OMEGA 384 BLOCK AS A SEAL CONSTRUCTION MATERIAL

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by

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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.

MSHA is continuing in its large-scale program with the U.S. Bureau of Mines (USBM) to evaluate the solid, substantial, and incombustible characteristics of seals. Solid concrete block seals and seals constructed of cementitious foam had previously been evaluated. Results of this initial phase of the seal evaluation program can be obtained by requesting the Industrial Safety Division (ISD) Open-File Report No. 06-213-90 from the ISD. A great deal of interest has been expressed by MSHA personnel and other concerned parties to evaluate the Omega 384 block as a seal construction material. This report presents an in-depth analysis of the construction of seals in underground coal mines using Omega 384 block, which is manufactured by Burrell Mining Products, Incorporated.

CODE OF FEDERAL REGULATIONS (CFR)

§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."

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.
USBM RI 7581\(^1\) 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

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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 USBM 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.
USBM RI 7581\textsuperscript{2} 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{3}, "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{2}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, 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 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.

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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 may improve the fire resistance of a 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 can be obtained by contacting the ISD.

PREVIOUS SEAL EVALUATIONS

Recently, MSHA’s ISD distributed an open-file report (No. 06-213-90) entitled, "Construction of Seals in Underground Coal Mines." This report presented technical information on the solid, substantial, and incombustible characteristics of seal construction methods and materials. The results were based on full-scale testing, including explosion testing at the USBM’s Lake Lynn underground limestone mine. However, only seals constructed of solid concrete blocks and cementitious foam were evaluated in the above-mentioned report. The solid concrete block seals were constructed with mortared joints and as drywalls, with and without center pilasters, and with and without keying (hitching) at the floor and ribs. The cementitious foam seals were constructed of various compressive strengths and varying thicknesses. Copies of ISD Open-File Report No. 06-213-90, including the results of solid concrete block and cementitious foam seals, can be obtained by contacting the ISD (see back of cover sheet for mailing address and telephone numbers).

CONSTRUCTION OF OMEGA 384 SEALS

The most recent series of full-scale testing involved seals constructed of Burrell Mining Products’ Omega 384 block. Omega 384 is a lightweight, glass-fiber, reinforced block, which is impervious to moisture and air leakage at pressure differentials of up to 8.0-inches water gauge. However, it is possible that leakage can occur through the joints and around the perimeter of seals constructed of Omega 384, just as with any other block seal. The size of a unit block is 16" x 24" x 8" and the weight is significantly lower than that of an equal-sized, hollow-core concrete block.

The criteria contained under CFR Title 30, Part 75.329-2 states that seals may be constructed of solid, substantial, and incombustible materials. Based on laboratory testing, it is the opinion of the ISD that the Omega 384 block meets or exceeds the incombustible criteria for seal construction.

[Consequently, the Omega 384 block also meets or exceeds the incombustible criteria of CFR Title 30, Part 75.316.2(b) for stopping construction in the opinion of ISD engineers.]

Although the Omega 384 block, in itself, has been shown to be impervious to air leakage, a full-scale examination was considered necessary to establish the air leakage through the joints and around the perimeter of an entire seal. Likewise, full-scale explosion testing was considered necessary to determine whether complete seals would be substantial.

The substantial criteria of Part 316-2(b) for stoppings is significantly different than the substantial criteria of Part 75.329-2 for seals. For stoppings 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 psf) 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 by the ISD 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 constructed four (4) different seals using the Omega 384 block in the USBM’s Lake Lynn Laboratory (LLL). Construction was completed in August of 1990 and the cementitious bonding agent, Burrell Bond, was allowed to cure for a minimum of 28 days. Burrell Bond is a fiberglass-reinforced bonding agent which, after curing, provides a significant amount of strength to seals or stoppings on which it has been applied and cured properly. These four seals were constructed as follows:

<table>
<thead>
<tr>
<th>Crosscut Location</th>
<th>Description</th>
</tr>
</thead>
</table>
| 2                 | Seal Thickness: 32 inches  
|                   | Number of Pilasters: 2  
|                   | Pilaster Thickness: 48 inches  
|                   | Pilaster Width: 48 inches  
|                   | Keying: Floor (6 inches) and Ribs (6 inches)  
|                   | Joints: Staggered  
|                   | Bonding Agent: All joints, inby face, and outby face  
|                   | with Burrell Bond  
|                   | Bond Thickness: 1/4-inch minimum  
<p>|                   | Wedging: Approximately 6 inches to 1 foot on top |</p>
<table>
<thead>
<tr>
<th>Crosscut Location</th>
<th>Description</th>
</tr>
</thead>
</table>
| 3                | Seal Thickness: 24 inches  
 Number of Pilasters: 2  
 Pilaster Thickness: 48 inches  
 Pilaster Width: 48 inches  
 Keying: Floor (6 inches) and Ribs (6 inches)  
 Joints: Staggered  
 Bonding Agent: All joints, inby face, and outby face with Burrell Bond  
 Bond Thickness: 1/4-inch minimum  
 Wedging: Approximately 6 inches to 1 foot on top |
| 4                | Seal Thickness: 24 inches  
 Number of Pilasters: 1  
 Pilaster Thickness: 56 inches  
 Pilaster Width: 72 inches  
 Keying: Floor (6 inches) and Ribs (6 inches)  
 Joints: Staggered  
 Bonding Agent: All joints, inby face, and outby face with Burrell Bond  
 Bond Thickness: 1/4-inch minimum  
 Wedging: Approximately 6 inches to 1 foot on top |
| 5                | Seal Thickness: 24 inches  
 Number of Pilasters: 1  
 Pilaster Thickness: 48 inches  
 Pilaster Width: 48 inches  
 Keying: Floor (6 inches) and Ribs (6 inches)  
 Joints: Staggered  
 Bonding Agent: All joints, inby face, and outby face with Burrell Bond  
 Bond Thickness: 1/4-inch minimum  
 Wedging: 6 inches to 1 foot on top |

A separate drawing of each of these seals is contained in Appendix A and each is identified according to their crosscut location during the explosion tests.

**PERFORMANCE OF OMEGA 384 SEALS**

On October 10, 1990, an explosion was initiated underground, which caused a pressure pulse of approximately 20 psig. Each of the four seals, constructed of Omega 384 block, survived. Previously, it was reported that the Omega 384 block meets or exceeds the incombustible criteria for seal and stoppages construction according to ISD engineers. The four Omega 384 seals are also considered to be substantial according to ISD engineers, if they are constructed as described above and as shown in Appendix A. However, other than substantial and incombustible, the criteria of Part 75.329-2 also calls for seals to be solid. The solid characteristic of a seal is directly related to the amount of air leakage that may occur after a seal is constructed.
MSHA's ISD has developed the following table as a preliminary guide in determining whether seals evaluated under the current test program are solid.

<table>
<thead>
<tr>
<th>PRESSURE DIFFERENTIAL (inches - water)</th>
<th>AIR LEAKAGE OF SOLID SEALS (cfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 1.0</td>
<td>100 or less</td>
</tr>
<tr>
<td>up to 2.0</td>
<td>150 or less</td>
</tr>
<tr>
<td>up to 3.0</td>
<td>200 or less</td>
</tr>
<tr>
<td>more than 3.0</td>
<td>250 or less</td>
</tr>
</tbody>
</table>

On October 18, 1990, air leakage measurements were taken across each of the Omega 384 seals. The following measurements will help the ISD determine the solid characteristics of each seal.

<table>
<thead>
<tr>
<th>OMEGA 384 SEAL LOCATIONS</th>
<th>PRESSURE DIFFERENTIAL (inches - water)</th>
<th>AIR LEAKAGE (cfm)</th>
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<tbody>
<tr>
<td>Crosscut No. 2</td>
<td>0.8</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>1.25</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>52</td>
</tr>
<tr>
<td>Crosscut No. 3</td>
<td>0.7</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>1.35</td>
<td>189</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>223</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>294</td>
</tr>
<tr>
<td>Crosscut No. 4</td>
<td>0.8</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>1.35</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>87</td>
</tr>
<tr>
<td>Crosscut No. 5</td>
<td>0.7</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>3.15</td>
<td>139</td>
</tr>
</tbody>
</table>

The table of results is compared to the table of maximum recommended air leakages developed by the ISD. The Omega 384 seals constructed in Crosscut Nos. 2, 4, and 5 are deemed to be solid according to the ISD guidelines. The seal constructed in Crosscut No. 3 is shown to have air leakages in excess of the maximum values recommended by the ISD and is not considered by the ISD to be solid.

Since the Omega 384 block is impervious to air leakage, the leakage measured and recorded after the explosion tests occurred through the joints or
around the perimeter. It is possible that the excessive leakage measured through the seal in Crosscut No. 3 was due to marginal construction techniques as related to sealing of the joints. This can not be stated with certainty as no air leakage measurements were taken before the explosion test.

CONCLUSION

The evaluation of the four Omega 384 block seals is completed. The Omega 384 block as a seal construction material is judged to be solid, substantial, and incombustible if constructed in the same manner as the seals in Crosscut Nos. 2, 4, and 5. However, the seal in Crosscut No. 3 was deemed to be inadequate based on the post-explosion leakage tests conducted. Additional testing would need to be conducted on this design to determine if it meets the criteria outlined in this report.
APPENDIX A
CROSSCUT NO. 3
OMEGA 384 BLOCK SEAL
ALTERNATING COURSES

SCALE: 3/8" = 1'
CROSSCUT NO. 4
OMEGA 384 BLOCK SEAL
ALTERNATING COURSES

SCALE: 3/8" = 1'