F.R. Note No. 323/1957
Research Programme Objective 35

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

MATERIALS SUITABLE FOR CLOTHING AIRCRAFT FIRE CRASH RESCUE WORKERS

PART IX: SUMMARY OF EXPERIMENTAL METHODS AND RESULTS

by

P. L. Hinkley, D. L. Simms and R. W. Pickard

This report describes the work carried out by the Fire Research Station for the Ministry of Supply under contract 7/exptl/745/PR3.

Summary

This note summarizes the results of experiments to assess the relative merits of different suits, gauntlets, boots and vizors designed for aircraft fire crash rescue workers.

August 1957.
File No. F.1061/16/8
F.5/3

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1. Introduction

This note summarizes work (1-9) done at the Joint Fire Research Organization for the Ministry of Supply to assess the relative merits of materials suitable for clothing aircraft fire crash rescue workers.

The problems of designing clothing for protection against heat and flames are discussed fully elsewhere(10).

A list of the materials discussed in this report is given in Appendix I. They are divided into four groups as follows:-

(1) Suiting (outer material, interlining, lining and underclothes.)
(2) Gauntlets (outer material, interlining and lining.)
(3) Footwear (outer leather, interlining, lining and socks.)
(4) Vizors.

These tests do not take into account such factors as moisture permeability or stiffness of the materials though these may greatly affect the comfort and performance of the garments.

2. Protection by Suitings

2.1. Experimental method

Tests were carried out to estimate the thermal protection afforded by the assemblies of materials against flames from a small petrol fire and against radiation. The protection was assessed by estimating the length of time the clothing would prevent dangerous skin temperatures from being reached.

The thermal protection afforded by the materials was measured with the assembly in slight compression. In practice, poor contact between skin and clothing would increase the thermal insulation because of better air circulation and the high thermal resistance of the air gap, but there are bound to be areas where the contact between the skin and the clothing is good, e.g. shoulder, knees, elbows, and the protection times obtained from the experiments must be taken as being more representative of these conditions. Horsemeat was used to simulate human flesh; the outer surface of the clothing assembly was exposed to the flames and the temperature rise of the surface of the horsemeat in contact with the assembly was recorded continuously. The time taken for the temperature to rise 25°C was taken as a measure of the protection afforded by the assembly; the flames were then extinguished and any further temperature rise recorded. Usually four tests were carried out on each assembly, the results are given in columns 5, 6 and 7 in Appendix II.

This temperature rise of 25°C is arbitrary and is probably greater than that needed to cause severe pain. However, choosing a lower value does not alter the general order in which the assemblies are ranked.(2)

The radiation test is similar to the flame test except that the $2\frac{1}{2}$ in. square area of the face of the assembly is exposed, not to flame but to radiation of an intensity of 0.5 $cal.cm^{-2}s^{-1}$ (2 w/cm^2) estimated to be the level likely to be encountered. The results are given in columns 8, 9 and 10 of Appendix II.

The flame test, except for fabrics having a high reflectivity was found to be only a little more severe than the radiation test.(Fig.1). It is, however, essential that it be used for highly reflecting materials.

2.2. Results

In general, the protection time is dependent more on the thickness of the materials (fig.2) rather than the particular type of fabric. An air gap is, however, of more benefit than a similar thickness of fabric.

The best outer material tested was Fearnought; however, it has been stated that this suffers from the disadvantage that it can absorb large quanities of water and become heavy. Lasting cloth disintegrated on heating and occasionally continued to burn after the petrol fire was extinguished. Some asbestos fabrics have the advantage of being non-flammable, but the protection times were shorter than for woollen materials of equivalent weight and the rise in temperature after removal of the source of heat tended to be higher. The use of a highly reflecting aluminized surface on the outside of an assembly increased the protection times against radiation by a factor of the order of 10. Against flames, the protection is less than this figure as convective heating is a significant part of the heat transfer. The flames also tended to soot up and damage the surface of the material and so reduce its reflectivity. After the removal of the heating source the temperature of the horseflesh remained constant or continued to increase for a long time owing to the low emissivity of the reflecting surface. The rubber bonded material gave protection for as long as the combination of a woollen outer material and an interlining. However, it cooled rather slowly after removal of the heating source and it was found to be flammable. The rubber bonding would provide a barrier to water.

The best interlining tested was wool pile. Although the measured protection times were slightly shorter than for open mesh fabric, the material continued to provide reasonable protection even if the outer layer was destroyed. A synthetic spacer fabric was found to be of no use because it melted.

Underwear was found to be of great significance; a string vest increased the protection times by a factor of from $1\frac{1}{2}$ to 2. (2) Orthodox woollen underwear produced no significant increase in the protection time. (9)

A flame retardant treatment applied to lasting cloth and fearnought had little effect on the protection time. This is because the heat contributed by the external source was large compared with that contributed by the burning material.

2.3. The effect of water on protection (6)

2.3.1. Effect of moisture content

Because the thermal properties of textiles vary with moisture content, the protection time may also vary. Experimental results showed that as the moisture content of a clothing assembly was increased from zero, the protection time at first decreased and then increased to a maximum at saturation. The effect over the range likely to be encountered in practice can probably be neglected. No experimental

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evidence was found that the wearer is likely to be scalded by steam from a damp protective garment.

2.3.2. Effect of "wetting down"

To study the possibility of workers being scalded whilst being "wetted down", - a process which provides extra protection - assemblies were exposed to radiation and when the temperature rise recorded had reached 25°C a jet of water was played on the outer face for 5 seconds.

With garments of high wettability the water penetrated the assembly to produce a sudden large temperature rise. An impermeable layer in the assembly prevented this temperature rise.

Thus, "wetting down" an operator should be carried out before he enters the fire zone unless he is wearing special clothing incorporating an impermeable layer.

3. Gauntlets

The experimental methods were as described above in 2.1. The best gauntlet tested consisted of a aluminized asbestos outer material with a lining of brushed knitted cotton. However, this gauntlet provided less protection than the suits against radiation and was very ineffective against flames. Its protection could be increased by a thicker lining but this may result in a loss of tactility.

4. Footwear

Footwear was tested in the same way as suitings and gauntlets but it was only tested against flames as it is rarely exposed to radiation alone. The best type of boot assembly had an interlining incorporating an air gap, such as open weave asbestos cloth or expanded neoprene. An aluminized layer inside the boot is of no value. Service boot leather was found to be a slightly better outer material than white chrome hunting side. The protection is improved considerably by thick socks.

The temperature of the boot continued to rise for a long period after the extinction of the flames. Thus footwear should be constructed so that it can be quickly and easily removed.

5. Vizors

5.1. Transmission of light and heat

The maximum tolerable level of radiation (11) for a period of up to three minutes is about 0.035 $\text{cal.cm}^{-2}\text{s}^{-1}$ (0.15 w/cm^2) and even this may be too high if the air circulation is restricted. Assuming that the rescue worker is exposed to 0.5 $\text{cal.cm}^{-2}\text{s}^{-1}$, the vizor should transmit less than 7 per cent of the radiation from a petrol fire.

Ideally, protection would be provided by a vizor which, whilst transparent to visible radiation, would reflect infra-red radiation. Reflection is preferable to absorption because, although both reduce transmission, with the latter the vizor becomes hot and then re-radiates upon the face. There is also the danger that the face may come into direct contact with it. Most of the vizors tested, however, absorbed heat. The effects of prolonged heating on the vizor were therefore studied as well as the transmission.

A vizor should not ignite under the most severe exposure conditions, nor should it distort or lose its optical properties on prolonged heating and it must not shatter if sprayed with water or foam whilst hot.

5.2. Experimental methods and results

The experimental source of radiation was a gas-fired panel, (12), and the vizors were exposed to 0.5 cal.$cm^{-2}s^{-1}$.

The transmission of light by the vizors was measured using a photographic exposure meter with a spectral response approximately the same as that of the eye. The transmission of thermal radiation was measured by a thermopile (13).

Any deterioration of the vizor during exposure was noted. After 2 minutes exposure of the glass vizors, a jet of water was directed at the front face. The results of these experiments are given in columns 2 - 6 of Appendix III.

The most satisfactory vizor was the composite glass one (4). The aluminium coated perspex vizor had the best transmission characteristics but the coating is easily damaged while if it is protected by a layer of lacquer this tends to become cloudy. The danger due to deformation of a perspex vizor to the wearer may be minimized by placing a suitable wire gauze behind the perspex. This also reduces the transmittance of the vizor to a safe level although visibility is disproportionately reduced by a polished gauze. Perspex may ignite under exceptional circumstances although the formation of bubbles should act as a warning. The vizor made from a thermosetting plastic was unsatisfactory as it crazed and ceased to be transparent rather suddenly, probably before unbearable pain would have been felt. The laminated glass vizors cracked when sprayed with water but did not shatter.

6. References

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APPENDIX I

Selection of Materials Tested

Purpose	Description	Appearance or Colour	J.F.R.O. Ref. No.	Thickness mm	Weight per unit area g/cm^2
Outer Material for Suits	Lasting cloth (flameproofed wool)	Blue	R.143	1.1	0.029
	Lasting cloth (wool not flameproofed	White	R.144	1.1	0.030
	Fearnought (wool not flameproofed or waterproofed)	White	R.154	2.9	0.080
	Asbestos cloth	White	R.145	0.8	0.038
	Serge (15% Nylon 85% wool)	Khaki	R.92	1.4	0.045
	Aluminized asbestos	Polished Aluminium	R.167	1.4	0.095
	Aluminized cotton	Polished Aluminium	R.166	0.4	0.048
	Double texture rubber bonded woollen material	Fawn facing Brown lining	R.151	3.4	0.15
nterlining r its	Wool pile (cotton backed)	Green White	R.146 R.177	4.0	0.045
	Open mesh fabric (cotton)*	White	R.148	5.1	0.049
	Spacer fabric (polyvinylidene chloride warp and polythene weft).	Green and Brown	R.61	10.5	0.13
ining r its	Cotton poplin	Off white	R.147	0.1	0.012
der-lothing	String vest (hand-knitted)	White string	R.63	5.4	0.092
	Woollen knitted underwear material	Off white	R.94		0.028
ter yer of otwear	Leather (chrome) hunting side	White	R.156	1.9	0.12
	Leather (chrome side) used in service boots	Polished Black	R.161	1.9	0.11

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* Also used for underwear.

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Purpose	Description	Appearance or Colour	J.F.R.O. Ref. No.	Thickness mm	Weight per unit area g/cm^2
Interlining of Footwear	Expanded neoprene	Black	R.159	3.1	0.098
	Expanded rubber	Black	R.157	3.2	0.21
	Leather (soft dry chrome split)	Natural	R.160	1.6	0.12
	Open weave asbestos cloth	White	R.59B	2.0	0.077
	Aluminium vynide laminate	Aluminium outside White inside	R.59C	0.6	0.069
Lining of Footwear	Goatskin	White	R.59D	0.9	0.069
	Natural kip	Natural	R.158	1.3	0.098
Sock	Knitted wool	White	R.60	1.5	0.043
Gauntlet Outer Cover	Aluminium faced asbestos cloth	Aluminium	R.72	2.0	0.12
	Asbestos cloth canvas backed	Off white	R.73A	1.9	0.12
Gauntlet Interlining	Jute canvas	Off white	R.73B	1.6	0.092
Gauntlet Lining	Cotton material	Off white	R.73C	0.6	0.021
	Brushed knitted cotton	Grey	R.69	1.9	0.031
	Linen canvas	Off white	R.70	2.0	0.086
Vizor	Perspex	Transparent	-	5	-
	Perspex backed by 40 mesh 34 s.w.g. bright steel wire gauze (wires diagonal)	"	-	5	-
	Tinted perspex	"	-	2.7	-
	Composite material (two sheets of glass bonded together with a semi-reflecting layer of copper between them separated by an air gap from a plastic sheet)	"	-	Laminated glass 3 mm. Air gap about 2 mm. Plastic 2 mm.	-
	Laminated glass	"	-	2.7	-
	Perspex with a semi-reflecting coating of aluminium (half lacquered)	"	-	5	-
	A thermosetting plastic	"	-	4	-

Protection against flames and radiatin afforded by various assemblies

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Materials				Flame tests			Radiation tests			
Outer	Interlining	Lining	Underwear	Time for 25°C temperature rise sec.	Further temperature rise °C	Additional time for further temperature rise - sec	Time for 25°C temperature rise sec.	Further temperature rise °C	Additional time for further temperature rise - sec.	Remarks
SUITS										
White lasting cloth	Wool pile	Cotton poplin	None	49	2	8	76	5	15	Lasting cloth tends to char away exposing the interlining.
	"	"	String Vest	78	2	11	not tested			
	Open mesh fabric (two layers)	"	None	64	4	21	83	3	24	
	Spacer fabric	"	None	35	0	None	40	6	20	
	"	"	String vest	not tested			60	5	10	
Blue lasting cloth (flameproofed)	Wool pile	Cotton poplin	None	58	2	9	53	3	7	ditto
Fearnought	None	Cotton poplin	None	34	2	8	53	2	9	When heated Fearnought swells to form a brittle mass of frothy carbonaceous material.
	Wool pile	"	"	82	1	26	110	3	25	
	"	"	String vest	142	1	22	not tested			
Asbestos cloth	Wool pile	Cotton poplin	None	37	5	11	62	3	17	
Aluminized asbestos	Open mesh fabric	Cotton poplin	"	27	7	44	460	5	550	
Rubber bonded material	None	Cotton poplin	"	65	7	27	45	8	26	
Khaki serge	None	None	None	15.5	2,5	2	not tested			
			Woollen knitted	13	5	6.5				
FOOTWEAR										
White chrome leather	Open weave asbestos cloth + aluminium vynide laminate	White goatskin	None	155	20	165	"	"	"	
			Two layers of sock	180	12	60	"	"	"	
	Open weave asbestos cloth	White goatskin	Two layers of sock	185	12	150	"	"	"	
	Expanded rubber	Natural kip	None	No results obtained			"	"	"	Rubber ignited and burned persistently
	Expanded neoprene	"	"	167	16	150	"	"	"	
	Chrome split	"	"	64	18	170	"	"	"	
Service boot leather	Expanded neoprene	"	"	185	12	36	"	"	"	
GAUNTLETS										
sbestos cloth	Jute canvas	Cotton material	"	23	6	8	65	2.5	15	
luminium faced sbestos cloth	None	Brushed knitted cotton	"	28	4	19	645	0	None	
	"	Linen canvas	"	19	10	16	270	0	None	

Transmission of heat and light by Vizors

Vizor	Transmission of radiation by the vizors				Time for serious distortion at $0.5 cal.cm^{-2}s^{-1}$ ($2 w/cm^2$)	Notes
	Infra-red heat radiation from a fire		Visible radiation transmittance per cent	Ratio of visible transmittance to infra-red transmittance		
	Transmittance Initial value per cent	Effective transmittance (including re-radiation) after 1 min. per cent				
Perspex	10	10.5	95	9.5	90	After 120 sec. bubbles formed in perspex. Vizor sagged inwards
Wire gauze backed perspex	7	8	45	6.5	70	Perspex badly distorted but the wire gauze was not distorted
Tinted perspex	12.5	16.5	20	1.5	75	
Perspex with semi-reflecting aluminium coating	3	4	45	15	90	Unlacquered coating darkened, lacquered coating became translucent
Laminated glass	22	-	95	4.5	-	After 105 sec. bubbles appeared between the laminations. Application of a jet of water after 120 sec. resulted in the front lamination being badly cracked but the rear lamination remained intact.
Composite vizor	1.7	1.7	30	17.5		Application of a jet of water after 120 sec. had no effect. The vizor was irradiated at 3 w/cm^2 for a further 60 sec. The plastic sheet became deformed and touched the glass and an opaque blister formed. A jet of water was again directed at the front face. Front lamination cracked but the rear glass lamination remained intact.
Thermosetting plastic.	10.2	15.2	91	8.9		After 90 sec. the vizor surface became "crazed" and by 120 sec. it was opaque and breaking up.

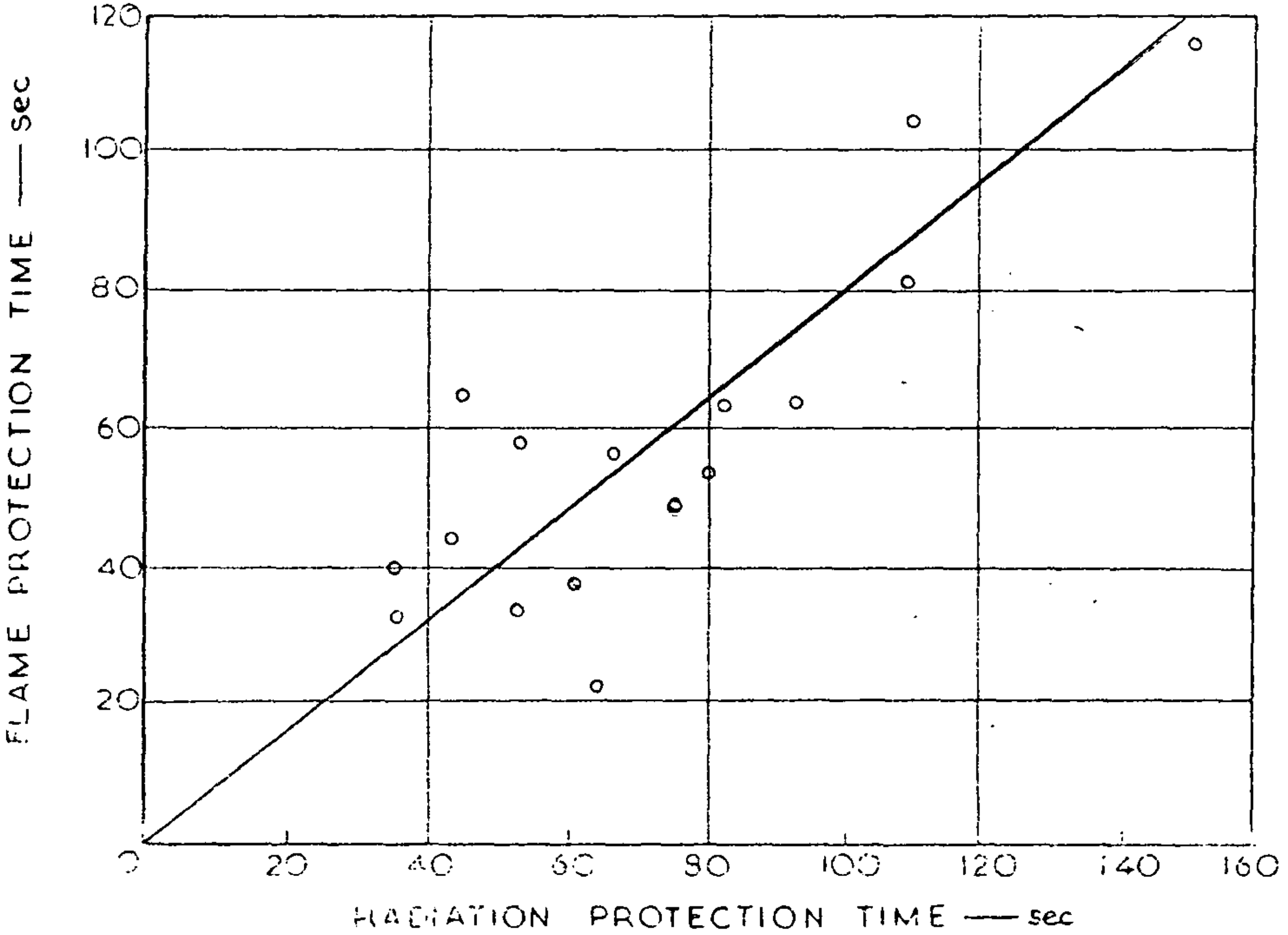

FIG I FLAME PROTECTION TIME AS A FUNCTION OF RADIATION PROTECTION TIME (NON-REFLECTING MATERIALS)

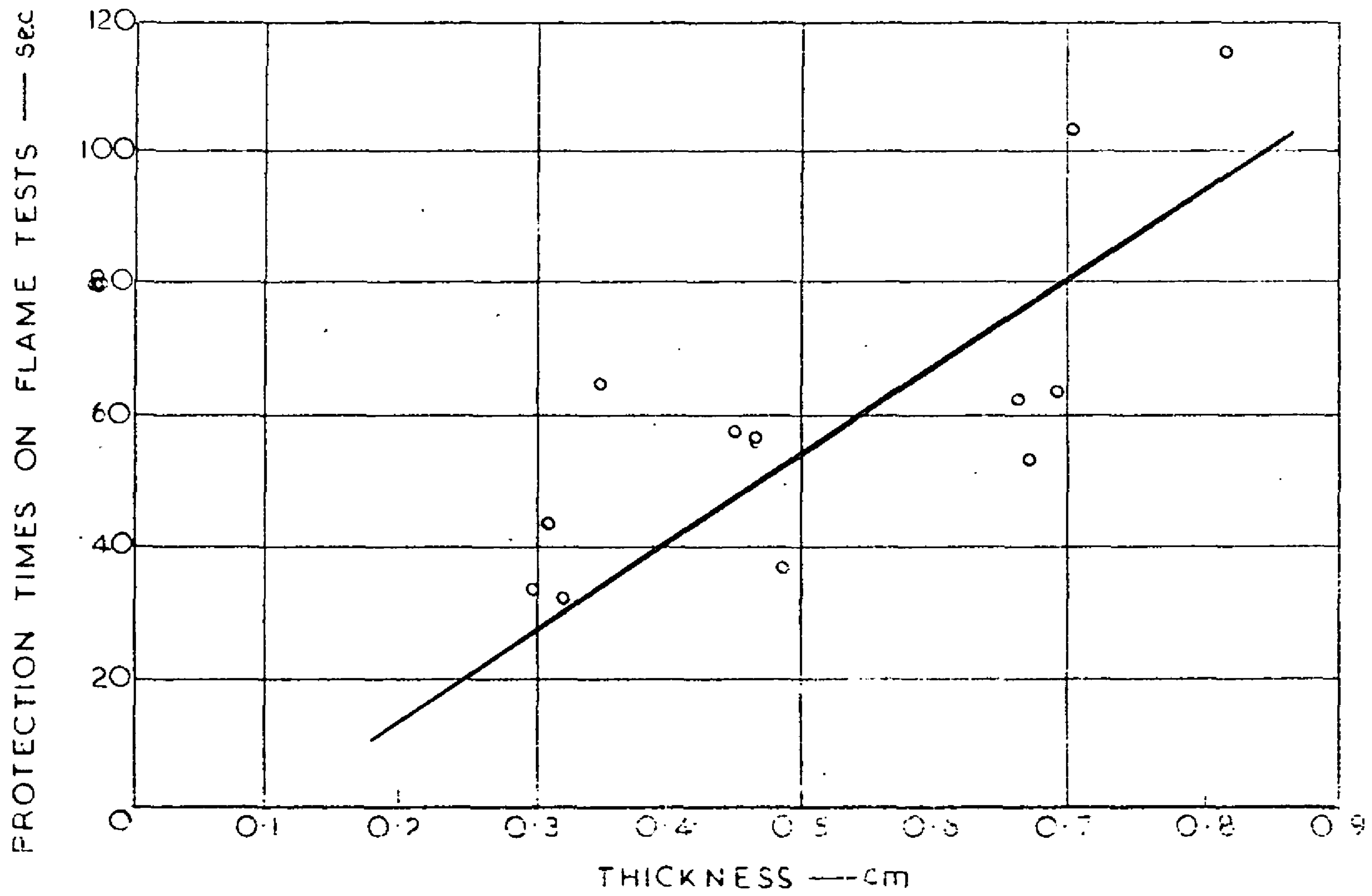

FIG. 2. EFFECT OF THICKNESS ON PROTECTION TIMES OF FLAME TESTS