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EVALUATION OF FLAMMABILITY OF FOOTWEAR UPPER MATERIALS:

PATENT AND REGULAR SHOE UPPER LEATHER VS. PORVAIR AND CLARINO POROMERICS

NAVY CLOTHING AND TEXTILE RESEARCH FACILITY
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The Chief of Naval Operations requested that the Navy Clothing & Textile Research Facility (NCTRF) investigate the flammability and burn hazard potential of poromeric materials (Porvair and Clarino), after poromeric shoes worn by a sailor caught fire and severely burned his feet. As a result, poromeric materials were compared with regular leather and patent leather under several heat and flammability conditions.

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The findings showed poromerics burn when exposed to open flames and are indeed potentially hazardous; while the leathers, including patent leather, which has an easy-care finish like the poromerics, are fire retardant. (U)

TABLE OF CONTENTS

LIST OF TABLES

EVALUATION OF FLAMMABILITY OF FOOTWEAR UPPER MATERIALS: PATENT AND REGULAR SHOE UPPER LEATHER VS. PORVAIR AND CLARINO POROMERICS

INTRODUCTION

The Chief of Naval Operations requested that the Navy Clothing and Textile Research Facility (NCTRF) investigate the effects of fire and heat on poromeric upper materials (Poromerics--shiny, synthetic, upper materials used in dress footwear of military personnel) after poromeric shoes worn by a sailor in an engine room caught fire and severely burned his feet. As a result, personnel throughout the Navy were instructed to avoid wearing poromeric shoes when working near high heat sources.

This report discusses general findings, flammability, and heat transfer data of a comparative evaluation of poromeric and leather shoe upper materials worn by Navy personnel.

DESCRIPTION OF EVALUATED MATERIALS

Shoe Upper Materials

Poromerics--permeable, synthetic materials with glossy shine:

Porvair (PR)--homogenous polyurethane from Porvair Ltd., Kings Lynn, U.K. ([illegible] inch thick).

Clarino (CL)--polyester PU-coated, non-woven from Kuray Co., Japan (4/64 inch thick).

Leathers--cattlehide leather, chrome-tanned:

Patent Leather (PL)--Braude Co., Woburn, MA (3/64 inch thick), with high-gloss surface.

Upper Leather (UL)--A.C. Lawrence Co., South Paris, ME (4.5/64 inch thick), with conventional top-grain surface.

The thickness of leather is reported in 1/64 inch, a trade practice. It is also called "1-ounce leather." A 3/64-inch leather is thus designated "3-ounce leather."

All specimens, except the UL, had high-gloss polyurethane finishes. The UL leather contained a conventional acrylic finish, which is maintained by polishing with commercial shoe waxes.

Combination of Shoe Upper Materials and Linings

PR, CL, PL, and UL were combined with an aluminum foil doubler interlining and a 1.1 oz per yd^2, 75/25 polyester/cotton, plain weave lining.

Military Dress Oxfords with PR, CL, PL, and UL Upper Materials

TEST PROCEDURES AND RESULTS

Preconditioning of Materials

All tested materials and footwear were conditioned in a standard atmosphere of 21 (± 1) degrees C and 65 (± 2) % rh for 72 hours.

Flammability Measurements

Procedure. To test flammability, specimens were subjected to a vertical flammability test as specified in Method 5903 of Federal Standard 191, Textile Test Methods. Specimens measuring 3/4 in by 12 in were fixed in a vertical frame, placed in a cabinet, and exposed at the bottom edge to a gas burner flame for 12 seconds. Table 1 shows the time the specimen continued to burn after the burner was turned off (i.e., "After Flame Time"), the time the specimen glowed after it stopped burning ("After Glow Time"), and the length of the char caused by the burning.

Results. Table 1 data indicate that poromerics were totally consumed by flames in 94 seconds or less, and they melted while burning. By contrast, the leathers showed excellent flame resistance, short after-flame and after-glow times, and char lengths of 0.1 in or less.

Table 1. Flame resistance—FED STD 191—Method 5903.

Specimen		After Flame Time (seconds)	After Glow Time (seconds)	Char Length (inch)
Porvair (PR)*		87	Totally burned	Specimen melted
Clarino (CL)*		94	Totally burned	Specimen melted
Patent Leather	PL-1	0	0	.1
	PL-2	0	3.5	.1
	PL-3	0	3.1	.1
	PL-4	1.2	0.2	.1
	PL-5	0	0	.1
	PL-6	.2	1.4	.1
Upper Leather	UL-1	0	0	0
	UL-2	0	0	0
	UL-3	0	0	.1
	UL-4	0	0	.1
	UL-5	0	0	0
	UL-6	0	0	0

*No additional specimens were burned because of extreme flammability of material.

Heat Transfer Measurements

Procedure. To test the effect of radiant heat fluxes resulting from fuel fires and hot objects, the four shoe materials were subjected to the fire simulator test developed by Audet (1). Audet's device uses two quartz lamps as its infrared radiant source, and the heat level is controlled by two General Radio Variacs. The heat pulse is directed toward a specimen fixed in a 4-in-high by 2-in-wide window located in front of a water-cooled heat flux sensor. The test specimen is mounted 0.5 inch in front of the sensor, which measures the rate of heat transfer through the test material. The output of the heat flux sensor is continuously recorded on a Honeywell millivolt recorder with a variable chart speed. The test required a 45-second, quartz-lamp preheat time to ensure a constant incident heat flux during testing. The tests were done under three different conditions.

Condition	Applied Heat Flux ($gcal/cm^2/sec$)	Time (seconds)
1	1.00	15
2	0.50	30
3	0.25	90

Condition 1 represents the radiant heat striking a person 20 feet from a 30 ft X 30 ft petroleum fuel fire (2). Condition 2 is the heat flux striking a person at 40 ft from the same fire. Condition 3 shows the effect when a person is 220 ft away. Condition 3 is a common situation in hot industrial environments.

When tested, the specimens were horizontal or parallel to the ground, which is the position of a vamp, or forepart, of a shoe.

Results. For Condition 1 (1.00 $gcal/cm^2/sec$ for 15 sec), Table 2 shows that unsupported poromerics yielded maximum transmission rates of 0.20 $gcal/cm^2/sec$ for PR and 0.13 $gcal/cm^2/sec$ for CL. The poromerics softened, melted, and sagged under this condition. The same supported specimens' poromeric-aluminum doubler-polyester/cotton lining retarded heat considerably. The maximum heat transfer readings were 0.03 $gcal/cm^2/sec$; however, the poromeric materials were obviously damaged as when tested alone. They softened, melted, and sagged, and in the case of the CL material, developed burn holes 5/16 inch and 1/2 inch in diameter.

(1) Audet, N. F., **Visor System Materials for Aluminized Firemen's Hoods (Report 2: Evaluation of Gold-Coated Plastic Substrates)**, NCTRF Report 113, June 1975.

(2) Salzberg, F., and Campbell, J., **Air Ground Fire Suppression and Rescue Systems**, ITT Research Institute, October 1965, p. 18.

Table 2. *Comparative heat transfer values of shoe upper materials vs. shoe upper materials with aluminum foil doubler and 1.1 oz/yd 75/25 polyester/cotton lining exposed for 15 seconds to radiant heat pulse of 1.0 gcal/cm²/sec.*

Shoe Upper (No Doubler, No Lining)				Shoe Upper (Aluminum Foil Doubler, Cloth Lining)			
Component	Maximum Heat* Transmission (gcal/cm²/sec)	Average Specimen Weight (g)	Remarks	Components	Maximum Heat* Transmission (gcal/cm²/sec)	Average Specimen Weight (g)	Remarks
[illegible] (PR) 1	.20	6.1	Softens & Melts	PR 16	.03	6.1	Softens & Melts
2	.15			17	.03		
3	.20			18	.03		
[illegible] (CL) 1	.11	5.4	Softens & Melts	CL 16	.03	5.4	Softens & Melts
2	.11			17	.03		
3	.13			18	.03		
[illegible] leather (PL) 1	.31	9.0	Finish melts	PL 16	.03	9.0	Finish melts
2	.30			17	.03		H_2O exudes on foil
3	.28			18	.03		
[illegible] leather (UL) 1	.33	9.1	Finish melts	UL 16	.03	9.1	No effect
2	.48			17	.03		H_2O exudes on foil
3	.35			18	.03		

*[illegible] residual heat transfer after termination of heat pulse

The leathers, PL and UL, showed maximum heat transfer rates of 0.31 gcal/cm²/sec and 0.48 gcal/cm²/sec, respectively. There was no sagging, the leather finishes melted, and the bright polyurethane finish of the PL was badly damaged. The PL leather substrate, however, was not damaged. Water, in the form of steam, exuded from both the PL and UL material and condensed on the heat sensor. This condensation contributed to the higher heat flux transmission values measured with these materials compared with the poromerics.

Supported leathers showed heat transfer values as low as the supported poromerics. In this case, the steam condensed on the foil interlining rather than on the sensor, which effectively reduced the total heat transmitted to the sensor. Supported UL finishes were hardly affected, and PL finishes melted less than the unsupported matched samples that were evaluated.

For Condition 2 (0.50 gcal/cm²/sec for 30 sec), Table 3 shows that unsupported poromerics produced maximum heat transfer rates of 0.09 gcal/cm²/sec for CL. Both PR and CL softened and melted less than the similar specimens of Condition 1, but CL shrank. The maximum heat flux level of all supported specimens was 0.03 gcal/cm²/sec. Supported specimens of PR softened, sagged, and entrapped condensed moisture on the foil interlining.

Unsupported leathers PL and UL showed appreciably smaller heat transfer values than the same materials in Condition 1. The maximum value for PL and UL was 0.21 gcal/cm²/sec. The finish of the supported PL was damaged, but the UL material was not affected. Both supported materials showed condensed water on the foil interlining. The maximum transfer rate under this condition was 0.03 gcal/cm²/sec, the same as for supported poromerics RP and CL.

Table 3. Comparative heat transfer values of shoe upper materials vs. shoe upper materials with aluminum foil doubler and 1.1 oz/yd 75/25 polyester/cotton lining exposed for 30 seconds to radiant heat pulse of 0.5 gcal/cm²/sec.

Shoe Upper (No Doubler, No Lining)				Shoe Upper (Aluminum Foil Doubler, Cloth Lining)			
Component	**Maximum Heat* Transmission (gcal/cm²/sec)**	**Average Specimen Weight (g)**	**Remarks**	**Components**	**Maximum Heat* Transmission (gcal/cm²/sec)**	**Average Specimen Weight (g)**	**Remarks**
Porvair (PR) 4	.06	6.1	Softens &	PR 13	.03	6.1	Softens &
5	.09		Melts	14	.03		sags
6	.06			15	.03		H_2O exudes
Clarino (CL) 4	.08	5.4	Finish Melts	CL 13	.03	5.4	Finish
5	.08		Substrate	14	.03		bubbles
6	.08		Shrinks	15	.03		
Patent Leather (PL) 4	.21	9.0	Slight finish	PL 13	.03	9.0	Much H_2O
5	.21		Melt and	14	.03		exudes
6	.20		Much H_2O exudes	15	.03		
Upper Leather (UL) 4	.21	9.1	H_2O exudes	UL 13	.03	9.1	Much H_2
5	.16			14	.03		exudes
6	.21			15	.03		

*No evidence of residual heat transfer after termination of heat pulse.

Table 4. Comparative heat transfer values of shoe upper materials vs. shoe upper materials with aluminum foil doubler and 1.1 oz/yd 75/25 polyester/cotton lining exposed for 30 seconds to radiant heat pulse of 0.5 gcal/cm²/sec.

Shoe Upper (No Doubler, No Lining)				Shoe Upper (Aluminum Foil Doubler, Cloth Lining)			
Component	**Maximum Heat* Transmission (gcal/cm²/sec)**	**Average Specimen Weight (g)**	**Remarks**	**Components**	**Maximum Heat* Transmission (gcal/cm²/sec)**	**Average Specimen Weight (g)**	**Remarks**
Porvair (PR) 7	.09	6.1	Softens &	PR 10	.03	6.1	Softens &
8	.09		Melts	11	.03		Melts
9	.08			12	.03		
Clarino (CL) 7	.08	5.4	Softens	CL 10	.03	5.4	Softens &
8	.08			11	.03		Sags
9	.10			12	.03		
Patent Leather (PL) 7	.10	9.0	H_2O exudes	PL 10	.03	9.0	H_2O exudes
8	.10			11	.03		
9	10			12	.03		
Upper Leather (UL) 7	.10	9.1	H_2O exudes	UL 10	.03	9.1	H_2O exudes
8	10			11	.03		
9	10			12	.03		

*No evidence of residual heat transfer after termination of heat pulse

For Condition 3 (0.25 gcal/cm²/sec for 90 sec), Table 4 shows that the supported poromerics yielded maximum heat transfer rates of 0.09 gcal/cm²/sec for PR and 0.10 gcal/cm²/sec for CL. Even though the total energy of the Condition 3 pulse was greater than for Condition 2 (heat flux X time), the effect on the finishes was the same as for Condition 2. The unsupported CL softened, curled, and showed some substrate shrinking. Unsupported leathers were [illegible] affected. The maximum heat transfer rate for both PL and UL was 0.10 gcal/cm²/sec.

These results show that an initial high heat pulse (1.0 gcal/cm²/sec) of short duration does significantly more damage than a lower flux pulse sustained over a considerably longer time interval, though the total incident heat energy for the lower flux pulse was greater. In the longer tests, there is more time for the materials to lose heat to the local environment.

Supported leather showed uniform heat flux values of 0.03 gcal/cm²/sec and condensed moisture on the foil interlining. The heat energy of Condition 3 did not seriously change the poromeric and leather finishes, but a PR specimen exuded plasticizer on the non-finish side.

A review of Tables 2, 3, and 4 shows that all of the supported specimens (poromeric and leather) had equivalent maximum heat transfer values (0.03 gcal/cm²/sec).

Table 5. Effect of hot foot test on Porvair (PR), Clarino (CL), patent leather (PL), and upper leather (UL) footwear; and match flames on toluene-soaked (5cc) toes of same.

Footwear	Hot Foot Test		Toluene Ignited
PR 1 left shoe 2 right shoe	Flame extinguishes slight melt	3 sec 2 sec	Finish melts. Flame extinguishes 3 sec
CL 1 left shoe 2 right shoe	Flame extinguishes slight melt	2 sec	Finish melts. Flame extinguishes 2 seconds. Match melts surface.
PL 1 left shoe 2 right shoe	Flame extinguishes slight melt	2 sec	Finish burns, melts very little, extinguishes 2 seconds
UL 1 left shoe 2 right shoe	Flame extinguishes in less than 4 sec. No effect on finish.		Flame extinguishes in less than 1 sec. No effect on finish.
UL 1 & 2 do not sustain flames even after toluene soak.			

Hot Foot and Burn Tests on Footwear

Hot foot and burn tests were done on PR, CL, PL, and UL dress oxfords (Bates Shoe Co., Webster, MA). Heads of BASF safety matches were placed in the waist section of the shoes between the welt and the upper and ignited. Maximum duration of the flame was 3 seconds (see Table 5). All urethane finishes were slightly affected: PR, CL, and PL. The UL finish did not change.

Hot foot tests were followed by solvent burn tests. Five cubic centimeters of toluene were poured on the vamp of the footwear and ignited after a 50-second soak. Polyurethane finishes of PR, CR, and PL melted. Flames lasted 2 and 3 seconds. There was minimum melting on the PL footwear and no melting of the UL finishes. The flame lasted less than 1 second on the UL footwear.

Burn Through Tests in Footwear

To simulate the effect of "super-heated" slag burning embers and red-hot particles falling on the footwear, a burning methanamine reagent tablet used for testing flammability of textile floor covering materials was placed on the vamp of each shoe. The tablet was held by forceps and lighted by a Bunsen burner. The duration of burning and the nature and dimensions of damage are shown in Table 6. The tablets burned through the poromeric shoes and burned from 90 to 166 seconds. Burn time was at least 76 seconds on all of the dress shoes.

Table 6. Effect of methanamine reagent table test on Porvair (PR), Clarino (CL), patent leather (PL) and upper leather (UL) footwear.*

Footwear	Burn Time (sec)	Results
PR 1 left shoe	90	Burn through, 5/8" hole leather lining does not burn
PR 2 right shoe	166	Air pocket accelerates burn through, 1½" hole, leather lining does not burn
CL 1 left shoe	94	Burn through, finish boils through, ¼" hole, leather lining does not burn
CL 2 right shoe	118	
PL 1 left shoe	110	Finish burns, ½" scar leather does not burn
PL 2 right shoe	120	
UL 1 left shoe	76	Finish barely affected, ¼" scar, leather does not burn
UL 2 right shoe	98	

*Burning Methanamine Reagent Tablet #1588, Eli Lilly Inc., 307 E. McCarthy St., Indianapolis, IN 46206.

A PR shoe whose separated lining created an air pocket burned 166 seconds. Leather linings prevented the tablet from burning completely through the poromeric footwear. Touching the lining from inside the shoe indicated that transferred heat would be significant. Resulting burn holes were at least 0.5 inch in diameter on the PR and CL oxfords whose urethane finishes supported combustion. A hole 1.50 inches in diameter occurred in one PR shoe where there was an air pocket between the poromeric material and the leather lining. The UL oxfords showed a 0.25-in diameter scar; the leather did not burn. The PL finish burned, but the underlying leather substrate did not burn. Instead, it showed a 1/2-in scar.

DISCUSSION OF RESULTS

Test results showed that poromerics are potentially hazardous materials in high heat environments. Therefore, they should be avoided as footwear components if personnel are to come in contact with flames or hot objects.

Patent leather (PL), which looks like poromerics, is a safer substitute and should be more comfortable and protective.

Standard leather is the more fire resistant and the least susceptible to damage from flame and hot objects.

Patent and regular leather showed significantly higher heat transfer rates than poromerics, but the rates were reduced significantly and were equal to the poromerics when lining combinations simulating regular footwear structures were applied. The maximum heat transfer rates for all of the supported structures were identical and relatively low (0.03 gcal/cm^2/sec). The findings suggest there is no heat transfer disadvantage for leather when used in combination with linings.

CONCLUSIONS

1. Upper and patent leather are more fire retardant than poromerics and should be safer under high heat conditions.

2. Patent leather seems to have all of the appearance attributes of poromerics and is more fire retardant.

RECOMMENDATIONS

1. Consider abandoning poromeric materials in the interest of safety, particularly in shipboard environments.

2. Investigate patent leather as a substitute for poromerics. A wear test of this footwear is being conducted by NCTRF at the U. S. Naval Academy.

3. Alert the Navy Resale and Services Support Office to potential hazards of poromerics and suggest use of patent and regular leather shoes as replacements.