qquad \ldots (3B)$$

Although the formulae actually give a quantitative relation between vertical flame speed or Figure of Merit and time of spread in the 45° test it is necessary to obtain the best values of the constants by a direct comparison between experimental results.

If the numerical constant of proportionality in equation 3B is found for the data in Table 1 a value of 2·8 is obtained (see Fig. 1). This corresponds to a figure of 35 in equation 3A instead of 47. The correlation between the two tests over the whole range of results is thus

$$M = 2{\cdot}8\ T_{45} \qquad \ldots (4A)$$

and the corresponding relation for the vertical flame speed is

$$V = \frac{35}{T_{45}} \qquad \ldots (4B)$$

The vertical flame speeds as calculated from equation 1 for the semi circular test and from equation 4B for the 45° test are compared with the measured vertical flame speeds in Figs. 2 and 3 respectively. The two estimated values of vertical flame speed are compared with each other in Fig. 4.

Discussion of results

When testing some materials it was found that the application of the pilot flame for only one second was insufficient to ignite the specimen. This was true for both coal gas and butane but to a greater extent with the butane flame (6). To use the American test to obtain a figure of merit a longer ignition time is required and continuous ignition with a butane flame has been recommended by the Textile Flammability Panel with this end in view. This procedure gives results which agree with those obtained using the coal gas flame.

The scatter of points about the line in Fig. 1 relating the figure of merit in the semi circular test to the time of burning in the 45° test is approximately constant throughout the range of values, except for some materials of high flammability. For these materials

TABLE 1

LIST OF MATERIALS AND RESULTS OF TESTS

Material	Weight oz. yd^{-2}	Vertical flame speed in. sec^{-1} (Torsion Balance)	Figure of merit (Semi-circular test)	Vertical flame speed calculated from semi-circular test in. sec^{-1}	Time on 45° test sec	Vertical flame speed calculated from 45° test in. sec^{-1}
Cotton Net	0·8	14	7	14·3	3·4*	10·3
Cotton Muslin	1·0	6·0	9	11·1	3·0*	11·7
Cotton Net	1·3	18	6	16·7	3·1*	11·3
Cotton	1·9	3·5	17	5·9	5·7*	6·1
Cotton	2·4	3·4	22	4·5	7·0*	5·0
Cotton Gingham	2·8	2·8	26	3·8	8·6*	4·1
Cotton	3·6	2·5	33	3·0	12·0*	2·9
Cotton Vinceyette	3·9	2·0	31	3·2	13·3*	2·6
Cotton	4·5	1·9	38	2·6	13·0*	2·6
Cotton Towelling	14·7	1·0	67	1·5	24	1·5
Cotton Flannelette	4·1	1·7	33	3·0	18·0*	2·0
Cotton Flannelette	4·1	1·9	33	3·1	19·2*	1·8
Cotton-Viscose Flannelette	4·6	1·9	39	2·6	14·5*	2·4
Viscose Net	0·5	16	6	16·2	2·8*	12·5
Viscose Net	0·6	12·6	8	12·5	2·8*	12·5
Viscose Net	0·8	9·4	9	11·4	4·1*	8·5
Viscose Ninon	1·9	4·8	21	4·8	5·4*	6·5
Viscose Locknit	4·6	1·9	56	1·8	16·6*	2·1
Viscose Lambspun	4·8	1·9	56	1·8	17·5*	2·0
Acetate Rayon	1·7	1·7	10	10·0	5.5	6·4
Acetate Rayon Lingerie	2·9	2·1	30	3·3	9·0*	3·9
Acetate Rayon	3.8	1·4	23	4·3	8·2*	4·3
Acetate Rayon Satin	4·9	0·9	22	4·5	9·0	3·9
Acetate Rayon Twill	6·9	0·9	42	2·4	12·0	2·9
Newsprint	1·6	5·6	15	6·7	6·0*	5·8
Chart Paper	1·7	6·8	13	7·7	4·6*	7·6
Thin Brown Paper	2·6	4·2	21	4·8	6·5*	5·4
Cartridge Paper	4·3	2·6	36	2·8	13·3*	2·6
Thick Brown Paper	4·4	2·2	39	2·6	11·6*	3·0
20% Wool 80% Cotton	4·0	2·1	44	2·3	30 *	1·2
40% Wool 60% Cotton	3·5	2·2	42	2·4	33	1·1
60% Wool 40% Cotton	3·7	2·3	50	2·0	47	0·8
Wool	3·7	0·7	47	2·1	19·0	1·8
Wool	3·9	0·8	47	2·1	D.N.S.	
Wool	5·6	0·7	49	2·0	20·0*	1·8
Wool Felt	7·1	not tested	148	0·7	50	0·7
Wool	7·5	0·3	136	0·7	D.N.S.	
Viscose-Terylene 50/50	9·0	1·1	80	1·3	23·6	1·5

D.N.S. - did not spread flame.

* - coal gas flame.

either the time of spread on the 45° test is too long, or the figure of merit given by the semi circular test is too low, in relation to the performance of materials of lower flammability. A comparison with vertical flame speed (Figs. 2 and 3) appears to suggest the former.

While on the semi circular test the vertical flame speed over wool cotton mixtures may be determined accurately they appear to give anomalous behaviour on the 45° test and these mixtures have been omitted in correlating the two tests (Equation 4A). This is no doubt due to the fact that the igniting butane flame did not penetrate the wool cotton fabrics very readily. Flame spread up the upper surface to burn the cotton thread before flame has spread up the lower surface. No explanation has been found for this behaviour, also noted elsewhere [6]. This difficulty is avoided in the semi circular test in which the fabric is ignited at the edge.

Figures 2 and 3 show that both tests can give an estimate of the vertical flame speed but a comparison of Fig. 4 with Fig. 2 and Fig. 3 shows that the two tests give results more like each other than is either to the vertical flame speed as measured by the torsion balance.

Both tests give too high an estimate of the vertical flame speed of acetate rayon and wool. When these materials burn vertically large drips are seen to fall, particularly with acetate rayon. This momentarily checks the burning as some of the burning material falls away.

The dripping does not occur to the same extent if the material is well supported as in the tests.

There are some materials which propagate flame vertically and therefore in the semi circular test but which will not propagate flame at 45°, for example, three of the heavy wools in Table 1. There is thus a practical limit to the sensitivity of the 45° test which will not be able to measure the vertical flame speed below a certain limit. Any material which will not spread flame more than one quarter of the way round the semi-circle will probably be affected in this way.

Conclusion

Both tests give measures of vertical flame speed or alternatively of the figure of merit and in this respect the difference between the tests is not generally significant. Materials such as acetate rayon, which drip when burning vertically will burn more slowly than estimated from the performance on a test and both tests give a similar result for such materials which may differ appreciably from the vertical flame speed. The 45° test, if it is to be used to measure the figure of merit, must have a stronger or more prolonged igniting source than a butane flame for one second.

Even a continuous butane flame is not strong enough to prevent incorrect results being obtained for wool and cotton mixtures on the 45° test. The best linear relation between the 45° test and the figure of merit measured by the semi circular test is

$$M = 2{\cdot}8\, T_{45}$$

APPENDIX

Relation between Semi-circular Test and 45° Test[2]

In equation (1) D/T is the mean velocity of spread up to the point D.

Hence equation 1 becomes

$$V = 0{\cdot}315\ D^{3}/2\ \bar{V} \qquad \ldots (1A)$$

where $\bar{V} = D/T$.

Since this is valid for a variety of materials spreading different distances around the semi-circle it follows that the variation of the velocity V_x at a point "x" on the semi-circle is the same for different materials. A convenient equation to assume for this variation is

$$V_x = \frac{dx}{dt} = \frac{A}{x^n} \qquad \ldots (2A)$$

where A is a constant for any one material. The fact that this implies an infinite starting velocity can be disregarded as a small correction to the origin of "x" will meet this difficulty without making a significant difference to the following argument. The equation also postulates a finite velocity just before the cessation of flame spread. This again is disregarded.

Now x/t is the mean velocity of spread $\bar{V}_x$ up to the point "x" so that from (2A)

$$\bar{V}_x = (n + 1)\ V_x \qquad \ldots (3A)$$

The above argument on the similarity of behaviour of different materials also implies that equation (1A) can be written

$$V = 0{\cdot}315\ X^{3}/2\ \bar{V}_x \qquad \ldots (4A)$$

Equation (2A) is therefore satisfied if $n = 3/2$. Hence from (3A) and (4A)

$$V_x = \frac{\frac{2}{5}\,V}{0{\cdot}315\ X^{3}/2} \qquad \ldots (5A)$$

If x is put equal to 5·25 in. the distance round the semi-circle to reach a slope of 45° we get the local velocity at a point where the slope is 45° as

$$V_{45} = \frac{V}{9{\cdot}4}$$

Strictly speaking there is a distinction between the time for the top of the flame to reach a given point and the time the base fabric has burnt through at that point. It is the latter which is measured in the semi circular test and the former in the 45° test. The use of the full distance of 5 in. may slightly overestimate the vertical flame speed, but in view of other approximations this is not important. Hence with a 5 in. spread in T_{45} seconds

$$V = \frac{47}{T_{45}}$$

References

(1) Flammability of clothing textiles. United States Commercial Standard CS 191-53.

(2) Thomas, P. H. and Wraight, H. "The American Flammability Test for Fabrics Compared with the Semi Circular Test". Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. Note 191/1955.

(3) British Standard B.S. 476 : Part II : 1955.

(4) Lawson, D. I., Webster, C. T. and Gregsten, M. J. "The Flammability of Fabrics". J. Text. Inst. 1955, 46. p. 453.

(5) Webster, C. T. "The Flammability of Fabrics Part II". Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization. F.R. Note 209/1955.

(6) A Summary of the Work of the Flammability Testing Panel of Textural Committee A. J. Text. Inst. 1956, 47 (9). p. 799.

PC.

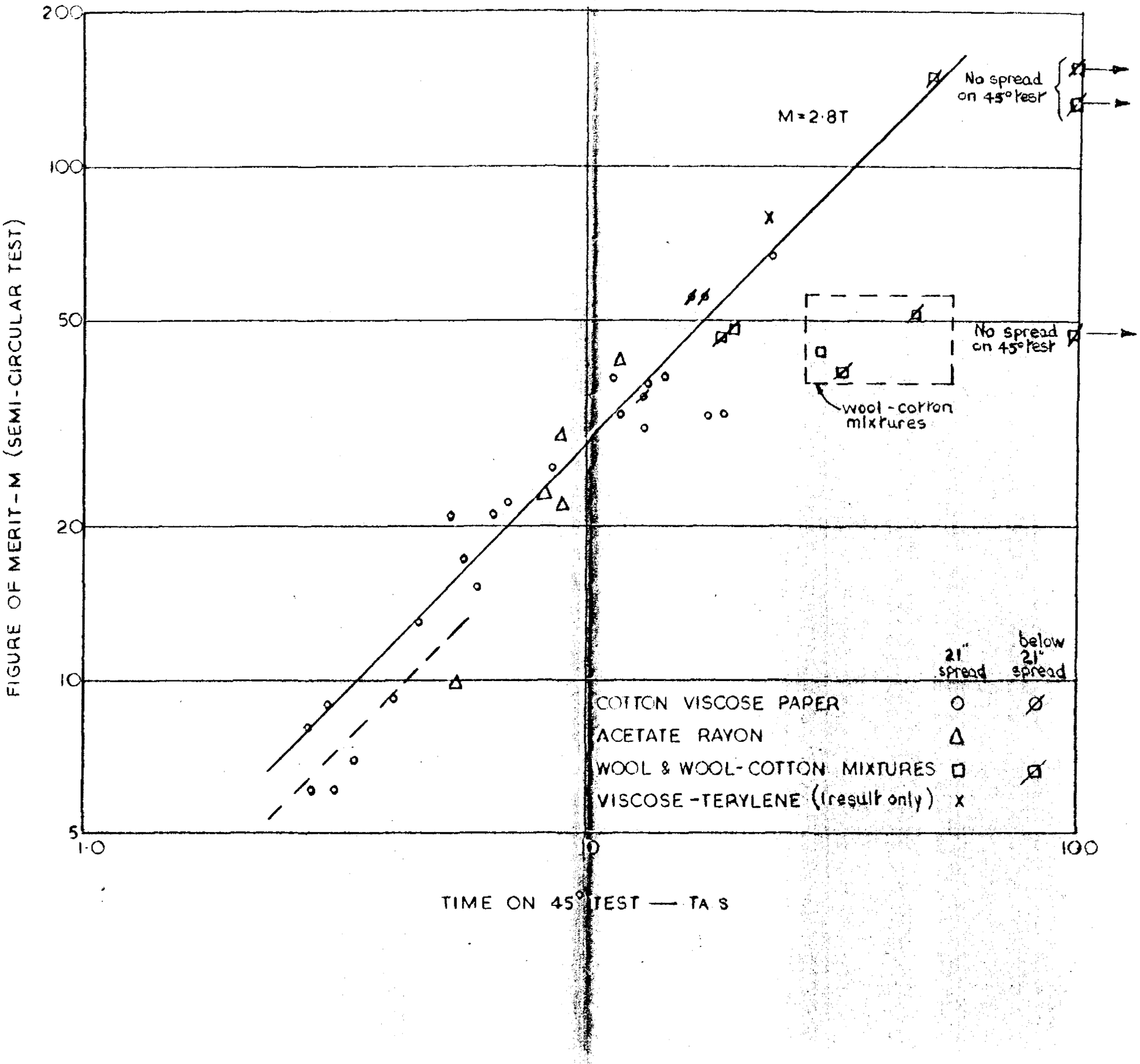

FIG. 1. COMPARISON OF SEMI-CIRCULAR & 45° TEST

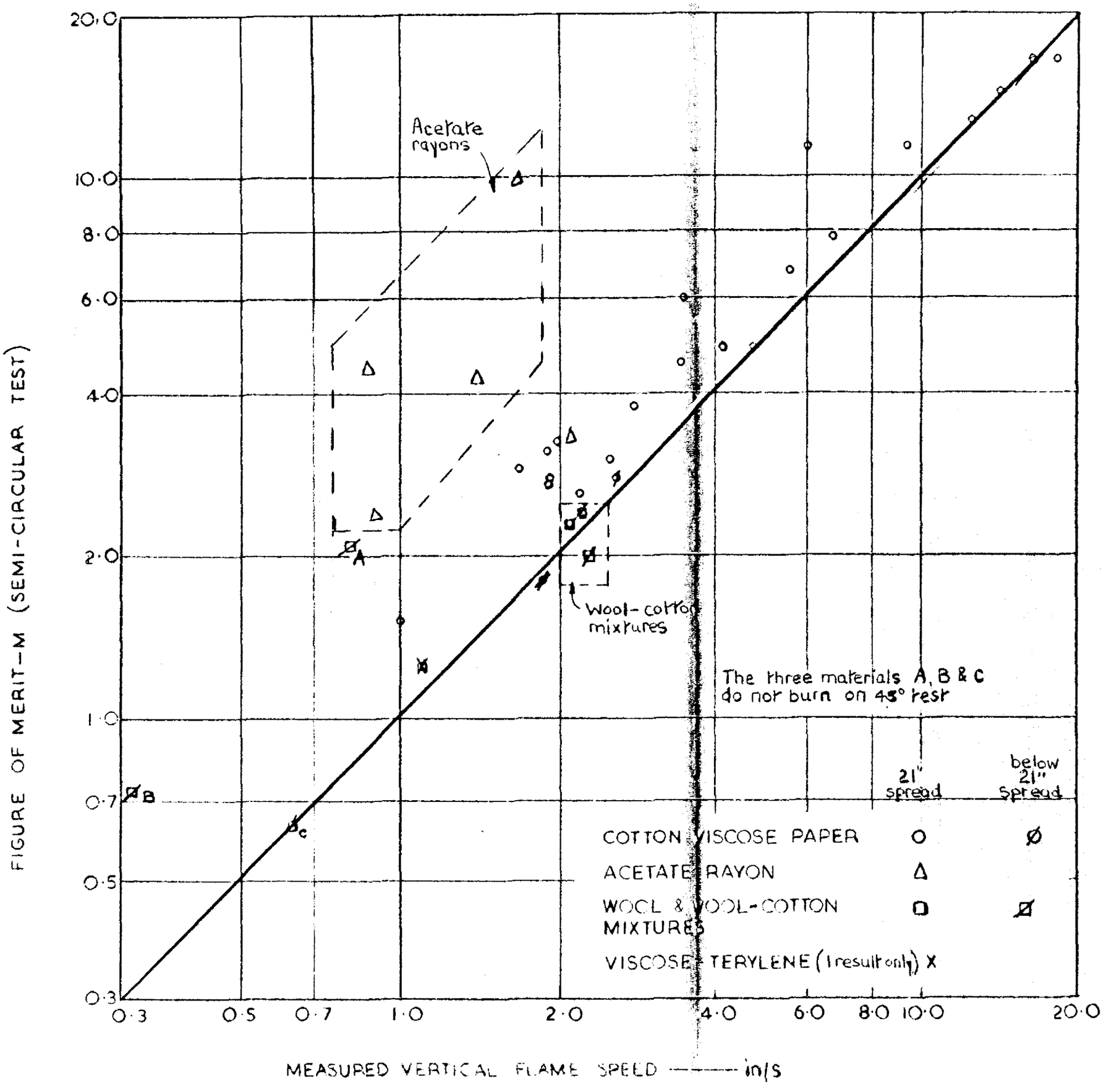

FIG. 2. SEMI CIRCULAR TEST — CALCULATED VERTICAL FLAME SPEED AND MEASURED VERTICAL FLAME SPEED

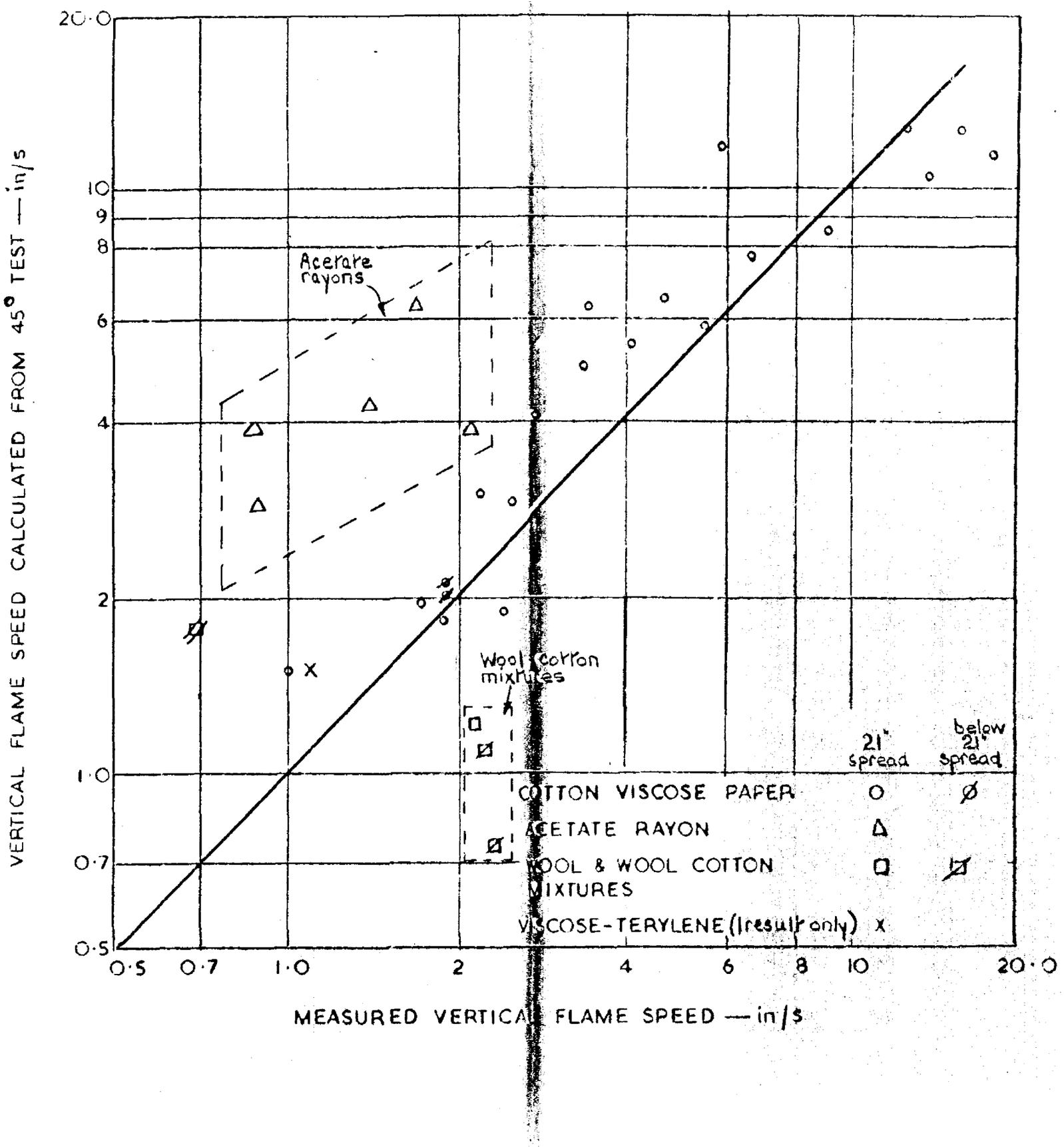

FIG 3. AMERICAN TEST — CALCULATED VERTICAL FLAME SPEED AND MEASURED VERTICAL FLAME SPEED

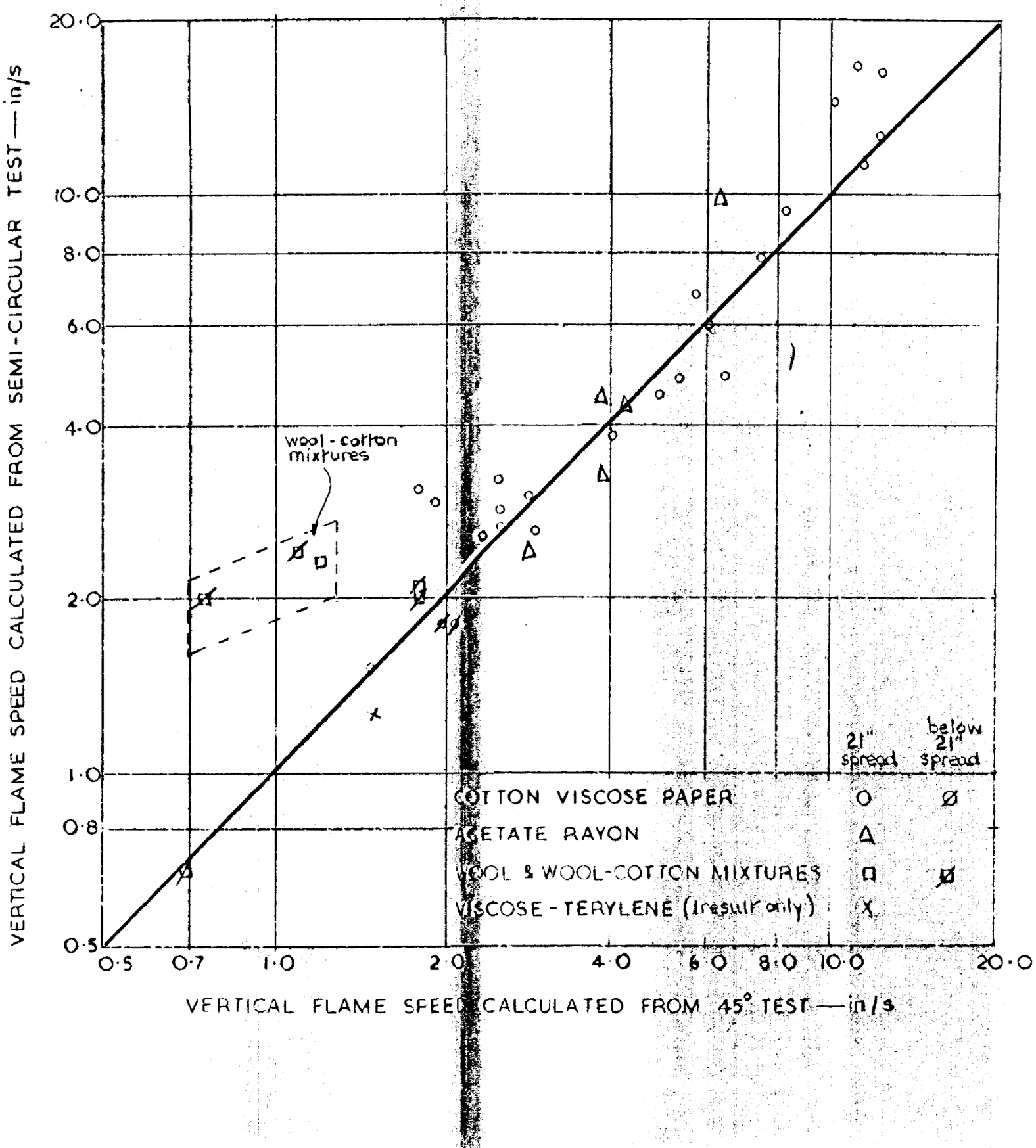

FIG. 4. COMPARISON OF SEMI-CIRCULAR AND 45° TEST