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U N C L A S S I F I E D

RESEARCH REPORT
on

HEAT-REFLECTING TEXTILES AS PROTECTIVE BARRIERS AGAINST INTENSE THERMAL RADIATION

Lab. Project 5046-3 Part 77, Final Report
NS 081-001

25 March 1955

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U N C L A S S I F I E D

Lab. Project 5046-3 Part 77
Final Report

SUMMARY

A study was conducted to determine the relative effectiveness of aluminum-foil-on-fabric and three other types of heat-reflecting textiles, for use as protective barriers against intense thermal radiation. The three groups consisted of

a. aluminum deposit on fabric,

b. white organic coatings on fabric and

c. bleached white goods.

The temperature-time histories of human skin and an epoxy-resin skin simulant contiguous to the irradiated cloth indicate that for a given radiant exposure the temperature rise of the backing behind the fabric with the aluminum foil coating is one-fifth that behind the bleached-goods group whereas the temperature rise of the backing behind the fabrics with the aluminum deposit and those with the plastic coatings is one-third that behind the bleached-goods group of cloths. Except for the bleached-goods group, which showed a high thermal resistance, but also a high transmittance, it may be expected that these heat-reflecting textiles will serve as effective barriers to intense thermal radiation provided they are separated from the background, in which case the backing will be damaged only negligibly before they are destroyed. It must be recognized that impairment of the textiles' reflective characteristics by soiling, laundering or abrading will reduce their protective qualities. The aluminum-on-cloth fabrics laundered poorly and exhibited low abrasion resistance.

TABLE OF CONTENTS

ADMINISTRATIVE INFORMATION

1. This investigation is part of the program initially proposed by Commander, New York Naval Shipyard, Confidential letter S99/L5, Serial 960-92, of 14 March 1950 and formally approved by Bureau of Ships speedletter S99(0)(348), Serial 348-75, of 6 April 1950. The Thermal Radiation Program at the Naval Material Laboratory is under the supervision of the Armed Forces Special Weapons Project.

2. The attention of the Naval Material Laboratory was first directed to the possibilities of FYRE-ARMOR by E. Cherubrier, the Clothing Supply Office (Research and Development Division), U. S. Naval Supply Activities, Brooklyn, New York, who also measured the physical characteristics of the various cloths, as reported herein.

3. This investigation was planned and executed under the direction of T. I. Monahan, Supervisor of the Optics Section.

INTRODUCTION

4. As part of its general thermal radiation program, the Naval Material Laboratory is investigating the heat resistance and protectiveness of textiles and other materials against the hazards of the intense thermal radiation of nuclear explosions. The ray-reflecting properties of certain paints, metallic surfaces and coatings have been used in the development of materials for protection against the radiant heat. One of the more recent developments in this field is a method to bond aluminum foil to textiles for the manufacture of protective clothings, known as Fyre-Armor[1,2]. This report compares the effectiveness of Fyre-Armor as a thermal barrier with three other different types of heat-reflecting textiles. Thermal degradation effects of the cloths and the temperature increases of substances behind them were used to determine the relative degree of protection which may be expected from these textiles if employed as canopies, cargo hold covers, curtains, tenting and protective clothing.

EXPERIMENTAL APPARATUS AND PROCEDURE

5. The source of thermal energy was a carbon arc, an Ellipsoidal reflector being employed to collect and condense the emitted radiation. The specimens, measuring $1\frac{1}{2} \times 4$ inches, were placed at the secondary focus, at which the irradiance was about 14-16 cal/cm^{2}sec. An epoxy-resin skin simulant, with a surface embedded thermocouple, was located zero and 2 mm behind the specimens when they were irradiated. For each of these positions, a recording potentiometer, modified to close the shutter after a preset deflection was reached, charted the temperature-time histories of the skin simulant. Exposures were made with the reflecting side facing the source, and with the fabric side facing the source. In some cases,

[1] See Bibliography

the untreated fabric was irradiated. The maximum temperature rises, time of exposure and thermal effects during and after exposure to the radiation were noted. Similar exposures were made with human skin as the backing; the temperature-time histories were obtained by means of a very fine thermocouple stretched lightly over the heel of the hand. The exposure cut-off was set for a deflection of 10 scale divisions, which correspond to approximately 10°C. Specimens in front of skin were kept taut with a 150 gm. weight hung from the lower end of the cloth. Small screw clamps held the specimens secure in front of the epoxy block. All samples were conditioned in an atmosphere of 65 per cent relative humidity at room temperature for a minimum of 24 hours. The critical radiant exposures (cal/cm^2) to cause destruction were determined, using the dynamic-exposure source method[3,4]. Physical properties, including reflectance, transmittance and absorptance for the carbon-arc spectrum, were determined for each textile. Some of the aluminized cloths were tested for laundering and abrasion resistance, using the normal textile testing methods[5].

RESULTS

6. The four heat-reflecting textiles are grouped according to the nature of their reflecting surfaces. A description of the cloths and some of their physical properties are listed in Table I. The thermal effects resulting from the degradation of the materials during and after exposure are given in Table 2. Included are data in terms of the radiant energies corresponding to some of these effects. The epoxy resin maximum temperature increases (°C/cal/cm^2), given in this table, were derived from one and, in some cases, two experiences for each cloth situation listed. The temperature-time histories of textile-covered skin were determined only for the 2mm spacing condition and at least three exposures were made for each cloth situation. The lowest of the three maximum temperature increases was used in calculating the data of Table 3, which gives the estimated radiant exposures to cause a 2+ mild burn. These values are not intended to be exact and may be as much as 50 per cent in error. They do, however, indicate the high permissible exposures. Table 4 lists the physical test data for some of the aluminum-faced whole cloths and base fabrics. Critical thermal energies to cause initial destructive effects are reported in Table 5.

ANALYSIS

7. The three significant physical properties of these textiles appear to be weight, carbon-arc reflectance and transmittance. In general, within each group, the temperature increases of the epoxy skin simulant behind the heavier fabrics were lower. Even though the bleached white goods had the highest thermal resistance, the temperatures of the backing were greater in these cases than those obtained behind the other groups. This was undoubtedly due to its greater transmittance, which was as great as 10 per cent, compared to 0 and 1 per cent for the aluminum-

surfaced cloths. The 2+ mild burn criteria are based on data drawn from the Naval Material Laboratory Report on the "Use of Polyethylene as a Physical Measuring System for Evaluating Physiological Burns Behind Fabrics[6], Figure 19, and using temperature rises 0.74 times those for polyethylene. These values, obtained by straight-line extrapolation over a wide range of exposures, are considered valid for comparing the thermal resistance of the various groups. The destruction data indicate the degree of protection which may be expected, for most equipment, to the point where the textile is destroyed. It must be recognized that protection by these fabrics depends upon their ability to retain a high reflectance and negligible transmittance. Physical tests indicate that these properties may be considerably altered by machine laundering and abrasion, limiting thereby their effectiveness as thermal barriers. In addition, the non-durable flameproofing treatments of the basic fabric to which the Fyre-Armor is applied, and of other base fabrics were of no value after washing.

CONCLUSIONS

8. The application of a highly reflecting surface to a base fabric appears to increase protection by a factor of approximately 3-10, depending upon whether the base fabric is glass, asbestos, or flameproofed cotton, respectively. The aluminum foil on fabric type of heat-reflecting textile, known as Fyre-Armor, is considered the best thermal barrier for protection of heat-sensitive substances against intense thermal radiation. Next in order of effectiveness are the aluminum deposits on fabric and organic coatings on fabric. When these barriers are spaced away from the backing, they are likely to be destroyed before any thermal damage to the backing ensues. For certain applications in which a limited degree of added protection is required, the bleached white goods are believed to be effective. It is acknowledged that high reflectivity is necessary for continued maximum protection and that the usefulness of these textiles may be limited in applications where soiling or damage are likely to modify the optical properties of the surface.

APPROVED:

A. B. JONES, Jr., CAPTAIN, USN
The Director

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2. Linicus, Dr. Ing. W., Dusseldorf, Protection Against Heat by Means of Aluminum Foil, Published in German magazine "ALUMINUM".

3. Naval Material Laboratory, Determination of the Energy of High-Intensity Radiation at the Focus of a Parabolic Reflector, Using (A) A Black-Body Receiving Cell; (B) Metal Foil Receiving Strips, Report No. 5046 Part IV (15 Jan 1948).

4. Naval Material Laboratory, Determination of Intensity Distribution at the Focus of a Parabolic Mirror and the Energy Density on a Moving Surface Using a Tungsten Lamp Source, Report No. 5046, Part V. (15 Jan 1948).

5. Textile Test Methods, Federal Specification CCC-T-191b (15 May 1951); Superseding Fed. Spec. CCC-T-191a (2 May 1933 and Supplement (8 Oct 1945).

6. Naval Material Laboratory, The Use of Polyethylene as a Physical Measuring System for Evaluating Physiological Burns Behind Fabrics, Lab. Project 5046-3 Part 42 (Nov. 1954).

*FYRE-ARMOR is the American name for the European Invention, TEMPEX.

TABLE 1

Description and Physical Properties of Heat-Reflecting Textiles

DESCRIPTION	Type of Base Fabric	THICKNESS (a) Whole Cloth (mils)	THICKNESS (a) Base Fabric (mils)	THICKNESS (a) Foil or Coating (mils)	WEIGHT Whole Cloth (oz/yd^2)	REFLECTANCE (%) Carbon Arc Spectrum	TRANSMITTANCE (%) Carbon Arc Spectrum	ABSORPTANCE (%) Carbon Arc Spectrum
Group I (Aluminum Foil on Fabric)								
Fyre-Armor - 7D64-R296	Cotton (flameproof)	23.3	21.0	5.5	13.4	87	0	13
" " " -22C	" "	24.0	24.5	7.8	14.8	80	0	20
" " Asbeston #1	Asbestos	14.4	17.5	1.6	16.5	85	0	15
" " - 4D58-R296	Cotton (flameproof)	19.4	15.5	6.8	9.5	89	0	11
Group II (Aluminum Deposit on Fabric)								
3M-24H120	Asbestos	31.6	30.4	-	17.6	82	0	18
3M-35BT115	"	37.4	43.2	-	19.6	80	0	20
3M-Flameproofed (10oz) Tan	Cotton	25.4	26.7	-	10.4	74	1	25
3M-131 Finish No. 138	Glass	9.1	-	-	7.6	75	1	24
3M-S-915A	Asbestos-Glass	16.5	20.4	-	9.3	83	0	17
3M-Flameproofed Cot.Drill 275	Cotton	17.8	18.7	-	6.1	73	1	26
Group III (Organic Coating on Fabric)								
Silicone - 3016	Glass	14.5	-	-	18.6	79	2	19
Vinyl - 126	Glass	17.4	-	-	18.3	69	5	26
Group IV (Bleached White Goods)								
100% Bleached Duck	Cotton	31.5	31.5	None	13.7	70	11	19
50% Bleached Duck	Cotton	31.4	31.4	None	13.4	71	10	19

(a) Federal Thickness Gauge (10 oz. wt.)

TABLE 2

Thermal Radiation Characteristics of Heat-Reflecting Textiles

TEXTILE	Thermal Radiation Characteristics (Irradiance = 14-16 cal cm^{2}sec)											
	Reflecting Side Irradiated						Fabric Side Irradiated			Base Fabric Only		
	0 mm Spacing			2 mm Spacing			2 mm Spacing			2 mm Spacing		
	EFFECT[a]	Critical Radiant Exposure (cal/cm^2)	Epoxy Temperature Rise (°C/cal/cm^2)	EFFECT[a]	Critical Radiant Exposure (cal/cm^2)	Epoxy Temperature Rise (°C/cal/cm^2)	EFFECT[a]	Critical Radiant Exposure (cal/cm^2)	Epoxy Temperature Rise (°C/cal/cm^2)	EFFECT[a]	Critical Radiant Exposure (cal/cm^2)	Epoxy Temperature Rise (°C/cal/cm^2)
Group I (Aluminum Foil on Fabric)												
Pyre-Armor-7064-R296	None	48	1.05	13	127	0.36	1457	75	0.69	13	12	3.8
Pyre-Armor-7064-22C	1	57	0.95	137	122	0.38	137	47	1.55	13	12	3.8
Pyre-Armor-Asbeston #1	17	48	1.27	137	101	0.50	14567	52	1.45	-	-	-
Pyre-Armor-4D58-R296	1	52	0.87	13	74	0.68	13567	46	1.30	None	8	6.6
Group II (Aluminum Deposit on Fabric)												
3M-24H120	1	54	0.97	137	100	0.49	1357	55	1.25	13	33	1.82
3M-35BT115	1	50	1.11	137	85	0.62	13567	57	1.16	13	31	1.49
3M-Flameproofed (10 oz) Tan	1	39	1.34	137	63	0.74	14567	40	1.55	13	13	3.67
3M-131 Finish No. 138	1	34	1.37	137	57	1.34	1457	25	3.00			
3M-S-915A	13	38	1.31	1347	48	1.05	14567	34	2.62	13	21	1.68
3M-Flameproofed Cotton Drill 275	137	18	2.75	1347	30	1.62	1457	22	2.66	12	8	5.78
Group III (Organic Coating on Fabric)												
Silicone - 3016	1	26	2.47	13568	72	1.09						
Vinyl - 126	1258	24	2.64	1348	47	1.26						
Group IV (Bleached White Goods)												
100% Bleached Duck	None	18	2.50	None	18	2.50						
50% Bleached Duck	None	16	3.27	None	17	2.64						

a - Symbols have following meanings:

1. Smokes
2. Chars
3. Chars through
4. Burns through
5. Flames
6. After flames
7. Aluminum melts
8. Blisters

TABLE 3

Radiant Exposures (cal cm^2) to Yield 2+ Mild Burns on Skin
Protected by Heat-Reflecting Textiles

TEXTILE	WHOLE CLOTH				BASE FABRIC ONLY		
	Reflecting Side			Fabric Side			
	Skin 2 mm	Epoxy 2 mm	Epoxy 0 mm	Epoxy 2 mm	Skin 2 mm	Epoxy 2 mm	Epoxy 0 mm
Group I (Aluminum Foil-on-Fabric)							
Fyre-Armor-7D64-R296	98	77	32	50	27	12	8
Fyre-Armor-7D64-22C	56	80	33	22	27	12	8
Fyre-Armor-Asbeston #1	129	58	29	23	-	-	-
Fyre-Armor-4D58-R296	70	48	37	30	33	9	6
Group II (Aluminum Deposit on Fabric)							
3M-24H120	83	53	31	24	30	15	12
3M-35BT115	75	46	26	25	22	20	13
3M-Flameproofed (10 oz) Tan	37	42	25	23	16	12	10
3M-131 Finish No. 138	77	26	27	12	-	-	-
3M-S-915A	39	34	27	13	18	19	10
3M-Flameproofed Cotton Drill 275	33	24	17	16	10	8	7
Group III (Organic Coating on Fabric)							
Silicone - 3016	100	26	13	-	-	-	-
Vinyl - 126	38	25	12	-	-	-	-
Group IV (Bleached White Goods)							
100% Bleached Duck	17	18	15	18	17	18	15
50% Bleached Duck	16	16	12	16	16	16	12

TABLE 4

Physical Test Data of Some Metaled Textiles and their Base Fabrics

PHYSICAL TEST		FA-7D64-R296 (a) Base Fabric	FA-7D64-R296 (a) Whole Cloth	FA-4D58-R296 (a) Base Fabric	FA-4D58-R296 (a) Whole Cloth	FA-(a) Asbeston #1 Whole Cloth	Perma- (b) Proof 300 Whole Cloth
Fabric Count: Warp		63	64	97	102	-	88
Fabric Count: Fill		47	48	62	59	-	53
Weave:		HBT		HBT		-	HBT
Weight:	(oz/yd^2)	11.4	14.0	7.2	9.9	11.3	9.1
Weight of Foil:	(oz/yd^2)	2.6		2.7		-	-
Thickness: 0.1 lbs	(in)	0.033	0.031	0.024	0.023	0.028	0.019
Thickness: 1.1 lbs	(in)	0.028	0.025	0.018	0.020	0.022	0.019
Tear Strength: Warp (Elmendorf Heavy	(gms)	3100	3200	2200	1900	2600	2600
Duty) Fill	(gms)	2600	3600	2500	2350	2700	2100
Breaking Strength: Warp	(lbs)	158	190	96	130	119	-
(Scott Tester) Fill	(lbs)	128	152	90	115	118	-
Hydrostatic): Coating Up	(lbs)	-	22	-	37	38	Permeable Fabric
Mueller) Coating down	(lbs)	-	200	-	112	82	
Flammability: Char Length (Vertical Flame Test):	(in)	1 7/8	-	2 3/4	-	-	-
Afterglow	(sec)	None	-	None	-	-	-

(a) Aluminum Foil on Fabric Types
(b) Aluminum Deposit on Fabric

C A U T I O N

on

TABLE 5

THIS TABLE CONTAINS THE NAMES OF MANUFACTURERS WHOSE PRODUCTS ARE DISCUSSED IN THIS REPORT. IT IS REQUESTED THAT THE PROPRIETARY INTERESTS OF THE MANUFACTURERS BE OBSERVED.

TABLE 5

Critical Thermal Energies of Heat-Reflecting Textiles

TEXTILE	CRITICAL ENERGIES			
	Surface Char (cal/cm²)	Char Through (cal/cm²)	Destruction (cal/cm²)	Aluminum Melts (cal/cm²)
(a) Group I (Aluminum Foil on Fabric)				
Fyre-Armor 7D64-R296		61		69
Fyre-Armor 7D64-22C		75		174
Fyre-Armor Asbeston #1		49		49
Fyre-Armor 4D58-R296		41		78
(b) Group II (Aluminum Deposit on Fabric)				
3M-24H120	27-34		91	
3M-35BT115	21		94	
3M-Flameproofed (10 oz) Tan	5-14		28	
3M-131 Finish No. 138	14-17		41	
3M-S-915A	22		69	
3M-Flameproofed Cotton Drill 275	4.0		16	
Group III (Organic Coating on Fabric)				
(c) Silicone - 3016	21		88	
(d) Vinyl - 126	18		72	
(e) Group IV (Bleached White Goods)				
100% Bleached Duck	72		118	
50% Bleached Duck	69		119	

(a) Fyre-Armor is the American name for the European invention TEMPEX; sponsored in this country by FAR-EX Corporation, 75 West Street, New York 6, New York.

(b) 3M Brand - Aluminum Fabric Finish; Minnesota Mining and Manufacturing Company
New Products Division
367 Grove Street
St. Paul 6, Minnesota

(c) Connecticut Hard Rubber Company, New and East Streets, New Haven 9, Connecticut

(d) Mobile Plastics Company

(e) Submitted by: Wright Air Development Center (Spec. CCC-D-771) Type III
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Commander, Air Proving Ground Command, Eglin Air Force Base, Florida ATTN: AG/TRB	1
Director, Air University Library, Maxwell Air Force Base, Alabama ATTN: CR-5464	2
Commander, Flying Training Air Force, Waco, Texas, ATTN: Director of Observer Training	2

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Commander, Headquarters Technical Training Air Force, Gulfport, Mississippi ATTN: TA & D		1
Commander, Air Force School of Aviation Medicine, Randolph Air Force Base, Texas		2
Commander, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio ATTN: WCOESP		1
WCRTY-2		1
Commander, AF Cambridge Research Center, 230 Albany Street, Cambridge 39, Massachusetts ATTN: CRW, Atomic Warfare Directorage		1
CRQST-2		1
Commander, AF Special Weapons Center, Kirtland Air Force Base, New Mexico, ATTN: Library		3
Commander, United States Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio ATTN: Resident College		1
Commander, Lowry Air Force Base, Denver, Colorado ATTN: Department of Armament Training		1
	OTHER DOD ACTIVITIES	
Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D. C.		1
United States National Military Representative Headquarters, SHAPE, APO 55, c/o PM, New York, N.Y. ATTN: Col. J. P. Healy		1
Assistant Secretary of Defense for Research and Development, Department of Defense, Washington 25, D.C. ATTN: Technical Library		1
Commandant, Armed Forces Staff College, Norfolk 11, Virginia, ATTN: Secretary		1
Commanding General, Field Command, Armed Forces Special Weapons Project, P.O. Box 5100, Albuquerque, New Mexico		6
Commanding General, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, New Mexico, ATTN: Technical Training Group		2

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Chief, Armed Forces Special Weapons Project, Washington 25, D. C. 15

PANEL ON THERMAS RADIATION

Professor H. C. Hottel, Massachusetts Institute of Technology, Cambridge, Massachusetts 1

Dr. E. O. Hulburt, Naval Research Laboratory, Washington 25, D. C. 1

Dr. H. E. Pearse, Strong Memorial Hospital, 260 Crittenden Blvd., University of Rochester, Rochester 7, New York 1

Dr. J. D. Hardy, Aviation Medical Acceleration Laboratory, Naval Air Development Center, Johnsville, Pennsylvania 1

OTHERS

Dr. E. F. Cox, Applied Physics Division, Sandia Corp., Albuquerque, New Mexico 1

Dr. Alvin C. Graves, Los Alamos Scientific Lab., Box 1663, Los Alamos, New Mexico 1

Director, Los Alamos Scientific Lab., PO Box 1663, Los Alamos, New Mexico, ATTN: Reports Library 1

Director, Engineering Research, University of California, PO Box 4063, Westwood Village Station, Los Angeles 24, California 1

Dr. William T. Ham, Medical College of Virginia, Richmond, Virginia 1

California Forest and Range Experimental Station, U. S. Forest Service, PO Box 245, Berkeley, California ATTN: W. L. Fons, Division Forest Fire Research 1

Professor G. C. Williams, Dept. of Cml Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts 1

Mr. H. D. Bruce, Forest Products Lab., North Walnut St., Madison 5, Wisconsin 1

Mr. A. A. Brown, Chief, Fire Research Division, Forest Service, USDA, Washington 25, D.C. 1

Technical Operations Inc., 6 Schouler Court, Arlington 74, Massachusetts ATTN: Dr. Frederick C. Henriques 1

Material Laboratory, New York Naval Shipyard. 5046-3, Part 77

RESEARCH REPORT ON HEAT-REFLECTING TEXTILES AS PROTECTIVE BARRIERS AGAINST INTENSE THERMAL RADIATION, by R. C. Maggio and T. B. Gilhooly. Final report. 25 March 1955. 7 p. tables. (APSWP-838)

UNCLASSIFIED

The relative effectiveness of four heat-reflecting fabrics was determined, including aluminum coatings bonded to the base fabric, aluminized deposits, white organic coatings, and bleached goods. The temperatures of human skin and an epoxy-resin skin simulant contiguous to the irradiated cloth indicate that for a given radiant exposure the temperature rise behind the fabric with the aluminum-foil coating is one-fifth that behind the white bleached goods; the resistance of the other two fabric types is intermediate.

1. Textiles - effects of radiation
2. Fire resistant textiles
3. Thermal radiation - physiological effects

I. Maggio, R. C.
II. Gilhooly, T.B.
III. NS 081-001
IV. APSWP-838

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