Construction of Seals in Underground Coal Mines

by

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CONSTRUCTION OF SEALS IN UNDERGROUND COAL MINES

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ABSTRACT

Abandoned areas of underground coal mines can be isolated from active areas through the construction of seals. Also, all areas of a coal mine from which the pillars have been wholly or partially extracted may be sealed. In either case, the current Code of Federal Regulations (CFR) states in Title 30, Part 75.329 that the seals should be solid, substantial, and incombustible so that an explosion on one side will be prevented from propagating to the other side. To satisfy these requirements, several different seal designs are already in use and other innovative materials and techniques are currently proposed for use in underground coal mines. An in-depth evaluation of these current and proposed seal designs is presented in this report.

INTRODUCTION

During the normal course of underground coal mining, it sometimes becomes necessary to seal off certain areas. CFR 30 Section 75.330 and 330-1 requires a plan for sealing abandoned sections and it is necessary for the mine operator to obtain approval of such plan. This approval is the responsibility of the Mine Safety and Health Administration's (MSHA) Coal Mine Safety and Health (CMS&H) District Manager under whose jurisdiction the mine is located. Sealing is also subject to local laws in some states. This report was written due to a request by CMS&H Headquarters for a report that summarizes the experimental results and technology of sealing. It is intended to provide up-to-date technical assistance to CMS&H personnel and other interested parties on the construction of seals in underground coal mines. The last report on seals was written in 1971 when the United States Bureau of Mines (BOM) published Report of Investigations (RI) 7581 entitled, "Explosion-Proof Bulkheads."

A commonly used seal is one that is constructed of solid concrete block, laid in a transverse pattern, keyed to the rib and floor, 16-inches thick, mortared joints, and with a center pilaster. This seal has been shown to effectively withstand explosion pressures exceeding 40 psi and it meets the criteria of Title 30 CFR Part 75.329-2 according to the definitions that MSHA's Industrial Safety Division (ISD) uses for solid, substantial, and incombustible. However, other seals using solid concrete block, cementitious foams, or other materials are sometimes specified in the plan submitted for approval. In some instances, MSHA's ISD has been requested to evaluate the proposed seals to determine their adequacy for the intended use. The ISD has done extensive work in seal evaluations and in the areas of incombustible materials, sealants, and strength considerations.

Recently, MSHA's ISD has worked with the BOM in determining suitable characteristics for the design and performance of underground coal mine seals. The BOM has performed explosion testing of a number of such seals at
their Lake Lynn Laboratory (LLL) as shown in Figure 1. The LLL is an abandoned limestone mine with entry size of 6-foot height and 20-foot width. Initially, tests were performed on various solid-concrete block seals of varying thicknesses and designs. The results of these initial tests are discussed in this report and are documented in Pittsburgh Research Center's Internal Report No. 4809 entitled, "Performance Evaluation of Solid Cementitious Seals." This report was co-authored by the BOM and MSHA's ISD engineers and copies are available by contacting the ISD at (412) 892-6933 or PTE 723-6933.

In addition to solid-concrete blocks, there is widespread interest in the construction of seals using other types of materials. Tests at the BOM's LLL have been conducted on a cementitious foam called "TEKFOAM", which is manufactured by Celtite\(^1\). Future tests are being planned at the same facility on Burrell Mining Products'\(^2\) "Omega 384" block.

The sealed area of an underground coal mine can have significant quantities of methane remaining even long after mining has ceased. Once the influx of methane into a sealed area reaches equilibrium, the methane concentration usually stabilizes well above the maximum explosive concentration of 15 percent. Methane explosions in this atmosphere would not be possible, except in the unlikely event that isolated pockets remained within the explosive range in the presence of sufficient oxygen. However, pressure development would be limited due to the fuel-rich conditions and the general lack of oxygen throughout the sealed area. Methane concentrations can also fluctuate during rapid barometric changes.

There are also underground coal mines with limited cover, above the water table, that have never detected any significant methane concentration. It would be expected that the atmosphere in the sealed area of such a mine would stabilize with a methane concentration below the minimum explosive concentration of 5 percent. Methane explosions in this atmosphere would not be possible unless significant quantities of coal dust were dispersed in areas with insufficient rock dust inhibiting. Research\(^3\) has shown that methane explosions are possible with methane concentrations below 5% if sufficient quantities of coal dust are also suspended.

Both of the abovementioned situations would be adequately protected by seals with a flexural strength of 20 psig. \(^*\) Reference?

Unfortunately, there are abandoned areas where the atmosphere remains within the explosive range of methane. Also, in mines where the abandoned

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\(^1\)Celtite Technik, 150 Carley Court, Georgetown, Kentucky 40324.

\(^2\)Burrell Mining Products International, Inc., P.O. Box 439, New Kensington, Pennsylvania 15068.

FIGURE 1. - Plan of the Lake Lynn Experimental Mine
areas stabilize with a methane concentration greater than 15 percent, the atmosphere would have been within the explosive range for a certain time. These situations also would require that seals be constructed in a way to prevent an explosion on one side from propagating to the other side. However, a seal constructed to withstand an explosion pressure wave of 20 psig may not be sufficient in these cases. In determining the design characteristics of seals in these areas, the following additional factors should be considered:

1. The strength of a methane explosion can be intensified by the presence of coal dust. The application of rock dust in the sealed area, particularly near the vicinity of the seals, would limit the involvement of coal dust in any explosion and, thus, pressures would be of reduced magnitude.

2. The size of the area protected by the seals is also an important consideration. Large areas can allow expansion of the burning gases and reduce the violence of the explosion.

3. The pressure drop across sealed areas has an effect on the leakage of the seals, and may prolong or prohibit the exclusion of air.

4. The ventilation of the seals is important to dilute any gases that may leak through to the active workings.

5. The type of roof rock can be a determining factor since there are recorded instances where roof falls have ignited methane. An evaluation of the roof rock and its propensity for methane ignition is important. The characteristics of the roof rock can become an important factor and sealing in an area where roof falls have ignited methane may not be the best choice. The determination should be on a case-by-case basis.

6. The likelihood that spontaneous combustion may occur in a sealed area is also an important consideration. Sealed areas with no possible ignition sources present no explosion hazards. Those areas that are susceptible to spontaneous combustion and where methane remains within the explosion range should be evaluated on a case-by-case basis to determine if sealing is a suitable choice.

CODE OF FEDERAL REGULATIONS (CFR)

Although this report primarily deals with Part 75.329-2, the Code of Federal Regulations (CFR) covers the sealing or ventilating of pillared or abandoned areas in Parts 75.329-2 and 75.330 in its entirety as follows:

§75.329-2 Construction of seals or bulkheads.

Pending the development and publication of definitive specifications for explosion-proof seals or bulkheads, such seals or bulkheads may be constructed of solid, substantial, and incombustible materials such as concrete, brick, cinder block, or
tile, or the equivalent, sufficient to prevent an explosion which may occur in the atmosphere on one side of the seal or bulkhead from propagating to the atmosphere on the other side; provided, however, that upon publication of definitive specifications, all such seals or bulkheads, including those in place at the time of such publication, shall be required to meet or exceed those specifications.

§75.330 Sealing abandoned sections.

[STATUTORY PROVISIONS]

In the case of mines opened on or after March 30, 1970, or in the case of working sections opened on or after such date in mines open prior to such date, the mining system shall be designed in accordance with a plan and revisions thereof approved by the Secretary and adopted by such operator so that, as each working section of the mine is abandoned, it can be isolated from the active workings of the mine with explosion-proof seals or bulkheads.

§75.330-1 Plan for sealing abandoned sections.

For approval the plan for isolating each set of cross entries, room entries, or panel entries shall include the following:

(a) A mine map at a scale not more than 500 feet to the inch which is sufficiently detailed to illustrate the mining system employed, depth of cover and dimensions of barrier pillars left in place bordering such areas, the proximity of all active workings, and the proposed location and sequence of construction of all necessary mine seals required, when mining is completed in a mining area. Such map shall illustrate the location of such mine seals as may be required should mining conditions necessitate abandonment of a mining area prior to the scheduled completion date.

(b) A detailed drawing or drawings of proposed explosion-proof seal construction which shall meet the requirements of §75.329-2. Such drawings shall show the pillars in which the seals will be erected and such pillars shall be of sufficient size and number to protect the seals.

Solid Seals

Part 75.329-2 states that seals "...may be constructed of solid, ...materials...". This "solid" aspect of a seal is the one that is designed
to prevent or reduce exchanges between the air on opposite sides of the seal. BOM RI 7581\textsuperscript{4} discusses the hazard of gas leakage from sealed areas and is excerpted in the following paragraphs.

"Sealing may not protect men in active workings unless the means taken to control gas leakage are effective. In exceptional cases only can gas-air exchanges between sealed and open areas be prevented. A leakage rate as small as 100 cfm will cause an exchange of more than 1 million cubic feet of atmosphere between open and sealed areas within a week. This exchange can be with intake as well as return air courses.

Changes in barometric pressure, the flow of ventilating air through the open portion of a mine, the different atmospheres in the open and abandoned areas, massive falls of roof, and stoppage of the mine fan cause flows of gas from and of air into sealed areas. Even if seals are airtight, gases can be forced through cracks and fissures in the roof, floor, and coal pillars. Ground movements after sealing can enlarge paths through as well as around bulkheads.

The quantity and time of flow depends on the prior barometric pressure history. For example, if a decrease in barometric pressure follows a relatively long period during which the pressure was rising, then initial gas flows may be small. Reportedly, air may temporarily continue to flow into the sealed area. Should the decrease, however, follow a relatively long period during which the barometric pressure had been constant then initial gas flows could be large. The time when flows become dangerous also depends on conditions within the sealed area, particularly its size, leakage paths, pressure and temperature gradients, extent of caving, and on the kinds and concentrations of accumulated gases.

To protect men in active workings from gob-gas leakage, pressures within sealed areas must be relieved and gas-air exchanges must be controlled. Gas will flow toward points of lower pressure. Pressures within the sealed area must be relieved to reduce the chance that points of lower pressure are in the active workings. This can be done in part by removing gases as they accumulate. In some mines, gases might be vented through boreholes to the surface. Pressure differentials between the sealed and open areas also can be controlled by pressure balancing."

A maximum acceptable leakage rate for varying pressure differentials has not been established. It is important that seals be maintained in an adequate state of repair and pressure differentials be kept to a minimum to

keep air leakage small. Also important is that a sufficient flow of
ventilation be provided against the seals to dilute gases leaking through the
seal.

Substantial Seals

Part 75.329-2 states that seals "...may be constructed of
...substantial...materials...". This "substantial" aspect of a seal is the
one that provides for a seal to have a significant flexural (bending)
strength. This is the ISD's interpretation of the intent of the criteria in
Part 75.329. Substantial is not related to the compressive strength of the
seal. In other words, the seal is not designed as a load-bearing control
and is not intended to provide roof support in the area where it is
constructed. However, a certain amount of roof support would be realized
from any seal. On the other hand, the forces generated during a coal dust
and/or methane explosion cause a shock wave to rapidly travel through the
entries and crosscuts of a mine. This force acts on the seal in the
horizontal direction and causes the seal to bend and, if the force is great
enough, the seal will fail as cracks appear on the opposite side and
eventually blocks are separated from the seal. In that event, the seal would
not have met the criteria of 75.329-2 in that an explosion in the atmosphere
on one side of the seal would have propagated to the atmosphere on the other
side.

Before actually performing explosion testing on any seal designs, it was
essential to establish a suitable performance characteristic related to the
flexural strength of any seal. Applying the term "explosion-proof" to the
flexural strength requirements of any seal would necessitate that each seal
be able to withstand any explosion pressures that may develop. Explosion
research in the BQM Experimental Coal Mine in Bruceton, Pennsylvania, has
shown that up to 127 psig may be developed during a worst-case underground
coal mine explosion, where optimum concentrations of coal dust and methane
exist. Pressure piling may also account for even higher pressures,
especially in areas that are not adequately vented.

During an underground coal mine explosion, the pressures developed are
greatest in the area where the explosion flame travels. This distance is
greatly dependent on the quantity of fuel present, along with many other
variables. However, the extent of flame is usually not widespread.
Explosions generally occur due to the activities of underground workers,
which, most of the time, is in the vicinity of an active working face. Seals
are not usually located in close proximity to such a face area. After the
flame of an explosion ceases to continue propagation, significant forces are
rapidly reduced. However, it is common for forces of less than 2 psig to
travel large distances underground, causing little damage.
BOM RI 7581\textsuperscript{5} states,

"Seldom, however, do pressures 200 feet and more from the origin of an explosion exceed 20 psig unless coal dust accumulations are excessive and the incombustible content of the dust is less than required by law."

Based on the investigation of the major underground coal mine explosions that have occurred in the last 13 years, it is reasonable to believe that seals are not generally subjected to pressures exceeding 20 psig during explosions. This pressure of 20 psig is a suitable performance characteristic for identifying the flexural strength requirements of seals constructed in underground coal mines.

Incombustible Seals

Part 75.329-2 states that seals, "...may be constructed of...incombustible materials. This "incombustible" aspect of a seal is the one that is intended to keep the materials used to build a seal from creating a fire hazard or from contributing fuel to any fire or explosion. Incombustible material will not contribute any fuel and will not itself burn during a fire or explosion. This is a very stringent test for seal construction materials. A less restrictive term is noncombustible. Noncombustible material would basically require that all construction materials used in seals to be subjected and pass the ASTM E-136\textsuperscript{6}, "Behavior of Materials in a Vertical Tube Furnace." For materials to pass this test, they must meet or exceed the following three conditions:

1. The recorded temperature of the surface and interior thermocouples do not, at any time during the test, rise more than 54°F (30°C) above the furnace temperature at the beginning of the test,

2. There is no flaming from the specimen after the first 30 seconds, and

3. When the weight loss of the specimen during testing exceeds 50%, the recorded temperature of the surface and interior thermocouples do not, at any time during the test, rise above the furnace air temperature at the beginning of the test, and there is no flaming of the specimen.

Another way to define incombustible for seals is that the total structure is capable of providing a certain fire resistance. The fire-resistance rating is essentially the time that the wall can be expected to resist the passage of heat, flame, or hot gases, any of which could ignite

\textsuperscript{5}Same as Footnote 3.

combustible material on the opposite side of the wall, when the wall is subjected to heat from a carefully controlled energy source, such as a furnace. Since miners do not work on both sides of any seal nor is the air on the abandoned side used for ventilation purposes, a 1-hour fire-resistance as per ASTM E-119\textsuperscript{7}, or equivalent, would be reasonable.

This rating is considered to be a reasonable time frame for miners to safely exit a fire area via an escapeway during an emergency. Wall partitions in buildings are assigned ratings according to the wall's fire resistance; ventilation control structures in mines are considered on an equal safety basis.

The ASTM E-119 method of test, "Fire Tests of Building Constructions and Materials," is recommended for use in determining the fire resistance of seal materials. The seal is constructed as one wall of a test furnace and the temperature inside the furnace (and on the seal) would increase rapidly initially and, during the first hour, the following temperatures are realized:

- 1000°F after 5 minutes
- 1300°F after 10 minutes
- 1550°F after 30 minutes
- 1638°F after 45 minutes
- 1700°F after 60 minutes

The wall should have withstood the fire endurance test without passage of flame or gases hot enough to ignite cotton waste for 1 hour. Transmission of heat through the wall during the fire endurance test shall not have been such as to raise the temperature on its unexposed surface more than 250°F above its initial temperature. Any other test deemed equivalent would also be acceptable.

Solid concrete block and mortar have been used extensively to construct seals in underground coal mines. Three (3) inches of concrete will provide a 1-hour fire resistance\textsuperscript{8} when subjected to the ASTM E-119 test. Also, cementitious foams are available for use in seal construction. These cementitious foams are incombustible in that they are made up entirely of inorganic materials and will not burn or contribute fuel to a fire or explosion. Other innovative blocks, such as Burrell Mining Products' Omega 384, have proven to be incombustible. It is important to note that concrete blocks, cementitious foams, and other blocks, such as Omega 384, should prove to be solid and substantial in addition to the incombustible before being used as a seal construction material.


On the other hand, there are combustible materials, such as wood, which are capable of providing a 1-hour fire resistance according to ASTM E-119. Basically, it only requires that such a seal be thick enough to prevent the passage of flame or hot gases for 1 hour. Like the cement-based materials mentioned above, a seal constructed of wood should also be solid and substantial. Heavy timber of 4 inches or greater thickness is capable of providing 2 hours of fire resistance.

To prevent significant air leakage from occurring, sealants may be applied to the face of a seal. A full-face coating of an acceptable sealant would improve the fire resistance of any seal. Also, if a fiber-reinforced sealant is used, the seal will gain additional strength. In the latter case, the solid, substantial, and incombustible aspects of the seal would be improved. Additional information on sealants is contained later in this report.

CURRENT SEAL TECHNOLOGY

There are many different seals used in underground coal mining today, however, very few have actually been evaluated through the large-scale testing. The previously mentioned joint BOM/MSHA program to evaluate seals is continuing. Most seals tested under this program have not proven to be substantial, although the solid and incombustible aspects have not posed any problems. BOM Internal Report No. 4809\textsuperscript{10} discusses seals constructed of solid concrete blocks and is excerpted in the following paragraphs:

MSHA has identified ten solid block cementitious seal configurations that merit investigation. All of these seals utilized 6-in by 8-in by 16-in solid-concrete blocks. In each of the configurations the seals are keyed to the ribs, using angle iron, and wedged at the roof but without any roof keying. When keying to the floor was done, angle iron was employed. All 1/8-in thick coatings applied utilized a fiberglass-reinforced portland cement. The configurations of special interest are as follows:

(1) Standard type thick-wall seal (wetwall): 16-in-thick seal with mortared joints with a center pilaster of 32-in thickness; keying to the floor;

(2) Thick-wall seal (wetwall): 16-in-thick seal with mortared joints with a center pilaster of 32-in thickness; no keying at the floor;


(3) **Thin-wall seal (wetwall):** 8-in-thick seal with mortared joints; center pilaster having a 24-in thickness; keying to the floor; 1/8-in coating on the inby11 side of the seal;

(4) **Thin-wall seal (wetwall):** 8-in-thick seal with mortared joints; center pilaster having a 24-in thickness; keying to the floor; 1/8-in coating only on the outby12 side of the seal;

(5) **Thick-wall seal (wetwall):** 16-in-thick seal with mortared joints; keying to the floor; no pilaster;

(6) **Thin-wall seal (drywall):** 8-in-thick; drywall construction (no mortared joints); center pilaster having a 32-in thickness; full face coating on both sides of seal; keying to the floor;

(7) **Thick-wall seal (drywall):** 16-in-thick seal; drywall construction (no mortared joints); center pilaster having a 32-in thickness; full face coating on both sides of seal; keying to the floor;

(8) **Thin-wall seal (wetwall):** 8-in-thick seal with mortared joints; center pilaster having a 24-in thickness; no keying to the floor; 1/8-in coating on the outby side of the seal;

(9) **Thick-wall seal (drywall):** 16-in-thick seal; drywall construction (no mortared joints); center pilaster having a 32-in thickness; keying to the floor; 1/8-in coating only on the inby side of the seal; and

(10) **Thick-wall seal (drywall):** 16-in-thick seal; drywall construction (no mortared joints); center pilaster having a 32-in thickness; keying to the floor; 1/8-in coating only on the outby side of the seal.

The objective of this research effort is to determine whether these ten solid block cementitious seals can withstand a 20-psig methane-air explosion without losing their structural integrity and resistance to leakage of mine gases.

In the first test series, a standard-type seal, having a 16-in. wetwall with a 32-in. pilaster, was positioned in the first crosscut outby the face where the explosion was initiated. A wetwall seal similar to the standard-type seal except without floor keying was in the second outby crosscut. A wetwall seal of 8-in. thickness, having a 24-in. pilaster and a coating on the explosion-side of the seal, was keyed into the floor in the third outby crosscut. A wetwall seal of 8-in. thickness, having a 24-in. pilaster and a

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11 For the purposes of these tests, the term "inby side" refers to the side of the seal closest to the face where the explosion is initiated.

12 For the purposes of these tests, the term "outby side" refers to the side of the seal farthest from the face where the explosion is initiated.
coating on the side opposite the explosion, was keyed into the floor in the fourth outby crosscut. Of these four seals, only the standard-type seal in the first outby crosscut maintained its integrity, clearly indicating the need for adequate keying of the seal to the floor and ribs.

In the second series of tests, three seals were located in crosscuts between C- and B-Drifts. The seals constructed from solid-concrete block were all tightly keyed into the ribs, and wedged at the roof. The standard seal withstood the explosion without any apparent damage. A modified seal (no pilaster) was located in the second outby crosscut between C- and B-Drifts. The explosion removed portions of the blocks in the uppermost layer, causing it to lose integrity. In the third outby crosscut, a thin drywall seal of 8-in. thickness with a pilaster of 24-in. thickness was positioned. A coating had been applied on both sides. Catastrophic failure of the seal resulted.

In the third series of tests, a modified seal (drywall) was located in the second outby crosscut between C- and B-Drifts. It was 16-in. thick, constructed with a 32-in. pilaster, and coated on both sides. No mortar was used between blocks. The explosion removed more than 90% of the seal, causing catastrophic failure. The standard seal still located in the outby crosscut between C- and B-Drifts withstood the explosion without any apparent damage.

Of the seven seals tested, only the standard-type seal maintained its integrity. A standard-type seal with no pilaster but with floor keying failed. All the thin-walled seals of 8-in. thickness made with mortar between the blocks failed—neither the use of a pilaster nor floor keying provided sufficient strength against the 20-psi explosion. The addition of coatings did not significantly augment the seal strength; however, coatings placed on high-strength seals, whose physical integrity would not be impaired by a 20-psi explosion, would help to minimize the air and gas leakage through the seal.

Table 1 summarizes the seal conditions and test results.
<table>
<thead>
<tr>
<th>Seal</th>
<th>Type</th>
<th>Location from face (ft.)</th>
<th>Maximum overpressure (psi)</th>
<th>Impulse per area (psi-sec)</th>
<th>Degree of damage</th>
<th>20-psi test outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Standard seal, thickwall, wetwall, pilaster, floor keying</td>
<td>84</td>
<td>21.8</td>
<td>4.55</td>
<td>None</td>
<td>Passed</td>
</tr>
<tr>
<td>2</td>
<td>Thickwall, wetwall, pilaster, no floor keying</td>
<td>134</td>
<td>21.2</td>
<td>4.03</td>
<td>Large opening at roof; two large cracks at left outby side; bottom displaced about 1 inch</td>
<td>Failed</td>
</tr>
<tr>
<td>3</td>
<td>Thinwall, wetwall, pilaster, floor keying, coating on inby side</td>
<td>234</td>
<td>19.3</td>
<td>2.98</td>
<td>All blocks removed except for bottom row</td>
<td>Failed</td>
</tr>
<tr>
<td>4</td>
<td>Thinwall, wetwall, pilaster, floor keying, coating on outby side</td>
<td>304</td>
<td>Approx. 15 (Pressure lower at #4 seal because of venting through the opening formed when #3 seal at 234-ft. location failed)</td>
<td>-</td>
<td>Large crack at top; blocks missing on outby side; pilaster sheared off</td>
<td>Failed</td>
</tr>
<tr>
<td>5</td>
<td>Thickwall, wetwall, no pilaster, floor keying</td>
<td>134</td>
<td>17.1</td>
<td>3.74</td>
<td>Minor damage; seal intact; mortar removed at top; some half blocks removed at roof line; approximately 1 sq.ft. leak area formed</td>
<td>Marginal at less than 20-psi pressure</td>
</tr>
</tbody>
</table>
### TABLE 1. – Summary of seal test conditions and results (Cont.)

<table>
<thead>
<tr>
<th>Seal Type</th>
<th>Location from face (ft.)</th>
<th>Maximum overpressure (psi)</th>
<th>Impulse per area (psi-sec)</th>
<th>20-psi test outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinwall, drywall, pilaster, floor keying, coating on both sides</td>
<td>234</td>
<td>17.7</td>
<td>2.45</td>
<td>Destroyed; only a few blocks remained on near ribs</td>
</tr>
<tr>
<td>Thickwall, drywall, pilaster, floor keying, coating on both sides</td>
<td>134</td>
<td>19.7</td>
<td>3.17</td>
<td>All blocks removed except for a few along both ribs and on the floor</td>
</tr>
</tbody>
</table>

**Evaluation of Methods of Construction for Block Seals**

Seal construction has been accomplished using solid concrete blocks as the typical construction material, however, the method used has varied widely. Careful construction techniques must be employed to ensure that the seal be constructed in a manner that will allow it to be solid, substantial, and incombustible. A solid seal is basically one that restricts the amount of air leakage that occurs at various pressure differentials. An incombustible seal is basically one that is constructed of incombustible material and, in no way, will assist the propagation of flame. These two aspects of seal construction are generally easier to accomplish and less affected by a method of construction than the substantial aspect of seals.

The ISD recommendations for the performance of a substantial seal is that it should be constructed in such a way as to prevent a 20-psig explosion pressure wave from propagating to the opposite side. On seals constructed of solid concrete block, joints must be staggered, joints must be mortared, a pilaster must be an integral part of the center of the seal, keying or its equivalent must occur at the floor and along both ribs, the seal must be at least 16-inches thick, and the seal must be made as tight as possible initially through wedging along the entire top. This commonly used seal has withstood explosion pressures exceeding 40 psi. This section of the report will discuss the effects of a pilaster and of keying, the significance of mortared joints, and a comparison of solid and hollow-core blocks.
Effects of Pilaster

There are several types of failure that can cause the failure of a given structure. Compressive, tensile, or shear stresses can exceed the capabilities of the structure and ultimately cause its failure. Concrete, for example, is significantly stronger in compression than it is in tension. Consequently, to improve its strength, concrete must either be reinforced along the plane that might be subjected to tension or the tension must be reduced. When a concrete beam is loaded, it begins to deflect. This deflection allows a curvature to occur in the beam whereas the concrete near the load is placed into compression and the concrete farthest from the load (from a cross-sectional viewpoint) is placed into tension. If the magnitude of the compression and tension is the same, the concrete will fail in tension.

Tension is directly related to deflection and deflection is related to the load that is placed on the structure and the distance between supports, or the span. A pilaster in the center of a thin-walled structure, such as a 16-inch-thick solid-concrete block seal, will significantly increase the amount of load that the seal can withstand prior to failure. This occurs because the pilaster acts as a support and resists deflection. For example, in a 16-foot-wide seal with no pilaster, the span is 16 feet if the seal is adequately supported at both ends. The same seal with a center pilaster would have two separate spans of less than 8 feet each.

A uniform load placed on an 8-foot span would result in substantially less deflection than the same load on a 16-foot span. Therefore, tension induced in the extreme fibers of the cross-section would be less in the 8-foot span than in the 16-foot span for the same load. For this reason, a center pilaster significantly improves the amount of loading that an underground coal mine seal can withstand, especially if the failure mode for the seal is the result of tensile stresses.

Early reporting by the BLM indicates that a pilaster shall be tied into the center of a bulkhead having a width greater than 16 feet or a height greater than 10 feet\(^\text{13}\). The ISO feels that these height and width requirements for pilaster installation are adequate.

Effects of Keying

Previously in this report, Table 1 listed test results on certain concrete block seal constructions. It is important to note that the typical standard concrete block seal was able to withstand a 20-psig explosion pressure wave. On the other hand, the same seal constructed without floor keying failed during the same test. This demonstrates that keying is an essential factor in construction of 16-inch-thick concrete block seals.

\(^{13}\)Memo from Barrett/Mitchell to Nagy, September 21, 1971, Subject: Explosion-proof bulkheads (seals) for Part 75.329-2 of Title 30, CFR, 8 pp.
Keying along the floor or the ribs is done to provide support around the perimeter of the seal. Keying prevents the seal from sliding or from experiencing other perimeter movement when subjected to the forces of an explosion. Keying, or hitching, is accomplished as a channel of material is removed from the floor and vertically along each of the ribs in about the same thickness as the seal. To be effective, the blocks keyed into the ribs should be keyed in at least 6 inches and the blocks keyed into the floor should be keyed in at least one-half the height of the block. That is, on block that is 8-inches high, the hitch should be made at least 4-inches deep. If the floor is solid, artificial keying can be accomplished by permanently attaching angle iron to the floor on both sides of the seal. The legs of the angle iron should be at least one-half as long as the height of the concrete block.

Keying can also be accomplished by cutting a recess into the floor and pouring a concrete footer in the recess. When laying concrete block on top of the footer, a strong bond must develop between the footer, mortar, and the concrete blocks. If the footer is at least 4 inches deep and acts as an inseparable member of at least the bottom course of concrete block, the top of the footer could be poured level with the grade. This would constitute keying.

If the bond between mortar and footer is significantly weaker than the bond between mortar and the first course of concrete block, then the first course of concrete block would have to be recessed into the floor.

Solid Blocks vs. Hollow-Core

Concrete masonry blocks are made in a variety of shapes and sizes and the composition of such blocks can include either lightweight or heavyweight aggregate.

An 8-inch hollow-core concrete block has nominal dimensions of 8 x 8 x 16, but the actual dimensions of 7-5/8 x 7-5/8 x 15-5/8 allows for a 3/8-inch thickness of mortar applied to all faces. (Mortar allows the overall construction size to meet the nominal dimensions, simplifying design requirements.) These same dimensions hold true for an 8-inch solid concrete block, except the solid block has flat faces on all six sides whereas the hollow-core block does not.

By the same token, the nominal dimensions of both the 6-inch hollow-core and the 6-inch solid concrete block are 6 x 8 x 16 and the actual dimensions are 5-5/8 x 7-5/8 x 15-5/8. Again, the solid block has six flat rectangular faces whereas the hollow-core block does not.

The nominal dimensions of the 4-inch hollow-core and 4-inch solid block are 4 x 8 x 16 with actual dimensions of 3-5/8 x 7-5/8 x 15-5/8. However, in both of these cases, all six faces are flat and rectangular.

An 8-inch hollow-core concrete block will weigh approximately 40 to 50 pounds when made with heavy aggregate, such as sand, gravel, crushed stone, or slag. The same block will only weigh 25 to 35 pounds when made with
lightweight aggregate, such as cinders, shale, or pumice. Likewise, the weight of 8-inch solid concrete block varies with the type of aggregate between 60 and 90 pounds.

A solid concrete block is one which has been defined by the American Society for Testing and Materials (ASTM) as having a hollow-core area of not more than 25 percent of the gross cross-sectional area. A hollow concrete block is one in which the hollow-core area exceeds 25 percent of the cross-sectional area. Generally, the hollow core of such units will be from 40 to 50 percent of the gross area.\(^\text{14}\)

For the purpose of sealing areas of an underground coal mine, seals constructed of concrete block are not required to display any specific minimum compressive strength because they are not designed as load-bearing controls. However, a typical hollow-core, non-load-bearing concrete block with a face shell thickness of 1-inch or more would have a minimum compressive strength of 300 psi.\(^\text{15}\) Similarly, a hollow-core, load-bearing concrete block with a face shell thickness of 1\(\frac{1}{4}\)-inch or more would have a minimum compressive strength of 800 psi. Also, a solid Grade A load-bearing concrete block has a minimum compressive strength of 1,600 psi.

All of the concrete block units are rigid materials and do not compress significantly prior to failure. Since floor heave or roof sag may occur, even in small increments, the compressive strength does play a major role in determining the load that the seal will withstand prior to failure. For example, the higher the compressive strength of the concrete block, the more loading that the seal can tolerate due to squeezing conditions prior to failure. It is also important to note that seals, which are somewhat loaded by minor squeezing, will be more capable of withstanding the pressure wave from a propagating explosion when compared to their unloaded counterparts.

The compressive strength of the concrete block determines the total load in the vertical direction that the seal can tolerate prior to failure. The pressure wave from a propagating explosion would subject the seal to a load in the horizontal direction acting on one of the faces of the seal. The flexural, or bending, strength of the entire seal determines the total load, or force, in the horizontal direction that the seal can tolerate prior to failure. Here, the entire seal, including both concrete blocks and mortar, are evaluated to determine whether the seal is "substantial" according to the regulations.

Both the concrete blocks and the mortar, acting together as a single unit, determine the flexural strength that each seal will exhibit. When subjected to a flexural stress, the first sign of failure occurs when tension fractures appear on the side of the seal opposite to the side where pressure has been applied. Usually, this fracture occurs along a mortar joint near the center of the seal. Concrete block and mortars have a higher strength in


\(^{15}\)Same as Footnote 1.
compression than in tension. In the case of seal construction, the cohesion or adhesion of the mortar is the weak link where initial failures would be expected to occur under the loading conditions experienced during a typical explosion. The cohesive strength of the mortar is determined by the amount of stress that the mortar can withstand prior to a failure occurring within the mortar itself. The adhesive strength of the mortar is determined by the amount of stress that the bond between the mortar and the concrete block can withstand prior to a failure along this plane.

The cohesive and adhesive strengths that the mortars provide to the overall seal strength are directly related to the mortar thickness and the total area of contact, respectively, that the mortar makes with the blocks in successive courses. Coating the entire solid top side of each concrete block is called full-mortar bedding. Another method of coating, especially for hollow-core mortar blocks, is to apply the mortar to all solid top side surface of each concrete block, except for the webs between the cores. This method is referred to as face-shell mortar bedding. Since more contact area is present in the full-mortar bedding, it would be expected that this method gives the seal more strength than the face-shell mortar bedding.

There are two factors related to the concrete blocks that allow for varying degrees of flexural strength; that is, the weight of the block and the area of contact between courses. A 16-inch-thick solid concrete block seal with a center pilaster, constructed in an area that is 7-feet high and 20-feet wide could weigh over 11 tons. A similarly constructed seal using hollow-core block may weigh 6 tons. Consequently, the flexural strength that a solid concrete block seal can withstand is nearly twice that of a seal constructed of hollow-core blocks, based only on its weight.

Also, full-mortar bedding allows approximately twice the contact area between blocks and mortar with solid blocks as face-shell mortar bedding allows between hollow-core blocks and mortar.

Mortared Joints vs. Drywall

Underground coal mine seals can be constructed in a variety of ways. Those constructed of solid concrete blocks can be built with mortared joints or as a drywall. As discussed in the previous section of this report, mortar is applied in a 3/8-inch thickness to all joints and interfaces. The cohesive and adhesive strengths of the mortar are very important as they are typically the weak link of a seal construction. When subjected to flexural stress, seals fall near the center along a mortar joint on the side opposite to the force. However, it does take a significant amount of force to generate this failure mode.

Seals constructed without the use of mortared joints are called drywall seals. These seals are built by stacking the solid concrete blocks on top of one another and then applying a full-face coating of a suitable mine sealant. Because sealants used in drywall applications are needed to increase the overall strength of the seal, only those sealants with reinforcing fibers would serve the purpose. Sealants must be applied to both sides of the seal in thicknesses that would provide the necessary strength.
Earlier in this report, Table 1 presented the test results on seven different seal constructions; two of which are drywall seals. Neither of the drywall seals was able to withstand a 20-psig explosion pressure wave. This would indicate that additional measures must be considered before a drywall seal would be regarded as substantial. For example, the seal may have to be thicker or the sealant may have to be applied in thicker coatings.

**Evaluation of the Materials of Construction**

The typical materials for seal construction involve blocks of some type. Concrete blocks can be made with different types and weights of aggregate to alter their density. Cinder, flyash, and coke breeze are among the different aggregate materials. Masonry block, containing "coke breeze" aggregate, has an aggregate material which consists of small coke particles. The block has been tested for fire resistance and can provide equivalent protection against fire when compared with a 6-inch masonry block wall. The units look like concrete blocks but are slightly darker in color. Other blocks can be formed from innovative materials and, if these blocks are used as seals, they need to be evaluated for solid (air leakage), substantial (strength), and incombustibility characteristics. This section of the report is intended to discuss Burrell Mining Products' Omega 384 block, cementitious foam, and other materials for seal construction.

**Omega 384**

Omega 384 is a lightweight, glass-fiber, reinforced block, manufactured by the Burrell Mining Products, Inc. The block is impervious to moisture and air leakage at pressure differentials up to 8.0 inches water gage. The size of a unit block is 16" x 24" x 8" and the weight is substantially lower than that of an equivalent size hollow-core concrete block.

Omega 384 block meets or exceeds both the incombustible criteria of Part 75.316-2(b) for stopping construction and the incombustible criteria of Part 75.329-2 for seal construction as judged by the ISD. Omega 384 has also been shown to be impervious to air leakage and, therefore, satisfies the solid criteria of Part 75.329-2 for seal construction. Of course, this also indicates that Omega 384 is an excellent stopping construction material from an air leakage standpoint.

The only other issue is related to the strength of the Omega 384 when built as a seal, or as a stopping. The substantial criteria of Part 75.316-2(b) for stoppers are significantly different than the substantial criteria of Part 75.329-2 for seals. For stoppers to be considered substantial, the ISD recommends that they withstand a static force of 39 pounds per square foot over the entire face of the stopping. Omega 384 has proven that it is quite capable of withstanding such a force. This value (39 psi) is the flexural strength that a 6-inch hollow-core concrete block stopping will withstand prior to failure.

On the other hand, the substantial criteria for seals has been defined in this report as seals that can withstand a loading of 20 pounds per square inch over the entire face of the seal. This 20 pounds per square inch is
equivalent to 2,880 pounds per square foot. This is significantly higher than the 39 pounds per square foot required of stoppings.

Burrell Mining Products is now in the process of building 4 separate, different seals underground at the BOM's IIL. These seals will be completed during August of 1990 and will be tested with a 20-psig explosion pressure pulse after the mortar cures for at least 28 days.

Cementitious Foams

Cementitious foams are available for seal construction from Celtite (TEKFOAM 10-80). Informational materials from Celtite identify TEKFOAM 10-80 as a single component, lightweight, nontoxic, noncombustible void-filling and structural cementitious foam. Supplied as a powder, it forms a low density foam when combined with air and water in a special purpose, self-contained foam-producing and pumping unit.

Foam is produced by the generation of bubbles within the mixed cementitious slurry as air, water, and TEKFOAM powder pass through the delivery pump. Foaming and gelling agents create and stabilize the foam until rapid hydration produces a permanent set.

TEKFOAM is designed for use with a foam-producing machine. TEKFOAM powder, water, and air are metered into a continuous mixer that supplies a positive displacement pump. Turbulence in the pump and discharge hose develop a foam from the mixed product. A minimum of 200' of 1" I.D. hose is required for proper foam development. A larger diameter hose section can be added to slow the emergent jet of TEKFOAM.

The maximum pumping distance will be determined by the consistency of the foam, pumping rate, and temperature. Six hundred feet can be achieved. Also, the volume of foam produced is up to fifteen times the original volume of powder.

Typically, foam placement is achieved either by injection through formwork, for example, to fill a roof cavity, or directly from the hose as in construction of a barricade or stopping. When injecting to fill a roof fall cavity, forms should be constructed to contain the foam. Due to the low density and thixotropic nature of the foam, this need only be lightweight construction. Injection is best achieved through a pipe inserted into the cavity. A second pipe inserted to the highest point of the void will give an indication of when the cavity is filled as well as provide a second injection point, should the first become obstructed.

Several factors will affect yield, density, strength development, set time, and pumping life of the foam. These are water content, temperature, pumping rate, discharge hose capacity, and mass of product placed. The following guideline figures are representative of values obtained under controlled conditions.
Water/Solids Ratio
Water Input, IGPM
Powder Input, lbs/min
Density, lbs/ft³
Compressive Strength, psi
   1 day
   6 days
   28 days
Approximate yield, bags/yd³
Set Time (to non-pourable) @ 70°F

Water and powder inputs on the foam-producing machine can be adjusted on-site to provide a range of compressive strengths.

Forms are to be in place prior to pouring the foam. Typical installations could include posts (4" x 4") on 4-foot, or less, vertical centers and planks (1" x 6") on 2-foot, or less, horizontal centers. At least three injection ports through the forms will help to uniformly control the distribution of foam cement within the form.

There is widespread interest in the construction of seals using various types of materials. Tests at the BOM's ILL have been conducted on "TEKFOAM". The purpose of this section of the report is to develop an ISD opinion as to which design parameters are necessary for the TEKFOAM seals to comply with the general criteria outlined in 30 CFR Part 75.329-2. The following discussion is related to flexural strength properties of seals in the horizontal direction when exposed to a 20-psi explosion pressure wave at the ILL. (Ability to withstand a 20-psig pressure pulse has been established by the ISD as a suitable performance characteristic.)

During the series of tests to evaluate the cementitious foam seals using TEKFOAM, six crosscuts were available for seal construction. Crosscut No. 1 has a standard, solid-concrete block seal constructed using solid 8-inch block laid transversely 16-inches thick with floor and rib key and a center pilaster. This seal has successfully withstood a number of 20-psig explosions without failure and, when properly constructed, has proven, over the years, to be an effective seal for underground coal mines. Crosscut Nos. 2 through 6 had seals constructed as follows:
<table>
<thead>
<tr>
<th>Crosscut No.</th>
<th>Seal Thickness</th>
<th>Design Compressive Strength</th>
<th>TEKFOAM Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8 feet</td>
<td>200 psi</td>
<td>12 bags/yd²</td>
</tr>
<tr>
<td>3</td>
<td>4 feet</td>
<td>200 psi</td>
<td>12 bags/yd²</td>
</tr>
<tr>
<td>4</td>
<td>4 feet</td>
<td>100 psi</td>
<td>8 bags/yd²</td>
</tr>
<tr>
<td>5</td>
<td>8 feet</td>
<td>50 psi</td>
<td>6 bags/yd²</td>
</tr>
<tr>
<td>6</td>
<td>4 feet</td>
<td>50 psi</td>
<td>6 bags/yd²</td>
</tr>
</tbody>
</table>

After curing, the TEKFOAM seals were exposed to a nominal 20-psig pressure wave generated by a methane explosion. The TEKFOAM seal in Crosscut No. 2 did not show any signs of physical damage. Air leakage tests were performed after the explosion. At a pressure differential of 1.0 inch of water, no leakage was detected through this seal. At a pressure differential of 4.25 inches of water, only 32 cfm of leakage was detected; this amount is considered insignificant. Based on visual observations after the explosion and the results of the air leakage tests, the 8-feet-thick, 200-psi TEKFOAM seal is considered to meet the criteria of Part 75.329-2.

The TEKFOAM seal in Crosscut No. 3 (4-feet-thick, 200-psi) had a few hairline cracks along the side exposed to the explosion force. At a pressure differential of 1.0 inch of water, 52 cfm of air leakage was detected. At a pressure differential of 4.25 inches of water, 114 cfm of air leakage was detected. Both of these amounts are considered insignificant. Based on visual observations after the explosion and the results of air leakage tests, the 4-feet-thick, 200-psi TEKFOAM seal is considered to meet the criteria of Part 75.329-2.

The TEKFOAM seal in Crosscut No. 4 (4-feet-thick, 100-psi) displayed a series of cracks on both sides after the explosion. Some of these cracks appeared continuous from one face of the seal to the other. Air leakage tests at both 1.0 inch and 4.25 inches of water resulted in insignificant leakage. Although the leakage was considered insignificant, visual observations of this seal have lead us to believe that its performance is marginal, at best. Additional testing would be required on TEKFOAM seals of 100-psi strength to determine what thickness, if any, would be deemed suitable to meet the criteria of 75.329-2.

The TEKFOAM seal in Crosscut No. 5 (8-feet-thick, 50-psi) displayed severe fractures on the face of the seal. These fractures appeared to extend through the entire seal. Air leakage at a 1.0-inch pressure differential was 180 cfm and at 4.25 inches of pressure differential was 420 cfm after the explosion. Although a maximum acceptable leakage rate for varying pressure differentials has not been precisely established, these values appear to be

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16 Design strengths may be slightly different than actual strengths, for example, the seal in Crosscut No. 4 was designed for 100 psi, but testing indicated an actual strength of 78 psi.

17 Tekfoam bags weigh approximately 45 pounds each.
significant. Based on these leakage rates and on visual observations after the explosion, it is recommended that 8-feet-thick TEKFOAM seals or less of 50-psi compressive strength not be constructed in underground coal mines. The 4-feet-thick, 50-psi TEKFOAM seal in Crosscut No. 6 was completely destroyed by the explosion, and is also unsuitable and does not meet the criteria of Part 75.329-2. Seals constructed with TEKFOAM of less than 50-psi compressive strength are also considered unsuitable.

Recommendations for TEKFOAM Construction

The recommendations presented here are based on the limited explosion tests that have been performed at the BOM's LIL. Additional recommendations will be presented at a later date after future test results are analyzed. These recommendations apply to Celtite's TEKFOAM product and other cementitious foams of similar formulations and design specifications. The recommendations are as follows:

1. The lowest seal in a set of seals must have a water pipe installed. However, water may accumulate behind the seal at a level below the water pipe if draining has occurred or at a higher level if the water pipe is closed. The long-term effects of water build-up, in general, and acid water, in particular, against a cementitious foam seal are not known. It is, therefore, recommended that cementitious foam seals not be constructed in areas where water accumulations may occur behind a seal.

2. Testing should be conducted to determine both short- and long-term effects of standing water of neutral pH and pH = 2.0 on TEKFOAM blocks of varying compressive strengths.

3. A significant amount of water is used during the construction of these seals. The long-term effects of drying out of the foam are not known. It is recommended that the brattice cloth and framing be left in place for the duration of the seal's life to reduce the amount of drying and to increase the time over which drying may occur.

4. In lieu of Recommendation No. 3, a face coat of a suitable sealant can be applied to the exposed surfaces of a seal after removal of the brattice cloth/timber framing.

5. Explosion tests have shown that 200-psi strength, 4-feet- and 8-feet-thick seals can withstand a 20-psig pressure wave. It is recommended that cementitious foam seals be approved in the ventilation plan if they are constructed of 200-psi compressive strength TEKFOAM (or other similar product) and are at least 4-feet thick.

6. It is recommended that additional testing be carried out on cementitious foams in thicknesses between 4-feet and 8-feet, and with compressive strengths between 100 and 200 psi to determine other suitable designs for underground coal mine seal construction.
(i.e. at 100-psi compressive strength, a 4-foot thickness was not proven to be totally effective and an 8-foot thickness was not evaluated during this series of tests).

7. It is recommended that cementitious foam of 50-psi compressive strength not be used to construct seals of any thickness at this time.

8. It is recommended that multiple injection ports (at least three) be incorporated into the brattice/timber forms for the purpose of uniformly controlling the distribution of the foam cement within the form.

Other Materials for Seal Construction

Although concrete block has been a typical material for seal construction, cementitious foams have recently been shown to have the initial strength required to also be used in seals. These are the only two materials that have thus far proven, through explosion research, to be capable of preventing an explosion on one side of the seal from propagating to the other side. Other materials for seal construction are being used or are currently being considered for use. One such seal is constructed using timber and another seal uses a plug of rock dust between stoppers placed several feet apart.

The ISD completed a technical evaluation of timber ventilation seals at a mine in Colorado during 1985. The results of this evaluation are fully documented in ISD Open-File Report #350-85.18

These timber seals were constructed in an area where significant convergence was expected and, therefore, concrete block seals would not have survived. These seals were built in areas where they would not be subjected to water accumulations. They were constructed of mine timbers with a minimum length of 3 feet and a minimum diameter of 4 inches. The timbers were laid skin-to-skin with the interstices filled with rock dust. Also, the exposed surface of the timbers was covered with 1.5 inches of gunnite. Under convergent conditions, gunnite would require a significant amount of maintenance due to spalling.

Actual explosion tests were not performed on these timber seals, but it would seem reasonable to assume that they would not be able to withstand explosion pressures of 20 psig upon initial installation. However, after a certain, minimal amount of convergence would occur, the seals would be tighter and could then possibly withstand the 20 psig that an explosion may exert upon them. Unfortunately, a certain degree of strength is required to make a seal substantial according to the criteria in Part 75.329-2. This strength must exist upon initial installation and at all times after

installation. Timber seals of any design would have to be subjected to a 20-psig explosion pressure to prove or disprove their substantial abilities. Future tests in the BOM ILL will attempt to further evaluate timber seals.

There are other materials that have been considered for seal construction. The BOM has reported on some of these designs in RI 7581[19].

Evaluation of Other Factors

There are many factors which require consideration when seals are to be constructed. Air leakage, strength, and the noncombustible aspects are all very important factors. Whether to use concrete or other type of blocks, cementitious foams, or even timber requires that additional factors be considered. Although each of these has been discussed in this report, there are two other factors of importance, which will be discussed in this section; namely, sealants and coal pillars.

Sealants

Sealants are generally used in underground mines to prevent spalling, delamination, or sloughage of coal ribe and roof, or to prevent air leakage through seals or stoppings[20]. Formal approval requirements do not currently exist. Up until 1985, sealants that did not contain any combustible constituents were assigned an acceptance number under a voluntary acceptance program established by the MSHA's Approval and Certification Center (AMCC). A list of acceptable sealants was maintained and distributed to field enforcement personnel and other interested parties. This list provided a useful tool for MSHA personnel responsible for approving mine ventilation plans. A product appearing on the list would not present a flammability hazard since it contained no combustible constituents. The list of currently suitable mine sealants is contained in Appendix A. All of these sealants are 100% cementitious and have a flame spread of zero. Also, they are noncombustible and are for application on both ventilation controls and coal surfaces.

The general list of acceptable sealants was compiled using noncombustibility as a criteria and strength characteristics of these materials were not considered. If it is desired to build a ventilation control by laying the masonry block up dry and coating the faces, a surface bonding mortar with strength characteristics is desirable.

Sealants meeting this requirement inherently have steel or glass fibers present in them. These fibers impart the strength characteristics necessary to meet the requirements.

[19] Same as Footnote 3.

Pillars

A seal must be solid to prevent significant air leakage from occurring. The air current would have a tendency to follow the path of least resistance, which, if not through the seal, may be around it. For this reason, seals should be constructed 10 feet or more from the corners of a pillar. This location would be more solid and subsequent ground movements would not be likely in unbroken areas of a pillar. The closer that the seals are located to the corners of the pillar, the shorter the distance that the air would have to travel to enter the adjacent airways. Airflow through a coal seam itself would adversely affect the spread of fire. Similarly, airflow is critical for the onset of spontaneous combustion to occur. With no airflow, or very limited airflow through the coal, spontaneous combustion would not be possible because oxygen in sufficient quantities would not be provided for the coal to self-ignite.

In 1971, the BOM presented recommended rules\textsuperscript{21} on constructing seals in underground coal mines. The best locations for constructing these seals is as follows:

Seals shall be 10 or more feet from the corners of a pillar.

Seals shall be constructed in solid ground that remains unbroken. Where this is not possible, the preferred site is where ground has settled. Floor heaving, pillar crushing, and roof convergence indicate unsettled ground. The forces causing these disturbances can damage seals, especially those made from rigid materials such as concrete and those with mortared joints.

Seals that might be damaged by roof loads should be constructed in openings driven parallel to the face cleats, where these exist, to reduce the intensity of the shearing forces along the ribs. When gas leakage might be a problem, advantage could be taken of roof loads by constructing seals in openings driven parallel to the butt cleat.

Additionally, concerning the pillars in the areas of seals, the MSHA Program Policy Manual makes the following statement:

"In the case of all development after the operative date of the Act, the mine Ventilation System and Methane and Dust Control Plan, as required under Section 75.316, shall include provisions for isolating each active working section of the mine from any other active workings by sealing with approved explosion-proof seals or bulkheads, if conditions so warrant. The pillars in the proposed seal areas shall be of sufficient size and number to protect such seals or bulkheads from excessive pressure."

\textsuperscript{21}Same as Footnote 10.
SUMMARY

This report presents a compilation of the information that MSHA has generated pertaining to the construction of seals in underground coal mines. Currently, the BOM is involved in subjecting seals of various materials and construction techniques to 20-psig explosion pressure waves at their LLL. Testing to this point has been very limited, but several seals have proven their strength qualities by surviving these explosions without showing signs of serious failure. This joint MSHA-BOM program is continuing and it is certain that other seals will be added to the list of those that are solid, substantial, and incombustible such that an explosion on one side of the seal will not propagate to the other side.

It is important to note that seal constructions utilizing cementitious materials, including mortars, are allowed a usual 28-day curing period prior to testing. After this curing period, these seals are considered to be fully installed. All seals must withstand a 20-psig explosion pressure wave at that time which they are considered fully installed. Wedging of a test seal is acceptable as the practice would occur when building an actual seal underground. However, a fully installed test seal does not include any increased strength, which would occur due to convergent conditions. Therefore, the fact that convergence may occur in any area where seals are to be constructed is not considered as a future strength-improving design. At the moment that a seal is completely constructed, it is considered fully installed and, at that time, must withstand a 20-psig explosion. This 20-psig pressure wave has been established by ISD engineers to be a reasonable pass/fail test for evaluating seals.

There are two types of seals that have met all the criteria of Part 75.329–2 for solid, substantial, and incombustible as been determined by ISD engineers. They are as follows:

1. Seal constructed of 6x8x16-inch solid-concrete block, or larger, with all joints mortared. This seal is keyed into the floor and ribs, and is wedged tightly against the roof. A center pilaster is constructed as an integral part in seals having a width greater than 16 feet or a height greater than 10 feet. The seal is 16-inches thick and the blocks are laid in a staggered pattern.

2. Seal constructed of cementitious foam. The cementitious foam has an initial compressive strength of 200 psi (12 bags/yd$^3$) and is poured between forms spaced at least 4 feet apart. The forms remain in place or, after removal, the entire face of the seal should be coated with a suitable sealant, as listed in Appendix A. There must be at least three (3) injection points in the forms prior to pouring the seal.