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EVALUATION OF MINE STOPPING SEALANTS AND SQUEEZE BLOCKS

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16. Abstract (Limit: 200 words)

A survey and test program was conducted to establish from materials now in use or available, the best sealants for concrete block stoppings, and the value of squeeze blocks for stoppings with mine convergence. Mines were surveyed for sealants currently used and commercial products surveyed for new sealant materials. An in-mine evaluation showed that, within limits, poor stopping construction practices rather than sealants were the cause of leakage.

Sealants were found that could be brushed on concrete block rather than trowelled to produce stoppings twice the strength of mortared joint stoppings, and equal in strength to dry- stacked stoppings, both standard construction techniques. The brush-on technique, along with improved construction practices, were proved on demonstration stoppings tested over a period of one year, and are now recommended by the Bureau in a new handbook.

Polystyrene boardstock was the most commonly used squeeze blocks, and was considered by mines using them to be helpful in maintaining stopping integrity under mine convergence conditions. Alternative squeeze block materials with overall properties better than polystyrene were found.

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Stopping sealants
Squeeze blocks
Concrete block stoppings
Cement-based sealant

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FOREWORD

This report was prepared by MSA Research Corporation, a division of Mine Safety Appliances Company, Evans City, PA under USBM Contract number J0395042. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of Pittsburgh Research Center with Robert Timko acting as Technical Project Officer. Mr. Joseph A. Gilchrist was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period October 1979 to April 1984. This report was submitted by the authors on March 1986 and contains no patentable features.

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INTRODUCTION

Air leakage through mine stoppings is a major cause of inefficient mine ventilation systems. In an effort to reduce this leakage, stoppings are often coated with sealants specifically formulated for reducing air leakage. These sealants are also used to repair stoppings that have cracked or buckled because of convergence of roof and floor.

Some mines with convergence problems are trying to reduce or eliminate cracking and buckling by incorporating a "squeeze block" into the stoppings. The stopping is built of concrete block in the conventional fashion. However, a row of squeezable block is substituted for concrete block near the base of the stopping, with the idea that as the roof sags, the squeeze block compresses and the concrete block beneath is not cracked. Presumably, then, such stoppings will leak less than those conventionally constructed.

Mine sealants and squeeze blocks had never been carefully assessed to determine their effectiveness in reducing air leakage through mine stoppings. This program was initially a 32-month program with the objective to establish, from materials now in use or available, the best sealant or sealants for concrete block stopping construction and the value of squeeze blocks for minimizing stopping failures. It was a 3-phase effort, consisting of (1) a survey of coal mines to determine commonly used squeeze block and sealant materials; (2) comparison testing of selected sealants and squeeze block materials; and (3) in-mine demonstration of the best candidates.

After about one year into the program, several factors dictated a modification to the program. In conducting the in-mine evaluation task of the sealant survey phase it became apparent that we were evaluating basic stopping construction techniques, rather than the ability of the sealant under evaluation to seal the stopping. Definitive information for selecting the better sealant materials now in use was not obtainable.

Also, in evaluating new commercially-available sealant candidates we found several modified cement-based materials that had the potential as "brush-on" mortars for cement block wall construction. This gave rise to the possibility of a new stopping construction technique that embodied the simplicity of constructing dry-stacked stoppings (i.e., block stoppings constructed first with no mortar, and then mortar troweled on one face) but resulted in the strength of wet-laid stoppings (conventional mortared joints).

Accordingly, the sealant evaluation task of the program was modified, and Phases II and III of the initial effort changed to evaluate mortar candidates for this new technique. The squeeze block task of the program was not altered. Phases II and III of the modified program consisted essentially of the following:

Phase II - Laboratory Evaluation of New Mortars

A comparison of three new mortar candidates with each other, with B-Bond (a fiberglass-loaded facing sealant) and with regular mortar. Selection of one new mortar and squeeze block for demonstration.

Phase III - In-mine Demonstration

The construction and year-long evaluation of stoppings employing squeeze blocks and the new construction technique under actual mine conditions.

The laboratory comparison of mortars and application techniques showed that modified mortars consistently outperformed plain mortars and that the application of these mortars with a brush rather than a trowel was easier to do, and resulted in stoppings equally as strong. The differences between various modified mortars, however, were small.

The in-mine demonstration stoppings further confirmed the use of the brush over a trowel to apply sealants and mortars. Using a brush made sealant application easier and increased the longevity of the stopping face and perimeter seals.

Key elements to good stopping construction practices were defined. Four stopping construction modifications were compared to standard mine stopping construction techniques in a total of 15 test stoppings that were followed over the period of a year. Stoppings in which care was taken to establish a good perimeter seal consistently leaked less and withstood weathering cycles better. The culmination in this effort was a handbook issued by the Bureau "Techniques for Constructing Concrete Block Stoppings" (R.J. Timko and E.D. Thimons).

The laboratory evaluation of squeeze blocks found several candidates more suitable as squeeze blocks than the one used most commonly. An in-mine evaluation of this practice, however, was hampered by production stoppages and dangerous roof conditions.

PHASE I - SELECTION OF CANDIDATE SEALANTS AND SQUEEZE BLOCKS

The basic objectives of Phase I were to select suitable sealant and squeeze block candidates for the Phase II testing. This was to be accomplished through a survey of sealants and squeeze blocks currently in use in mines, an in-mine evaluation of the more promising candidates, an evaluation of properties desired in sealant and squeeze block materials, and a survey of commercial products not currently being used by the mining community that may prove superior in performance to those in use. Six sealant candidates; 3 now in use, and 3 new candidates, and four squeeze block candidates were to be selected for evaluation.

Survey of Sealants and Squeeze Blocks Now in Use

Eighteen mining companies, encompassing 60 separate mines, were surveyed to obtain a broad view of sealants and squeeze blocks in use. The questions asked of cooperating mine companies, and eventually individual mine personnel, were as follows:

1. What type of stopping sealants are being used?
2. Are they multipurpose sealants or are they specifically designed for coating concrete block stoppings?
3. How are the sealants applied?
    a. Are they painted or troweled on?
    b. Do they require special application equipment?
4. Are you using squeeze blocks; if so, what kind?
5. How are the squeeze blocks used in stopping construction?

Mine management personnel were contacted initially for survey permission. Subsequent discussions were held with individual mine personnel knowledgeable of stopping practices. No problem was experienced in conducting the survey.

The basic survey was conducted by phone with a follow-up letter, where requested. The mail survey minimized the inconvenience to mine personnel.

The mining companies were selected to provide a broad overview of coal mine types, locations, and thus problems which may have bearing on the type of sealant or squeeze block employed. Because of higher overburden, mines in the Pittsburgh seam, for example, are more likely to have closure problems than those in the Upper and Lower Freeports. Mines that have high overburden, poor roofs, or practice retreat mining, will have problems with closure not experienced elsewhere. New mines, with small areas, would present a different problem on ventilation losses than perhaps older mines, and western mines may have logistical problems with certain sealants or sealant components as well as mine conditions that would dictate the prevalent use of one type of sealant over another.

The survey results are shown in Table 1. It includes the location of mines, description, stopping type, sealant, and any comments dealing with sealants or squeeze blocks.

Sealant Summary - A summary of the sealants reported, their basic compositions and frequency is shown in Table 2.

TABLE 2 - Summary of stopping sealants in mine survey

Sealant	Basic Composition	No. of Mines
Block Bond* (or B-Bond)	fiberglass (AR) - cement	31
Mortar	sand (rockdust) - cement	15
Sackrete	ready-mix sand - cement	8
Stoppit	sodium silicate - styrofoam beads	8
Surewall	fiberglass (E) - cement	4
Inca 1000	fiberglass (E) - cement	2
Plaster	gypsum	1
None (mortared joints only)		5

*Bloc-Bond and B-Bond are identical materials and, thus, listed together. Bloc-Bond was the precursor to B-Bond.

Some mines reported the use of more than one stopping sealant, so the list totaled more than 60.

Dry-stacked and mortared(wet) stoppings were both popular. Twenty-three mines employed dry-stacked stoppings exclusively, while another 25 used dry-stacking for at least a portion of their stoppings. Fiberglass-loaded cement sealants were by far the most popular for these, with the alkaline-resistant(AR) fibers favored over the non-

TABLE 1 - Results of mine survey for sealants and squeeze blocks

Mining company	Mine and location	Mine depth(ft)	Seam mined	Type stopping construction	Sealant	Comments
Bethlehem Steel	Windber #78 Cambria Div., PA	360	Upper Kittanning	Mains - wet, Side entries-dry, no footers	None	
"	Slope #33 Cambria Div., PA		Lower and Upper Kittanning	Mostly wet	B-Bond	Heaving problems
"	Revloc #32 Cambria Div., PA	950	Lower Kittanning	Dry, no footers	Bloc-Bond	" "
"	Revloc #32 Ellsworth Div., PA	300	Pittsburgh	Wet, solid block, no footers	Bloc-Bond	
"	Marianna #58 Ellsworth Div., PA	600 to 1000	Pittsburgh	Dry, small cement footer	Bloc-Bond	Some bottom heaving
"	Somerset #60 Ellsworth Div., PA	300 to 600	Pittsburgh	Dry-intake; wet-returns, no footers	Mortar	" "
R&P Coal Co.	Urling #3, Indiana, PA	210	Lower Freeport	Dry	Mortar	
"	Jane Mine, Elderton, PA	275	Lower Freeport	Dry	Mortar B-Bond	
"	Emilie #1, Elderton, PA	250 to 300	Lower Freeport	Dry	Sakrete, B-Bond	
"	Urling #1 Schelocta, PA	200	Lower Freeport	Dry	B-Bond	
Consolidation Coal Company	Laurel, Central City, PA	400	Lower Kittanning B	Dry, footer to level	B-Bond	
"	Renton, Renton, PA	300	Upper Freeport	Dry, no footer	Plaster	
"	Westland #1, Washington, PA	Drift	Pittsburgh	Dry	Bloc-Bond	Tried 4-5 others; Bloc-Bond sticks best
"	Westland #2 Washington, PA	Drift 150	Pittsburgh	Wet	None or Mortar	

TABLE I (continued)

Mining company	Mine and location	Mine depth(ft)	Seam mined	Type stopping construction	Sealant	Comments
Consolidation Coal Company	Montour #4 Lawrence, PA	250 to 500	Pittsburgh	Wet and dry	Mortar and rockdust	
"	Highwall #65 Cadiz, OH	80 to 200	Pittsburgh #8	Dry, 2-in x 8-in plank footer	Bloc-Bond	
"	Franklin #125 Cadiz, OH	70 to 200	Pittsburgh #8	Wet	Bloc-Bond	Pulling out, opening new longwall beside; lots of roof deterioration
"	Oak Park #7 Cadiz, OH	550	Lower Freeport #6-A	Wet and dry	Bloc-Bond	
"	Ireland, Moundsville, WV	Slope	Pittsburgh	Dry	Bloc-Bond	
"	Mathies Coal, Finleyville, PA	300	Pittsburgh	Wet and dry	Air Stop (Surewall)	
Duquesne Light	Warwick #203 Greensboro, PA	350	Sewickley	Dry	Bloc-Bond	
"	Canon Coal Co., Clarksville, PA	300	Pittsburgh	Dry	Inco 1000 Surewall	
Republic Steel	Banning #4 West Newton, PA	150 to 300	Pittsburgh	Wet and dry	Sackrete mortar	Retreat mining; 2-4 yr life
Florence Mining	Blacklick Mine, Seward, PA		Lower Kittanning	Dry	Bloc-Bond, if any	
"	Florence #2 Seward, PA		Lower Kittanning	Mostly wet	Premix mortar, if any	
"	Florence #1 Seward, PA		Lower Kittanning	Wet-intakes dry-returns	Bloc-Bond	
U.S. Steel	Maple Creek 102 New Eagle, PA	260	Pittsburgh	Wet and dry	Mortar (sand and rockdust)	
Leechburg Mining	Foster Mine Leechburg, PA	70	Lower Kittanning	Wet and dry	Mortar	

TABLE 1 (continued)

Mining company	Mine and location	Mine depth(ft)	Seam mined	Type stopping construction	Sealant	Comments
U.S. Steel	Robena, PA Greensboro, PA	450	Pittsburgh	Wet and dry	Mortar	
Penn Power	Lady Jane Collieries, Phillipsburg, PA	200 to 400	Lower Kittanning	Dry	Stoppit	Convenient
U.S. Steel	Dilworth Rice Landing, PA	160	Pittsburgh	Wet-mains; dry-belt	Wet, no sealant dry, B-Bond	
Bethlehem Steel	Fawn Mine Saxonburg, PA	180 to	Upper Freeport	Dry	Mandoseal, Bencoat, Bloc-Bond	
Peabody Coal Co.	Sunnyhill Mine, New Lexington, OH	Drift	No. 6	Dry	Surewall	
Oglebay & Norton	Saginaw Mining Co. St. Clairsville, OH	300	Pittsburgh #8	Wet and dry	Bloc-Bond	
North American Coal Corp.	Powhatan #7 Powhatan Pt., OH	Drift	Pittsburgh #8	Dry	B-Bond	
Mercury Coal & Coal Co.	Morgantown, WV	Drift	Upper Freeport	Dry	Mortar and rockdust	Cheaper; low pressure
Valley Camp Coal Co.	Triadelphia, WV	600	Pittsburgh #8	Dry	Stoppit	
Rawl Sales	Rawl, WV	Drift	Alma	Wet	Mortar, Surewall	
Eastern Assoc.	JoAnne Mine, Rachel, WV	400 to 500	Pittsburgh	Wet-mains; dry-panels	Mortar (Burrellcrete)	Squeeze blocks 2 months
"	Harris Mine #2 Bald Knob, WV	1200 to 1400	Campbell Creek	Wet	Mortar	6-in Chemfoam used as footer under block walls; about 20 installed

TABLE 1 (continued)

Mining company	Mine and location	Mine depth(ft)	Seam mined	Type stopping construction	Sealant	Comments
Eastern Assoc. Coal	Federal #1 Grant Town, WV	600	Pittsburgh	Wet-mains; dry-panels	Mortar (Sackrete)	3-in Chemfoam in lower half of permanent stoppings-1 1/2 yrs; had tried Bloc-Bond but went back to mortar
"	Federal #2 Fairview, WV	800	Pittsburgh	Mostly wet	Mortar (Sackrete)	Chemfoam on bottom or half way up (4-5 yrs)
Consol. Coal Co.	Blacksville #2 Wana, WV	800	Pittsburgh	Wet and dry	Mortar cement rockdust	2-in Chemfoam used at middle of stopping over 4 1/2 yrs; will squeeze to 1/8" in 3 months
"	Ireland Mine Moundsville, WV	600 to 700	Pittsburgh #6	Wet-mains; dry-panels	B-Bond	2-in Chemfoam used at middle of stopping 4 yrs in some areas
Peabody Coal Co.	Alston #4 Centertown, KY	220	Kentucky #9	Dry - solid core block	Bloc-Bond and Stoppit	
"	Ken #4 South Beaver Dam, KY	80 to 140	Kentucky #9	Dry	Bloc-Bond	Some bottom heaving
"	Star, Graham, KY	150	Kentucky #9	Dry	Bloc-Bond	
"	Alston #3 Centertown, KY	80 to 250	Kentucky #9	Dry	Bloc-Bond & Stoppit	
"	Sinclair Slope Drakesboro, KY	250	Kentucky #9	Dry - solid core block laid flat	Bloc-Bond	Some bottom heaving
Webster Coal Co.	Dotiki Clay, KY	150	Kentucky #9	Dry - solid core block laid flat	Bloc-Bond	Stoppit used on temporary stoppings
"	Retiki Henderson, KY	650	Kentucky #9	Solid dry; flat	Bloc-Bond FiberBond	
Kaiser Steel Corp.	Sunnyside, UT	2000	Upper and Lower Sunnyside	Wet	Sackrete mortar	

TABLE 1 (continued)

Mining company	Mine and location	Mine depth(ft)	Seam mined	Type stopping construction	Sealant	Comments
Kaiser Steel	Sunnyside Sunnyside, UT	2500	Sunnyside	Wet	Sackrete	
American Coal Co.	Deer Creek Mine Huntington, UT	1800	Blind Canyon	Wet and dry	Mortar, Stoppit, Rigid foam	
Plateau Mining Co.	Star Point Mine Price, UT	1800	Hiawatha and Wattis	Wet	Stoppit or none	
Soldier Creek	Soldier Canyon Price, UT	1400 to 2000	Rock Canyon	Dry - panels; wet-haulage	Mortar	
Coastal States Energy Co.	S. Utah Fuel Co. Salina, UT	500 to 1400	Hiawatha	Dry	Mortar Mandoseal	Uses honeycomb fire retardant card-board squeeze block
United States Steel Mining Co.	King Mine Hiawatha, UT	1400	Hiawatha	Wet	Stoppit, Airtrol	
Consol. Coal Co.	Emery Mine Emery, UT	300 to 500	IJ	Wet mains	Sackrete	2-in Chemfoam used at middle of stopping for 1 1/2 yrs.

alkaline-resistant fibers(Type E). Mortar facings, or no sealant at all were generally found on the wet stoppings. These appear to be the only two options.

Squeeze Block Summary - Squeeze blocks were used infrequently, although 15 of the mines surveyed reported trouble with heaving. Eight mines surveyed used squeeze blocks and seven of these used Chemfoam M, an expanded polystyrene (EPS) foam insulation board stock with fire retardant added. It was used generally as a 2-inch thick layer positioned between the lower courses of block.

Our survey indicated satisfaction by mine management with the use of squeeze blocks to help maintain the integrity of the stoppings.

Selection of Sealant Candidates for In-Mine Evaluations - Stoppings using five (5) of the most commonly used sealants, and the most common squeeze block material were to be examined as a task of Phase I. According to our survey, mortar and fiberglass-loaded cementitious materials were by far the most commonly used sealants. The remaining were a variety of sealant types. Because of shipping costs, many products were only distributed locally, but similar products were marketed elsewhere under a different brand name.

There are a considerable number of sealants marketed, and a list of those currently acceptable is maintained by the Mine Safety and Health Administration (MSHA) Materials and Acceptance Branch, Triadelphia, WV. About 20 manufacturers from this list were contacted to obtain information on the general composition, properties and uses of their products. They can be categorized as follows:

1. Mortar
2. Alkaline-resistant (AR) fiberglass-loaded cement products
3. Non-alkaline-resistant (E) fiberglass-loaded cement products
4. Vermiculite-containing cement products
5. Perlite-containing cement products
6. Silicate (water glass) formulations
7. Epoxy
8. Others - additives, polymers, etc.

Non-alkaline resistant fiberglass compositions were given a separate listing. These products, marketed because of the obvious popularity of the alkaline-resistant product, are significantly less expensive and, according to suppliers, hold up just as well.

Our selection of sealant candidates for in-mine testing included most of the categories above. They were:

- Mortar - Standard cement-and-sand mortar. This material was used to lay a wet (mortared joint) stopping and also to seal the face.

- B-Bond and Bencoat (Benco Industrial Supply, Greensburg, PA) - Cement-based material containing alkaline-resistant glass fibers approximately one-half inch in length. Bencoat contains fewer fibers and therefore is less expensive than B-Bond.

- Inca-1000 and Surewall (Inca-1000, The Inca Co., Wilkes-Barre, PA; Surewall, W.R. Bonsal Co., Conley, GA) - Cement-based materials containing non-alkaline resistant glass fibers approximately one-half inch in length. Surewall contains sand; Inca-1000 does not.

- Mandoseal (J.P. Austin & Assoc., Pittsburgh, PA) - A vermiculite-loaded, cement-based product that can be either sprayed or trowelled. Originally developed in England as an anti-spall coating. W.R. Grace markets a similar product.

- Mine-Shield - A mineral wool-loaded, cement-based product (commonly called Unisul). Can be sprayed on or trowelled. Final product has a rough textured surface that can readily be penetrated with finger pressure.

- Stoppit (Michael-Walters Industries, Louisville, KY) - A silicate-based material. A trowel-grade product is sold in 5 gal buckets for sealing wet-laid blocks. A caulking-grade is available for larger voids. The caulking grade product contains polystyrene beads for bulk and resilience. This was the product evaluated in our in-mine tests.

Chemfoam M, an expanded polystyrene (EPS) board supplied by Benco Industrial Supply of Greensburg, PA, was the obvious squeeze block material choice. Besides being observable locally (West Virginia mines), it was employed in 7 of the 8 mines surveyed that used squeeze blocks.

In-Mine Stopping Evaluations

Nine mines were visited in evaluating sealants and squeeze blocks for concrete block stoppings. The stoppings were examined in detail, and a history of each was obtained from mine personnel. Included was information on the following:

- quality of construction - to include such information as; wet or dry-wall block construction; size and type of footer, if any; construction practices at rib- and roof-stopping interfaces; and present condition and age.

- sealant data - type, coverage, age, thickness, how applied and condition.

- squeeze block data - type, location, and performance.

- air leakage data - leakage rates measured by either the Brattice Window or SF_6 depletion technique.

Over 80 stoppings were examined. Only 43, however, had suitable pressure drop to measure the leakage rate. The data for these are summarized in Table 3.

No comparisons as to the effectiveness of the sealants as an air seal could be drawn from the data. Although the program called for an in-mine evaluation of different sealants, the in-mine evaluation resulted more in an evaluation of stopping construction practices rather than of sealants. Even an unsealed solid block stopping, laid wet, showed little leakage when well constructed. Stoppings without audible and visible leaks, however, were rare regardless of the sealant used.

The major sources of stopping leakage were along the roof and ribs. Some of the problems encountered were poor initial seals at these locations, cracks opening up when the stoppings shifted, or air leakage through adjacent strata. It was apparent that better construction practices would produce considerable improvement. The use of footers, keying at the ribs, and proper wedging and void fillings at the roof would appear to be more effective construction practices

Surface cracks on the stopping faces seldom appeared to have much leakage. Many of these surface cracks appeared to be caused by the lack of a footer, or uneven floors. They were usually filled with cement or coated with rock dust.

There is evidence to suggest that good construction practices are a necessary part of the initial installation and not something that can be added to the stopping at a later date. Leakage rates of over 300 $ft^3/min \cdot 100\ ft^2/in\ H_2O$ were found through two new stoppings erected in older areas having weathered roof and rib conditions. The stoppings and sealants appeared satisfactory, with no visible cracks. Air leakage, however, was audible through the weathered strata surrounding the stopping.

TABLE 3 - Summary of in-mine sealant evaluations

Stopping Identification	Sealant	Type Construction	Type Block	Age	ΔP in. H_2O	Leak Rate (ft^3/min)	Leak Rate (ft^3/min) 100 ft^2)	Leak Rate at 1 in ΔP (ft^3/min) 100 ft^2)	Measurement Technique	Comments
Mine No. 1										
19	Mortar	Wet	Solid	6 mo	0.5	20	14	26	SF_6	Looked very good
20	Mortar	Wet	Solid		0.5	168	117	207	BW*-6x12	Contained mandoor
18	Mortar	Wet	Solid	12 yr	0.5	18	14	26	SF_6	
103	Mortar	Wet	Solid	18 yr	2.6	32	28	51	SF_6	
28	Mortar	Wet	Solid	18 yr	2.6	16	16	7	SF_6	Slight audible leak
27	Mortar	Wet	Solid	18 yr	2.6	20	19	8		Good; only few cracks showing as dust lines
26	Mortar	Wet	Solid	18 yr	2.6	14	15	6	SF_6	Slight audible leak; many dust lines
25	Mortar	Wet	Solid	18 yr	2.6	27	25	11	SF_6	Dust lines 20% of joints
Mine No. 2										
2 Left	B-Bond	Dry	Hollow	4 yr	1.6	992	1044	715	BW-12x12	Repaired 1 month before; stopping shifted after repair
3 Left	B-Bond	Dry	Hollow	4 yr	1.6	67	74	51	SF_6	5% sealant separation from block face
4 Left	B-Bond	Dry	Hollow	4 yr	1.6	108	109	75	SF_6	10% sealant repatched; 10% peeling
5 Left	B-Bond	Dry	Hollow	4 yr	1.6	124	138	95	SF_6	Stopping shifted at rib & roof
					1.6	113	125	86	BW-4D	
6 Left	None	Wet	Hollow		1.6	138	153	105	SF_6	Audible leaks
1 Right	B-Bond	Dry	Hollow		1.5	786	786	570	BW-12x12	Stopping shifted 1-in;sealant applied only on joints
2 Right	B-Bond	Dry	Hollow		1.5	576	636	461	BW-12x12	Stopping shifted slightly
3 Right	B-Bond	Dry	Hollow		1.5	331	349	253	BW-12x12	1/4-1/2 in shift; leakage around edges
4 Right	B-Bond	Dry	Hollow		1.5	123	130	94	SF_6	Audible leak but no shifting
5 Right	B-Bond	Dry	Hollow		1.5	61	68	40	SF_6	Slight audible leak; no shifting; no cracks

TABLE 3 - Summary of in-mine sealant evaluations (continued)

Stopping Identification	Sealant	Type Construction	Type Block	Age	ΔP in H_2O	Leak Rate (ft^3/min)	Leak Rate (ft^3/min 100 ft^2)	Leak Rate at 1 in ΔP (ft^3/min 100 ft^2)	Measurement Technique	Comments
Mine No. 3										
1	Mandoseal	Dry	Solid	2 yr	2.4	191	201	92	SF_6	Audible leak at wedge at roof line
2	Mandoseal	Dry	Solid		2.4	181	134	61	SF_6	Audible leak at floor;poor seal
3	Glassflake & silicate	Dry	Solid		2.4	1351	1107	503	BW-12x12	Leaking through cracks in roof slate
Mine No. 4										
1	None	Wet	Solid		2.4	53	55	25	SF_6	Block starting to spall;leaks along roof
2	None	Wet	Solid		2.4	50	53	24	SF_6	Less cracking & audible leak than #1
4	None	Wet	Solid		2.4	25	29	13	SF_6	No audible leaks; a few vertical cracks
Mine No. 5										
61	Stoppit	Dry	Hollow	2 yr	0.28	11	23	61	SF_6	Slightly audible leak at wedges at roof line
62	Stoppit	Dry	Hollow		0.28	46	86	226	SF_6	Audible leakage at wedges
63	Stoppit	Dry	Hollow		0.28	40	64	169	SF_6	Seal poor around wood filler block
64	Stoppit	Dry	Hollow		0.28	40	83	217	SF_6	Plastic pipe through wall but sealed off
65	Stoppit	Dry	Hollow		0.28	22	45	119	SF_6	Looked good;too near belt to hear leaks
66	Stoppit	Dry	Hollow		0.28	18	43	114	SF_6	Sealed on return side; fresh patches on belt side
Mine No. 6										
1 Left	Inca 1000	Dry	Hollow	1 wk	0.7	498	453	604	BW-12x12	Much leakage through fractures in ribs
3 Right	Inca 1000	Dry	Hollow	1 wk	0.7	528	510	680	BW-12x12	Much leakage through fractures in ribs
4 Right	Inca 1000	Dry	Hollow	1 wk	0.7	529	498	664	BW-12x12	Much leakage through fractures in ribs

TABLE 3 - Summary of in-mine sealant evaluations(continued)

Stopping Identification	Sealant	Type Construction	Type Block	Age	ΔP in H_2O	Leak Rate (ft^3/min)	Leak Rate (ft^3/min 100 ft^2)	Leak Rate at 1 in ΔP (ft^3/min 100 ft^2)	Measurement Technique	Comments
Mine No. 7										
1	Squeeze Block & Plaster	Wet	Solid	5 mo	0.26	152	137	461	SF_6	No audible leaks; 2 layers Chemfoam as footer
2	Squeeze Block & Plaster	Wet	Solid	3 wk	0.14	74	54	316	SF_6	2 layers Chemfoam as footer
3	Plaster	Wet	Solid	3 yr	0.28	36	35	110	SF_6	Crushing and face spalling
4	Plaster	Wet	Solid	3 yr	0.28	27	21	65	SF_6	Looked good; no audible leaks
5	Plaster	Wet	Solid	4 yr	1.5	57	46	31	SF_6	Slight cracking at roof; slight whistle
6	Plaster	Wet	Solid	4 yr	1.5	42	28	20	SF_6	Some cracking; no audible leaks
Mine No. 8										
46	Surewall	Dry	Solid	3 yr	0.66	38	32	46	SF_6	Couple fractures in roof
52	Mondoseal sprayed over old mortar seal	Dry	Solid	3 da 7 yr	0.56	9	11	19	SF_6	No audible leaks Old mortar on return side looked good
Mine No. 9										
21	Mine Shield (Unisol) sprayed over Bloc Bond	Dry	Hollow	2 wk 2 yr	0.36	102	106	241	SF_6	Sprayed low press slide; holes blown through
25	Mine Shield (Unisol) sprayed over Bloc Bond	Dry	Hollow	2 wk	0.26	17	20	60	SF_6	No audible leaks

Stoppings constructed with solid block had a much lower average leak rate when compared to a hollow block construction, indicating that the additional cost for solid block may be justified.

Mines with convergence problems, presently using squeeze blocks, were convinced of their effectiveness in preventing crushing and cracks. Test results tended to support this conclusion. Not enough stoppings with and without squeeze blocks were measured, however, to reach valid conclusions.

Survey of Commercial Sealant Candidates

The program called for a search for commercially available materials that had potential to be sealants. These candidates would be carried through the laboratory test phase for comparison with materials currently used.

There was a wide spectrum of materials that could have been selected as potential sealant candidates -- far too many for the scope of the program. A sealant must meet some basic requirements, however, to satisfy MSHA guidelines on the ability of stoppings to withstand a fire or explosion. Past work by the Bureau, as well as our own survey, placed priorities on other sealant properties that would be desirable.

In reviewing the requirements, it was apparent that a sealant for a wet-wall stopping need not have all the properties required for a dry-stacked stopping. A mine employing wet-wall stoppings with very little convergence needs only a low-cost sealant to reduce the porosity of the concrete block. There are many paints or other coatings that could accomplish this. The Bureau has already shown that a commercially available masonry paint will readily work (3). This area, therefore was pursued no further.

A mine having wet-wall stoppings that develop minor cracks could use a sealant that would resist cracking and maintain the seal. To achieve this a sealant should be flexible, with some surface thickness. Flexibility dictates an organic-based product, which could place it in conflict with MSHA's flammability requirements.

Dry-stacked concrete-block stoppings, on the other hand, require sealants that provide the required strength, low air permeability, and flexibility in the one material. Strength and low air permeability are currently being met with the fiberglass-loaded cements. These sealants lack flexibility, however, and crack if the stopping becomes stressed. For mines with convergence and minor cracking problems, sealant resiliency or flexibility is preferred. Thus, the search for a better sealant for dry-stacked stoppings centered on fiber-loaded material for strength, with organics added for flexibility. A summary of these general sealant requirements is shown in Table 4.

Mines with major convergence problems, building either wet or dry-wall stoppings, should use squeeze blocks to minimize cracking, and then select the appropriate sealant for the type stopping being placed.

From the foregoing discussion we concluded that the search of the commercial markets for sealant candidates for wet-wall stoppings should focus on flexible coatings that are inexpensive, safe, and easy to apply. For dry-stacked stoppings, a material having similar properties but with added fibers for strength is needed. Both would have to meet MSHA underground requirements, and both would be required to pass application and adhesion tests under practical mine conditions.

The new candidate search included areas that had been searched several times for a variety of reasons. They included:

- Bureau reports on stopping construction practices.

- Bureau reports on sealants for uranium mines to minimize radiation hazards, and personal communication with John Franklin (Bureau of Mines, Spokane) who was in charge of the project.

- The up-to-date detailed study by MSAR (EPA Contract 68-03-2507) in search of a sealant for controlling hazardous chemical spills.

- Accumulated company background searching for suitable mine anti-spall coatings.

It also included reviews of current literature, dealing with coatings, roof and floor maintenance , and the construction industry.

Samples of candidates which appeared to meet the basic requirements were requested for first hand observations. The candidates were compared in the following areas; method of application, cure time, presence of noxious or irritating fumes or dusts, continuity of film surface at recommended thickness, film hardness and adhesion to block surfaces. These are general properties which may or may not make the sealant a good candidate for underground use.

TABLE 4 - Summary of sealant requirements of concrete block stoppings

Requirement	Stopping Type: Wet-wall	Stopping Type: Dry-Stacked
Strength	Not needed, mortared joints provide strength.	Needed. MSHA suggests stopping strength be equivalent to wet-laid stopping. Fiberglass-loaded materials applied to one or both sides suggested.
Low Air Permeability	Needed, but shown to be available in a number of materials, including relatively inexpensive paints.	Needed - should be a property of sealant providing strength.
Flexibility	Needed - to maintain seal against minor cracking and shifting.	Needed - preferred as a property of initial sealant, rather than as a second coating.
Flammability	Must meet MSHA in-mine standards	Must meet MSHA in-mine standards

A listing of those materials in use as mine sealants as well as possible sealant candidates, is shown in Table 5. Sources, compositions, method of application, and approximate costs at the time of the survey have been compiled.

Adhesion Testing

The application and adhesion of materials to dry concrete blocks was the screening test for new sealant candidates. The sealant was applied over wire mesh pull tabs, allowed to cure, and then stressed in tension on an Instron device until failure. This test gave a practical value of the sealant application requirements, curing characteristics and adhesion to dry concrete blocks. Researchers were also able to get an idea of sealant flexibility by studying its release characteristics.

The Instron unit was a Model TT-DL Instron Universal Testing Instrument using a highly sensitive electronic weighing system with load cells that use strain gages for detecting and recording the tensile load. A moving crosshead is operated by two vertical drive screws and a positional servo-mechanism for unique accuracy. A synchonized, variable speed chart allows a large choice of magnification.

Test Procedure - A schematic of the test set-up and procedure is shown in Figure 1. Pull tabs were formed from 1/4-in mesh, welded joint hardware cloth. The tabs were L-shaped with each leg measuring 2-in by 2-in. Two were placed back to back to give a single upright leg for attachment to the Instron and to give essentially a vertical pull. A frame, 3/16-in thick with a 4-in by 6-in opening, was centered over the tabs to provide a uniform area thickness as the sealant was applied to the tabs and block. Clamps were also designed and fabricated for holding the concrete block to the moving crosshead, and for attaching the pull tabs to the load cell.

The technique was first tested by attaching two sets of tabs to a concrete block, the first with epoxy putty, and the second with a resilient, fiber-loaded asphalt emulsion. The epoxy putty was chosen to produce a fast, hard set with a maximum adhesion to the block. It took nearly 400 lbs to pull the tab, with the graph showing a nearly clean, sharp break. The asphalt sample, on the other hand, released at a maximum of 20 lbs, with the graph showing a broad, two-humped curve. The asphalt at the edges of the tabs stretched nearly 1/4-in before separating, indicating that it would be effective in maintainig a seal against minor cracking or shifting.

Sample Testing - The test samples were prepared in triplicate, cured seven days and placed in tension on the Instron. For most samples

TABLE 5 - Listing of sealant candidate materials

Sealant	Supplier	Approximate Composition	Type Application	Cost Per Unit	Application Thickness[1]	Coverage Per Bag	Cost/ 100 ft^2
Fiberglass Loaded Cements							
B-Bond	Benco, Greensburg, PA	Portland Cement, AR fibers	Trowel or spray	$6.50-7.05 (bag)	1/8 in	57 ft^3	$11.40
Bencoat	"	Portland Cement, less AR fibers	"	4.70-5.75 (bag)	"	"	8.25
Inca 1000	Inca Co., Wilkes Barre, PA	Portland Cement, E fibers	"	5.90-6.30	"	50 ft^2	11.80
Surewall	"	Portland Cement, sand, E fibers	"		"	"	
Quickwall	Quikrete Co., Columbus, OH	Portland Cement, fibers	"				
Thoro-Stucco	Thoro Systems Products	Cement, lime, Acryl 60	"	8.73/80 lb	"	80 ft^2	11.00
Tite-Bond	Allied Block Chem. Co., New Eagle, PA	Portland Cement, E Fibers	"	5.50	"	50 ft^2	11.00
Celtite 10 Airtite	Cellite, Inc.	Water mixed polymers, fiberglass (premixed)	"	12.20/50# pail	"	100 ft^2	12.00
Stoppit	Mitchel-Walters Industries	Sodium silicate, styro-foam	Trowel	15.60/60# pail	1/16 in	250 ft^2	6.25
Lightweight Cements							
Mandoseal	J.P. Austin Co.	Vermiculite, cement	Spray	3.95	1/2 in	36 ft^2	11.00
Zonolite Mine Sealant	W.R. Grace	" "	"		"	40 ft^2	
Flaymbar 69X	Ocean Chemicals, Inc. Savannah, GA	" "	Trowel or spray	11.80	"	31 ft^2	38.00
Tite-Seal	Allied Block Chem. Co.	" "	"	3.50	"	33 ft^2	10.50
Strataseal MS-1	Strataseal, Inc. McMurray, PA	Perlite, cement	"	6.50	1/4-1/2 in	43-86 ft^2	7.60
Brattiseal	Thoro System Products	"	"	5.16	1/8 in	50 ft^2	10.32
Mine Shield	Unisul, Inc.	Mineral Wool, cement	Spray	6.75	1/4 in	150 ft^2	4.50
Mine Shield	American Energy Products	Magnesia cement	Trowel or spray	6.87	1/4 in	40 ft^2	17.00
Cement-based with Polymeric Additives							
Strataseal Block Lok	Strataseal, Inc.	Cement, polymers, Ca silicate	Trowel	6.50	1/8 in	100 ft^2	6.50
Top-n-Bond	Flintkote Stone Products Company	Cement, polymers	Brush	5.52	1/16 in	180 ft^2	3.06
Thoroseal +	Thoro System Products	Cement, lime, sand, acrylic	"	6.80+2.75	25 mils	225 ft^2	4.25

TABLE 5 - Listing of sealant candidate materials (continued)

Sealant	Supplier	Approximate Composition	Type Application	Cost Per Unit	Application Thickness[1]	Coverage Per Bag	Cost/ 100 ft^2
Sika Top 144	Sika Chem. Corp.	Polymer + dry mix, no water	Brush	18-21/gal	18 mils	200 ft^2	10.00
Thoroseal + Plastic Mix	Thoro System Products	Polymer + dry mix, no water	Trowel or spray	7.33	1/8 in	72 ft^2	10.00
Sakrete Mortar	Flintkote Stone Products Company	Cement, sand, lime	Trowel	3.40	"	40 ft^2	8.50
Thorocrete	Thoro System Products	Cement, sand, acrylic	Trowel or spray	4.56	"	40 ft^2	11.40
Sikaset Mortar 544	Sika Chem. Corp.	High strength mortar	Trowel				
Organic-based							
Liquimat	Tremco	Asphalt emulsion	Brush	24.75/5 gal	1/8 in	100 ft^2	24.75
RL-L-112	Tremco	Rubberized asphalt emulsion	"	42.00/5 gal	"	100 ft^2	42.00
Black Fibered Emulsion	Celcoat	Asphalt, plasticizers $AlSiO_2$	"	17.50/5 gal	9 mil	100 ft^2	17.50
Pleko Fluid Rubber	Celcoat	Fluidized rubber	"	22.00/gal	18 mil	50 ft^2	44.00
Hydro-Epoxy	Acme Chemicals	Epoxy	Brush or spray	15.00/gal	1/16 in	100 ft^2	15.00
Sikaflex-la	Sika Chem. Co.	Polyurethane Elastomer	Trowel or gun	21.00/gal	1/16 in	100 ft^2	21.00
Ter-Polymer Sealant 5100	VIP Enterprises	Emulsion ter-polymer acrylic	Brush, roller	11.00/gal	1/16 in	100 ft^2	11.00
Polysar Latex XD674	Solar Chemical Corp.	Water-emulsion rubber	Brush, spray	12.00/gal	6 mil	150 ft^2	8.00

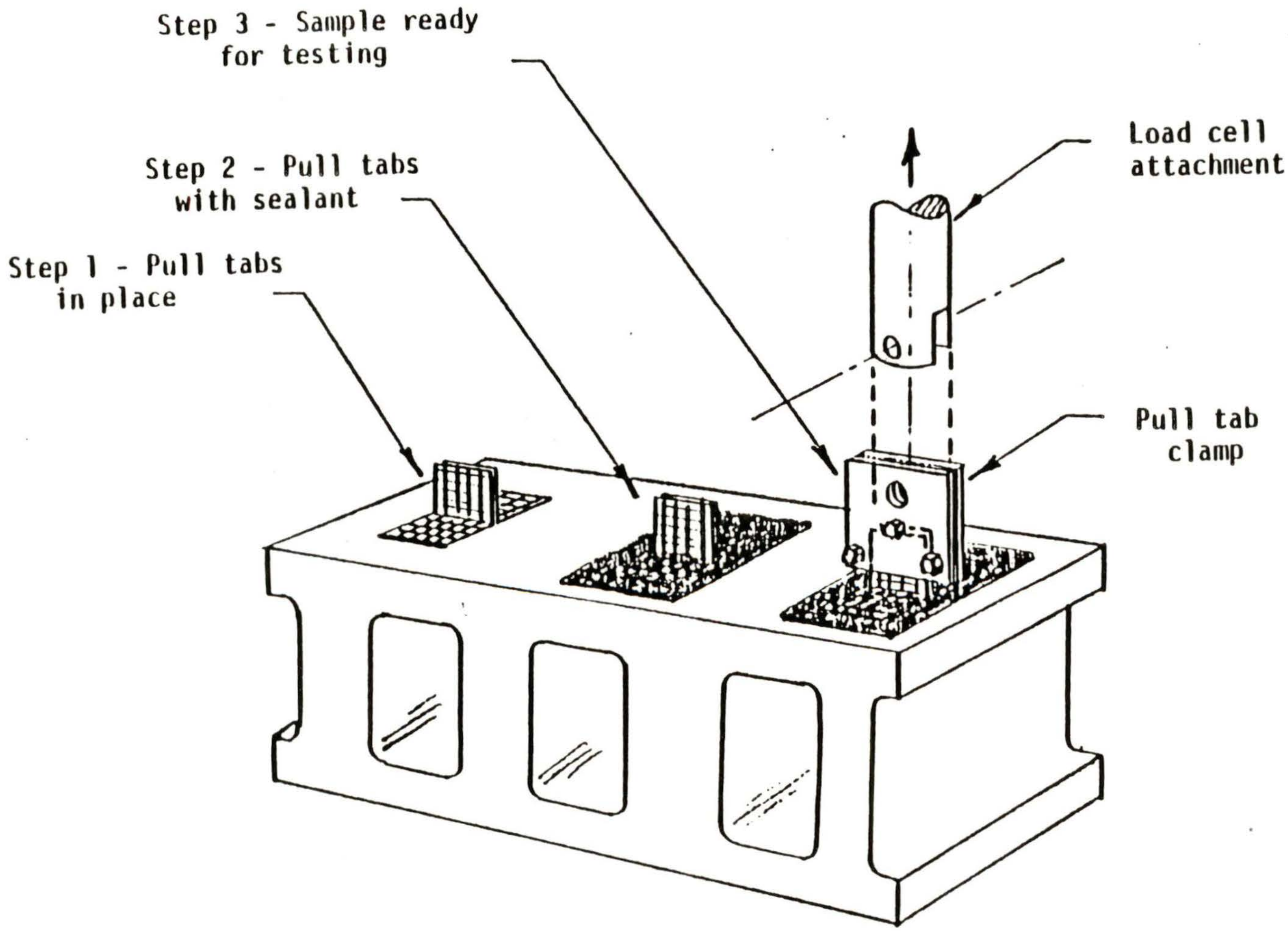


FIGURE 1. Schematic of adhesion test procedure

the curing was conducted at room temperature and high humidity (in plastic bags with excess water). However, for the silicate-based sealants requiring the loss of water, the cure was done at room conditions. The data are summarized in Table 6. An explanation of the column headings and an interpretation of the data are as follows:

- Peak Pull - is the highest number recorded on the Instron, and occurred at point of initial break in the sample. For the stronger sealants, such as the fiberglass-loaded cements, this was a measure of the adhesive strength of the sample to the block. For the weaker sealants, it represented the strength necessary to pull the wire tab out through, or away from, the sealant. High numbers are obviously significant. Low numbers should be viewed in combination with other results, such as percent of area remaining on the block, as to whether the break was sealant/sealant or sealant/block.

- Number of Borders Lifted - The samples were applied on two "L" shaped tabs placed back to back to form an inverted "T" using a 1/8-in thick rectangular metal frame as a guide. The frame size was such as to leave a one-inch-wide sealant border in contact with the block around the tabs. Each tab had three such borders, or a total of six borders per test specimen.

  The number recorded in the table under this heading, is the total number of borders lifted off the block out of the six possible. This was taken as an indication of the rigidity of the sealant, and thus a tendency toward spalling if the adhesive strength is exceeded. High numbers are not good, but should be viewed relative to the peak pull necessary to make the break. Obviously, a high number of borders lifted along with a low peak pull would be unfavorable.

- Percent Area Remaining - This column shows the relationship between the adhesion of the material to the block and its internal strength or cohesion. The softer, lightweight concretes, therefore, show a higher percent. Again, the higher percent is desirable as an indication of the ability to resist spalling.

- Approximate Angle of Flex - This angle was not measured but was estimated. A crack in the sealant usually forms immediately on the initial break (peak pull) but the angle given is an estimate of how far the tab could raise before the top or inner surface of the hinge point would separate, forming a face crack. The higher the angle, the greater the distortion possible in the block wall before leakage would be expected.

TABLE 6 - Summary of Instron data

Test No.	Sealant	Composition	Peak Pull (lbf) #1	#2	#3	Ave.	No. of Borders Lifted #1	#2	#3	% Area Material Remaining on Block	Approximate Angle of Flex Before Crack Opens	Comments on Application and Release
ORGANIC BASED:												
1787-64	Tremco RL-L-112	rubberized emulsion	60	saved	45	53	0	0	0	100	3/8-in stretch	continuous pull until free
-66	Polysar Latex XD-674	latex emulsion	24	33	saved	29	0	0	0	40	1-in stretch	fantastic stretch
-68	Thorosheen	acrylic emulsion	41	35	saved	38	0	0	0	70	1/16-in stretch	left pinholes as dried - no significant stretch
FIBER BONDED:												
-46	B-Bond	fiberglass, cement	175	188	175	179	0	2.5	4	30	50°	good adhesion and flex
-28	Inca 1000	fiberglass, cement	65 precracked	175	160	168	0	4	4	60	20°	trowels easy except for
-40	Sure Wall	fiberglass, sand, cement	65	85	105	85	5	2.5	5.5	25	5°	gritty, harder to trowel, poor adhesion
-38	Quikwall	fiberglass, cement	160	165	170	165	3	5	5	50	25°	took more water than specified
-72	Thoro-Stucco	fiberglass, Thoroseal	85	77	78	80	2	2.5	2	50	60°	excess fibers appears to lower strength
-27	Celite 10-15 Airtite	AR fibers, silicate base	88	75	110	82	0	0	0	90	70°	very convenient, no mixing
LIGHTWEIGHT CONCRETES:												
-30	Mandoseal	vermiculite, cement	35	45	65	48	0	0	0	100	30°	will not flow under trowel, does not adhere well
-36	Zonolite Mine Sealant	vermiculite, cement	50	—	50	50	0	3	3	100	30°	will not flow under trowel, does not adhere well
-32	Strata seal MS-1	perlite, cement	38	57	80	58	4	4	4	50	20°	mixes, trowels, adheres better than Mandoseal
-56	Mine Shield (Unisul)	mineral wool, cement	48	18	30	39	0	0	0	100	70°	not practical to hand mix and trowel
-62	Flaymbar 69X	fibers, insulation, cement	6	13	14	11	0	0	0	100	50°	good flex, volume, adhesion, easy to apply
MORTARS (with polymer additives):												
-42	Sakrete mortar	cement, sand, lime	32	35	32	33	5	2	2	75	20°	little strength
-44	Sakrete + Acryl 60		68	50	58	59	0	0	0	90	20°	greatly improved adhesion
-48	B-Bond + Acryl 60		250+	95 precracked	200	230	0	0	6	50	50°	mortar layer crumbled as wire pulled free on first tab

TABLE 6 - Summary of Instron data (continued)

Test No.	Sealant	Composition	Peak Pull (lbf)				No. of Borders Lifted			% Area Material Remaining on Block	Approximate Angle of Flex Before Crack Opens	Comments on Application and Release
			#1	#2	#3	Ave.	#1	#2	#3			
MORTARS (continued)												
-74	Sakrete + Gill 33 Superbond		67	72	63	67	5	2	3	50	5°	improves bond but not flex
-70	Thoroseal with Acryl 60	cement paint	120	135	150	135	0	0	0	100	30°	showed tendency to release slow and crumble
-54	Thoroseal Plaster Mix with Acryl 60		170	110	160	147	4	6	3	50	20°	one tab barely cracked
-52	Thorocrete	cement, sand, dry acrylic	127	152	185	155	2	0	3	50	25°	borderline between slow and quick release
-60	Sikaset Mortar 544	high strength	210	215	215	213	5	5	5	5	10°	two tabs did not crack mid-line, very hard
-34	Strataseal Block-Lok	cement-calcium silicate	250+	110	100	185	0	0	5	95	40°	cured shows some surface cracking
-50	Top-N-Bond	cement-copolymer	220	165	260+	215	0	0	0	90	60°	good, kept crumbling as it released slow

Discussion of Test Results - The sealants tested can be grouped into the four general composition based areas: organics, fiber-bonded, lightweight concretes, and mortars (with and without polymer additives).

The organic-based sealants were tested primarily for use on wet-laid stoppings where additional strength is not needed. The main property looked for was the ability of the sealant to maintain a seal under stress during cracking. Of those tested, Polysar-latex XD-674 and Tremco's RL-L-112 were superior. The Tremco product, however, is considerably more costly (an estimated $42.00 versus $8.00 for 100 ft^2 coverage). There is also a flammability question on some of these materials.

The three remaining sealant groups were tested primarily for dry-stacked stopping construction. Of these, the fiber-bonded and mortar (especially with polymer additives) classifications appeared to be superior to the lightweight concretes. B-Bond, Inca 1000, and Quickwall had the highest strength of the fiberglass-loaded group. Their strength could be enhanced with the addition of a polymer.

B-Bond with Acryl 60 (sample 1787-48) showed significantly higher values than B-Bond alone (1787-46) as did Sakrete with Acryl 60 (1787-44) versus Sakrete (1787-42). The mortars with polymer additives, as a class, gave higher adhesion values than any of the samples tested. Some of these (Thoroseal and Top-N-Bond) showed promise and were tested as a brush-applied mortar to be applied on the joints in a pseudo dry-stacking technique for building stoppings.

Celtite, a silicate-base sealant, had some very commendable properties. Although grouped in the lower three in adhesive strength, Celtite had better application characteristics, lifted no borders, and showed a high flex angle before a crack appeared. Since it is premixed, the savings in labor and material could be considerable over what is normally lost from broken bags or excess mixed and discarded material. This product, reportedly used extensively in England, looked promising. Stoppit, a similar silicate-based sealant produced in the United States, was not tested.

The lightweight cements are normally machine-sprayed and, therefore, were not considered viable for this contract. All showed weaker adhesion than the fiberglass products. Of the ones tested, Strataseal MS-1 appeared to be the best candidate for hand-mixing and troweling.

Survey of Squeeze Commercial Block Candidates

The search for commercial squeeze block candidates concentrated generally on major plastic and rubber manufacturers. Desirable properties for squeeze block materials were that they be; durable, readily available, relatively inexpensive, able to meet flammability requirements for in-mine use, compressible without cracking, and able to remain plastic for a long period of time. These properties dictate that the material be basically organic in composition.

The search was started through sales personnel, and they, in turn, talked to technical personnel who may have some knowledge of simple modifications to existing products that would better meet our specific requirements.

It was anticipated that the flammability standard would be the most difficult to meet. The flammabillity of some materials could be modified with fillers to minimize this problem, however fillers may adversely affect plasticity properties. This program did not include material modifications nor did it include the testing of materials so modified. Selections were based on information supplied from the manufacturers.

Compressibility testing was conducted on most materials, noting evidence for cracking under load. Preliminary leak testing was also conducted.

Table 7 shows a comparison of all materials surveyed as potential squeeze block candidate materials. Other than Foamglas, all will burn if exposed to flame. In addition, some have other properties that are more detrimental to their selection.

ChemFoam, expanded polystyrene (EPS) boardstock, is presently being used as squeeze block material by some mines, and is considered to be effective. It is apparently the least expensive. EPS will soften and melt at about 170°F.

Foamglas has excellent fire resistance and compressive strength. Unfortunately, it readily cracks when compressed, resulting in substantial leakage.

Armaflex, a fire resistant material used primarily for refrigeration pipe insulation. This material has low compressive strength and is the most expensive.

W.R. Grace Co. silicone foam is used extensively for sealing conduit and utility openings for fire protection in the construction industry. It is open-celled and will burn upon exposure to intense

TABLE 7 - Comparison of squeeze block candidates

Candidate	Composition	Fire Resistance	Compressive Strength lbf/in^2	Cost ft^2/in	Comments
ChemFoam	Polystyrene	Poor - will melt and burn	14	\$0.16	Will soften and melt at about 170°F
Foamglas	Blown glass	Excellent	100	0.40	Cracks on compression
Tremco's	Phenol-formaldehyde	<25 flame spread index		0.30	Partially open celled
Armaflex	Rubber-based	<25	6	1.50	
Thermalite	Foamed poly-urethane	<25	25	0.43	1 in. thick commercial foil-backed insulation
Quality Foam	Foamed poly-urethane	<25	20-25	0.43	Available in 2-in thick
W.R. Grace	Silicone foam	<25			Open-celled and flexible. Presently a sprayed system.
Honeycomb-Circle Industries	Paper-based		39	0.60	

flame, but is considered to be fire resistant. At present, however, it is not available in pre-cast boardstock.

Circle Industries Corp. paper-based honeycomb is being used in a western mine as squeeze block material and in many locations is not available. It does not appear to perform well. The long-term effect of moisture on the paper could also be suspect.

The remaining organic-based rigid foams were considered the best of the group. All are available as commercial insulating boards. Although the Tremco Corp. phenol-formaldehyde foam is somewhat open-celled, it should seal against air under normal mine conditions. The Instron test results appeared favorable, with no visible cracks. However, upon release of pressure it showed little memory.

The urethane foams also appeared favorable. Two samples of Quality Foam from UICS, Inc. were compressed on the Instron. In a preliminary test, the first sample showed no sign of fracture. The second was tested for air leakage. It was compressed from 2 1/4-in to 1/2-in in thickness with no air leakage, but showed some leakage as pressure was released and the foam expanded back to over 1 1/2-in thickness.

In summary, the rigid urethane, isocyanurates and phenolic foams all appeared to be superior to EPS (ChemFoam) as squeeze block candidate materials. All are organic and thus will burn when exposed to flame. When subjected to a slow heat rise, however, polystyrene will melt and may destroy the integrity of a stopping wall. The remaining candidates, on the other hand, tend to bake out and char, but retain their structural integrity to temperatures beyond 300°F. When compressed significantly between two concrete blocks, the stopping wall should withstand a direct flame for a minimum of one hour without loss of integrity.

Phase I Conclusions

The original program objective was to evaluate sealants and squeeze block materials on their ability to reduce ventilation air leakage through concrete block stoppings. As originally structured, three sealant candidates were to be selected from those presently used in mines, and three new candidates were to be selected from commercially-available materials. These six were to undergo further evaluation in Phase II and be reduced to the two most promising for in-mine demonstrations.

The selection process was hampered by problems with the in-mine evaluation. A considerable number of promising new candidates existed.

Moreover, the desired properties of sealants vary according to whether their potential use is for dry-stacked or wet-laid stoppings.

In conducting our in-mine evaluation task of Phase I, it became apparent that we were evaluating stopping construction practices, rather than the ability of the sealant to maintain an air-tight stopping. Almost all of the stoppings that we observed and measured leak rates on were intact and reasonably well sealed. Excessive leakage, if it occurred, was most generally the result of poor perimeter seals at the roof, floor, and rib, or through porous strata surrounding the stopping.

We evaluated both wet-wall and dry-stacked stoppings. Sealants for wet-wall stoppings need not have strength, and a previous Bureau report (3) noted that many common materials (mortar, latex paints, etc.) when applied to concrete-block stoppings reduce air leakage to a reasonable value. Wet-wall stoppings, therefore, can be readily sealed.

Dry-stacked stoppings, on the other hand, must be coated with a sealant that will also provide strength. MSHA guidelines suggest using fiberglass-loaded cement-based sealants on both sides, since concrete-block stoppings, coated thusly, have been shown by ASTM E72 (2) to be equivalent in flexural strength to wet-wall or mortared-joint stoppings. Six glass fiber enhanced mortars have been shown to meet ASTM E72 requirements, and are recommended for this use by MSHA's technical service group.

In preliminary tests of the fiberglass-enhanced group some differences were noted in their adhesive strength to concrete block. However, since all candidates had been shown to meet ASTM E72 requirements, there appeared to be no criterion in which to make a selection between them.

Sealant flexibility is a very desirable property. Thus, if a stopping does crack or shift, the ability of the sealant to flex and maintain an air-tight seal across any voids would be very desirable. Sealants for wet-walled stoppings require only this property, since stopping strength is inherent in the mortared joints. Dry-stacked stoppings, on the other hand, need sealants having greater strength. To make the surface resilient, a second sealant would likely have to be applied.

The survey of new, commercially-available, sealant candidates was successful. New fiberglass-loaded and polymer-modified candidates were located having excellent strength. We also found and examined flexible concrete-block coating materials. These included asphalt emulsions, latex rubbers, acrylic emulsions, and polyurethane elastomers. Although they appeared promising, all were liquids, having questionable flame-spread properties.

Brush-on Stopping Construction Technique - While conducting the screening tests of the sealant candidates on dry concrete block it was found that latex-modified mortars, applied by brush on the joints of dry- stacked blocks, created a wall having considerable strength. Block wall specimens, coated with brush-applied sealant, appeared to be as strong as conventional wet-laid and dry-stacked specimens with fiberglass-loaded sealants troweled on both sides. Thoroseal and Top-N-Bond were two promising materials tested.

Preliminary tests gave rise to the possibility of a new stopping construction technique that combine the simplicity and skill of constructing dry-stacked stoppings with the strength of wet-walled stoppings. In this technique. the latex-modified mortar was brushed onto the joints as they were dry-stacked in place. The finished product was a wall having equivalent strength to wet- walled stoppings. The same material could be used to face the block and joints for additional strength and air resistance. The program was thus modified to evaluate this promising technique and compare it to existing practices.

Modified Program - The objective of the modified program was to demonstrate a new and improved technique for concrete-block stopping construction that would replace both wet-wall and dry-stacked stopping construction practices. Phases II and III of the original program were modified to the following:

Phase II - Laboratory Evaluation of Sealant and Squeeze Block Candidates

A comparison of three new mortar candidates with each other, B-Bond (a fiberglass-loaded mortar) and regular mortar. Selection of one new mortar and squeeze block for demonstration.

Phase II - In-mine Demonstration

The construction and year-long evaluation of stoppings employing squeeze blocks and the new technique under actual mine conditions.

PHASE II - LABORATORY EVALUATIONS OF SEALANT AND SQUEEZE BLOCK CANDIDATES

The flexural strength of concrete block specimens, built using standard stopping construction practices, was compared to stoppings built with the brush-on test procedure developed for this program. Eight new candidate sealants were compared with standard mortar in wet-laid joints, and with B-Bond on dry-stacked joints. Two were selected for in-mine demonstrations.

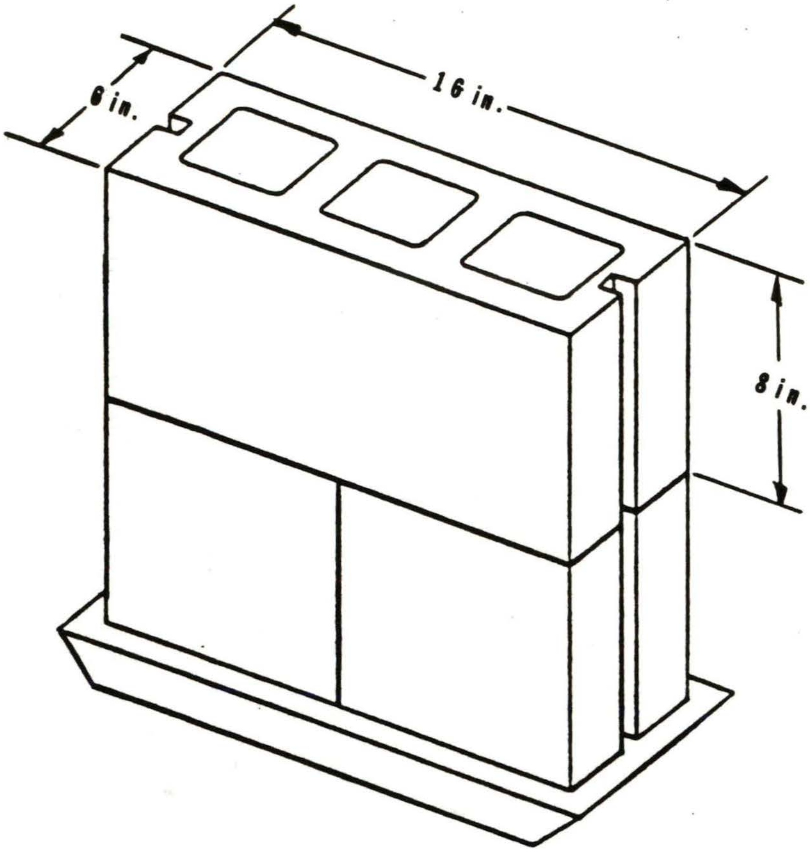
Several new squeeze block candidates were evaluated and compared with polystyrene, the one presently being used. Strength and flammability properties were measured and one candidate selected for in-mine demonstrations.

Flexural Strength Testing of Sealants

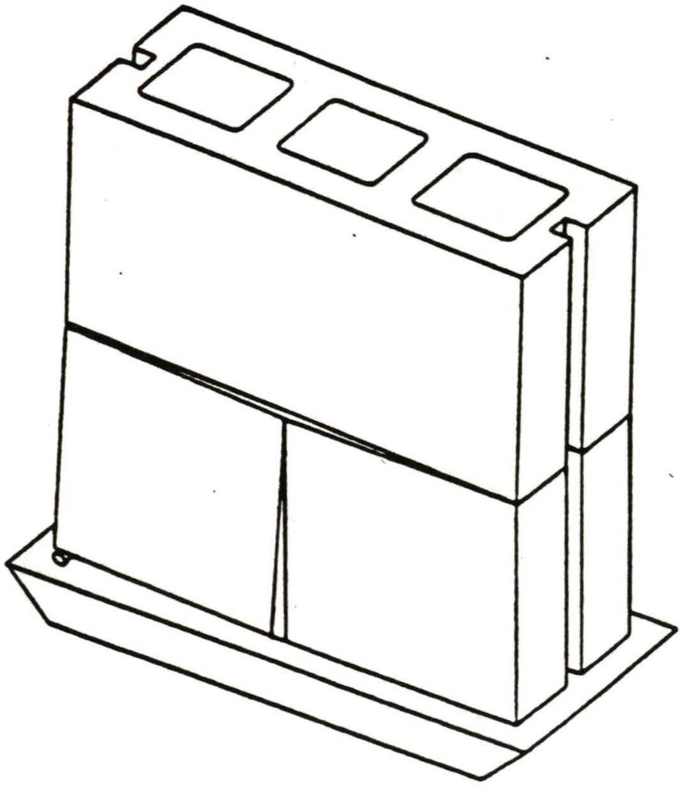
The flexural strength of block joints was measured on 6 in-thick block coated with the candidate mortars. Samples were tested and compared with common industry standards; mortared joints, and dry-stacked and trowelled faces, using (1) both brushed joints and faces; and (2) dry-stacked blocks with brushed faces only (Figure 2) Samples were tested in both the aligned and misaligned configurations -- the latter simulating a less-than even block course, which would frequently be the case in at least the lower courses of many concrete block mine stoppings.

Procedure - For the aligned tests, a 2-in by 6-in wood plank was used to give a flat base. Two standard 6-in deep half-blocks were used for the bottom course, and a full 6-in deep block for the top. For the misaligned tests, one of the half-blocks on the plank was raised 3/8 in at one end, thus causing gaps in both the matching vertical half-block and subsequent horizontal full-block joints. Mortar and sealants were applied as follows:

- standard trowelled joint construction - Sakrete mortar was used on all joints as in normal wet-laid block construction.
- standard dry-stacked construction - blocks were dry-stacked and 1/8-in B-Bond sealant trowelled on both faces.
- brushed joints and faces - the matching vertical joint surfaces of the half-blocks were first coated with candidate sealant using a 6-in plastic-bristle white wash brush and then placed together. The top



Aligned



Misaligned

FIGURE 2. Block pattern for flexural tests

surfaces of both blocks were then coated using the brush, and the full block set on top. The faces of all three blocks were then painted with the sealant.

- dry-stacked-brushed faces only - blocks were first placed into position and then coated both sides.

For the brush-on specimens, two coats were applied to each side. In the first, the blocks were given a uniform coat, making sure that the joints were filled. The sealant was brushed on to leave a coating rather than brushed out as a paint application. The second was applied similarly within 15 to 20 min thereafter. The final coating thickness was about 1/16-in on the block face. Filling occurred at the joint line and, especially on misaligned specimens where gaps were manufactured, sealant filled in between the blocks.

The samples were prepared in triplicate, enclosed in polyethylene to insure high humidity, stored at 70-80°F for seven days, and tested on the Instron using 3-point loading on laid-flat samples (Figure 3). The load point was on the one-half block joint only, keeping the full block free, thus testing the joint strengths and not the break strength of the full block.

Test Results and Discussion - The individual test results and comments are shown in Tables 8, 9 and 10. A summary comparison is shown in Table 11.

Of immediate interest was that the strength of the specimens constructed with the newer techniques were well in excess of those with the standard mortared joints. MSHA has a general recommendation that the strength of all permanent stoppings be equal to or greater than concrete block stoppings with mortared joint construction. The specimens using this method broke at about 1600 lbf. In general, specimens prepared by the newer techniques (sealant brushed-on joints and faces, and dry-stacked with mortar brushed-on only the faces) required over 3200 lbf to break.

The test results proved the strength of stoppings dry-stacked and troweled both sides and showed that simple modifications to this technique can perform at least as well. A large number of specimens actually showed block failure rather than joint failure, with some results in excess of 4000 lbf pressure.

With few exceptions, all of the cement-based sealant candidates met the general strength requirement. Fiber-loaded cementitiious candidates did well; those having latex additives did exceptionally well.

Another point of interest was that the use of a brush to apply sealant resulted in candidates as strong as those trowel-applied. This

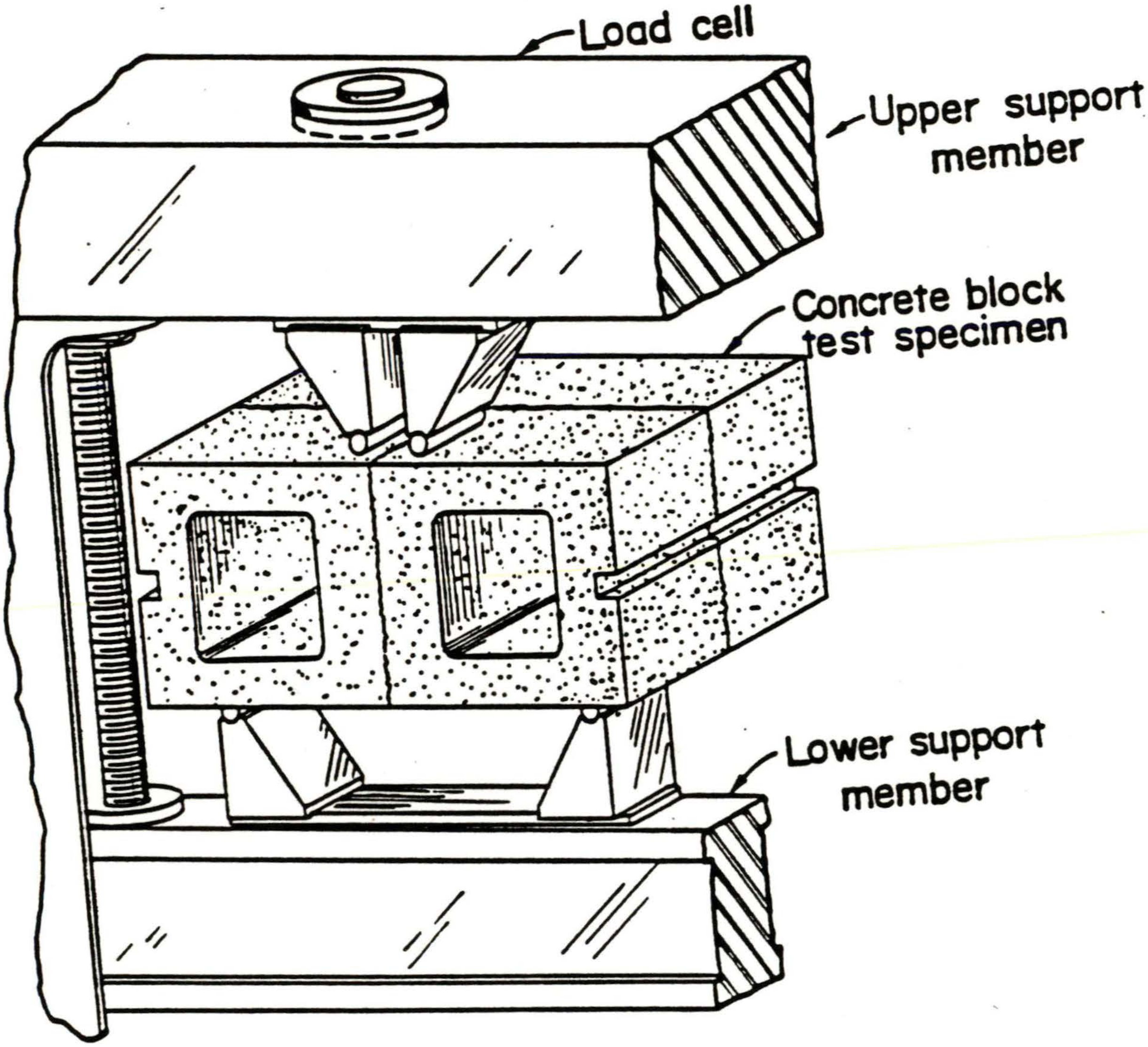


FIGURE 3. Schematic of specimen placement on Instron

TABLE 8. Flexural test data for standard industry procedures

Material	Type Construction	Force to break (lbf) Aligned	Force to break (lbf) Misaligned
Sakrete Mortar	Standard troweled mortar joints	1680	1750
		1420	1800
		1850	1370
		Avg. 1650	Avg. 1640
B-Bond	Dry-stacked and troweled to 1/8" both sides	2500[2]	3340[1]
		3740[2]	3000[1]
		3500[1]	3000
		Avg. 3247	Avg. 3113

[1]End section of half-block broke
[2]Full block broke in middle

TABLE 9. Flexural test data for specimens dry-stacked and brushed-on both faces[1]

Material (brand name)		Force to Break (lbf) Aligned	Misaligned
B-Bond		3700	3740
		3040	3660
		3060	2900
	Avg.	3267	3433
Brattiseal Brush Grade with Acryl 60		2660	2600
		3960[2]	2120
		3240	1760
	Avg.	3287	2160
Brattiseal with Fibers		3340[2]	3460[2]
		4080[2]	2040
		2800	3060
	Avg.	3407	2853
Genstar Mine Sealant		2660	3400[2]
		3960	4060[2]
		3300	3540
	Avg.	3307	3667

[1]All test results are for 7/81 test series
[2]End section of half-block broke

TABLE 10. Summary of flexural test data for specimens brushed-on both joints and faces

Material (brand name)	Supplier	How Packaged		Force to Break (lbf) Aligned	Force to Break (lbf) Misaligned	Comments
Sakrete Mortar	Flintkote (now Genstar)	20,40 & 80 lb bags		2500		Brushed on easily. Used additional water.
				2060		
			Avg.	2280		
B-Bond	Quikrete	50 lb bags		3120[1]	2960[1]	Very creamy; brushed and adhered well.
				3400[1]		
			Avg.	3260	2960	
"	"			>5000[1]	3360[1]	
				3160[1]	820[2]	
				4340[1]	3240	
			Avg.	4187	3300	
Brattiseal Brush Grade with Acryl 60	Thoro Systems	60 lb pails		3100[1]	3500[1]	Brushed on and filled vertical joints well
				3140[1]	3160[1]	
				3240[1]	3160[1]	
			Avg.	3160	3273	
" "	"			4600[1]	3240	
				3960[1]	3880[1]	
				4080[1]	3540	
			Avg.	4213	3553	
" "	"			8000[3]		Used solid half-blocks
Brattiseal with Fibers	Thoro Systems			4800[1]		
				4800[1]		
			Avg.	4800		
Top-N-Bond	Flintkote (now Genstar)	40 lb bags		2660	2220	Did not adhere to brush. Flowed out of vertical joints. Splattered off brush.
				2540	2960[3]	
				2640	2720[3]	
			Avg.	2613	2633	

TABLE 10. Summary of flexural test data for specimens brushed-on both joints and faces (continued)

Material (brand name)	Supplier	How Packaged	Force to Break (lbf)		Comments
			Aligned	Misaligned	
Flintkote Mine Stopping Sealant (new material)	Flintkote (now Genstar)	48 lb bags		2700 2060 2050	Not much improvement over Top-N-Bond for spread or fill of vertical cracks.
			Avg.	2270	
Genstar Mine Sealant	Genstar		>5000[1] 4120[1] 4040[1]	3460[1] 3700[1] 3800[1]	
			Avg. 4387	3653	
" "	"		6800[3]		Used solid half-blocks.
Bond-On-Vinyl Latex Concrete Patcher	Wall Firma, Inc.		4740[1] 5520[1]	4000[1] 4600[1] 3760[1]	
			Avg. 5130	4120	
Sika-top 144	Sika Chemical	44 lb bags and 26 lb pails	830 800 1000	300 420 370	Creamy, brushed well. Some difficulty filling vertical joints.
			Avg. 877	363	
Steel Bond	Burrel Construction		3060 3420	1940 2000 1330	Samples prepared and supplied by Burrell. Humidity not maintained during cure.
			Avg. 3420	1757	

[1]End section of half-block broke
[2]Not included in average
[3]Full block broke in middle

TABLE 11. Summary of flexural tests

Material (brand name)	Supplier	Industry Standards; Force to break (lbf) Aligned	Industry Standards; Force to break (lbf) Misaligned	Brushed Joints & Faces; Force to break (lbf) Aligned	Brushed Joints & Faces; Force to break (lbf) Misaligned	Dry-Stacked, Brushed Faces; Force to break (lbf) Aligned	Dry-Stacked, Brushed Faces; Force to break (lbf) Misaligned
Sakrete	Flintkote	1650 (standard mortared joints)	1640	2280			
B-Bond	Quikrete	3247 (dry-stacked-troweled)	3113	3260[1] 4167[1]	2960[1] 3300[2]	3267	3433
Brattiseal-Brush Grade with Acryl 60	Thoro Systems			3160[1] 4213[1]	3273[1] 3553[2]	3287	2160
" " "	" "	(one test using solid half-blocks)		8000[3]			
Brattiseal with Fibers	" "			4800[1]		3407[1]	2853[2]
Genstar Mine Sealant	Flintkote			4387[1]	3653[1]	3307	3367[1]
" " "	"	(one test using solid half-blocks)		6800[3]			
Bonds-on Vinyl Latex Concrete Patch	Wall Firma, Inc.			5130[1]	4120[1]		
Top-N-Bond	Flintkote			2613	2633[3]		
Flintkote Mine Stopping Sealant (New)	"				2270		
Sika-Top 144	Sika Chemical			877	363		
Steel Bond	Burrell Construction			3240	1757		

(1) End section of half-block broke - all tests
(2) End section of half-block broke - one test or more
(3) Full block broke in middle

is best illustrated with B-Bond in Table 11, which shows similar results for all three techniques. In fact, joint failure rather than block fracture occurred for specimens with sealant brushed on at both joints and faces. Exceptionally high strength is possible for this technique. In two tests where solid half-blocks were substituted for hollow core blocks to eliminate the block failure under test, the force to break the joint was 6800 and 8000 lbf, respectively.

Evaluation of Squeeze Block Candidates

Four squeeze block candidate materials from the Phase I survey listing, and a fifth added later were further evaluated to determine their suitability for in-mine use. All were organic foams; foam types, suppliers and identities were as follows:

Foam Type	Supplier	Foam Identification
Phenolic	Koppers Company, Inc. Organic Materials Group Pittsburgh, PA 15219	Exeltherm X-tra SFA-1112-833 Standard Roof Board
Polystyrene	B-Bond Industries P.O. Box 271 Latrobe, PA 15650	Chem Foam
Isocyanurate	R.J. Stern Company 4800 1st Avenue, South Birmingham, AL 35222	Max Seal
Polyethylene	Dow Chemical Company Hanging Rock, OH 45635	Ethafoam 220 PLK
Polyurethane	Foam System Company Riverside, CA 92507	FS-24

The foams were compared on the basis of proprietary data considered important for their potential in-mine use. The information included the following:

- adhesion
- closed cell content
- compressive strength
- memory
- flame spread index
- ignition temperature

Data for four of the samples were obtained on test samples received. Some data for the polyurethane foam,(Foam Systems' FS-24) however, was taken from tests conducted on a previous MSAR contract evaluating rigid foams (5).

Adhesion - The adhesion testing was done using basically the procedure described in the Bureau of Mines Report on Rigid Foam in Mines (4). Pull tabs were cemented to the foam with a sealant and the cured samples pulled on the Instron device. Eight-in-square foam samples were cut from each of the materials and then run through a fine tooth band saw to remove any skin or lamination. This gave a surface similar to the edge exposed to the sealant used in a mine. B-Bond was selected as the test sealant since it was the most commonly used in the mines. The pull tabs were 4 inch square plates of perforated metal (1/2 -in holes) with a 1/4-in eyebolt in the center.

The samples were prepared by first making a small recess in the center of each block to clear the nut on the eyebolt. B-Bond was then mixed and brushed onto the face of the test sample until all pores appeared filled. The pull tab was then set in the fresh mortar and additional B-Bond applied until the tab was completely covered. Finally, a 6-in diameter ring was placed around the tab and the mortar outside the ring was removed.

The test samples were prepared in triplicate, cured for seven days at ambient temperatures and high relative humidity, and placed in tension on the Instron. The test results are shown in Table 12.

B-Bond adhered best to urethane and polyethylene foams, with polystyrene adhesion slightly less. No data exists, however, to suggest that the adhesion of B-Bond to even phenolic foam, which was the weakest rested, was not adequate.

Closed-Cell Content - A closed-cell content evaluation of the foam candidates was conducted to determine air permeability. A high percentage of closed-cells in the samples would be expected to have low permeability.

Closed cell determinations were done by the DuPont method. With this technique a comparison is made by air displacement of a container with and without the sample. Comparing the apparent volume of the sample due to gas displacement with the bulk volume of a measured sample gives the percent closed cell content. The data are summarized in Table 13.

Compressive Strength - The compressive strength at 10, 15 and 20% deflection and modulus were determined on 2-in cubes of candidate samples. The results are shown in Table 14.

Polystyrene foam, a product already seeing use in mines as squeeze block materials, is stronger than polyethylene but weaker than the other three candidates. Polyethylene appears to be the only candidate not suitable for squeeze blocks from the strength standpoint.

TABLE 12- Adhesion data for foam candidates

Foam Type	Adhesion (lbf)	Comments
Phenolic	106	Lifted a thin layer of foam over 33% of the surface area
	108	Lifted a thin layer of foam over 25% of the surface area
	124	Lifted a thin layer of foam over 50% of the surface area
	Average 113	
Urethane	252	Broke a circle out of the 1-in thick foam and lifted off cardboard backing
	232	" " "
	216	
	Average 233	
Isocynurate	159	Lifted a thin layer of foam over entire area
	202	" " "
	182	" " "
	Average 181	
Polyethylene	280	Pull tab bent before breaking loose at surface. B-Bond broke and remained along one edge of tab
	202	B-Bond pulled from surface of the foam on a little over 50% of the surface under the tab.
	224	" " " " " " " "
	Average 235	
Polystyrene	225	Pulled a cone out of the foam
	200	Pulled some B-Bond off surface
	234	Mostly pulled B-Bond off surface.
	Average 220	

TABLE 13- Closed cell content of candidate foams

Foam Type	Measured Vol. (cm^3)	Apparent Vol. (cm^3)	% Closed Cell
Phenolic	131.0	124.8	95.3
Urethane*	--	--	95.2
Isocyanurate	131.0	119.8	91.4
Polyethylene	131.0	114.2	87.2
Polystyrene	125.2	115.6	92.3

*Data obtained on Contract J0308006 for Foam Systems FS-24 (5)

TABLE 14- Compressive Properties of Candidate Foams

Foam Type	Size (in)	Weight (lb)	Density (lb/ft^3)	Compressive Strength (psi)			Modulus (lbf/in^2)
				10%	15%	20%	
Phenolic	2x2x2	0.0115	2.5	8.25	13.50	19.25	116.6
Urethane*	2x2x2			20.9			49.0
Isocyanurate	2x2x2	0.0056	1.2	2.87	7.47	11.75	92.87
				2.40	5.75	9.50	75.75
Polyethylene	2x2x2	0.0104	2.2	0.32	0.75	1.38	14.15
Polystyrene	2x2x1.91	0.0038	0.9	0.65	1.44	2.43	19.23

*Data obtained on Contract J0308006 for Foam Systems FS-24 (5)

Memory - Memory, or recovery after compression, was measured on the Instron using foam samples 8-in by 8-in and 2 to 5-in thick. The samples were placed between two metal plates, compressed to approximately 85% of original thickness, and then released. The thicknesses were measured with a vernier caliper. A summary of the test data is shown in Table 15. Urethane and polyethylene foams showed the most rapid and complete recovery of all the media tested.

Flame Spread Index - Samples were subjected to the ASTM E162 Radiant Panel Test. In the test 1-in thick, 6-in by 18-in samples of the candidate are clamped into the sample holder (Figures 4 and 5) and exposed to a gas-fired radiant panel of a specific heat flux. A pilot flame ignites the upper edge and the resultant flame front progresses down the sample. Flame propagation is measured as a function of time. The total test time is 4 min.

The sample off-gas captured in the exhaust stack is also monitored for temperature and smoke content (by light obscuration). To obtain a temperature rise (T) for the sample, the peak temperature is compared to a baseline temperature. That value is combined with the burning rate data to calculate the flame spread index (Is). Both a peak and an integrated (total) smoke content are recorded for comparison.

The flame spread index (I_s) is the product of the heat evolution factor (Q) and the fame spread factor (F).

$$I_s = FQ$$

The heat evolution (Q) is the increase in stack temperature. The slame spread (F) is a function of the speed with which the flame front advances between three-inch-spaced bench marks. A summary of the test data is shown in Table 16.

Low flame spread values (Is) are desired, and on this basis EPS foam appeared to be far superior to the others. However, these tests for EPS are meaningless. Rather than burn, EPS samples melt to a small sample of viscous liquid soon after being placed in front of the radiant panel. Thus, EPS squeeze blocks, subjected to such heat in a mine, and without a protective sealant coating, would melt and collapse the stopping. The phenolic foam had the lowest flame spread of the remaining four foams, the isocyanurate had the highest.

Ignition Temperatures - Organic materials have rather definite flash and self-ignition temperatures. Ideally, foams used on stoppings should have as high ignition temperatures as possible, since the lower the ignition temperatures, the more likely ignition could take place.

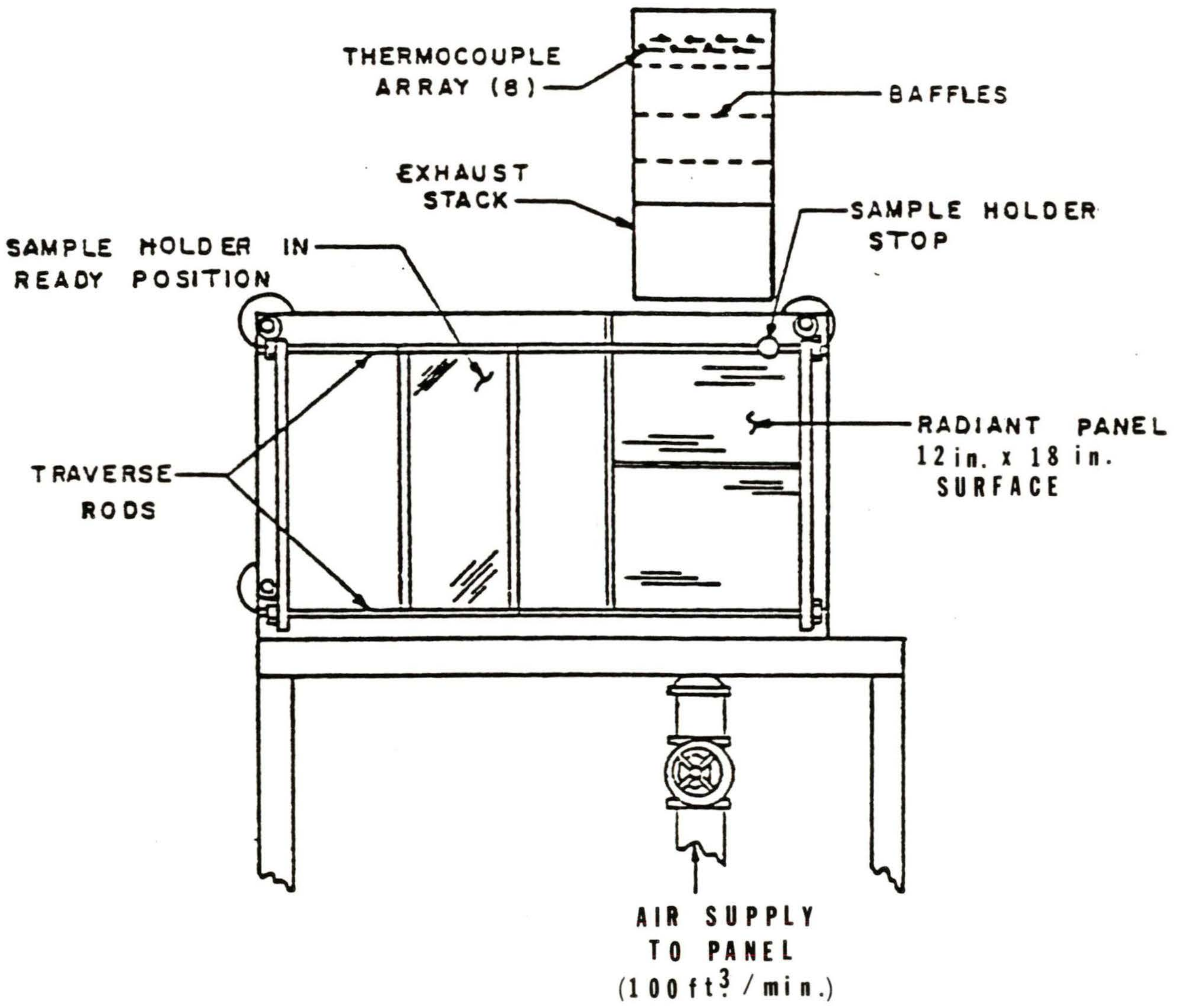


FIGURE 4. E162 radiant panel test facility (front view)

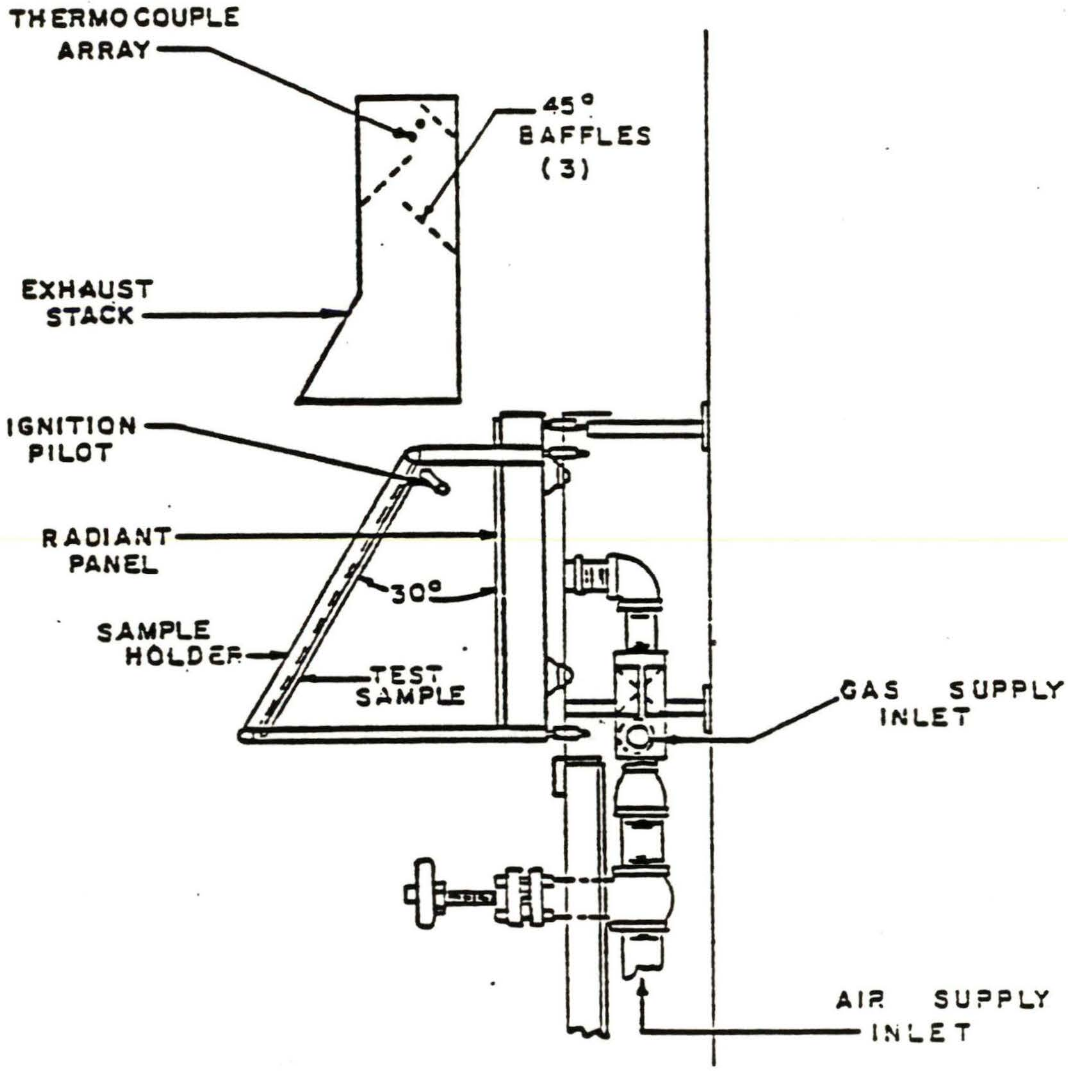


FIGURE 5. E162 radiant panel test facility (side view)

TABLE 15 - Memory data for foam candidates

Foam Type	Original Thickness (in.)	Compressed (% of Original)	Force on 8-in by 8-in block (lbf)			Recovery(% of orig.thickness)	
			(Peak)	(After 1 min)	(After 30 min)	(Immediate)	(After 15 min)
Phenolic							
without facing	2.445	84	2000	1600	1380	88	88
with facing	3.025	78	2000	1620	1420	82	82
Urethane	4.687	85	1680	1400	1160	96	98
Isocyanurate							
without facing	3.535	85	1001	800	670	89	91
with Al foil facing	3.655	85	800	680	560	89	90
Polyethylene	2.095	84	530	440	360	96	98
Polystyrene	1.925	86	780	600	420	88	89

TABLE 16 - Radiant panel data for candidate foams

Foam Type	Q	F	Is	Min Burned	Inches Burned	Smoke Peak	Smoke Total
Phenolic	1.4	10.4	14.5	6.3	6	5	1,250
	2.1	15.4	32.4	7.0	8	8	1,040
	1.0	9.3	9.1	6.9	5	7	840
	1.0	11.3	11.1	7.5	6	6	,940
Avg.	1.4	11.6	16.8	6.9	6.3	6.5	1,018
Std. Dev.	0.5	2.7	10.7	0.5	1.3	1.3	175
Urethane*	4.1	15.0	62	--	6	16	2,110
	3.6	17.4	63	--	6	19	2,385
	2.8	22.0	60	--	6	22	2,660
	3.4	25.0	85	--	8	18	2.160
Avg.	3.5	19.9	68	--	6.5	19	2,329
Std. Dev.	0.5	4.5	12	--	1.0	2.05	251
Isocyanurate	1.4	55.0	77.0	0.8	12	24	1,660
	2.8	136.5	382.0	0.5	18	44	2,530
	2.8	85.1	238.4	0.5	18	52	2,960
	2.1	81.0	170.1	0.5	11	31	1,980
Avg.	2.3	89.4	216.9	0.6	14.8	37.8	2,282
Std. Dev.	0.7	34.1	128.4	0.2	3.8	12.6	577
Polyethylene (all samples burned completely)							
	1.4	23.0	32.2	4.0	18	30	5,040
	2.5	34.8	87.6	4.0	18	20	3,130
	1.4	32.3	45.3	4.0	18	37	4,870
	2.1	32.4	68.0	4.0	18	7	1,660
Avg.	1.9	30.6	58.3	4.0	18	23.5	3,675
Std. Dev.	0.5	5.2	24.5	0.0	0.0	13.0	1,597
Polystyrene (sample melted out of holder - no burn)							
	0.7	1.0	0.7				
	0.7	1.0	0.7	DATA MEANINGLESS FOR			
	0.7	1.0	0.7	TEST COMPARISONS			
	0.7	1.0	0.7				

*Data obtained on Contract J0308006 for Foam System FS-24 (5)

The ignition temperatures of the candidate foams were determined using ASTM Method D1929-77, Procedure B.(1) The apparatus essentially consists of a vertical tube furnace containing a 10-in long ceramic tube having an inside diameter of 3 in. Heated air is passed up through the ceramic tube at a velocity of 5 ft/min. A foam sample is lowered into the furnace, the temperature increases, and the sample observed for evidence of ignition for 5 min.

The lowest furnace temperature at which ignition occurs is called the self-ignition temperature. The minimum temperature at which the gases ignite and flashback to the sample is called the flash ignition temperature. To determine the flash ignition temperature, a small pilot flame is located in the gas stream as it exits the furnace.

The ASTM method was not designed for cellular plastics so certain modifications in the sample size were made. Normally, a 3/4-in by 3/4-in cubic sample weighing 3 ±0.5 g is used. This is not possible with foams, therefore equal volumes of foam (3/4-in by 3/4-in x 1-1/2 in) were used without reference to weight. Ignition tempertures are shown in Table 17.

Comparison of Foam Properties - A summary of comparison test data on the five foam candidates is shown in Table 18. Since there are no recommended values for the various properties to base a selection on, only summary comments are given.

Sealant adhesion to all five candidates appeared to be adequate. The tests, however, were conducted on new samples, and did not show the effects of aging or to long-term exposure to high humidity.

The closed cell content values indicated that all would be an adequate barrier to air transmission.

The compressive strength values for all foams except polyethylene were well in excess of EPS. Polyethylene foam, therefore, may be too weak for stopping use.

Foam memory values were highest for urethane and polyethylene. They would probably adjust best to stopping shifts. All samples, however, show some degree of resilience.

The flame spread index showed that EPS melted when exposed to heat. This would destroy the integrity of a stopping. On the other hand, the phenolic foam proved to be the most flame resistant.

Flash ignition and self-ignition temperatures should be as high as possible. Polyethylene and EPS has the lowest performance, but no criteria are available for exclusion of one foam over another.

Selection of Candidates for In-Mine Demonstrations

B-Bond and Brush Grade Brattiseal, were the two sealants selected for in-mine demonstrations.

TABLE 17 - Flash and self-ignition temperatures for foam candidates

Foam Type	Ignition Temperature (°C) Flash	Self
Phenolic	490	506
Urethane*	445	525
Isocyanurate	488	495
Polyethylene	310	324
Polystyrene	380	390

*Data obtained on Contract J0308006 for Foam System FS-24(5)

TABLE 18 - Summary of squeeze block test data

Foam Type	Adhesion (lbf)	Closed Cell Content (%)	Compressive Strength (lbf/in^2) 10%	20%	Memory (15 min) (% of Original	Flame Spread (Is)	Ignition Temp.(°C) Flash	Self
Phenolic (without facing)	113	95.3	8.25	19.25	88	17	490	506
Urethane	233	95.2	20.90	---	96	68	445	525
Isocyanurate	181	91.4	2.63	10.65	89	217	488	495
Polyethylene	235	87.2	0.32	1.38	96	58	310	324
Polystyrene (EPS)	220	92.3	0.65	2.43	88	unobtainable	380	390

B-Bond brushed on easily and adhered well. One pass gave good coverage, and there was little tendency for splatter. The fibers tended to deposit in the joints, helping to seal and bridge them.

Brush Grade Brattiseal, with latex additive Acryl 60, also brushedon well. Vertical joints were readily filled, and joint strength was exceptional. Although a new product, it has undergone the ASTM E72 wall flexural test with brush-applied joints and faces. Results showed strength about twice that of wet-laid construction.

Top-N-Bond showed considerable strength, but would not adhere well to plastic bristled or nylon brushes. It worked better with natural fibered brushes, but the natural fibers tend to become limp when wet. Flintkote Mine Stopping Sealant had similar problems. Sika Top 144 proved to be too fluid for filling vertical cracks.

Chemfoam M, an expanded polystyrene (EPS) foam board stock, was selected as the squeeze block material for the in-mine demonstrations. It had MSHA acceptance for use as a perimeter seal underground and served as a suitable squeeze block material to test the concept. Several other foam candidates (phenolics, urethane) have better flammability properties and would have been favored, but also would have required acceptance by MSHA before they could have been used.

PHASE III - IN-MINE DEMONSTRATION

New stopping construction techniques using brushed-on sealants were evaluated and compared through a series of test stoppings constructed in Rochester & Pittsburgh Coal Company's (R&P) Urling #1 mine near Shelocta, PA. Fifteen demonstration stoppings were constructed comparing new techniques with conventional dry-stacked stoppings. Construction labor and materials, leakage rates, and general conditions were compared when new and at 6 and 12 months after construction. The results confirmed our laboratory tests to the extent that a handbook, Techniques for Constructing Concrete Block Stoppings(6), has been issued by the Bureau on this subject, and it is the topic of regular in-mine demonstrations by Bureau personnel.

Squeeze blocks were evaluated in Republic Steel Corporation's Kit #1 mine near Philippi, WV. Eight test stoppings were constructed. Because of interrupted schedules and resulting bad roof conditions, all stoppings were either destroyed or badly damaged. Enough was learned from the tests, however, to show that squeeze blocks had potential for maintaining stopping integrity under some mine closure conditions.

New Stopping Techniques

The test stoppings were constructed in the West Main area of R&P's Urling #1 mine. The stoppings separated intake from return air immediately at the base of the shaft. Thus, they were subjected to freeze-thaw cycles throughout the test period. The stoppings were designated numerically left (L-1, L-2) and right (R-1, R-2, etc).

These stoppings were constructed in front of existing stoppings. The old stoppings were subjected to about 1.5 in H_2O pressure differential and had very audible leakage, generally around the stopping perimeter. After each test stopping was constructed, several blocks were removed from the old stopping for free movement of air behind the new stopping. The air volume between the old and new stoppings was used for the leakage rate determination.

Stopping sizes were approximately 5-ft high by 18-20 ft long. Six-in deep, hollow-core block were in each stopping. Eight courses were typically necessary for each stopping.

All stoppings were constructed by mine personnel under the contractor's direction. Generally the crew consisted of two men; a brattice man and a helper. The same brattice man built all but two stoppings. The helpers varied.

During construction, the contractor provided supervision on perimeter preparation, footer, mortar mix, and joint and stopping construction. He also recorded times required for various operations, and took photographs. Where problems were evident or options available, mine personnel were solicited for comments and opinions. The contractor received excellent cooperation from both the work crew and mine supervision during the whole effort.

Immediately following construction, air leakage rates through stoppings were determined, then repeated after 6 months, and again after 12 months. General conditions were also noted during each air leakage evaluation. Resealing of some stoppings was also conducted after 12 months.

Four conventional dry-stacked stoppings that had sealant troweled on were compared with the brush-on technique. These were stoppings selected at random in a nearby working section. Their construction was unsupervised, and were more typical of stoppings built in this mine. In the evaluation they are designated A through D.

Description of Stopping Construction Techniques - Descriptions of the four new stopping construction techniques evaluated along with a similar description of the conventional dry-stacked stopping construction employed in the mine, are shown in Table 19. Proceeding down the table, the construction types are modifications of each technique just above, and, in general, represent an increase in complexity in either pre-preparation or degree of finish. They range from a simple substitution of brush-on sealant application for the trowel application in conventional dry-stacked stopping, to the installation of wet-laid solid-core block stoppings with extensive perimetrical pre-preparation. Realistically, the dry- stacked stoppings would be constructed in low pressure situations, whereas the more complex wet-laid stoppings would be for the high-pressure, main entry ventilation areas.

Specific construction details for each of the test stoppings are shown in Table 20. Both B-Bond and Brattiseal were used as brushed-on joint and face sealants, and different mortar mixes tested as footer materials. No significant sealant differences were noted in either ease of application or quality of completed construction. Differences in the latter were attributable to construction practices rather than materials.

Brush-on sealant application was a significant improvement over application with a trowel. Laborers, especially those unfamiliar with masonry block construction, found that sealants could be more easily applied with a brush. Whether on joints or stopping faces, the brush allows inexperienced personnel to apply sealant with little waste and to produce a stopping with excellent strength. In addition, the smooth

TABLE 19. Description of stopping construction techniques

Construction Type	Description Features
Conventional	Footer - Base course on cleaned floor, loose material used to level. Stopping construction - 6-in hollow core block dry-stacked and wedged. Sealant - Troweled, intake face only.
Dry-stacked, brushed	Footer - As above Stopping construction - As above Sealant - Brushed on intake side only.
Dry-stacked modified	Footer - Floor cleaned, mortar used to level. Ribs - Keyed to remove loose material. Stopping construction - Dry-stacked, each course wedged and mortared between end block and rib. Sealant - Brushed on intake side only.
Wet-laid, hollow core	Footer - As above Ribs - As above Stopping construction - As above but block wet-laid using brush to apply mortar. Solid core block on top and bottom courses. Sealant - Two coats brushed on intake; return perimeter sealed.
Wet-laid solids	Footer - As above Ribs - As above Stopping construction - As above with solid core block throughout. Sealant - Brushed on intake face only.

TABLE 20. Details of demonstration construction stoppings

Stopping Designation	Construction Type	Block Type	Sealant/Application	Footer Material
A	Dry-stacked/troweled	Hollow-core	B-Bond/troweled	None
B	" "	"	"	"
C	" "	"	"	"
D	" "	"	"	"
R-6	Dry-stacked/brushed	Hollow-core	B-Bond/brushed	None
R-8	" "	"	"	"
R-5	Dry-stacked/modified	Hollow-core	B-Bond/brushed	Strataseal mortar mix - wet
R-7	" "	"	"	Strataseal mortar mix - dry
R-1	" "	"	Brattiseal/brushed	Strataseal mortar mix - wet
R-12	Wet-laid/Hollow core	Hollow-core	Brattiseal/brushed mix - wet	Strataseal mortar
R-13	" "	Solid top and bottom courses	B-Bond/brushed	Brattiseal mortar mix - wet
R-14	" "	"	Brattiseal/brushed	" "
R-15	" "	"	B-Bond/brushed	" "
R-16	" "	"	Brattiseal/brushed	" "
R-1	Wet-laid/solids	Solid core	Brattiseal & B-Bond/brushed	Burell mortar mix -dry
R-2	" "	"	B-Bond/brushed	Brattiseal mortar mix - dry
R-3	" "	"	Brattiseal/brushed	Brattiseal mortar mix - dampened
R-4	" "	"	B-Bond/brushed	Strataseal mortar mix-wet
L-2	" "	"	Brattiseal/brushed	Brattiseal mortar mix-wet

brush finish provided shows up any missed cracks or holes. This is especially noticeable when sealing stopping perimeters, where a trowel application would leave rough surfaces.

Several other stopping construction improvements were noteworthy. These included:

- clearing loose materials and imbedding the first course of block in wet mortar to establish a good seal and for ease in leveling.

- removing loose rib material and applying mortar between the end block and rib for a better seal at this interface.

- using solid-core 6-in block for the base and top courses. This not only provided a firm base on the wet mortar and a solid surface for wedges at the roof, but by having the option to lay the solids flat or upright, provided flexibility in adjusting the stopping height to fit the opening.

- Placing wedging at the roof and rib perimeters parallel to the stopping and about forced about 1/2-in into the void between stopping and roof. This allowed space for sealant and for establishing a cove-like seal with the brush that encompassed the edge of the stopping and the adjacent rib or roof, establishing an excellent seal.

- sealing the perimeter of the stopping on the return side.

Labor and material requirements - The labor and material requirements for the test stoppings are shown in Table 21. Information for the dry-stacked and trowelled control stoppings were estimated by mine personnel.

No differences in labor or materials were found or expected for the brush application of sealant over similar trowel-applied dry-stacked stoppings. A labor increase of less than two hours and only two additional bags of mortar provided higher performing perimeter seals (dry-stacked, modified). Wet-laid stoppings, on the other hand, required more than twice the labor and three times the sealant. Similar results would also be expected for wet-laid, high-pressure stoppings.

TABLE 21. Labor and materials for stopping construction techniques

Designation	Construction Type	Construction Labor Breakdown (manhours)						Materials
		Rib & Floor	1st Course	Mid-section	Last Course & wedging	Sealant Application	Total	No. of 50 lb Bags Used
A	Dry-stacked/troweled	Not Available					4-5(est.)	2 (est.)
B	" "	"						
C	" "	"					"	"
D	" "	"					"	"
R-6	Dry-stacked/brushed	0.2	0.3	2	1.5	2	6.0	2
R-8	" "	0.1	0.6	1	0.5	2	4.2	2
R-5	Dry-stacked/modified	1	0.2	2	0.5	2	5.7	4
R-7	" "	1.2	0.2	2	0.5	2	5.9	4
L-1	" "	1.5	1	2.8	0.8	1.5	7.6	4
R-12	Wet-laid/hollow-core	1	2	4	3	3	13	5
R-13	" "	1	1	4	3	2	11	6
R-14	" "	2	2	5	2	2	13	7
R-15	" "	2	2	5	2	2	13	5.5
R-16	" "	1	1	4	1	2	9	7
R-1	Wet-laid/solid core	5.2	2	5	5.8	2	20	6
R-2	" "	5	1	5	4	2	17	6.5
R-3	" "	6	2	4.5	3	1	16.5	6.3
R-4	" "	2	1	4	1	2	10	5
L-2	" "	1.5	1	5.5	1	2	11	6

The table shows labor in excess of 5 manhours for the rib and floor preparation of stoppings R-1, 2 and 3, the first test stoppings constructed. Unusual care was taken to establish a level footer base and to sump deep, square keys in the ribs. These pre-preparations were later reduced to include only cleaning loose materials from ribs and roof and leveling the floor, procedures maintained throughout the remaining test stoppings. Air leakage and subsequent maintenance required justified this decision.

Air Leakage rates - Air leakage rates through the demonstration stoppings were measured within one month after construction, after 6 months, and after 1 year. Comparative data for conventional dry-stacked stoppings were obtained for only the initial period. The results are summarized in Table 22.

Stopping air leak rates were measured by the Bureau's sulfur hexafluoride (SF_6) tracer gas depletion technique. The sampling technique for all stopping examinations was to enclose a volume on the return side of a stopping, release and mix the SF_6 in the enclosed volume, and monitor the SF_6 concentration versus time as air leakage through the stopping diluted the SF_6 in the enclosed volume.

For the conventional stoppings, the enclosed volume was prepared by erecting a brattice curtain an arbitrary distance from each stopping. The modified stoppings were built in the same crosscuts and on the intake sides of the conventional stoppings, hence the conventional stoppings enclosed the volume.

As expected, conventional dry-stacked stoppings had the highest air leakage. Considerable improvement occurred merely by brushing-on the sealant rather than troweling. Even better results were achieved when care was taken to prepare the perimeters. The improvement in air tightness, observed for the wet-laid hollow core stoppings over comparable solid-core stoppings, was probably due to a second coat of brushed-on sealant. In this research there appears to be no justification for using solid-core block for high-pressure applications.

The results at 6 months showed very little difference from the initial results. In fact, slightly lower leakage rates were observed. The theory was that dust, entrained in the ventilation air, partially sealed small holes remaining in the stoppings, resulting in reduced air leakage. This theory was plausible because dust tracks were observed around many small holes in the sealant on stopping faces.

Air leakage for all stopping types increased significantly in the second 6-month interval. Since these measurements took place in early spring, they reflected the effects of freeze-thaw cycles on stoppings near the intake shaft and shrinkage due to the exceptionally low

TABLE 22. Air leakage versus time for stopping construction techniques

Designation	Construction Type	Leak Rate ($ft^3/min \cdot 100\ ft^2/in\ H_2O$) Initial	6 months	1 year	Reseal
A	Dry-stacked-troweled	139	--	--	--
B	" "	340	--	--	--
C	" "	56	--	--	--
D	" "	26	--	--	--
R-6	Dry-stacked/brushed	78	77	256	60
R-8	" "	59	27	211	39
R-5	Dry-stacked/modified	58	44	158	58
R-7	" "	46	27	69	50
L-1	" "	47	24	137	41
R-12	Wet-laid/hollow core	5	2	18	--
R-13	" "	12	5	12	--
R-14	" "	13	10	42	--
R-15	" "	8	5	13	--
R-16	" "	9	6	21	--
R-1	Wet-laid/solid core	46	25	51	46
R-2	" "	32	20	35	31
R-3	" "	28	25	41	32
R-4	" "	35	21	35	24
L-2	" "	50	36	125	59

humidity. Air leakage was most evident around the stopping perimeter. Cracks due to shrinkage, slight wall shifts, and spalling on adjacent roof and ribs were noted.

Those stoppings with the least rib and roof pre-preparation were affected the most while the wet-laid stoppings were affected least. Total air leakage, however, still favored the two-coat, wet-laid, hollow core stoppings.

Resealing was accomplished by brushing-on additional sealant at the roof and rib interfaces. This extended the total seal 8 to 10-in onto the strata. With the stopping exposed to differential air pressures, air leakage locations were audible. Sealant was applied where audible air leakage occurred until the noise stopped. This simple maintenance effected rather dramatic decreases in air leakage for the dry-stacked stoppings, which had been most affected by atmospheric conditions. The same maintenance resulted in only slight improvements in the wet-laid stoppings.

<u>Squeeze Block Demonstrations</u>

A total of seven test stoppings were erected in Republic Steel Corporation's Kit #1 Mine in Philippi, WV, as part of a plan to demonstrate the effectiveness of squeeze blocks in maintaining the integrity of stoppings during strata convergence. The stoppings were constructed in a working section as well as a main entry. Each area, thus, had both test and "control" stoppings.

Two-in thick Chemfoam M, an expanded polystyrene boardstock, was used as the squeeze block material. The stopping construction plan basically followed that currently being employed in the mine; the use of dry-stacked 6-in solid core block sealed on only one side. At the contractor's request, the mine used Brattiseal mortar mix as a footer and between the end blocks and the ribs. All roof line wedging at the was kept parallel to the face and recessed about 1-in to allow room for a mortar seal. B-Bond was used as the face sealant.

The squeeze blocks were placed at two locations: (1) on the first course; and (2) between the top course and the 2-in oak cap blocks. Squeeze blocks near the bottom of stoppings built in high coal seams appeared to cause a stability problem. During one installation, a stopping ten courses high rocked badly on the EPS squeeze blocks. One miner had to support it until a second miner was able to get the concrete block stacked to the roof and wedged. Once wedged, however, the stopping was stable.

<u>Test Results</u> - A series of unfortunate circumstances kept test results to a minimum. Although the initial stoppings were installed in

March 1981, a strike, followed by a mine shutdown extended the installation time of the seven stoppings to more than 6 months. During mine inactivity, a series of roof falls destroyed several stoppings. One additional stopping was destroyed during clean-up. The remainder had to be abandoned when the mine ceased production in the sections because of poor roof conditions.

Only one stopping was tested for air leakage. The leak rate of a section stopping was measured at 43 $ft^3/min \cdot 100\ ft^2/in\ H_2O$, using the SF_6 depletion technique. Although not exceptionally leak free, the test was to have followed the change in the stopping as it took on stress.

The leak rate was measured with the SF_6 depletion technique using a contractor-developed variation on the Bureau's parachute stopping to establish a pressure differential across the test stopping. Differential pressure across the stopping is not normally present in a developing section. To produce the pressure differential for this and other similar test stoppings, the contractor developed a portable system capable of developing pressures in excess of 1.5-in H_2O.

The system consisted of the Bureau-developed emergency parachute stopping and a centrifugal fan. The 30-foot diameter parachute stopping, coated with Acryl 60 to further reduce air permeability, was erected in a crosscut on the fresh air site. Six-ft lengths of sash cord were used to tie it to roof bolts and spads (Figure 6). The cords were spaced about 3 1/2 ft apart around the perimeter of the parachute. Three spring poles were used initially to span the chute across the crosscut opening, with masonry nails used to further close gaps between the chute and ribs. A fan inflated the parachute, thus creating a pressure against the intake side of the test stopping.

Pourable Floor Sealant

Most air leakage through a stopping takes place at the stopping perimeter. When a stopping is built directly on the broken material remaining after mining, a significant quantity of air leakage will be through the floor. This is a problem because several months may elapse between construction and when the stopping is finally exposed to a significant pressure differential. When leakage is finally detected, the stopping usually is too remote for corrections to be made.

Initial research was performed on techniques that would enable mine laborers to build stoppings directly on this broken material. Following the positioning of the first course of concrete blocks, a low viscosity liquid sealant would be poured inside the hollow-core blocks or, if solid core blocks are used, the sealant would be poured down the block face. The liquid would penetrate the broken material to a depth great enough to restrict future air leakage. In effect, a pour-in-place

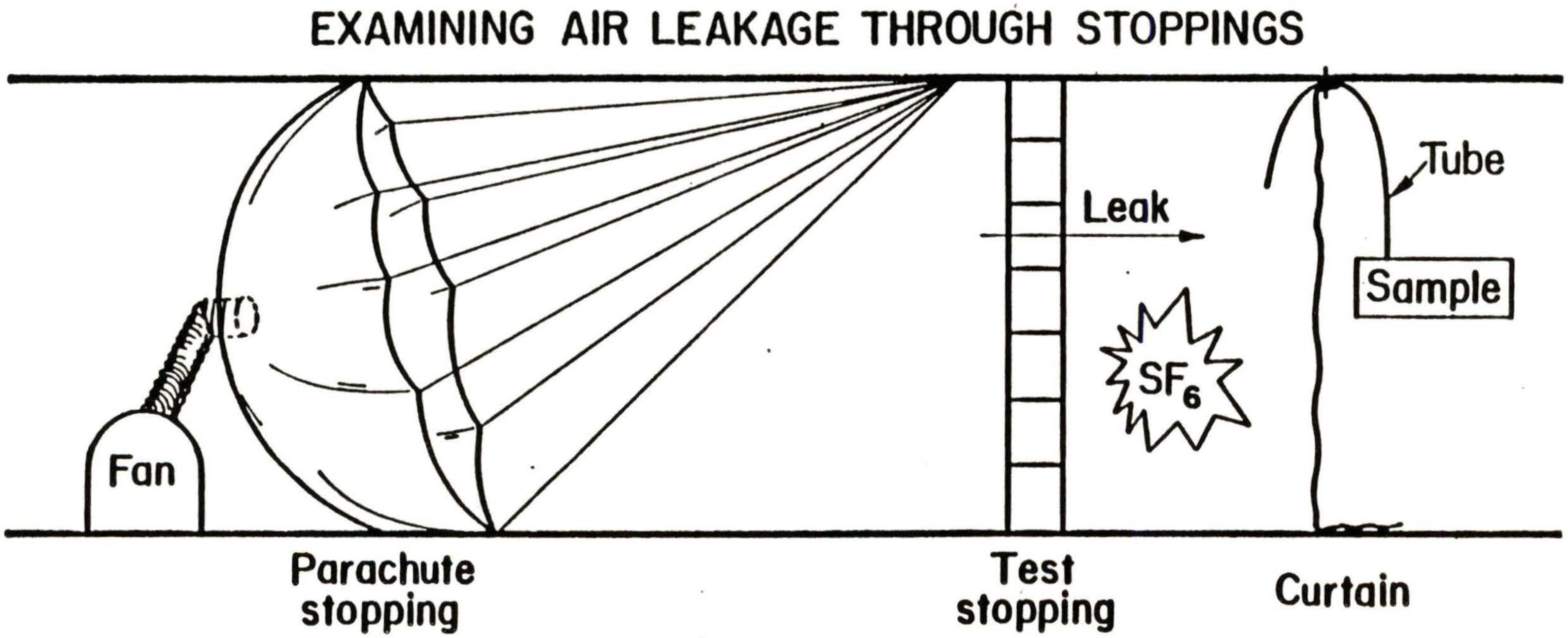


FIGURE 6. Schematic of parachute stopping placement for leak rate tests

footer, made of broken material and held together with the sealant, would be created.

Laboratory tests were performed on this potential technique using a sodium silicate-based sealant with added hardeners for improved rigidity and surfactants for improved penetration. This evaluation was only moderately successful. The tests employed placing crushed and sieved mine floor material into short lengths of 4-in diam polyvinyl chlorate (PVC) plastic pipes. This sealant was then poured into the pipe and absorption time measured. The samples were allowed to cure for a minimum of 7 days at ambient temperature and humidity. After curing, the air leakage rate was measured and the sealant penetration determined.

Examining the results of this preliminary test, it was obvious that the performance of a pourable sealant was directly dependent on the size of material used for the sample. Since mine floor is comprised of many different sizes of material, pourable sealant performance would depend directly on the particular material at the stopping site. In other words, what may work at one location may be worthless at another.

A second technique, designed to decrease the time required to build and seal a stopping as well as reduce perimetrical stopping leakage, was evaluated underground at Rochester and Pittsburgh Coal Company's (R&P) #1 Mine. During this research the technique was used only during stopping resealing. However, it showed promise for new stoppings as well.

Initial stopping construction involved building the walls directly on broken floor material. The stoppings were dry-stacked; no mortar was applied between the concrete block joints. After construction the stoppings were coated with brush-applied cementitious mortar.

Air leakage measurements were taken after construction, at 6 months, and again at 1 year. Bars 1 through 3 in Figure 7 show the results of the air leakage tests. Air leakage was reduced after 6 months. This occurred because of small imperfections in the stopping face being sealed with airborne rock dust, a hypothesis proven by dust streaks located across the stopping face at each small hole. The one year test, performed in the early spring, showed a significant air leakage increase. The stoppings may have been exposed to several freeze-thaw cycles through the winter, which would tend to cause the large increase in air leakage. Audible leakage was evident, especially at the stopping perimeters.

To reseal these stopping walls, a trench was cleared at the base of each stopping. A 1 gal bottle of Sealtite Polybind DLR, a latex emulsion, was combined with 3 gal of water and poured into the trench.

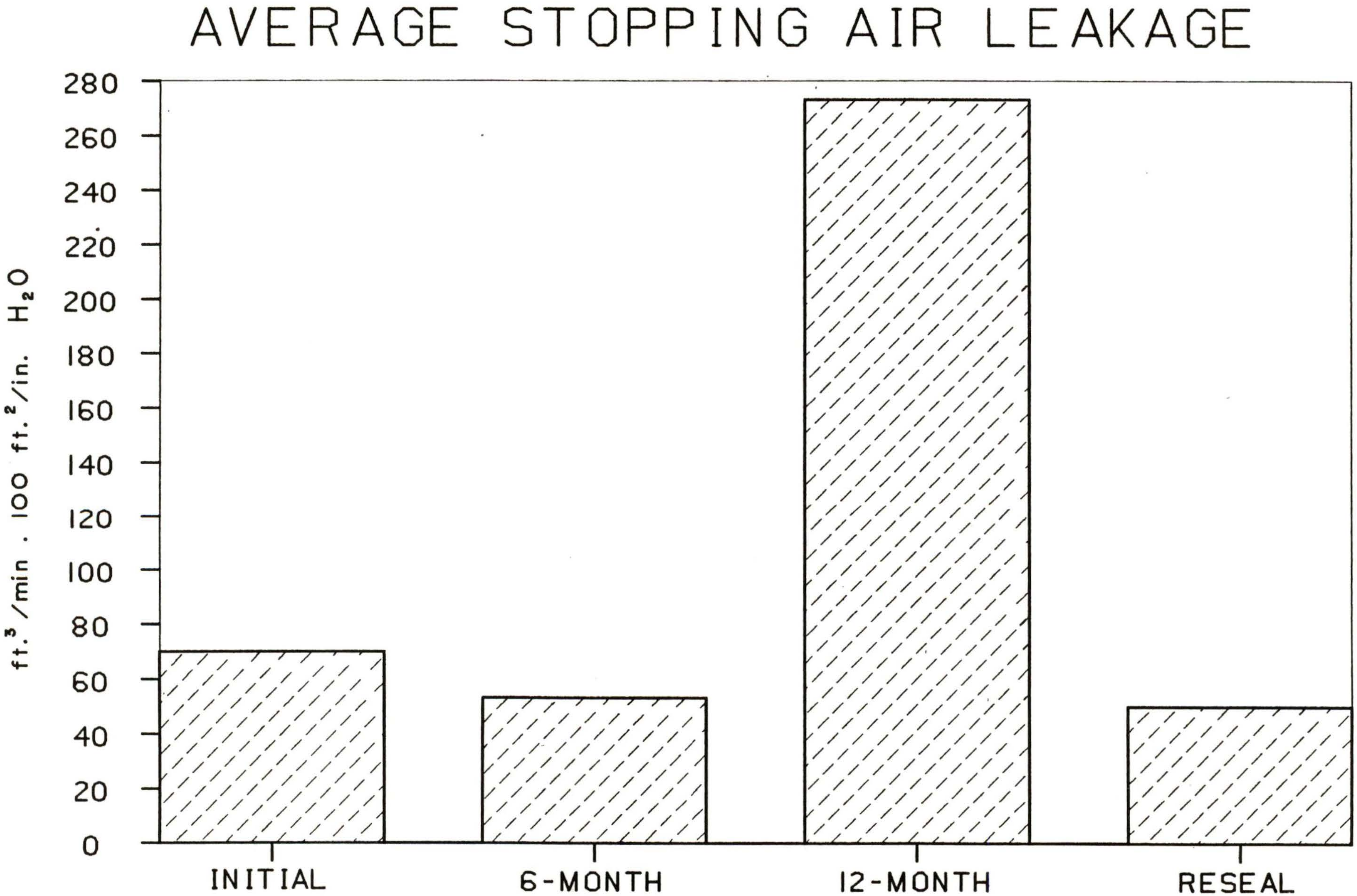


FIGURE 7. Air leakage of stoppings resealed at footer

Because of the pressure differential that existed across the stoppings, the liquid was immediately drawn into any voids at the base. To further aid the rigidity of the resealing liquid, dry B-Bond, a fiberglass-reinforced cementitious sealant, was poured into the liquid and mixed to form a paste-like sealant. This mixture was brush-applied into any imperfections across the stopping face, the stopping perimeter, as well as the floor.

The results of this test, seen in Bar 4 of Figure 7, were very encouraging. Stopping leak rates were reduced to less than those measured when the stoppings were originally built.

SUMMARY

A survey of commonly-used sealants for concrete block mine stoppings showed that fiberglass-loaded cement-based sealants were favored. An in-mine evaluation of these sealants revealed that stopping construction practices, rather than sealant used, were determining factors on air leak rates. Most air leakage occured around the stopping perimeters.

New latex-modified mortars, with and without added fibers, were found in a survey of commercial products. These were significantly stronger than standard mortars. These commercially available mortar-sealants can be brushed onto concrete block joints and surfaces to provide adequate strength, and improved sealing capability over conventionally-sealed block stoppings. The "brush-on" mortar stopping construction offers advantages to mines where laborers lack familiarity with masonry tools. Applying mortar with a brush requires little or no experience. Thus, almost anyone can erect a strong, airtight stopping, with minimum instruction.

New stopping construction techniques using brushed-on mortars and sealants were evaluated by building 15 test stoppings and comparing them with standard mine stopping construction. Labor and materials required were compared, as well as air leak rates and general condition. Air leakage through the stoppings was measured at construction completion, after 6 months, and again after 12 months. Those having additional preparation and a perimeter seal exhibited less air leakage and were damaged less by in-mine freeze-thaw cycles.

Key elements to better stopping construction were identified. Sealing the stopping perimeter meant the removal of loose material at the floor, construction of a mortar footer, keying the ribs back to solid coal, applying mortar between the end block and the rib as each course is laid, and making a good seal at the roof. As the last course was laid, wedges were driven between the roof and top blocks parallel to, but about one-in back, from the stopping face. This permitted room for a good mortar seal. Bulk mortar applications at the perimeter were still performed with a trowel, but using a brush rather than a trowel to finish the mortar, fills small voids more effectively and results in a smooth finish that readily reveals any unsealed openings.

Expanded polystyrene (EPS) foam squeeze blocks were used in some mines having strata convergence problems. Mine personnel believed that these were effective in maintaining stopping integrity under closure conditions. EPS, however, melts at relatively low temperatures. Better flame resistance properties are available in phenolic or urethane foams or other similar materials.

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