Performance of Selected Coatings Applied to Polystyrene Block Walls Under Simulated Mine Fire Conditions

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A test program was undertaken by the Mine Safety and Health Administration (MSHA) to determine the feasibility of coating polystyrene block walls for fire protection. Selected coatings, used in the mining industry, were tested under semilarge scale, simulated mine fire conditions to determine the appropriate thicknesses of these coatings for protection of the polystyrene foam block against fire for specified time periods. Building plasters containing gypsum and perlite and an expanded vermiculite, portland cement, and limestone coating were particularly effective in protecting the foam blocks against the heat of the simulated mine fire.

INTRODUCTION

THE IMPETUS FOR THIS TEST PROGRAM was a proposed Mine Safety and Health Administration (MSHA) regulation[1] for gassy metal and nonmetallic mines, mining noncombustible ores, which would allow the use of stoppings (walls built in the mines to close openings for the purpose of coursing ventilating air to active working areas) constructed of foam-type blocks, provided that they were coated with suitable fire resistant materials.

The primary advantages of erecting a stopping using foam plastic block are a reduced construction time (about 2 hours with a two person crew) when compared to a masonry block, or wood timber structure, and added safety, since the materials are lightweight and can be cut with a handsaw. A wood stopping takes approximately 8 hours to build and requires the handling of heavy timber, which could result in back injuries, pinching of fingers, splinters, etc. Cutting the timber also involves use of a chain. saw, a potentially dangerous piece of equipment. Foam-block stoppings, when

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properly constructed, also offer excellent compressibility properties and, hence, can withstand floor heave and roof sag in mines better than other nonresilient types of stoppings.

Two potential problem areas associated with construction of foam-block stoppings are the combustibility of the block and the overall strength or "substantiality" of the structure. In the event of a nearby fire, it is important that the structure offer some resistance to the penetration of heat and flame, which could divert smoke and gas into the adjacent airways. The products of combustion from burning plastic materials also may pose a hazardous situation. The Threshhold Limit Values (TLVs) of certain decomposition products of foam plastic type materials are on the order of a few parts per million."

With these potential problem areas in mind, the study attempted to focus on two major items pertaining to polystyrene stopping construction and performance. They were as follows:

1. To determine the bonding characteristics of the various coatings to polystyrene blocks.
2. To determine the minimum application thickness, for specific coatings, to achieve adequate fire protection for polystyrene block walls.

FIRE RESISTANCE TESTING

TEST FACILITY

Fire resistance testing was performed in the Industrial Safety Division's fire gallery. The gallery is a modified "X" shaped structure constructed of 4 ft high, concrete filled, cement block walls and an arch shaped, corrugated steel roof. The interior surfaces of the gallery have been lined with **4** in. of ceramic blanket material to protect them against the heat generated during the test fires. Junction boxes, located on the exterior walls of the gallery, provide interfacing cable for temperature and velocity recording instrumentation. Ventilation is provided by a high capacity fan capable of producing up to 100,000 cfm at a pressure drop of 8.0 in. water gage. A plan view of the gallery is shown in Figure 1. The fire zone was located in the east section of the gallery. A nominal 6 ft by 6 ft opening was constructed using 8 in. concrete blocks covered with a thin coating of fiberglass reinforced mortar. The roof of the fire zone was covered with a ceramic blanket, held in place with bolted 1 in. steel straps and backed with 1/2 in. noncombustible calcium silicate based board.

DEVELOPMENT OF STANDARD TEST FIRE

Wood Crib: It was initially decided to use a crib constructed of wood as a source of heat for the test fire. The crib was patterned after the wood crib utilized in the "Enclosed Room Fire Test," a test utilized by the industry to evaluate coatings over foamed plastics for a 15-min. fire protection rating."

A l/2 in. thick noncombustible board wall was installed in the opening of the fire frame. The crib was centered with respect to the wall, 4 in. above the floor, 1 in. from the face of the wall. Nine 20 gage Type K thermocouples were equally spaced on the surface of the board and served to measure temperatures generated by the burning crib. The crib was ignited with an electric match and allowed to burn for 30 min. A circular foil radiometer was placed in the wall above the crib and measured the irradiative heat flux impinging on the wall during the test. The fire zone and location of thermocouples and radiometer are shown in Figure 2. There was no ventilation in the gallery during this preliminary fire test. Temperatures generated as a result of this crib fire are shown in Figure 3. The average heat flux measured by the radiometer was 2.3 Btu/ft^2/sec. This flux remained fairly constant for a period of about 17 min. The maximum temperature measured on the surface of the wall was 734 °F (390°C) at the bottom center location, This temperature is considerably higher than the average temperature reported in Figure 3 at this location due to the absence of significant heat at the location of the left and right bottom thermocouples.

Analysis of the data from the preliminary crib fire revealed that the fire was limited to about a 15-min useful time period where constant heat fluxes could be measured In addition, the temperatures measured on the surface

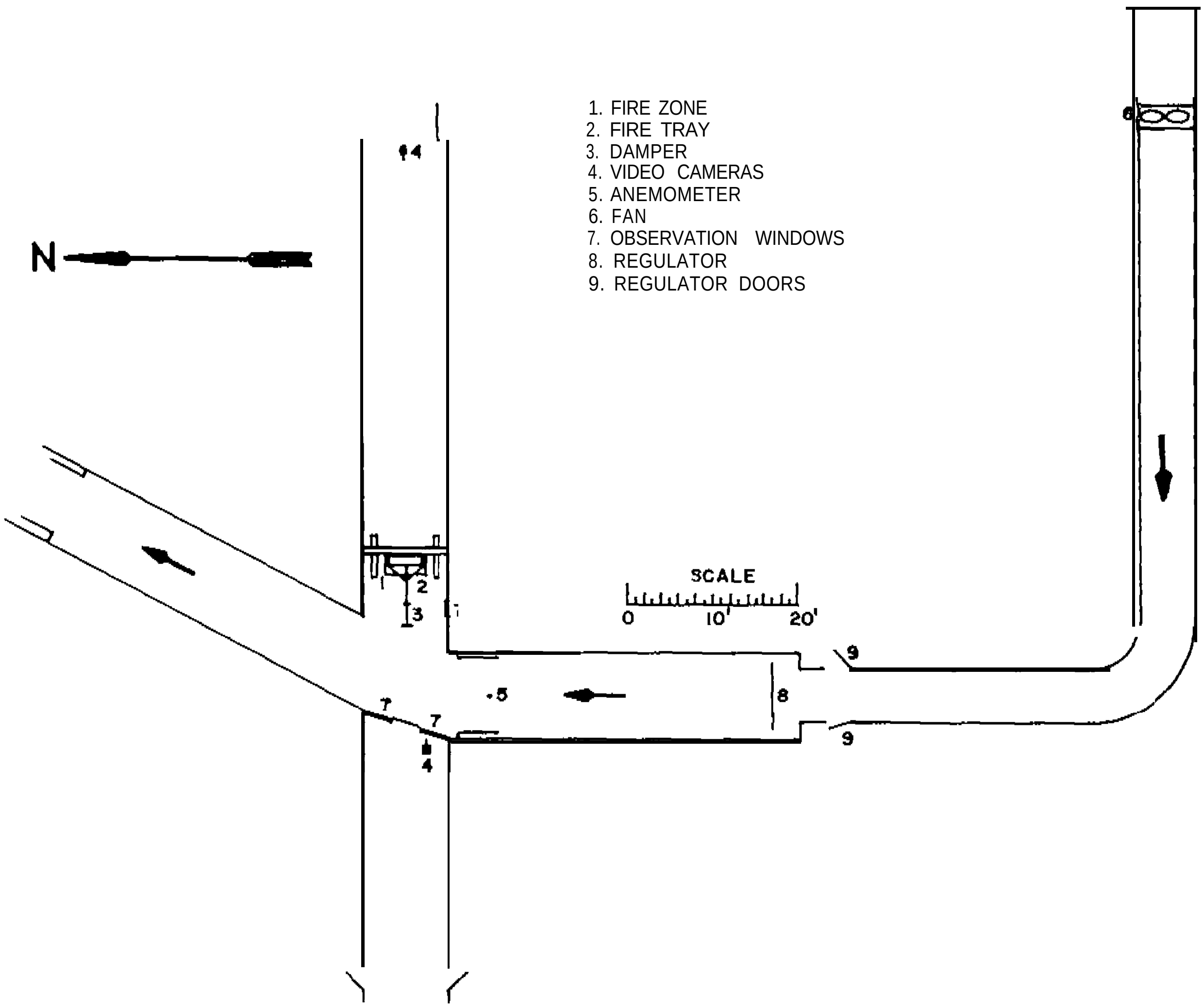

Figure 1. Plan view of fire gallery.

of the wall were considerably lower than those that were desired to enable a rigorous evaluation of the fire resistance characteristics of the walls to be tested. For these two reasons, it was decided to select an alternative source of heat for our test program. After considerable deliberation, it was decided to experiment with a flammable liquid fire. Use of a flammable liquid would enable careful control of the heat release rate and overall burning time, and would also result in much higher temperatures on the surface of the wall. All three of these factors were beneficial to the objectives of our program.

Diesel Fuel: Approximately 6 gal of No. 2 diesel fuel (heat of combustion = 20,000 Btu/lb) were placed in a mortar box measuring 4 ft long by 2 ft wide by 10 in. deep. The mortar box was placed in front of and 1 in. out from the wall. The fuel was ignited by mixing with 1/2 gal of gasoline and use of an electric match. The fan, running with minimum blade pitch and no regulation, provided about 1,600 fpm (104,000 cfm) of air. The fire burned for about 15 min. The inefficient burning characteristics of diesel fuel under the conditions employed in the test resulted in the generation of thick, black smoke, which obscured viewing of the test through the observation port. The maximum temperature reached was 1,283°F (695°C) near the lower right side of the wall. Use of this fuel resulted in a much hotter fire of more uniform heat flux distribution on the surface of the wall. The behavior of the fire was acceptable in all areas except smoke generation.

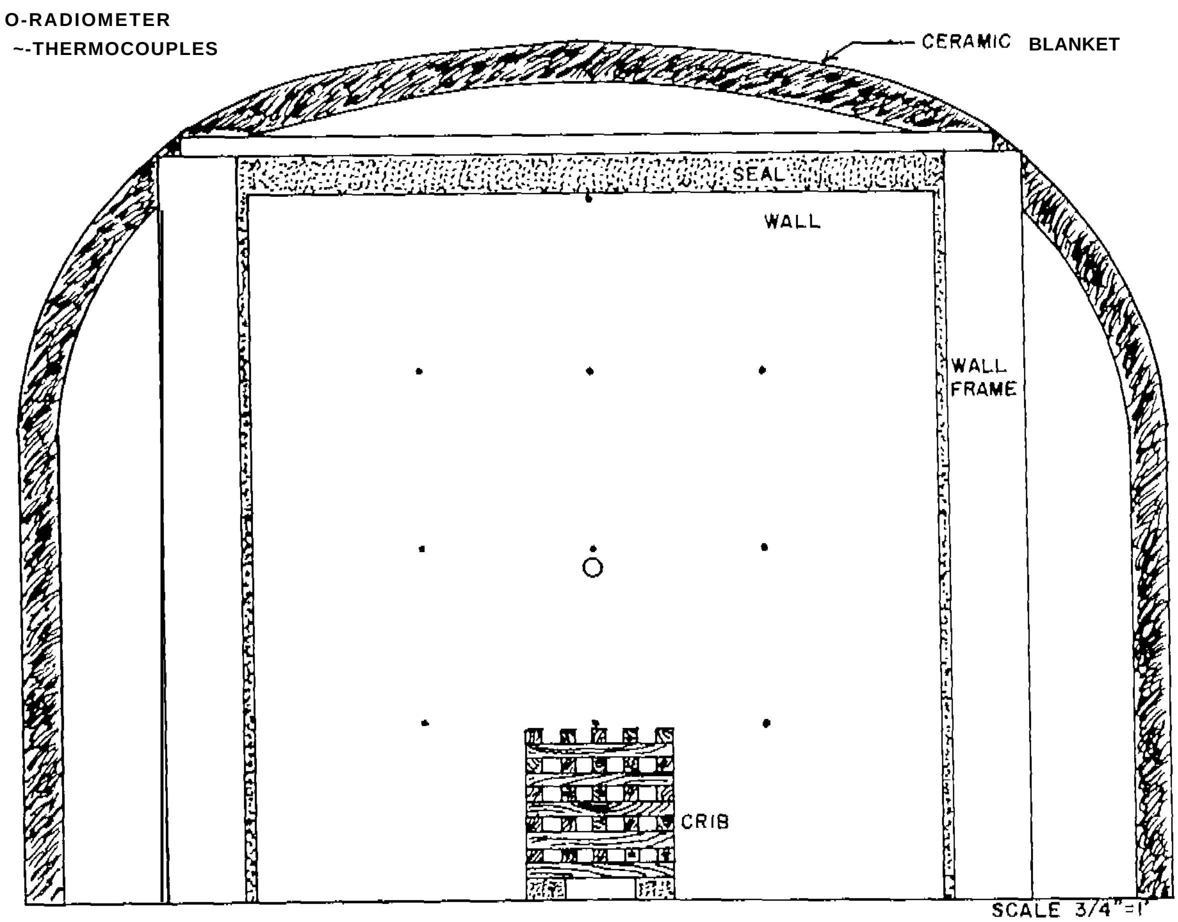

Figure 2. Fire zone instrumented with radiometer and thermocouples.

Flammable Solvent: After experimenting with various cleaner burning flammable liquids, we decided on a flammable solvent, used in the manufacturing of rubber (heat of combustion = 20,608 Btu/lb), consisting of a blend of about 80 percent hexanes and 20 percent cyclicparaffins.

A block wall, built with 8 in. by 16 in. by 8 in., 2-celled, concrete blocks, laid with wet mortar joints, was constructed in the opening of the fire frame for this test. The wall was instrumented with surface thermocouples placed in locations identical to those of the wood crib test.

To provide a fuel reservoir for this test and future fire testing, a fire tray was constructed using 1/4 in., cold-rolled steel plates. The dimensions of the tray were 48 in. long by 9 in. wide by 12 in. deep. An insulated 1/2 in. stainless steel tubing line was attached to the front of the fire tray near the bottom. This line delivered flammable liquid into the tray at a prescribed rate during the test. A peristaltic pump, located outside of the gallery, pumped flammable liquid from two 5 gal containers into the fire tray. The bottom 3 in. of the fire tray was covered with water to prevent heat damage to the stainless steel tubing and walls of the tray. The flow of fuel into the tray was remotely controlled through a switch in the main control building.

The tray was centered with respect to the wall, placed 1 in. from the

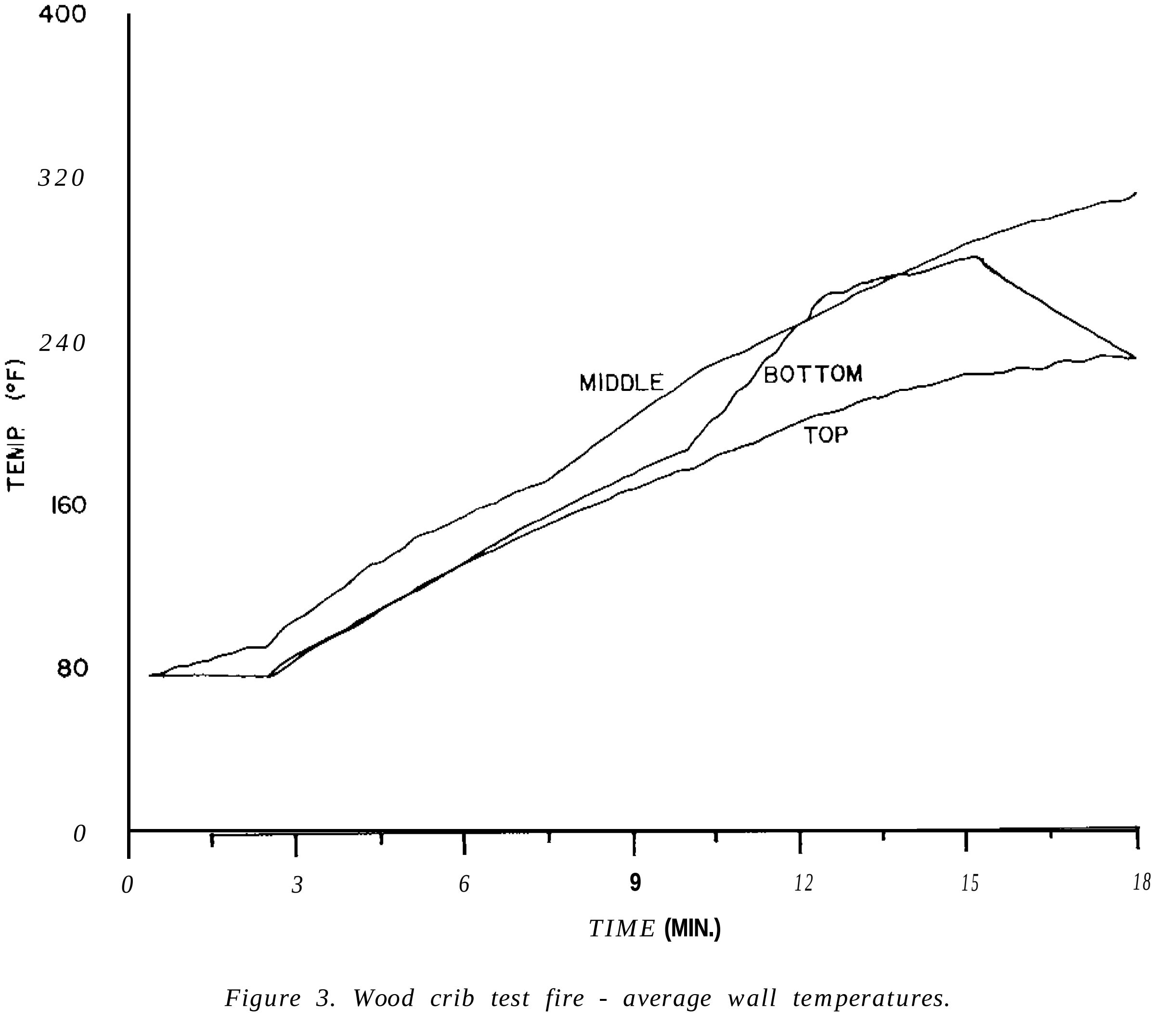

Figure 3. Wood crib test fire - average wall temperatures.

front, and filled to a flammable liquid depth of approximately 3.0 in. over the water. This provided about 5 gal of liquid initially, which would sustain about 25 min of burning. The pump could be remotely activated to permit flow of fuel into the fire box, enabling longer fire durations, if necessary. A damper system was constructed to control the size of the fire if excessively high temperatures were being generated in the gallery. The damper could be manually activated to close the top of the fire tray.

A **1** hr test was conducted using this liquid as a source of fuel. The liquid burned clean at a relatively uniform rate of 0.1 in/min, generated a minimal amount of smoke permitting observation of the walls, and provided temperatures on the surface of the concrete block wall comparable to those of diesel fuel. A plot of average temperatures measured is shown in Figure **4.**

Due to the inherent air flow regime within the gallery, the flames from the test fire appeared to concentrate on the right side of the wall and the

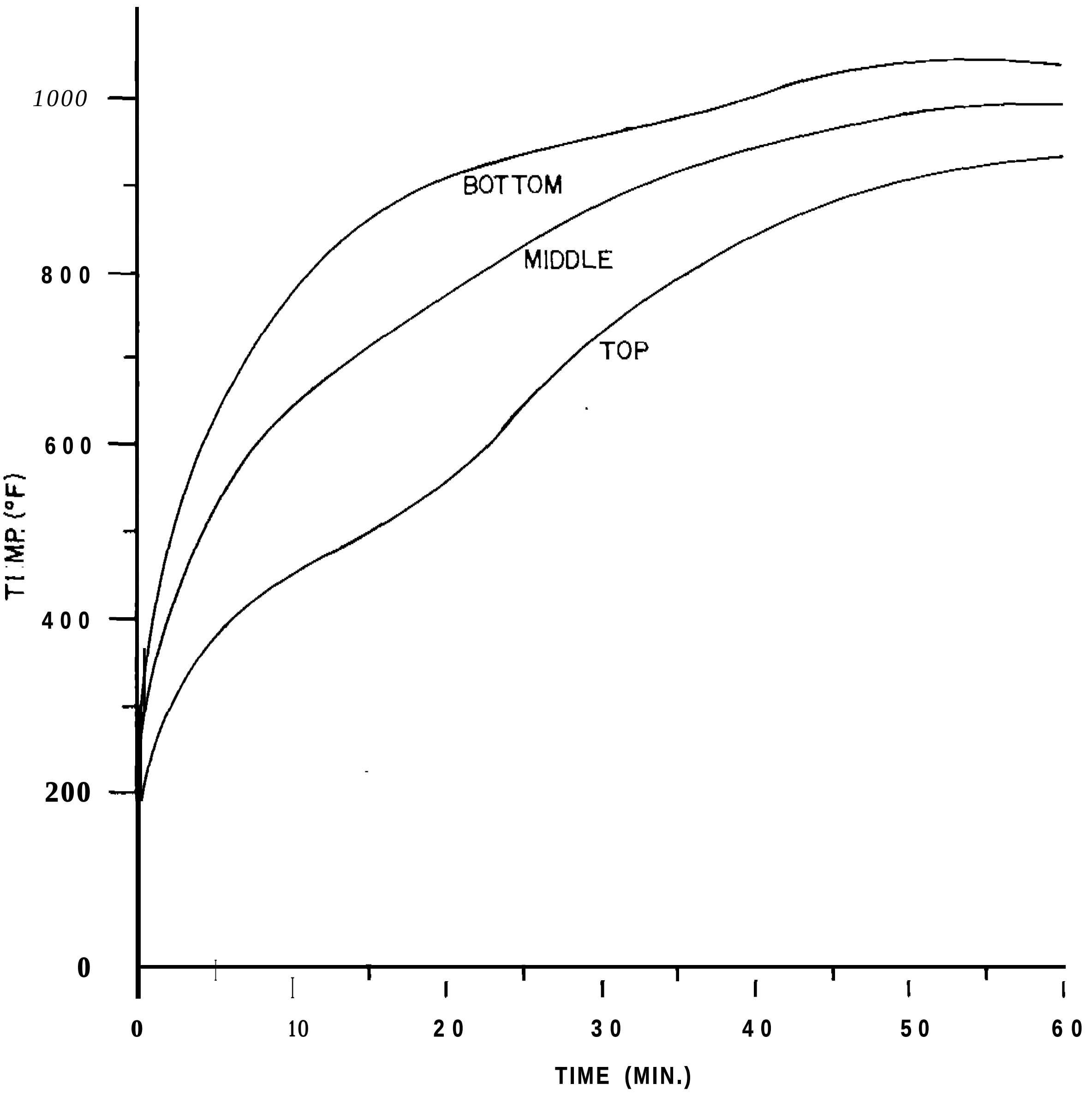

Figure 4. Flammable liquid test fire - average temperatures on surface of concrete block wall.

hottest temperatures were consistently measured there. These temperatures are shown in Figure 5.

The heat production rate of a fire involving this liquid was calculated to be 23,600 Btu/min. The average heat flux on the wall was determined to be 2.5 Btu/ft^2/sec and remained constant throughout the duration of the test.

FIRE TESTING

COATINGS APPLIED TO POLYSTYRENE BLOCK WALLS - RATIONALE

Fire testing was undertaken to investigate the effects of various types of coatings, commonly used in the mining environment, as barriers to prevent or impede the penetration of flame and heat into the foam blocks in the event of a fire.

The flammable liquid test fire was chosen because of its inherently controlled heat release properties and also because of the fact that this type of fire would simulate what could happen in the event of a diesel fuel or similar flammable liquid fire near a stopping in an underground mine. Diesel fuel is often used in underground mines and a scenario such as the one employed in the testing was not entirely unlikely. The heat of combustion and heat release rate of diesel fuel and the paraffinic solvent, in burning pool fires, are similar in nature.

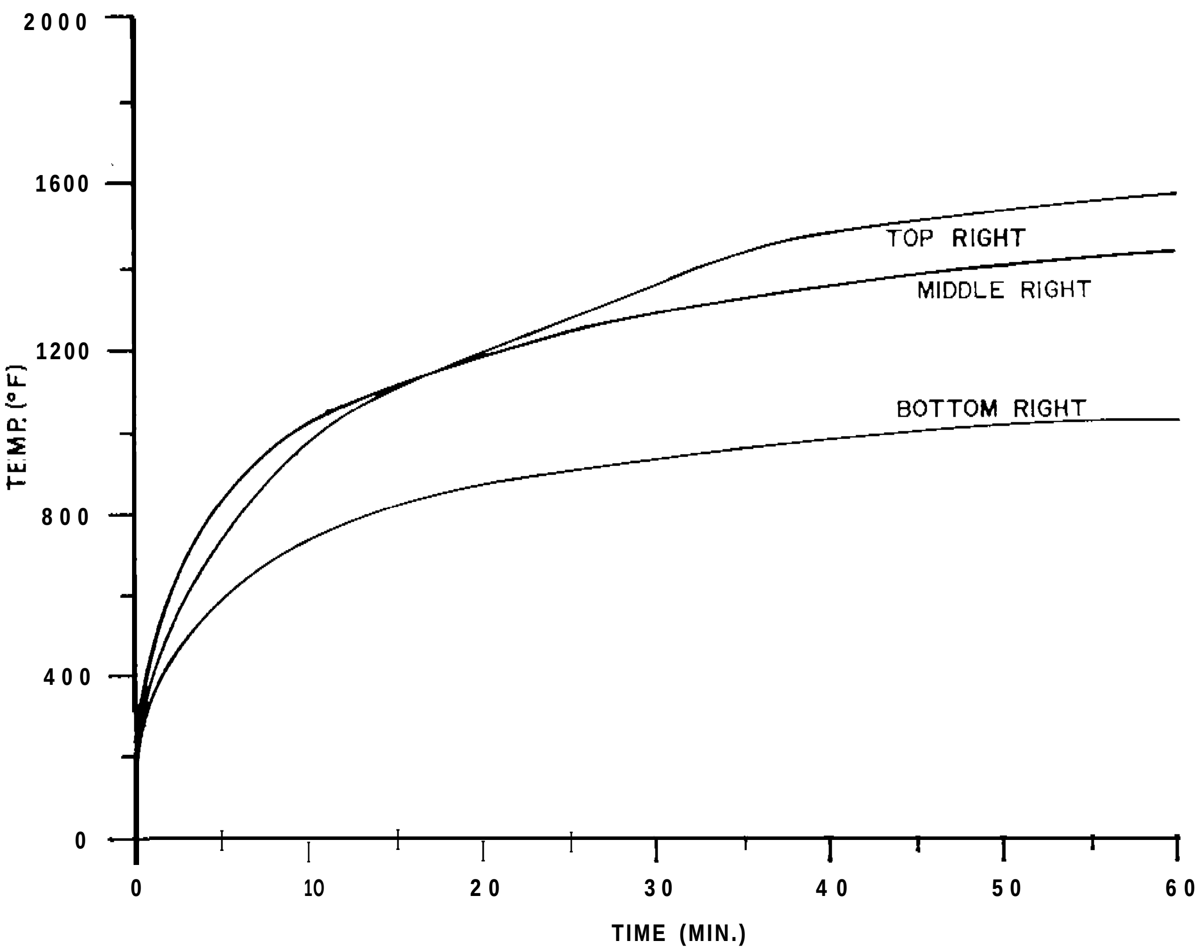

Figure 5. Flammable liquid test fire - temperatures on right side of concrete block wall.

Foam-block walls, measuring 6 ft by 6 ft by 12 in. thick, were constructed using 1 lb/ft^3 density polystyrene (Styrofoam) blocks. The walls were covered with various coatings applied in selected thicknesses, principally determined by analysis of some small scale, heat penetration test results conducted by our laboratory and recommendations provided by the specific coating manufacturers. The coated walls were moved into place in the fire zone and sealed around the perimeter using 6 lb/ft^3 density, ceramic fiber blanket material. The fan was set to provide an air flow of between 350 and 400 ft/min (23,000-26,000 cfm) past the fire zone during testing. This value was believed to be representative of the flows which could be found in the airways of metal and nonmetallic mines. Each wall was instrumented with 27 Type K, 20 gage thermocouples, which were used to monitor temperatures during the fire. The locations of the front, back, and interface thermocouples are shown in Figure 6.

The walls were subjected to the heat and flame of the test fire until an excessive heat rise was evident on the backside or failure of the coating occurred, whichever came first. In this manner, a relative comparison of the various coatings and thicknesses could be made. The ideal coating system would be one which would prevent the melting of the polystyrene foam blocks for a period equal to the maximum duration of the test, which was about one hour.

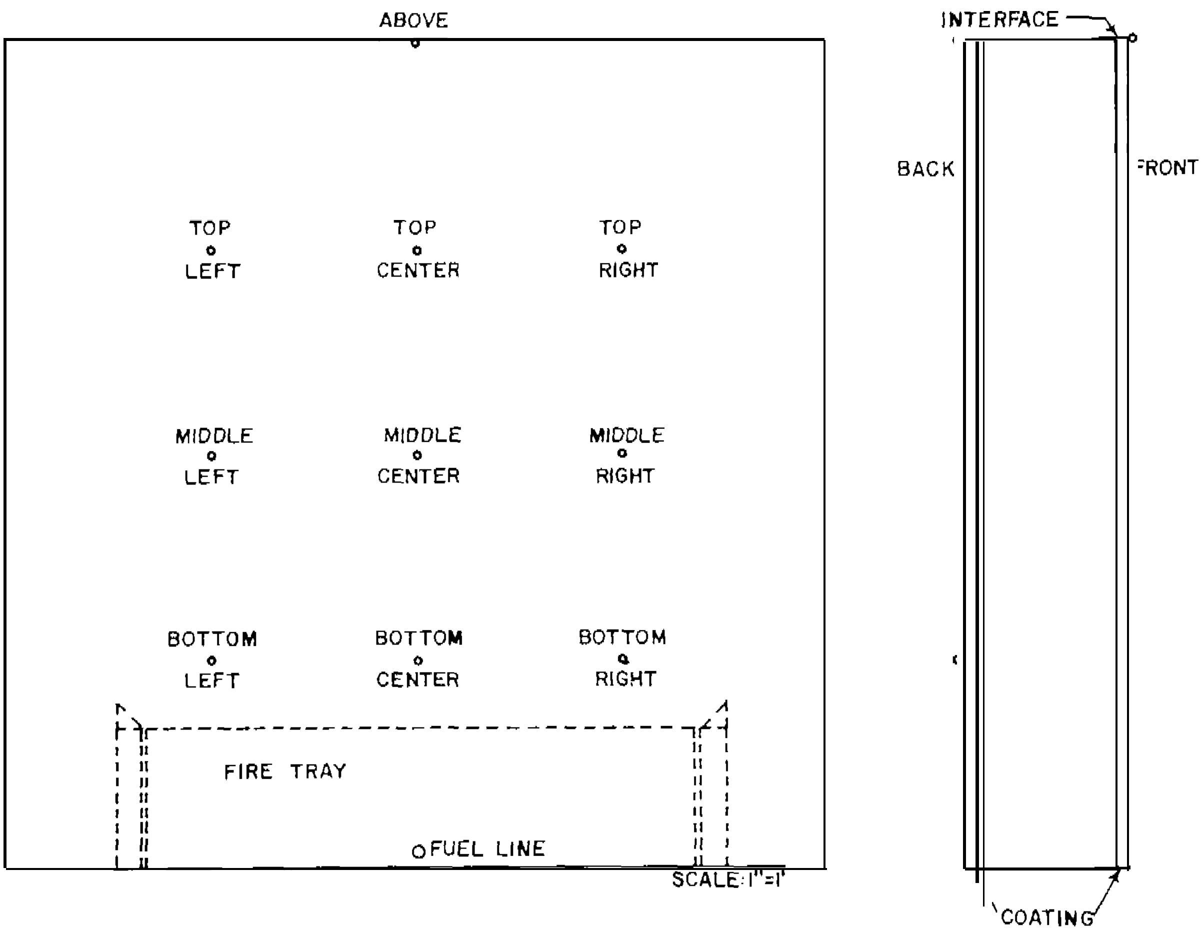

Figure 6. Test wall thermocouple locations.

DESCRIPTION OF COATINGS TESTED

A total of nine different classes of coatings were tested. These materials were representative of the common types of coatings being used in the mining industry, from a compositional standpoint. In addition, a ceramic fiber blanket material was tested as a potential fire resistant covering for the foam block walls. A list of the materials tested, along with their important characteristics, is given in Table 1.

TABLE 1. *Coating Materials Used in Fire Tests (coating 6 ft X 6 ft foam block walls)*

Coating Number	*General Composition*	*Density* (lb/ft^3)	*Thickness in.*	*Bags Required (face)*	*Primer*	*Application Technique*
1	Fiberglass, reinforced surface bonding mortar	~96	1/4	3	Yes	Wet spray
			1/2	4	Yes	
2	Cementitious coating consisting of 3 parts calcium carbonate, 1 part cement, plus small amount fiberglass	~160	1	9	Yes	Dry spray
			1/2	6	Yes	
3	Cementitious coating consisting of 3 parts sand, 1 part cement, plus small amount fiberglass	~160	1	9	Yes	Dry spray
			1/2	6	Yes	
4	Construction plaster containing perlite and gypsum	~80	1	2.5	Yes	Trowel
			2	4.5	No	
			1/2	1.3	No (R)	
5	Coating composed of expanded vermiculite, Portland cement and limestone	60	1	5	No (R)	Wet spray
			2	7	No	
			1/2	2.5	No (R)	
6	Mixture of inorganic mineral wool fibers and hydraulic setting inorganic binders	50	1	3	No (R)	Dry spray
			1/2	1.5	Yes	
7	Coating comprised of cellulose mixed with liquid sodium silicate	50	1/2	10 gal.	No (R)	Trowel
8	Cement-based insulating plaster with polystyrene beads	23	1	1	No (R)	Trowel
			1 1/2*	1.5	No (R)	Trowel
8	No. 8 with thin plaster finishing coat added	23	1	2 +1 bag finishing mix	Yes (R)	Trowel
9	Polyurethane foam in kit form	2.0	2	1 pack	No	Spray
10	Ceramic fiber blanket	6	2	N/A	No	Impaled on ceramic spikes
			3	N/A	No	

(R) represents surface of block roughed with wire brush prior to coating.
*Two pounds of glass fiber added per bag of plaster.

COHESION/ADHESION TESTING OF THE COATINGS APPLIED TO POLYSTYRENE BLOCKS

Cohesion/adhesion testing was conducted in accordance with ANSI/ASTM E736-80, "Standard Test Method for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members."" For our purposes, this test investigates the bonding capability of various fire resistive coatings as applied to polystyrene blocks proposed for stopping construction. It is very important that good bonding within the coating and at the interface of the coating and the block exist to insure adequate protection against fire. The cohesion/adhesion qualities of all the coatings listed in Table 1 exceeded the maximum requirements of the test, consequently, all of the coatings tested were considered to exhibit adequate bonding to the polystyrene blocks.

TEST WALL CONSTRUCTION AND COATING APPLICATION TECHNIQUES

As previously mentioned, the 6 ft by 6 ft test walls were constructed using 12 in. high by 24 in. long by 12 in. deep polystyrene blocks (melting point = 266 °F or 130°C) of nominal 1.0 lb/ft^3 density. Three blocks were laid on the floor side-by-side and formed the bottom course of the test stopping. The following courses were formed by staggering the joints and using half blocks, where applicable. Steel rods, 1/4 in. in diameter (20 in. long), were pushed into the blocks on 2 ft centers and served to anchor the courses together. This method facilitated the application of the coatings, also.

Coatings were applied according to the recommendations provided by the manufacturers. The method of application is also listed in Table 1. Selected walls were treated with a latex primer to enhance adhesion characteristics. This treatment is also noted in the Table.

TEST RESULTS

COATING No. 1 - Fiberglass Reinforced Surface Bonding Mortar

Test No. 1: A coating of 1/4 in. was applied to both sides of the wall using a wet spray technique. Because of the thin coating that was applied, only 3 min elapsed before the melting temperature of polystyrene was exceeded. At 25 min, flames were observed on the backside of the wall where polystyrene vapors had penetrated the coating. The integrity of the coating remained excellent during the test fire, which lasted 45 min. Small cracks were observed in the wall after cooling. It is not known when these cracks occurred. Virtually no polystyrene remained between the slabs after the test.

Test No. 2: A 1/2 in. coating was applied to both sides of the wall using a wet spray technique. The coating on the fire side and backside remained intact for the duration of the test, which was about 55 min. The backside of the wall was observed to be burning in a few select areas where polystyrene vapors were emanating. A few hairline cracks developed during the fire or upon cooling. The foam block melted completely within the two l/2 in. slabs of the coating. The first evidence of melting occurred at about 6 min near the bottom center of the wall. Temperature rises on the back of the wall began to occur at about 14 min.

COATING No. 2 - Cementitious Coating Consisting of 3 Parts Calcium Carbonate/l Part Cement/Glass Fibers

Test No. 3: A 1/2 in. coating of calcarious aggregate gunnite was applied to both sides of the wall by means of a dry spray technique. Cracking and spalling of the coating were observed early into the test. The test was terminated at 23 min due to a malfunction of the fuel feed system. No significant temperature rise was observed on the backside of the wall during this period. The wall remained intact with the exception of the cracking and spalling in some places.

Test No. 4: Both sides of the wall were covered with a nominal 1 in. coating of calcarious aggregate gunnite applied in the same manner as Test No. 3. Cracking and spalling of the coating were observed early into the test. At about 14 min into the test, a large hole formed in the coating allowing the polystyrene to melt out. The fire then became intense, causing the wall to eventually collapse. After about 17 min, temperatures began to rise on the back surface of the wall. The test was terminated in 28 minutes.

COATING NO. 3 - Cementitious Coating Consisting of 3 Parts Sand / l Part Cement/Glass Fibers

Test No. 5: A 1/2 in. silica-based aggregate gunnite was applied to both sides of the wall using dry spray techniques. Like the other gunnites tested, spalling and cracking occurred early into the test. The wall collapsed after 9 min. The backside of the wall eventually collapsed also. Temperatures in excess of 1652°F (900°C) were observed after the wall collapsed and the Styrofoam got involved in the fire.

Test No. 6: A silica-based aggregate gunnite coating was applied to both sides of the wall in a nominal **1** in. thickness by the technique previously discussed for gunnites. Spalling was observed 2 min into the test. The coating appeared to spa11 in l/2 in. thick layers. At 19 min, the upper right center section of the wall collapsed. The back of the wall remained intact; however, an 18 in. crack was discovered at the right center portion of the wall. The test was terminated in 21 min. No significant temperature rises were observed on the backside within this time period,

COATING NO. 4 - Construction Plaster Containing Perlite and Gypsum

Test No. 7: A 1/2 in. coating of plaster was applied by trowel to the front side and l/4 in. applied to the backside of the wall. Minor cracking and spalling were observed at about 6 min into the test and became more pronounced as the test progressed. Parts of the wall began to sag at 28 min. The wall failed at 35 min. The first evidence of significant temperature rise on the back of the wall occurred at about 20 min. At about **10** min, the foam began to melt in the middle right area of the wall at the interface.

Test No. 8: A 1 in. coating was applied, by trowel, to the face of the wall. The backside was coated with US in. of the plaster. The coating protected the foam from melting for over 25 min. Some cracking was noticed about 9 min into the test. At 44 min, the top right corner fell away, The first indication of heat on the backside of the wall occurred at the 40 min mark. After the test was complete, the wall was examined. The foam remained intact on the left and lower right side of the wall.

Test No. 9: Two in. of plaster was applied to both sides of the polystyrene block wall. Minor cracks were observed in the wall beginning at about 17 min. Interface temperatures climbed to 212°F (100°C) and remained there for the duration of the test, which was 60 min. There was no melting observed at the coating/block interface during the fire test period. Examination of the wall after the test revealed that the cracks did not penetrate more than 3/4 in. into the coating.

COATING NO. 5 - Expanded Vermiculite, Portland Cement, and Limestone

Test No. 10: A nominal 1/2 in. coating was applied to both sides of the wall using a wet spray technique. Minor cracking of the wall on the right side was observed at about the 7 min mark. Melting of the foam block occurred at about the same time in the middle right portion of the wall. The wall remained intact during the duration of the test, which lasted 44 min.

Test No. 11: A nominal 1 in. thick layer was applied to each side of the wall. Minor cracking was observed at about 15 min into the test and was concentrated on the right side of the wall where flame impingement was heaviest. The first evidence of polystyrene foam melting occurred at about 28 min at the bottom center of the wall. Temperatures began to rise on the backside of the wall at about 30 min.

Test No. 12: A 2 in. thick coating of material was applied to the face of the wall. Small cracks were observed in the wall at about 33 min into the test. The maximum temperature reached by the interface thermocouples was 212°F (l00°C) during the 60 min duration of the test. This interface temperature is believed to be due to water vapor from the coating being driven away from the source of heat. Since the coating was allowed to cure for only 6 days, excessive moisture in the wall undoubtedly enhanced the fire test performance of this specimen. The backside of the wall was cool to the touch at the 60 min mark.

COATING No. 6 - Inorganic Mineral Wool Fibers and Hydraulic Setting Inorganic Binders

Test No. 13: A nominal 1/2 in. coating was applied to both sides of the wall using a dry spray technique. At the 12 min mark, flames were observed on the backside of the wall. Cracking and failure occurred 3 min after the test was completed. Melting of the foam first occurred at 4.2 min near the hottom center of the wall.

Test No. 14: A nominal 1 in. coating of this material was applied to both sides of the wall using a dry spray technique. A small amount of cracking was observed after the test was terminated and the wall allowed to cool. The first onset of foam melting occurred at about 9 min at the middle right corner of the wall. Temperatures began to rise on the backside of the wall at the 20 min mark. The test was terminated at 60 min. The two slabs remained intact, but the foam had melted almost completely after exposure to the test fire.

COATING No, 7 - Cellulose Pulp Mixed with Liquid Sodium Silicate

Test No. 15: A 1/2 in. coating was troweled on the front side of the wall. The backside was coated with 1/4 in. of the material. Melted foam was observed oozing through the coating at about 7 min. The coating began to peel away at the top right at about 24 min. The test ended at 27 min.

COATING NO. 8 - Cement Based Insulating Plaster with Polystyrene Beads

Test No. 16: The wall was trowel coated on both sides with 1 in. of insulating plaster containing polystyrene beads. In addition, the front side was covered with a l/8 in. coating of plaster finish material. Cracks began appearing in the finish coat at about 21/2 min. The coating continued to crack and spall until the bottom middle portion of the finish coat fell off at about 7 min, 30 sec. The entire right side of the wall collapsed in about 14 min. The fire then increased in intensity until the test was terminated at about 16 min by quenching with water.

Test No. 17: This test examined the 1 in. insulating plaster coating, on both sides, without a finish coat. Minor cracks began to appear in the wall at the 15 min mark. At about 23 min, the cracks became more pronounced. Flames from burning polystyrene became visible at about 37 min. The wall fell shortly thereafter. The test was terminated at 38 min.

Test No. 18: The foam block was covered with a nominal 11/2 in. of insulating plaster, which contained approximately 4.0 percent, by weight, glass fibers. Measurements taken after the test on coating thickness indicated that some portion of the wall received only a 1 in. covering of the material. The backside of the wall was given a l/2 in. coat of the same material. The first indication of melting occurred at about 43 min in the top right portion of the wall. The coating remained intact for about 58 min; the duration of the test. Melting was indicated at two points during the test period, at the top right and middle right. Some cracking was discovered after the wall had cooled. It is not known if this cracking occurred during the test or after cooling. Additional melting occurred after the fire had gone out due to residual heat in the wall.

COATING No. 9 - Polyurethane Spray Foam

Test No. 19: A 2 in. layer of non-fire-retardant urethane foam was sprayed over the block wall. The foam was allowed to cure for one day. No coating was applied to the backside of the wall. The wall was totally engulfed with flames in 30 sec. At 2 min, 40 sec, the wall began to sag followed by total collapse at 51/2 min. The fire was extinguished with water at 12 min, 33 sec.

COATING No. 10 - Ceramic Fiber Blanket

Test No. 20: Two in. of 6 lb/ft^3 density, ceramic fiber blanket was impaled over the foam block using a ceramic stud fastening system (Figure 7). The covering was installed in two 1 in. layers using 24 in. wide pieces of blanket and staggering the edges of the material between the layers. The first indication of melting occurred 12 min into the test at the bottom left section of the wall. The test was terminated after 19 min because excessive melting had occurred at the interface between the blanket and foam. During this period, no significant rise of temperature occurred on the back surface of the foam block.

Test No. 21: Three in. of blanket was applied to the polystyrene foam using ceramic studs and hold-down clips. The application technique was similar to the previous test. The first indication of melting occurred at about 20 min near the upper right side of the wall. At the 60 min mark, seven out of nine interface thermocouples indicated melting had occurred. The blanket remained in place for the duration of the test.

FIRE RATINGS CRITERIA

The following criteria were used to determine the relative fire ratings for various coatings applied in specific thicknesses to walls constructed from polystyrene foam blocks:

1. No massive cracking (>1/2 in.), spalling, or delamination of the face coating can occur within the period of the fire rating.
2. The transmission of heat through the face coating during the period of the fire rating shall not raise the temperature of more than two of the interface thermocouples to 266°F (130 °C) (the melting point of polystyrene block).

Although admittedly subjective in nature, implementation of criterion effectively eliminates coatings which do not perform well when exposed to very high temperatures, from a materials integrity standpoint. Massive cracking, spalling, etc., lend themselves to the enhancement of flame penetration into the foam block resulting in the likelihood of a fire or, at the very least, melting of the foam block. Small cracks are permitted, provided the coating can still function to meet the second criterion.

The second criterion was established to insure that the face coating would function to prevent the penetration of heat which would result in the

TABLE 2. *Fire-Resistance Test Results of Polystyrene Block Walls with Selected Coatings/Coverings*

Coating No.	Test No.	Coating Thickness (in.)	Cure Time (days)	Time to Reach 266°F (130°C) at Interface (min)	Failure Time (min)	Failure Mode	*Max Temp. Unexposed Side (°F)	General Comments
1	1	1/4	165	3.0	5	2	60	Coating remained intact for both tests
1	2	1/2	162	6.0	7	2	60	
2	3	1/2	139	15.5	3	1	60	Massive spalling and cracking
2	4	1	129	13.0	10	1	60	
3	5	1/2	142	5.2	2	1	60	Massive spalling and cracking
3	6	1	134	14.7	2	1	60	
4	7	1/2	100	10.2	17	2	122	Cracking — wall fell at 35 min
4	8	1	93	25.2	33	2	80	Top corner fell at 44 min
4	9	2	32	>60	>60		194	Minor cracks
5	10	1/2	233	7	13	2	104	Minor cracks
5	11	1	231	28.2	32	2	104	Minor cracks
5	12	2	6	>60	>60	-	154	Minor cracks.. No melting of foam for duration
6	13	1/2	202	4.2	6	2	64	Some cracks
6	14	1	196	8.7	12	2	104	Some cracks
7	15	1/2	244	7	12	2	158	Foam seeped thru coating at 7 min
8	16	1 w/finish coat	202	9.2	3	1	60	Extreme cracking
8	17	1	208	10.5	18	2	60	Minor cracks
8	18	1 1/2 w/glass fibers	32	43.2	>60	-	169	Coating intact for duration of test
9	19	2	1	2	2	2	60	Wall collapsed in 5.5 min
10	20	2	N/A	11.7	12	2	86	-
10	21	3	N/A	20.2	24	2	60	No melting of foam for 20 min

*Indicates temperatures measured prior to wall failure according to established criteria.

FAILURE MODE KEY
1 - Massive cracking, spalling, or delamination of face coating.
2 - Melting at more than two locations at block/coating interface.

melting or decomposition of the polystyrene block, which it is designed to protect. The criterion does allow for melting at up to two locations during the period of the rating provided criterion 1 is met. Examination of the test data utilizing this criterion indicated that allowance of overtemperature at a maximum of two interface locations did not compromise the overall objectives of the test (to provide a barrier against the passage of heat and flame for a given period of time), while, at the same time, giving the operator a greater selection of coating materials to choose from. A maximum of two overtemperature locations was chosen since it would ensure that at least 50 percent of the foam block was intact behind the coating and that block existed around at least portions of all four edges of the stopping. Meeting of these two conditions should result in adequate bonding area between block and coating to prevent failure of the coating within the time period of the rating.

SUMMARY OF TEST RESULTS

Table 2 summarizes the fire test results of the polystyrene block walls covered with the selected coatings. The failure times of each coating are listed along with the criterion under which failure occurred. The gunnite walls and the insulating plaster/styrene bead formulation with finish coat failed due to the massive spalling or cracking criterion. All other coatings and the blanket covering (Coating No. 10) failed due to melting of the foam block at more than two locations. A 1 in. thick application of Coating No. 2 (silica aggregate gunnite with added glass fibers) resulted in melting of the foam at an earlier time when compared to a 1/2 in. coating of the same

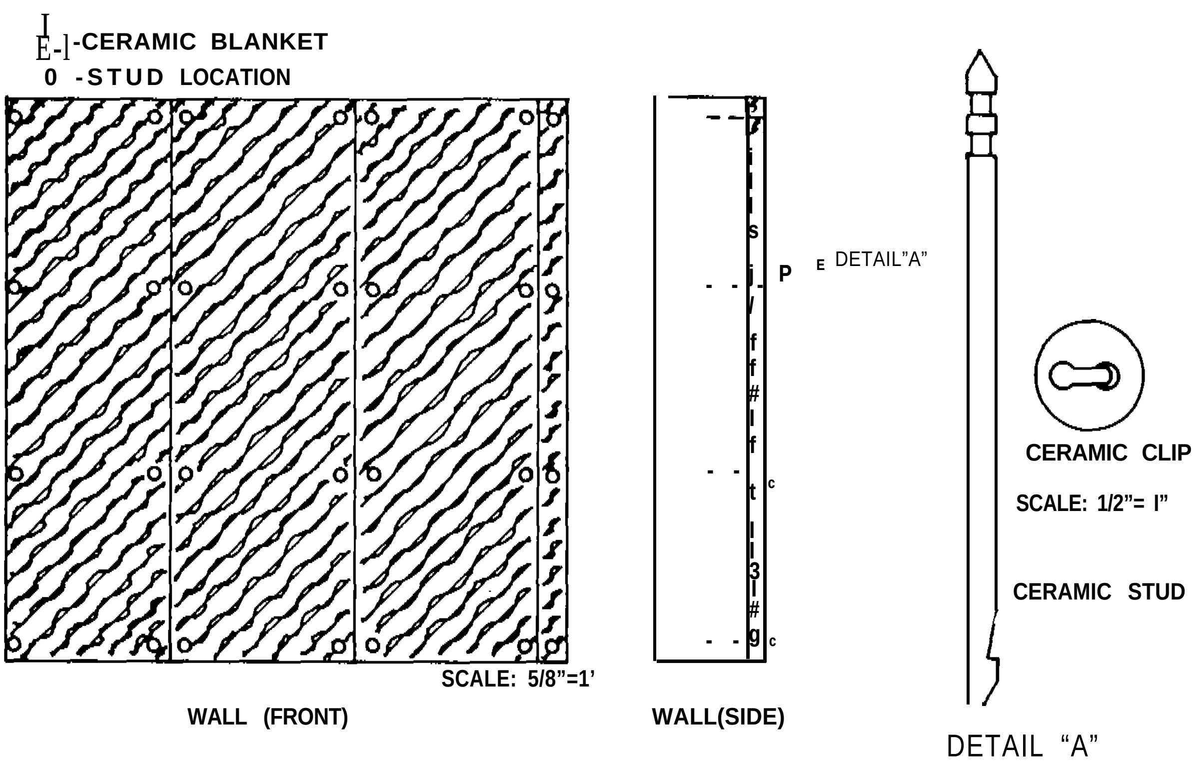

Figure 7. Ceramic blanket fastening system.

material. This is believed to be due to a large crack, which developed early into the test, exposing unprotected foam to the heat of the test fire.

No appreciable air leakage was observed through any of the walls tested during the period for which the wall was rated. Furthermore, thermocouples measuring temperatures on the unexposed sides of the walls indicated that temperatures necessary to ignite combustible materials, approximately 520°F [5] (271°C), were not even approached during the period of the ratings. The highest temperature measured on the unexposed side was 194°F (90°C), reached at about 55 min into the test which investigated a 2 in. coating of perlite and gypsum construction plaster.

FILE RATINGS

Implementation of these criteria resulted in the establishment of fire ratings, as previously mentioned, at 15, 30, and 60 min time periods. It should be pointed out that the term “fire rating” and the criteria used to define it have been developed solely for the purpose of evaluating polystyrene stopping systems in a possible underground mine fire scenario.

The fire ratings developed in this report should not be confused with, or be compared to, the fire resistance ratings generated from the results of consensus test standards such as the American Society for Testing and Materials (ASTM) Test Method E-119[6] for fire performance of building constuction or equivalent test methods (Underwriters Laboratory Standard UL 263[7] or NFPA 261.)[8] The test conditions and specimen sizes for these standard fire resistance tests are significantly different and may not lend themselves to equivalency when compared with our test results.

Table 3 provides a list of suitable coatings which will provide fire ratings of a given time period when covering polystyrene block materials. The tests were conducted using 12 in. thick blocks. The ratings generated would be expected to be applicable to thicker block constructions, also.

CONCLUSIONS

1. All nine coatings tested displayed adequate bonding characteristics to polystyrene block. Roughing the surface of the foam blocks, in selected tests, did not appear to improve the bonding characteristics of the coatings (when compared to unroughed specimens).
2. Use of polyurethane coatings to cover the entire face of foam-block stoppings does not contribute to the fire resistance of the overall stopping and is ***not*** recommended.
3. Use of gunnite and/or shotcrete as fire resistant coatings over foam block is ***not*** recommended. These high density, cement based coatings have a tendency to entrap moisture, which vaporizes upon heating and causes significant spalling and/or delamination.
4. Three of the coatings tested, the perlite plaster, cement-based plaster with insulating polystyrene beads, and the expanded vermiculite, portland cement, limestone coating, were effective in providing ade-

quate protection of the foam against fire for specified time periods as described in Table 3.

5. Three inches of 6 lb/ft^3 density ceramic blanket protected the foam block for a period of 15 min when exposed to the simulated mine test fire.

TABLE *3. Fire ratings* of selected coatings/coverings over polystyrene block stoppings*

Coating Number	*Description*	*Thickness in.*	*Fire Rating (min)*
4	Construction plaster containing perlite and gypsum	1/2 1 2	15 30 60
5	Coating composed of expanded vermiculite, portland cement, and limestone	1 2	30 60
8	Cement-based insulating plaster with polystyrene beads	1	15
8	Cement-based insulating plaster with polystyrene beads and glass fibers added	11/2	60
(covering)	Ceramic fiber blanket (6 lb/ft^3 density)	3	15

*NOTE: No effort was made to monitor the moisture content of the test walls. It is realized that the moisture content is an important parameter in the determination of the fire resistance of a test specimen. For the most part, the walls were allowed to cure for months, under ambient conditions, in the Division's fire gallery.

REFERENCES

[1] "Safety Standards for Gassy Metal and Nonmetal Mines," Proposed Draft, Federal Register, Vol. 50, No. 107, June 4, 1985, pp. 23612-23658.

[2] "Threshold Limit Values and Biological Exposure Indices for 1985-86," Second Printing, American Conference of Governmental Industrial Hygienists, 6500 Glenway Ave., Bldg. D-7, Cincinnati, Ohio 45211.

[3] Bulletin PICC-401, Society for the Plastics Industry, Inc., March 1980.

[4] "Standard Test Method for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Ap plied to Structural Members (ASTM E736-80)," American Society for Testing and Materials (ASTM) 1980.

[5] Schwartz, Kenneth J., and Lie, T. T., "Investigating the Unexposed Surface Temperature Criteria of Standard ASTM E119," ***Fire Technology,*** Vol. 21, No. 3, August 1985, p. 169.

[6] "Standard Methods of Fire Tests of Building Construction and Materials (ASTM E119-83)." American Society for Testing and Materials (ASTM) 1983.

[7] "Fire Tests of Building Construction and Materials (UL 263)," Underwriters Laboratories, Inc., 333 Pfingsten Rd., Northbrook, Illinois 60062.

[8] "Standard Method of Fire Tests of Building Construction and Materials (NFPA 251)," The National Fire Protection Association (NFPA), Batterymarch Park, Quincy, Massachusetts 02269.