B-14

DEVELOPMENT OF PERFORMANCE STANDARDS FOR EXPLOSION-PROOF ENCLOSURES

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INTRODUCTION

The design requirements for explosion-proof enclosures used in gassy areas of underground mines are contained in Part 18, "Electric Motor-Driven Mine Equipment and Accessories," of Title 30, U.S. Code of Federal Regulations (CFR). These regulations define an explosion-proof enclosure as "An enclosure that complies with the applicable design requirements in subpart B of this part and is so constructed that it will withstand internal explosions of methane-air mixtures: (1) Without damage to or excessive distortion of its walls or cover(s) and (2) without ignition of surrounding methane-air mixtures or discharge of flame from inside to outside the enclosure." Experience has shown that enclosures constructed to the design requirements of subpart B and subsequently explosion tested to verify their ability to satisfactorily withstand an internal methane-air explosion can operate in the mining environment without a loss of integrity.

However, the present design requirements do not allow for much deviation, and the approval process is primarily based on enclosures constructed to these requirements. Therefore, any innovative design attempts by an enclosure manufacturer would require substantial effort on his part to prove that the enclosure is as safe as an enclosure constructed to the requirements of subpart B. Consequently, almost all designers of explosion-proof enclosures adhere to the design requirements.

Since 1977, the U.S. Bureau of Mines has been conducting research that will lead to the development of performance standards for explosion-proof enclosures. These new standards will provide a method of approving enclosures for use in mines based solely on the performance of the enclosure during specified tests. It is visualized that two tests would be conducted on most enclosures. One test is similar to the present internal methane-air explosion test in that it would verify that the enclosure would not transmit an explosion to a surrounding methane-air atmosphere. The other test, a hydrostatic pressure test, would verify the structural integrity of the enclosure. In some instances, a test to ensure the ruggedness of the enclosure might be required.

Before a performance standard can be written, substantial baseline data must be accumulated on the equipment presently in operation. Therefore, Bureau of Mines research has consisted primarily in the determination of characteristics of materials commonly used in enclosures. Such materials include steel, aluminum, polycarbonates, asbestos, and various sealants. Emphasis is placed on how these materials satisfy the present design requirements and produce an explosion-proof enclosure. The minimum safety factors contained in the requirements of subpart B will then be determined and this data used to develop failure criteria for the performance standards.

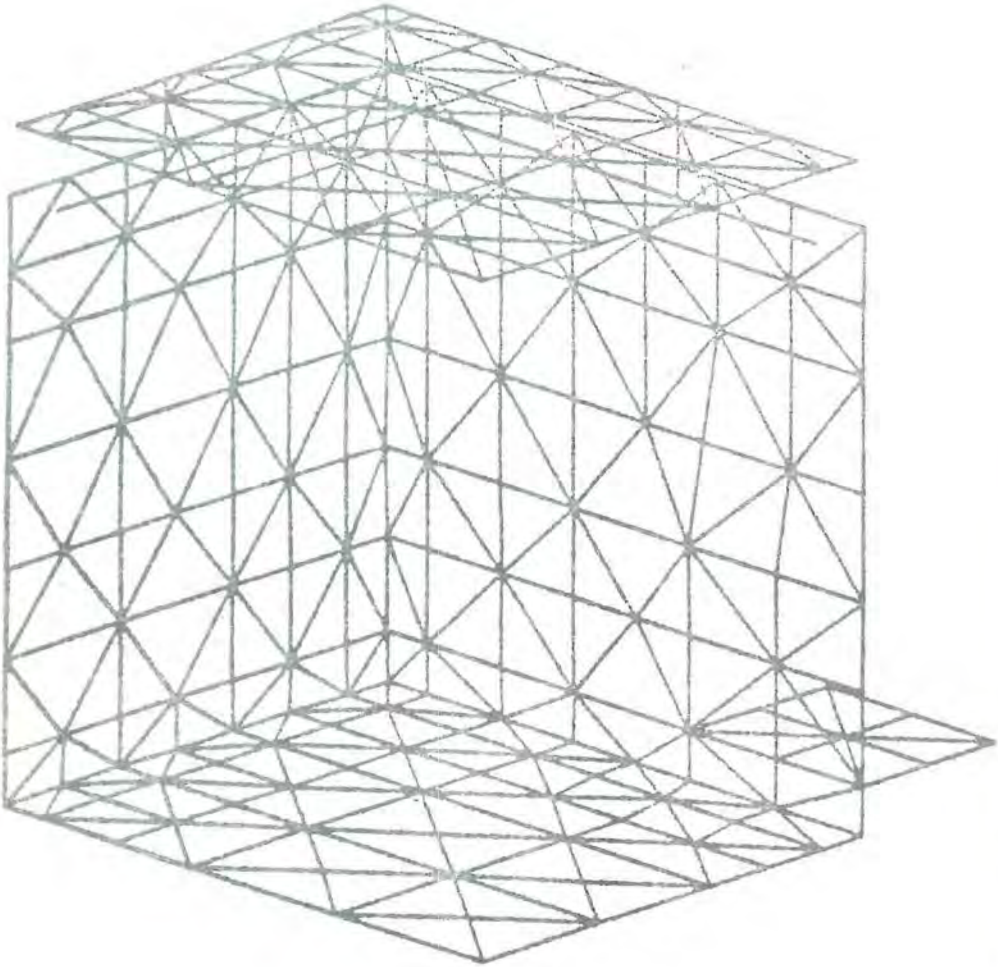

Figure 1.--Finite-element grid of Enclosure I with one-quarter symmetry

Figure 2.--Enclosure prepared for hydrostatic test

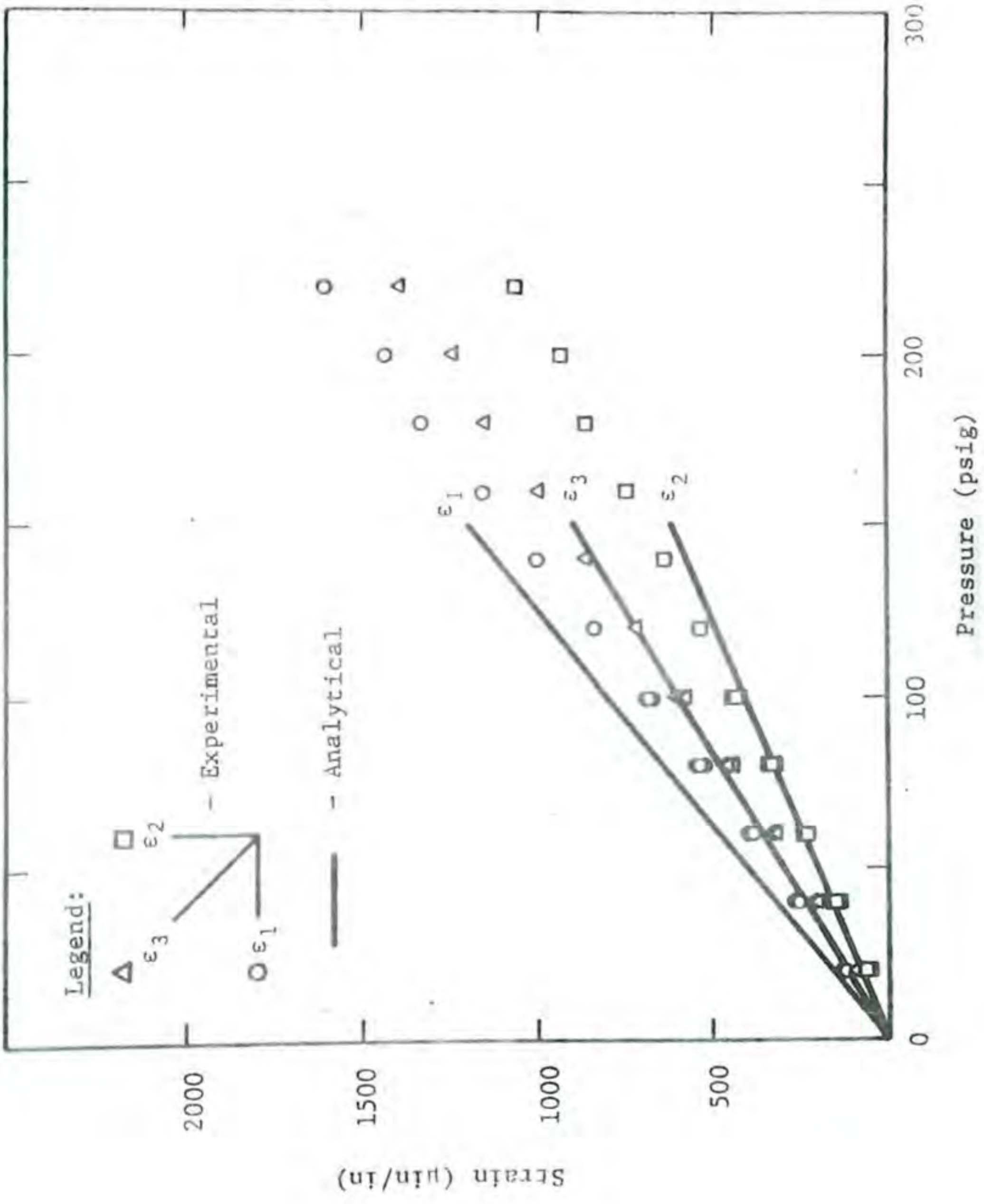

Figure 3.--Rosette No. 1 data comparison

STRUCTURAL INTEGRITY

A finite-element computer model is being used to ascertain the structural integrity of existing explosion-proof enclosures. A finite-element model consists of many small elements, each of which has stress and deflection characteristics easily defined by classical theory. By proper element selection and writing any necessary constraint equations at the corners or "nodes" of the elements, a good analysis can be obtained of the stresses generated in the enclosure by an internal loading function. Figure 1 shows a three-dimensional, quarter model of the explosion-proof enclosure pictured in Figure 2.

The computer code selected to perform the finite element analysis is ANSYS. This code is commercially available and contains all the capabilities deemed necessary for analyzing explosion-proof enclosures. It has a library of finite elements that includes general shells, three-dimensional beams and solids, and gap elements. It has the capability of performing elastic, elastic-plastic, or thermal stress analysis and static or dynamic loading.

The first analyzed enclosure is shown in Figures 1 and 2. It was constructed of 0.635 cm (0.24 in) A36 structural steel except for a 1.27-cm (0.50 in) 6061 aluminum alloy cover. The free-air volume of the enclosure was 0.016 m^3 (0.58 ft^3). The enclosure was subjected to a static internal loading of 689.5 kPa (100 psi), and the principal stresses in the different surfaces were determined. The results showed that the outside edge of the cover tended to seal against the flange, and no gaps would develop unless elongation (yielding) of the bolts occurred. Therefore, it would be reasonable to recommend the use of high-strength bolts in the covers of explosion-proof enclosures.

The results also indicated where initial yielding of the structure would occur. In determining the yielding of the structure the von Mises yield criterion was used (it assumes that the structure will yield when the distortion energy equals the distortion energy in simple tension). A combined stress, called the von Mises stress, is defined as

$$\sigma_{VM} = 0.707 \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2},$$

where σ_1, σ_2, σ_3, are principal stresses. The von Mises criterion expressed in terms of stresses states that yielding will occur when

$$\sigma_{VM} = \sigma_0,$$

where σ_0 is the yield stress in simple tension. Utilizing this criterion it was predicted that the structure would first begin to yield on the interior of the side plate at its connection with the bottom at an internal pressure of 565.4 kPa (82 psi).

To verify the predicted stresses in the enclosure, a hydrostatic pressure test was conducted on the enclosure. At five different locations (see Figure 2), three-element, 45°, single-plane rosette strain gages were mounted to the enclosure. Vacuum grease was applied to the flanges to minimize water leakage, and the bolts were torqued so that no gaps larger than 0.051 mm (0.002 in) existed. The enclosure was then pressurized in 137.9-kPa (20 psi) increments to a final pressure of approximately 2,000 kPa (290 psi).

Some of the experimental strain data are shown in Figures 3 and 4. The data from the experiment agreed relatively well with the analytical predictions in the

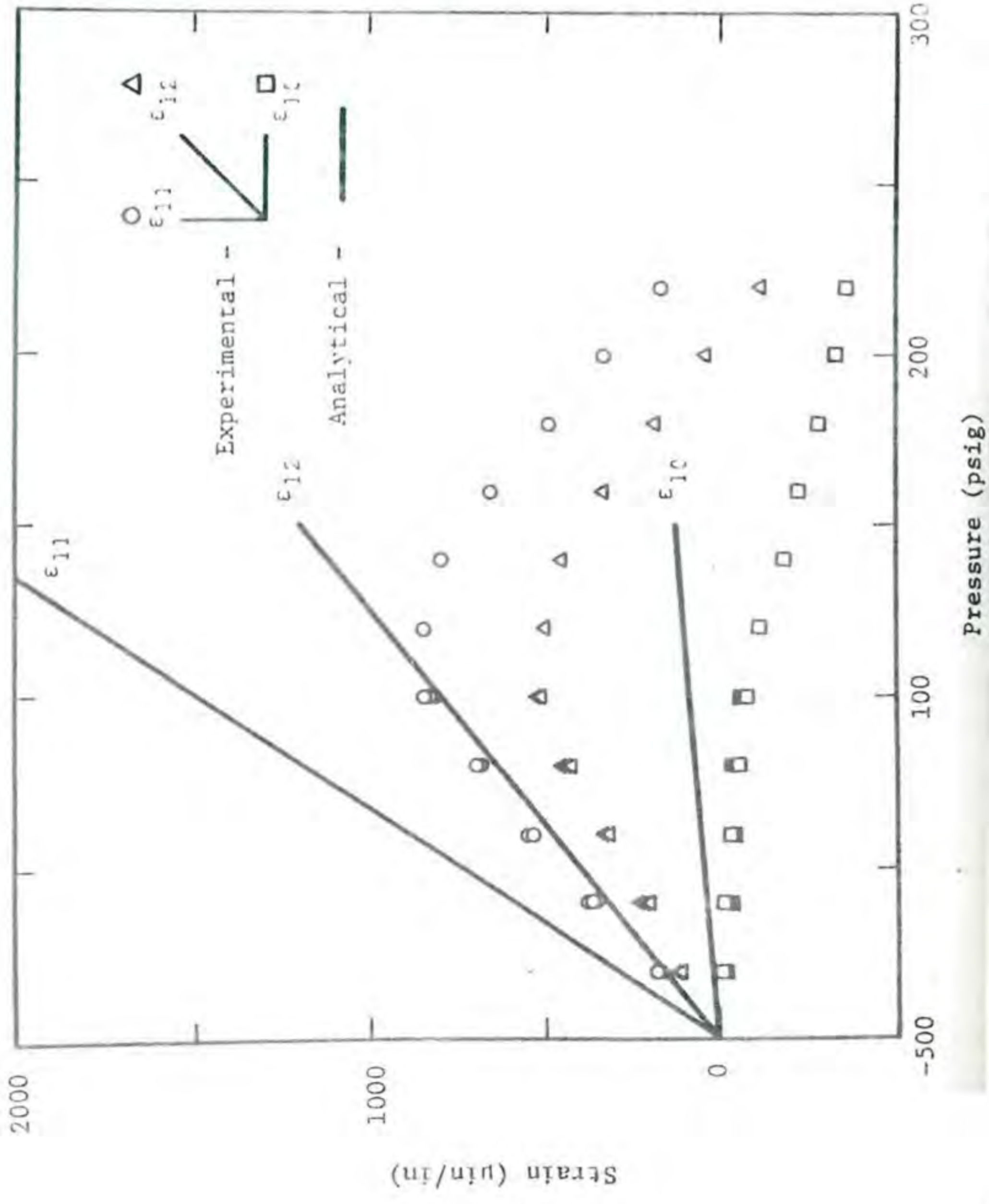

Figure 4.--Rosette No. 4 data comparison

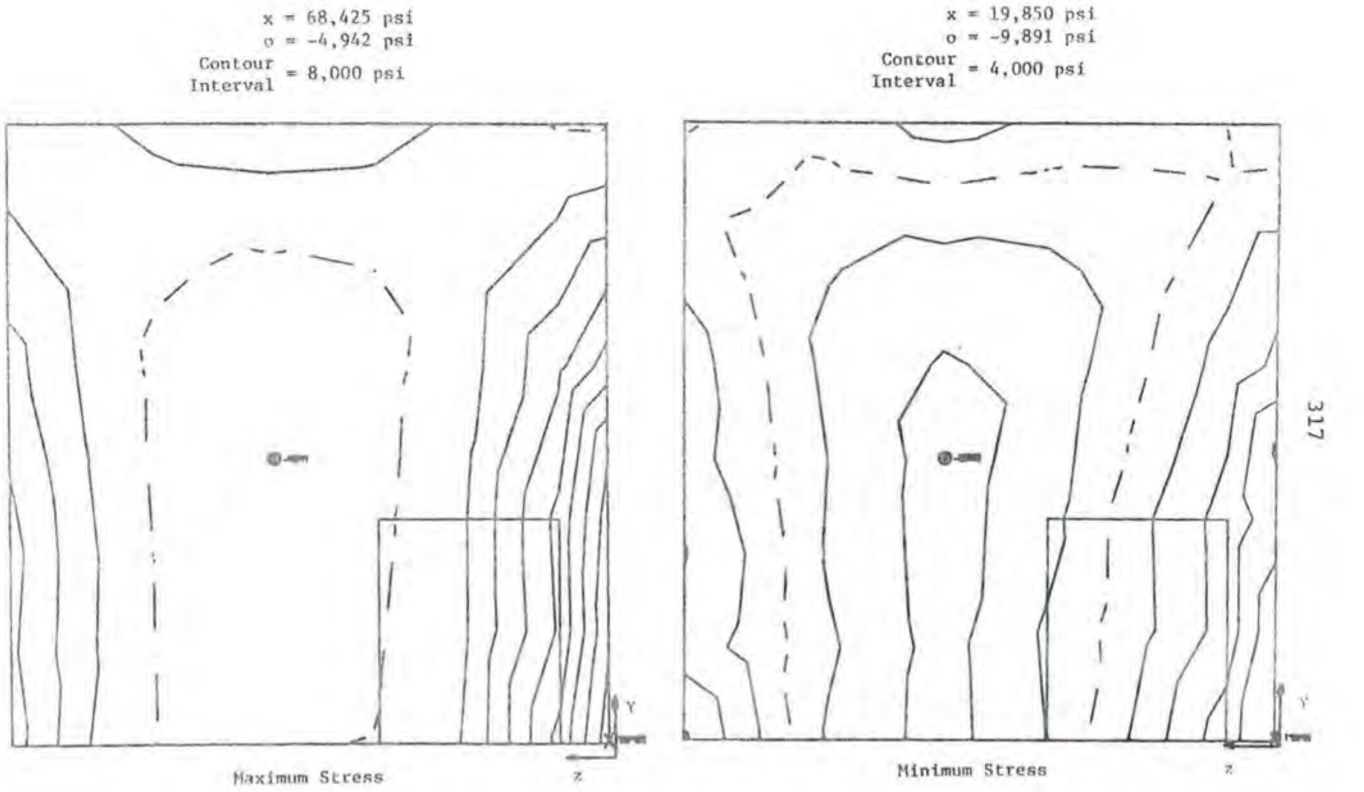

Figure 5.--Principal stresses (bottom surface) in side shell

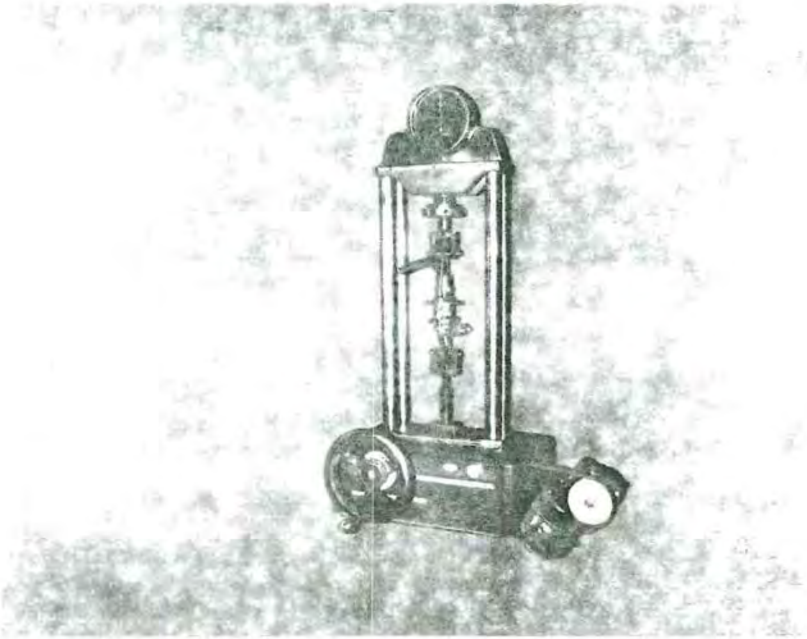

Figure 6.--Dillon Model K tensile tester

elastic range. The most unusual behavior occurred at the rosette placed on the side wall near the bottom (Figure 4). This unusual strain recording was caused by yielding in the weld joint between the bottom and side plates at very low pressures.

In determining the safety factor of this enclosure, a design pressure of 1,034 kPa (150 psig) (i.e., safety factor = 1) was used. A safety factor for each component of the enclosure was determined by

$$\text{Safety Factor} = \frac{P_{VM}}{P_{design}} ,$$

where P_{VM} is the pressure that will give the von Mises stress. The safety factor of the cover was 3.8, the bottom 0.9, the ends 2.0, and the sides 1.7. Using the minimum component safety factor for the entire enclosure, it is seen that this enclosure has a safety factor of 0.9. Although this may seem unsafe, one must remember that the design pressure was an arbitrarily selected value.

Similar tests have been conducted on three other enclosures with experimental results similar to the predicted results. The geometry and material of these other enclosures were as follows:

(1) Rectangular shaped, steel plate.
(2) Cylindrical shaped, cast steel.
(3) Rectangular-shaped, cast aluminum with four glass windows.

WELD JOINT DESIGN

After the weld joint in the first enclosure yielded at a relatively low pressure, it became apparent that a better understanding of weld joint design was needed. Since no one welding standard is recognized by all manufacturers of enclosures, it was decided to survey the standards available and the present welding practices to find the best match.

American Welding Society Standard D14.4-77, "Classification and Application of Welded Joints for Machinery and Equipment," is believed to be the best match. It establishes common acceptance criteria for classifying and applying welds that are used in enclosure fabrication. It also covers design, workmanship, and quality control requirements (e.g., dimensional checks, nondestructive acceptance test criteria). The standard is presently being circulated to enclosure manufacturers for their comments.

The weld used on the first enclosure was a partial joint penetration fillet weld. The fillet weld was a corner joint welded on only one side, the outside. This type of weld joint design satisfies the design requirements for explosion-proof enclosures, in that it is "a continuous gas-tight weld."

According to AWS D14.4-77, this type of weld is a Class V. This classification of weld joints is based on the design of the joint and its anticipated performance under static and dynamic loads. Weld joints are divided into six classifications and a joint efficiency of 100 percent means that the full permissible design stress of the base metal may be utilized. The Class V weld joint design has a joint efficiency of 50 percent for static loads and 20 percent for dynamic (dynamic being defined as a loading function with a minimum 20,000-Hz frequency). If it was determined that a stronger weld was needed here, by changing the manufacturing process to make double-sided welds, a Class IV weld could be achieved. The Class IV weld has a joint efficiency of 80 percent for static loads and 40 percent for dynamic.

The importance of having good weld joint design was evidenced by the computer model of the enclosures. Figure 5 shows a stress contour plot of the side shell. This plot shows that the maximum stress for the structure, and the location of the highest stress concentration factor, is at the corner weld. In fact, it can be safely assumed that for most enclosure designs the corners will be the areas of maximum stress and highest stress concentration. Thus, to achieve satisfactory results from a performance test, the enclosure designers will need to assess their weld joint designs.

CABLE ENTRIES

Cables that extend through the wall of an explosion-proof enclosure must pass through a cable entry. The cable entry fulfills two functions for cables entering an enclosure. Its primary function is to seal the flame path around the cable so that explosions within the enclosure cannot be transmitted to the outside along the cable. A secondary function is to provide a degree of strain relief for the cable.

A cable entry consists of three major components--the packing nut, the stuffing box, and the packing material. The packing nut and stuffing box designs vary from manufacturer to manufacturer; however, the most predominantly used packing material is asbestos. The inherent flame retardant charcteristic, effective sealing quality, and availability have contributed to its wide use. However, recent recognition of health hazards associated with the manufacturing of asbestos may soon make it difficult to acquire asbestos rope for use in the cable entries.

Since cable entries using asbestos have worked so well in the past, it was decided that performance standards for cable entries should also be developed to aid in evaluating new packing materials. Because it was thought that most new packing materials would be synthetic elastomers, the performance standards were written with that in mind.

Obvious performance tests to be conducted on new packing materials are for the determination of their potential toxicity hazard and flammability characteristics. These material tests will be conducted utilizing existing test criteria.* Another test would be the explosion performance of the entry. This would be accomplished by installing the new cable entry on the enclosure during the explosion testing of the enclosure. An understanding of cable variations on a mining machine and how miners presently enter cables into the asbestos cable entry was required before any more performance standards could be written.

Typical cable sizes used on mining machinery range from 0.97 cm (0.38 in) to 6.07 cm (2.39 in) in diameter. The smaller cables are used on-board the machine for controls, lighting, and other functions; larger ones are used for trailing cables. In addition, a variety of cable jacket materials including braided asbestos, neoprene, polyvinyl chloride, and others must be accommodated. Typical diameter variations between the minimum and maximum allowable values vary about 0.76 mm (0.03 in) for small cables and up to 2.54 mm (0.10 in) or more for the larger sizes. Moreover, the cable cross sections are not round, and this condition can be pronounced in multiconductor cables.

In interviews and observations of personnel entering cables into a conventional asbestos entry, the following findings were made:

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* Mine Safety and Health Administration, "Interim Fire and Toxicity Criteria for Acceptance of Products Taken Into Underground Mines." Draft No. 2, March 22, 1977.

(1) Packing a cable entry is very labor intensive and may require as much as 30 minutes.
(2) Proper packing of the entry is highly dependent upon the care and skill of the assembler.
(3) The torque applied to the packing nut is primarily a matter of feel or judgment.

The above findings on cable variations and packing procedures led to the development of two additional performance standards. One test is a minimum torque test, and the other is a pull-out test.

The torque test was developed through observations of personnel packing cable entries. Measurements were made of the amount of torque applied to the packing nut to give what the assembler felt was adequate compression of the asbestos. The torque test, therefore, requires that a packing material must be capable of supporting a compression nut seating torque of 20.34 nt-m (15 ft-lb_f) minimum for all cable sizes.

The purpose of the pull-out test is to determine the force required to pull the cable out of a properly packed entry. The tests were conducted on the conventional tensile testing machine shown in Figure 6. The cable is inserted into the entry and then the entry is attached to the tensile machine. The entry is pulled at a constant rate of 0.33 cm/min (0.13 in/min) until the cable slips in the entry. At this time, the pull-out force is recorded. Based on tests conducted on various cable sizes and jackets, a minimum acceptable pull-out force of 155.7 nt (35 lb_f) is recommended when the cable is pulled at the constant rate of 0.33 cm/min (0.13 in/min).

CONCLUSIONS

Research to develop performance standards for explosion-proof enclosures will continue. The results to date have been promising, and they have revealed much about the mechanisms of containing an explosion. Other parallel areas that are in the early stages of developing performance standards include potting compounds (both solid and liquid), adhesives, and epoxy resins.

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REFERATI,ДОКЛАДИ, PROCEEDINGS,

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