RECOMMENDED ACCEPTANCE TESTING CRITERIA FOR ADHESIVES AND SEALANTS FOR EXPLOSION-PROOF ELECTRICAL ENCLOSURES

Prepared for
United States Department of the Interior
Bureau of Mines

By
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78284

INTERIM TECHNICAL REPORT

SwRI Project No. 02-5414
Prepared Under USBM Contract No. H0387009

uary 9, 1980

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO HOUSTON

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U.S. Lindholm
Director, Department of
Materials Sciences

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In this report, factors which currently enter into the design, manufacture, and quality assurance of explosion-proof enclosures are reviewed, with special emphasis given to the sealing concepts and sealants/cements, per se, for lenses. The physical and mechanical properties of a number of representative sealants and adhesives are measured, and found to exhibit great variance, with few discernible trends which might afford a firm base on which to establish minimum property standards. Accordingly, acceptance criteria for adhesives and sealants are suggested based on the survivability of an explosion-proof enclosure as a structure, rather than upon the minimum material properties of its constituents. Procedures for surface preparation of adherends, and for quality assurance, also are proposed.

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FOREWORD

This report was prepared by Southwest Research Institute in the Department of Materials Sciences in San Antonio, Texas under U. S. Bureau of Mines Contract No. H0387009. The contract was initiated under the Coal Mine, Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Research Center with Roger L. King acting as Technical Project Officer. A. G. Bolton was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period September 6, 1978 to November 6, 1979. This report was submitted by the authors on January 9, 1980.

The project was managed by Dr. Philip H. Francis of SwRI, until his departure in June, 1979, following which Dr. James Lankford of SwRI assumed the role of manager. Dr. Francis was principal technical contributor. Dr. Patrick E. Cassidy, Associate Professor of Chemistry at Southwest Texas State University in San Marcos, served as project consultant on matters related to polymer chemistry and adhesive bonding.

The authors are grateful to several individuals for their special contributions to this program, namely: Don Weed (SwRI), for his specimen manufacturing; Richard Atiyeh (SwRI), for his careful testing of all specimens; William Mallow (SwRI), for consulting assistance on polymers/adhesives; and Dr. Pat Cassidy (SWTSU), consulting contribution on adhesives and surface preparation.

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I. INTRODUCTION

In this report, factors which currently enter into the design, manufacture, and quality assurance of explosion-proof enclosures are reviewed, with special emphasis given to the sealing concepts and sealants/cements, per se, for lenses. The physical and mechanical properties of a number of representative sealants and adhesives are measured, and found to exhibit great variance, with few discernible trends which might afford a firm base on which to establish minimum property standards. Accordingly, acceptance criteria for adhesives and sealants are suggested based on the survivability of an explosion-proof enclosure as a structure, rather than upon the minimum material properties of its constituents. Procedures for surface preparation of adherends, and for quality assurance, also are proposed.

II. BACKGROUND

A. Explosion-Proof Enclosures

The purpose of this chapter is to establish some of the background that is needed to evaluate current and potential problems associated with sealants, cements, and potting compounds used in the structural assembly of explosion-proof enclosures.

Electrical equipment, including lights, connections, etc., of the types normally found in coal mines, are potentially hazardous devices due to their use in potentially explosive mining environments. There are many kinds of electrical equipment which are used in mining operations. Federal regulations require that when electrical equipment is located in an area which may contain a methane-air gas mixture, the equipment must be encased in an explosion-proof enclosure, or be intrinsically safe. In this report, only those devices are considered which may employ sealants or adhesives in constructing the enclosure, as in potting or bonding windows used in headlights and similar fixtures.

A.1 Types

Title 30 of the Code of Federal Regulations (CFR), Part 18, provides the following definition of an "explosion-proof enclosure" as

> "... an enclosure that ... 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."

There are several different types of electrical equipment which fall under this definition: power enclosures, distribution boxes, splice boxes, and ballast boxes are among them. The focus of this report, however, is on luminaires, or lighting fixtures which are mounted on coal mining machines. The windows and lenses built into luminaires are often fixed in place with adhesives, cements, or potting compounds, and are generally subjected to more severe thermal environments than are other explosion-proof enclosures.

There are three different kinds of luminaires used in contemporary coal mining operations. The following definitions serve to describe these three luminaires.

Fluorescent luminaire - A long fluorescent light tube surrounded by a tough plastic tubular lens and protected by a metal cage. These fixtures are mounted on the sides of coal mining machines to illuminate the mine roof and rib.

Headlight - A light source (incandescent, high pressure sodium, or mercury vapor) in a heavy metal enclosure, mounted on the front of coal mining machines to illuminate the face and region of forward movement.

Machine luminaire - A light source (incandescent, high pressure sodium, metal halide, or mercury vapor) in a heavy metal enclosure, mounted on the sides of coal mining machines to illuminate the mine roof and rib.

A.2 Environmental Exposures

Mine lighting equipment must be designed to endure rather severe and uncontrolled environmental conditions. Specific conditions can vary widely with the type and location of the mine, operator handling of equipment, and other factors. There are no design criteria currently available to guide equipment designers, except 30 CFR, Part 18. In fact, very little is known quantitatively about environments to which mine lighting equipment is likely to be subjected. Below are discussed in brief and general terms some of the more important environmental parameters.

Chemical

Most mine environments where self-propelled mining equipment is deployed may be characterized by highly humid, non-condensing air at temperatures in the range of 5° - 20°C. The effects of moisture on equipment are further aggravated by the acid generated from the exposure of iron sulfide minerals found in the coal and overburden. The presence of pyrite (iron disulfide) in rock materials generic to coal mines produces, on oxidation by exposure to air, ferrous iron and sulfuric acid. Further reactions occur to produce ferric hydroxide and more acid.(1) These products develop as water filters through the overburden, drips from the roof, and flows along the floor from areas where acid mine draining accumulates. Acid is also carried by the damp air environment and by general work activity and may infuse electrical equipment, causing corrosion and other environmental susceptibility problems.

The following water chemistry has been suggested as characteristic of acid mining conditions.(2,3) To one liter of 0.01N H_2SO_4, add the following:

$CaSO_4$	$\cdot$ $2H_2O$	0.344g
$MnSO_4$	$\cdot$ H_2O	0.024g
$Al_2(SO_4)_3$	$\cdot$ $18H_2O$	0.186g
$FeSO_4$	$\cdot$ $7H_2O$	0.997g
$MgSO_4$	$\cdot$ $7H_2O$	0.246g

This chemical composition was developed by the U. S. Environmental Protection Agency in the early 1970's as a simple formula which has the most critical constituents of typical acid mine drainage chemistry. It is widely used today as an unofficial "standard" for simulating waterborne contaminants found in coal mine environments.(4)

Thermal

Although air temperatures in coal mines generally are mild, mine lighting equipment can be exposed to high temperatures from the lighting elements. Furthermore, as these lights are turned on and off, cyclic thermal loading of materials and components can occur. Federal regulations (see Section II.A.4 of this report) impose a maximum external surface temperature limit on explosion-proof enclosures of 150°C; temperatures inside lighting enclosures can and do exceed this value. The exception to this requirement is the case of polycarbonate lenses which, according to MSHA policy memorandum of April 22, 1977, may not exceed 240°F (116°C) on the inner surface.(5) Title 30 of the CFR, Part 18*, presently imposes a thermal shock test on windows and lenses used in luminaires. This test requires the lens to be heated to 150°C, then quenched in a water bath at 15° - 20°C.

Electro-magnetic

At present, no significant amounts of ozone or corona are believed to exist in the explosion-proof enclosures. However, trends are to use higher voltage levels underground and inside the enclosures, which may in turn create more significant electro-magnetic levels.

Light

Ultraviolet (UV) light in coal mine environments normally will be generated only by luminaires. Unfortunately, luminaires often employ organic adhesives and sealants in their design, and these organic compounds in many cases are susceptible to crazing, embrittlement, and loss of adhesion under exposure to UV light. Typical maximum luminaire outputs are associated with 175W mercury vapor lamps (which produce significant UV light) and 70W high pressure sodium lamps (which do not produce significant UV light), both of which are used in machine luminaires. The inside dimensions of these enclosures are only slightly greater than those of the bulb which they contain, exposing the surrounding structure to rather high temperatures.

*Paragraph 18.66 (b)

Mechanical

Very little data are available to define the mechanical shock and vibration environment experienced by mining equipment in service. One study(6) has reported on vibration levels at various locations on continuous coal miners. These measurements indicate maximum absolute vertical excitations of from 2.4 g at 0.5 to 0.8 kHz, to about 15 g at 4 kHz, depending upon the accelerometer location and on the kind of operation in which the miner was engaged at the moment. Comparable values were found in the horizontal directions. These g levels may be misleading, however, since the referenced report provides only g-level as a function of excitation frequency; the maximum g level due to sources at all frequencies simultaneously could be much higher.

Perhaps the mechanical environments of most concern are those associated with accidents or misuse of the equipment, such as dropping, being struck by heavy objects, etc. These environments are of concern not only because they can be severe, but also because they are unknown and largely uncontrollable. The only guidance presently available for assessing shock environments is the impact test required for windows and lenses in Paragraph 18.66(a) of Title 30 of the CFR, Part 18. This test imposes shock energy levels on lenses of up to 8 ft-lb (10.8 J) by a falling weight.

A.3 Hazards

The principal hazard associated with luminaires and other explosion-proof enclosures is the potential for catastrophic mine explosion. Enclosures are not designed to be air-tight structures, and therefore in time may contain a methane-air mixture in equilibrium with the partial pressures of the gaseous constituents found in the mine. Any malfunction of the light unit such as arcing or a bursting lamp, or sparking of the structure by frictional impact, may then trigger an explosion within the enclosure. This explosion must be contained: the unit must hold together and there must be no flame propagation from inside to outside the enclosure.

There is an ancillary hazard potential associated with luminaires that needs to be considered in design and in the setting of standards. The light output from the luminaire must not decrease over time and with use to levels that are considered unacceptable for safe working conditions. Decreased light output may develop from several sources, among them lenses gathering an excessive coating of coal dust, and the capacity of some plastic lenses (such as polycarbonates) to yellow and/or craze with ultraviolet light exposure. This decreased output will increase the internal operating temperature to levels that may be unacceptable.

A.4 Federal Regulations

The Federal Coal Mine Health and Safety Act of 1969 provided for the imposition of standards to ensure adequate illumination during coal mine operations. In October 1976 the final standards were promulgated in the Federal Register. These standards gave the mine lighting equipment industry 18 months to become fully compliant, i.e., until April 1, 1978.

Equipment to be lighted includes continuous miners and coal-loading equipment of all types, self-loading hauling equipment when used as a loading machine, cutting and drilling equipment for the face, roof-bolting equipment, haulage equipment, short-wall, and long-wall mining equipment, and all other types of self-propelled electric face equipment. These regulations require illumination of working places at a surface brightness of 0.06 foot-lamberts (0.021 cd/m^2), while self-propelled mining equipment operates in the working place. The effect of these recent standards has been to increase greatly the lighting requirements of all underground coal mine operations. Until these standards came into being, only headlights were used. As a result of the new standards, the mine lighting equipment industry has been gearing up for increased production of conventional and new lighting equipment.

Federal requirements which govern the design and use of explosion-proof enclosures are embodied in two documents. The first of these is Title 30 of the Code of Federal Regulations, Part 18 (Electric Motor Driven Mine Equipment and Accessories--formerly known as "Schedule 2G"). This document prescribes MSHA's responsibilities for qualifying explosion-proof enclosure designs and prototype hardware and specifies that windows and lenses must be protected from mechanical damage through structural design, location, or guarding (Paragraph 18.30). Headlight lenses must have physical characteristics equivalent to those of 1/2-in. (1.27-cm) tempered glass (Paragraph 18.46) and must meet impact and thermal shock requirements set forth elsewhere (Paragraph 18.66). Enclosures and other mechanical or electrical components must maintain surface temperatures not to exceed 150°C (302°F) under normal operating conditions (Paragraph 18.23)*, and cast or welded enclosures must be designed to withstand a minimum gage pressure of 150 psi (1.034 MPa), or 200% of the maximum pressure experienced (whichever is greater) as a result of MSHA's explosion tests (Paragraphs 18.31, 18.62). In addition, MSHA may require static pressure tests on each enclosure at 150 psi or 150% of the maximum pressure recorded in MSHA explosion tests, whichever is greater (Paragraph 18.67). This document also specifies the qualification testing of enclosure structures. The procedure involves electrically igniting various methane-air and coal dust mixtures within the enclosure and verifying that the resulting explosion does not ignite a methane-air gas environment surrounding the enclosure or rupturing the enclosure, or permanent distortion of the enclosure or development of after-burning (Paragraph 18.62).

The second source of Federal regulatory requirements can be found in MSHA (formerly MESA) memoranda dated February 18 and April 22, 1977.[(5)] The "February 18" memorandum provided clarification, with respect to glass and adhesive materials, of the Title 30, CFR, Part 18 requirements that enclosure designs should be constructed of suitable materials, built with good workmanship, designed on the basis of sound engineering principles, and be safe for its intended use. This memorandum defines the air gap dimension for

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*The exception to this rule is the case of polycarbonate lenses, whose <u>inside</u> surface temperature must not exceed 240°F (116°C), as will be discussed later.

explosion-proof enclosures* and requires the adhesive to have a hardness less than that of the window to which it is bonded. It also places requirements on the adhesive manufacturer, and on the enclosure manufacturer who uses the adhesive, that the adhesive be chemically compatible with the substrates to which it is to be bonded, that use procedures be provided, and that the enclosure manufacturer follow these procedures without exception. The requirements promulgated in the "February 18" memorandum specifically excluded headlights already in service, on the basis that such equipment had not demonstrated problems and that they all had mechanical backup rings behind the lenses for fail-safe design. Headlight designs seeking certification after that date would be subject to all the "February 18" requirements.

The "April 22" memorandum(5) adopted all the requirements of the prior memorandum, but expanded those requirements to apply to polycarbonate materials used for windows and lenses. Most importantly, the "April 22" memorandum placed responsibility of the enclosure manufacturer to provide MSHA with data to show that the temperature on the inside surface of the polycarbonate would not exceed 240°F (116°C) after eight hours of continuous use and that the ultraviolet radiation from the light source will not reduce the light output from the unit by more than 20% after one year of continuous operation.

As a result of an MSHA meeting held on May 26, 1977, a few revisions to the "April 22" letter were ordered. These allowed the polycarbonate supplier to furnish "facts" concerning performance, not necessarily "certification" as called for earlier, and also permitted "other appropriate analysis" to replace Izod impact test data on polycarbonates. In addition, the following paragraph (Paragraph 7) was deleted as a requirement:

> "Manufacturers of certified enclosures used as a machine-mounted luminaire shall have the MESA retest four enclosures that after certification were machine-mounted and used for at least two, but not more than four, months in underground coal mines. Failure to submit and pass this subsequent testing is cause for rescinding the certification."

It should be noted that MSHA still has the right, by power of language used in the certification letter, to take as many as four enclosures from the manufacturer's inventory and test them subsequent to certification. Failure to pass these tests can void the certification.

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*An "air gap" is the required separation of the lens from its inner retaining structure in the event of adhesive/sealant failure. Its purpose is to aid in easily identifying failed adhesives/sealants during field inspections; it also serves to restrain the lens from falling into the enclosure, thereby striking the lamp. The term "air gap" is not to be confused with the "flame arresting path," which applies only to non-bonded, contiguous metal surfaces. Its purpose is to control the space between the contiguous surfaces and to ensure adequate length dimension so that combusting gases created by an ignition within the enclosure will not ignite external combustible gases.

A.5 Luminaire Manufacturers

Table 1 exhibits the current manufacturers of explosion-proof luminaires known to the writers. Addresses and names/telephone numbers of key persons within the companies are listed in Appendix C. The table is intended to indicate the kinds of luminaires presently manufactured, the supply market, and the various design concepts for installing and sealing lenses. Although the subject of this report embraces all explosion-proof enclosures (not just luminaires) where adhesives and sealants are used, particular emphasis is given to luminaires because of the more severe thermal environments to which their structural cements are subjected. Moreover, many of the manufacturers represented in Table 1 produce other kinds of explosion-proof enclosures, and the materials used and construction details are similar.

The data in the table were drawn from a survey of manufacturers as to their current and anticipated product lines, as well as design concepts, materials used, Q.A. procedures followed, etc.* Some explosion-proof enclosure components, such as lamps, are purchased from outside suppliers.

B. Sealing Concepts for Lenses

B.1 Structural Design and Materials Aspects

This subsection reviews some of the structural design aspects of explosion-proof luminaires with specific emphasis on windows and lenses held in place by sealants and adhesives. Many headlight, machine light, and fluorescent luminaire designs now found in the field use mechanical attachments, without any cement or sealant materials. These designs are not reviewed here. Also, while the designs discussed here are to be considered representative of industry practice, no claim is made that all design variations are represented. Figures 1a-1f, associated with this discussion, are schematics only; no scale is implied, and all designs are shown without lamps for simplicity.

Many headlight designs secure their glass windows with a threaded cover which fits over the lens to fasten it mechanically. One departure from this practice is shown in Figure 1a, where the glass is seated in an epoxy prior to securing the threaded cover. In this particular design the cover is made up of cast ductile iron and the headlight body of cast steel. The epoxy is not required to provide any significant adhesive strength, but merely acts as a sealant. A more compliant adhesive, such as an RTV,** may be more suitable in this case.

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* Although these data are believed accurate, individual manufacturers should be contacted to verify information in cases where parts of Table 1 are to be used as a primary information source.

** Room-Temperature Vulcanizing silicone adhesives.

TABLE 1. SUMMARY OF CURRENTLY SUPPLIED LUMINAIRES

Manufacturer	Luminaire Equipment	Housing Material	Window Material	Sealants Used	Design in Lieu of Sealants
NO. 1	Fluorescents : Yes	Machinable Steel	Polycarbonate (Mobay)	RTV to Seal; 2-part Epoxy for Adhesive	- - -
	Headlights : Yes; a,b,c	Cast/Ductile Fe, Brass, or Al.	Soda-Lime Glass (PPG)	RTV	- - -
	Machine Lights: Yes; b,c	Cast/Ductile Fe, Brass, or Al.	Soda-Lime Glass (PPG)	RTV	- - -
NO. 2	Fluorescents : Yes	Steel	Polycarbonate (Mobay)	None	Threaded, with O-ring
	Headlights : Yes; a,b,c	Cast Iron	Borosilicate or Soda-Lime Glass	None	Proprietary Mechanical Contact Process
	Machine Lights: Yes; a,b,c	Cold Rolled Steel	Borosilicate or Soda-Lime Glass	"Chico" Inorganic Cement	Cage with Tension Members to Hold End Caps
NO. 3[2]	Fluorescents : Yes	Steel and Aluminum	Polycarbonate (G.E.)	None[3]	Threaded Cylinder or Close Tolerance Sleeve
	Headlights : No	- - -	- - -	- - -	- - -
	Machine Lights: No	- - -	- - -	- - -	- - -
NO. 4	Fluorescents : Yes	Steel Cage with Brass Fittings	Polycarbonate	None	Slipfit Design (Rothreads)
	Headlights : Yes; c	Steel	Borosilicate Glass (CGW)	None	Lead Washers[4]
	Machine Lights: Not Yet MSHA-approved	- - -	- - -	- - -	- - -
NO. 5	Fluorescents : Yes	Steel and Ductile Iron	Polycarbonate (G.E.)	RTV (G.E. #108)	- - -
	Headlights : Yes; a,b,c	Ductile Iron or Cast Aluminum	Soda-Lime (S,E)	2-part Epoxy (Armstrong)	- - -
	Machine Lights: Yes; c	Welded Steel or Cast Aluminum	Soda-Lime (S,E)	RTV (G.E. #108)	- - -
NO. 6	Fluorescents : No	- - -	- - -	- - -	- - -
	Headlights : Yes; a,b,c	Ductile Iron, Brass, or Aluminum	Borosilicate Glass	RTV[1]	- - -
	Machine Lights: No	- - -	- - -	- - -	- - -

TABLE 1. SUMMARY OF CURRENTLY SUPPLIED LUMINAIRES (CONTINUED)

NO. 7	Fluorescents : Yes	Steel	Polycarbonate	None	Threaded
	Headlights : Yes; b(6)		Hardened Glass	Epoxy and RTV	
	Machine Lights: No	- - -	- - -	- - -	- - -
NO. 8	Fluorescents : Yes	Aluminum and Bronze	Polycarbonate (extruded)	None	Threaded
	Headlights : Yes; a,b	Aluminum, Bronze, and Ductile Iron	Tempered Glass	None	Mechanical
	Machine Lights: Yes; c	Aluminum and Bronze	Polycarbonate (Injected)	None	Threaded
NO. 9	Fluorescents : Yes	Cast Brass Ends, Steel Frame	Polycarbonate (G.E.)	None(5)	Slipfit
	Headlights : No	- - -	- - -	- - -	- - -
	Machine Lights: No	- - -	- - -	- - -	- - -

LEGEND

a = incandescent

b = mercury vapor

c = high pressure sodium

NOTES

(1) Seeking MSHA approval to replace RTV with epoxy.

(2) Equipment not in production; are seeking licensee to manufacture and market.

(3) One design is qualified for RTV as optional - Ensign prefers not to use sealants.

(4) Going to new design where glass is fused to housing.

(5) "Intrinsically safe" circuit rather than explosion-proof; not subject to methane-air explosion test.

(6) Designed and manufactured by Mosebach Mfg. Co., Pittsburgh. Distributed by National Mine Service.

ABBREVIATIONS

GE = General Electric Co.

CGW = Corning Glass Works

PPG = Pittsburgh Plate & Glass

RTV = Room Temp. Vulcanizing (Silicone)

S = Swift Glass Co.

E = Elgin Precision Glass Co.

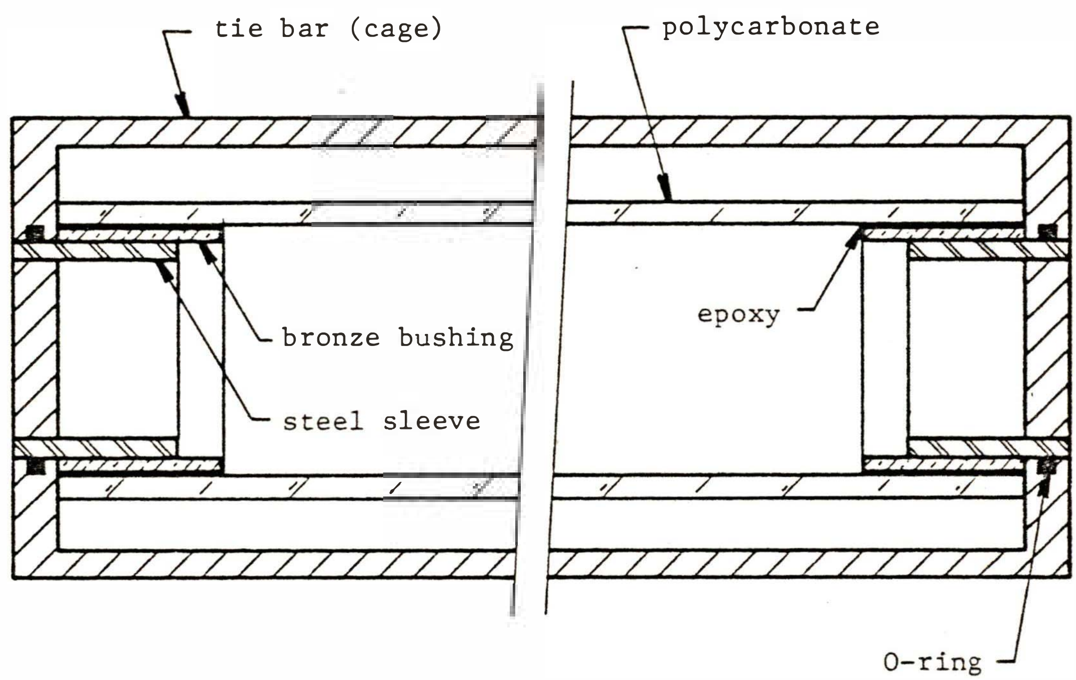
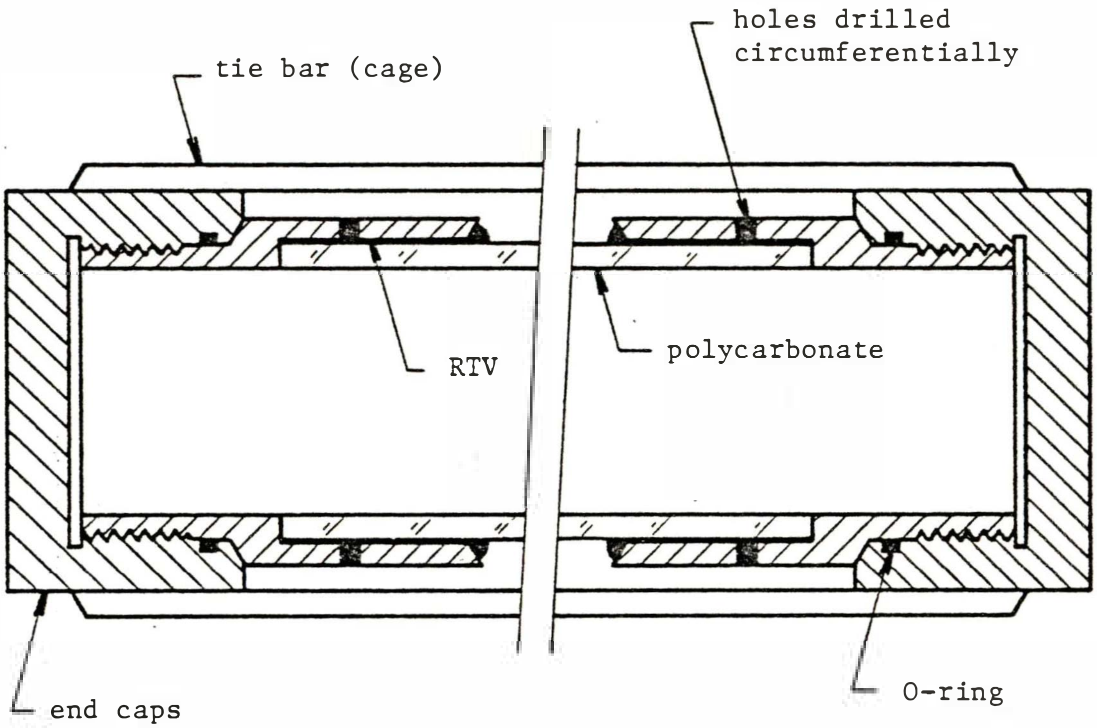

tie bar (cage)
polycarbonate
epoxy
bronze bushing
steel sleeve
O-ring

FIGURE 1e



holes drilled circumferentially
tie bar (cage)
RTV
polycarbonate
end caps
O-ring

FIGURE 1f

Figure 1b shows the first of three machine light design concepts found in practice where the lens (in all cases, glass) is seated with an adhesive or sealant. In this particular case the glass is held in place by an epoxy which bonds the outer perimeter of the lens to the housing, which is either aluminum or ductile iron. The RTV silicone provides minimal tensile adhesion strength, and acts primarily as a sealant and as a lens setting compound. There is no internal backup ring, only pins to restrain the lens from falling away should the adhesive fail, and the epoxy is considered crucial to the mechanical integrity of the lens. Figure 1c shows another approach where the lens, in this case rectangular, is held in place by a bolted cover frame, backed up by a recess in the lens frame opening. The glass is first set on shims, then the RTV is applied with a hand gun, and left to set. The cover is then bolted to the housing, which is either case aluminum or welded steel.

Another design concept for a machine light is illustrated in Figure 1d. In this case a mechanical cage, which surrounds the cylindrical glass lens with steel bars for protection, provides the structural support at the ends needed to resist excessive internal pressure. The cement, in this design an inorganic Portland cement formulation, provides a seal only, and is held in place during setup by a butyl rubber dam material. The cement expands during cure and the surrounding constraint ensures the cement is in a state of compression, thus preventing cracking or separation. This design has been used since 1948 when it was approved by Underwriter's Laboratory.

Figures 1e and 1f show two approaches, which are similar to one another, for constructing a fluorescent luminaire using a cylindrical polycarbonate tube for a lens. In both cases the end caps are held together by a case consisting of bars parallel to and surrounding the polycarbonate tube. In Figure 1e a layer of epoxy is used to bond the inner surface of the tube to the outer surface of a bronze bushing, which is slipped over a steel sleeve. O-rings are used to provide a water barrier. Figure 1f shows a similar design concept, but where the outer surface of the polycarbonate tube is bonded to the inner surface of the end caps, in this case with an RTV silicone. Adhesion is enhanced with a series of radial holes placed circumferentially around the end caps, then filled with RTV. In neither of these two fluorescent luminaire designs is the adhesive used primarily to provide adhesive strength, but merely acts as a sealant.

B.2 Lens Materials

There are two categories of materials used for making windows or lenses for explosion-proof enclosures. The first of these is glass and is used for nearly all flat lenses. The two most common varieties of glass used are borosilicates and soda-lime, and they are manufactured by a number of glass suppliers.* The borosilicates ("Pyrex" is a well-known borosilicate glass trademark of Corning Glass Works) in most cases have adequate impact strength without having to be tempered. They exhibit good resistance to water corrosion and to general environmental weathering. Soda-lime glass

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*Anchor-Hocking, Corning Glass Works, Elgin Precision Glass, Pittsburgh Plate and Glass, and Swift Glass, to name a few.

often must be tempered (regular temper or heat strengthened) to meet MSHA impact strength requirements. It is somewhat less resistant to water corrosion and to general environmental weathering than the borosilicates, but about equally acid resistant. Soda-lime glasses may have iron impurities which tend to make these lenses hold in heat more than the borosilicates. Thus, MSHA usually will rate the borosilicate lens for a higher wattage lamp than the soda-lime lens. Borosilicate and soda-lime glasses are often supplied with a color tint, and the supplier will furnish thermal expansion data to the enclosure manufacturer, who in turn usually conducts his own impact testing for quality control purposes.

At the present time polycarbonate is the predominate, if not the only, kind of organic material used for enclosure lenses. Polysulfones, acrylates (such as "Plexiglas" by Rohm & Haas Co. and "Lucite" by DuPont) and other varieties of plastic are sometimes mentioned, but have not yet found their way into the production of explosion-proof enclosures. Polycarbonate (supplied under the trademarks "Merlon" by Mobay Chemical, and by General Electric as "Lexan") is used for all fluorescent luminaires and comes in tempered and stress relieved extrusions. At least one enclosure manufacturer does his own annealing of polycarbonate. Polycarbonate is much lower in cost than glass, is easily threaded, and has excellent impact resistance. Compared to glass, however, polycarbonate has very limited temperature resistance. Its mechanical properties begin to drop off markedly at about 120°C, and it turns yellow and begins to lose its transparency about 150°C. Current MSHA regulations (see Subsection II.A.4) require that the maximum temperature on the inner surface of a polycarbonate window be limited to 240°F (116°C). Also, mercury vapor lamps produce significant ultraviolet (UV) light, enough that polycarbonates (which degrade in the presence of UV light) cannot be used with these lamps. High pressure sodium, on the other hand, produces so little UV light that polycarbonate windows can be used with these lamps. Finally, polycarbonate is soluble in many solvents and should not be cleaned or wiped in the field with any solvent unless the chemistry of the solvent to be used is known not to be deleterious to polycarbonate.*

In application, to diffuse light tubular polycarbonate luminaire lenses are usually fitted with a thin (0.04 cm) textured polycarbonate film, or diffuser sheet, in contacting the inside surface of the tube.

B.3 Sealants and Cements

At the current time two different types of organic adhesives are used in the explosion-proof luminaire industry: epoxies and silicones.** In addition, one manufacturer uses a proprietary inorganic cement compound known as "Chico"; more will be said about this later.

* During assembly of polycarbonate components, ethyl alcohol is a good cleaning agent.

** More correctly, silicones are known as synthetic polymers.

Depending upon the design particulars of the enclosure, lenses may require an adhesive with high strength capacity, a sealant or gasket with minimal adhesive capacity, or no element or sealant at all, as in the case of purely mechanical designs. Where the design calls for a true adhesive, several features aside from adhesive strength should be considered in making the adhesive selection. Among these are (1) long-term tolerance to environments without becoming brittle and losing mechanical properties, (2) minimum shrinkage due to natural aging, (3) permanent barrier protection to water infiltration (which may add to the explosive pressure potential),[7] and (4) acceptable level of emission of combustible decomposition products.

The use of epoxies in luminaire equipment is somewhat limited at the present time, and RTV silicones are more prevalent. The subject of epoxy adhesives covers a wide ground, but for the sake of general discussion all epoxies are either one- or multi-component systems, depending upon whether the resin and hardener (curing agent) are stored separately or are blended into a single system. In addition, all epoxies are either basic resin systems or modified systems.[8] The basic materials have no additives and, therefore, are in a hard, brittle state. Modified systems may have additives, such as fillers or other resin alloys, or may have chemical modifications made to the resin and/or curing agent. Most one-component systems require elevated temperature curing, and as such are not very practical for luminaire manufacturing operations. The two-component epoxies, such as the Armstrong epoxy (T-900) and the Dolph epoxy (CB-1078 resin with RE-2001 reactor) do require careful and skillful mixing of the monomer and hardener. Epoxy adhesives have good high temperature performance and low shrinkage, but are very sensitive to formulation and to application procedures.

For gasketing applications, where adhesive strength is of less importance than filling and sealing properties, silicone sealants are used widely in the explosion-proof enclosure industry. Most common is the one-component, room-temperature vulcanizing (RTV) variety, which have an indefinite shelf life when covered. They usually require no primer for application and volatilize acetic acid during cure. RTV silicones possess outstanding resistance to ultraviolet radiation and to ozone, and have chemical inertness, thermal stability, low temperature flexibility, and long-term aging characteristics.[9] Among the principal suppliers of RTV silicone adhesives are Dow Corning, General Electric Co., Rhodia, Inc. (which markets RTV products produced by Rhone-Poulenc in France), and Stauffer Chemical Corp.

Anaerobic adhesives, a class of thermosetting adhesives which are otherwise known as room-temperature acrylics, form a companion to the silicones for use as industrial sealants. They have not yet, however, been used to any important extent in the enclosure industry. The name "anaerobic" derives from the fact that these adhesives remain liquid in air, but set up when deprived of air, as in clamped-up gasket operations. Anaerobic adhesive proponents claim several benefits over two-component epoxies, urethanes, and other classes of organic adhesives:[9] cure without heat or mixing, chemically stable with indefinite shelf life, and the fact that the adhesive remains uncured outside bondlines, which permits better, less costly assembly and cleanup. These materials are, however, usually more susceptible to flow, which can lead to cracks and gaps.(8) General Electric Co. and Loctite Corp. are among the suppliers of anaerobic adhesives.

It should be mentioned that lead gaskets also are permitted under Paragraphs 18.27 and 18.46 of Title 30, CFR. Unlike the adhesives and sealants previously mentioned, lead has no adhesive capacity and its use, therefore, is restricted to designs in which no reverse movement of the two mating surfaces can occur. Also, there must be rather high tolerances on planarity and parallelism for lead to be used successfully as a gasketing material. On the other hand, lead has no vapor permeability, which may be a design advantage.

There are at the present time no U.S. Standards available which set performance requirements for various classes of sealants and adhesives used in explosion-proof enclosures. Indeed, little guidance is available from other nations who regulate their underground coal mining operations. As one example of such standards as do exist, the following is the current British standard for materials used in cementing:(10)

> The materials used for cementing shall be chemically stable, inert, and resistant to external influences (for example, to water, oil, and solvents, or else be effectively protected against these influences. They shall have a permanent thermal stability adequate for the maximum temperature to which they will be subjected, within the rating of the electrical apparatus. The thermal stability is considered adequate if the limiting value for the material exceeds this maximum temperature by at least 20K, the minimum value being 120°C.

One enclosure manufacturer, Crouse-Hinds Co., uses a proprietary Portland Cement compound known as "Chico"™ sealing compound (after Crouse-Hinds Company)* in luminaire designs where sealants are required. It has made this material for over 25 years (and sells it commercially). Crouse-Hinds has used it in sealing applications where others might use epoxies and claims there is no long-term chemical attack of the glass by the "Chico"™.

B.4 Industry Concerns and Experience

During the initial stages of this project, several enclosure manufacturers were contacted regarding, among other things, their own experience with luminaire materials and designs. This subsection presents some of these opinions, although no claim is made that these viewpoints are uniformly held throughout the industry or that all other relevant experiences have been included.

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*Consists of a formulation of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, and $CaSO_4$.

Somewhat more than a year prior to the MSHA letter of April 22[5] (see Subsection II.A.4), a leading producer of luminaire equipment used a brittle two-part epoxy of high adhesive strength to cement in glass windows. An incident occurred where a window in one of these luminaires unbonded from its retaining structure and became loose. As a result of this incident, enclosure manufacturers took a fresh look at their designs, materials, and quality control procedures. The April 22 regulations require that in the range 0° - 150°C the adhesive must not be as hard as the glass or other substrate. The new two-part epoxies, which have this capability and can meet the MSHA requirements, have been in the field only two to three years. Thus, there is no long-term service experience available on these epoxies.

One manufacturer still uses a relatively brittle two-part Armstrong epoxy to cement the circular glass window into its headlight. This manufacturer would prefer to use a more compliant adhesive, but has decided against a design change because of the time and expense in getting MSHA approval. This company's spokesman argues for more flexible regulations to facilitate adaptation of new technology for more reliable equipment.

Some concerns have been raised about the possibility of excessive in-service temperatures on the inside surfaces of glass lenses used with mercury vapor and high pressure sodium luminaires. The temperatures achieved on the surface of lamps depend on the type and power rating of the lamp as well as on the mechanical design and construction of the enclosure. Maximum permissable bulb surface temperatures are limited by ANSI* standards, and are 450°C (842°F) for mercury vapor lamps and 900°C (1652°F) for tungsten-halogen lamps. Although lamp temperatures as measured in still, open ambient air are relatively low, on the order of 80°C (176°F) to 150°C (302°F) depending on lamp type and rating, lamps operating in enclosures will see substantially higher temperatures, perhaps approaching ANSI limits. When lamps operate at excess wattage or when coal dust lightly covers the lens, providing further equipment insulation, the bulb temperature will be even higher. When the ANSI permissables are compared to performance of lens glass, however, there is cause for concern. Soda-lime glass will begin to lose its temper stresses at about 260°C (500°F) within about a year; the tolerance of borosilicate glasses may be about 40°C (104°F) higher. Moreover, as the glass loses temper unsymmetrically from one side, it may induce edge rotations which can give rise to debonding, cracking, etc., of adhesives and sealants. Thus, there is some concern that additional MSHA requirements should be placed on glass inner surface temperatures. Specific recommendations are given in Appendix B of this report.

Another manufacturer has raised a concern with high pressure sodium lamps, which increase ("by easily 10%") their arc voltage with age. Manufacturers use ballast to regulate voltage/wattage drift, but there is some question as to the adequacy of this practice. After 5,000-10,000 hours of operation, the wattage increases. In addition, published mine voltage surges are very large--larger than ballast can accommodate. One pertinent question is, how much margin of safety is built into the MSHA temperature requirements (240°F internal temperature, 150°C external maximum)? Also,

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*American National Standards Institute

are those who use polycarbonate windows aware that the window will see higher temperatures intermittently over time? This manufacturer expressed concern over what, if any, safety factor is built into the MSHA 150°C requirement, and whether those who use polycarbonate lenses in explosion-proof enclosures are aware that the lenses may see higher temperatures intermittently over time. Apparently, the 150°C requirement resulted from Bureau of Mines tests conducted several years ago, which showed that that is the lowest temperature at which some coal dusts can autoignite.[11] This being the case, there is no margin of safety incorporated into the MSHA requirement. Furthermore, whether or not enclosure manufacturers are aware of the possibility of temperature excursions above 150°C, it would be naive to believe that manufacturers account for such excursions in any systematic sense in their designs.

Each manufacturer has evolved a design philosophy for explosion-proof enclosures and, to some extent, his reproachment of other design philosophies represents his justification of past experience. So it is with threaded versus bonded polycarbonate cylinders, inorganic versus organic cements, epoxies versus silicones, etc. One manufacturer has mentioned a potential problem in using aluminum structure for enclosure frames. Iron particles, it is claimed, can embed themselves in the aluminum, setting up local ferrite reactions in the presence of moisture to produce pitting. More importantly, however, as a general rule aluminum alloys, being more electronically active than most steels, generate hotter sparks when struck than do steels, and often have a lower sparking threshold. This makes aluminum alloys more potentially hazardous than steels; indeed, for this reason aluminum structure is not allowed in gassy mining operations in several countries (e.g., in West Germany) or must be protected with a heavy epoxy or similar paint (e.g., in the United Kingdom) when used in such environments.

Research both in the United States and in Europe has shown that aluminum alloys striking against rusted steel can be incendiary, and ignitions have been created in laboratory tests with 6.4% methane-air mixtures.[12] Recent standards issued in Western Europe by Cenelec and adopted as British Standards limit the light alloy content of electrical apparatus used in mine environments to 15% by weight of Al, Ti, and Mg, and to 6% total weight of Ti and Mg.[13,14]

C. Industry QA Practices

The information presented in this subsection was developed primarily from personal discussions with appropriate people at three different enclosure manufacturing companies. Other inputs came from telephone discussions with adhesive suppliers and other equipment manufacturers, and with USBM and MSHA personnel. The objective here is to present a brief, but representative picture of current QA practice in the industry.

At the present time, manufacturers of explosion-proof enclosures have great freedom in designing their own quality assurance (QA) programs. There is no direct MSHA requirement which dictates a specific QA protocol, and, as a result, there is considerable variation of QA format within the industry. All manufacturers of end use equipment are required by MSHA to demonstrate a program of some kind, and a few such programs are quite thorough. General guidance for QA program development is available in Title 30, Part 18 of the Code of Federal Regulations (CFR), Subpart C. Good business practice, desire to develop and maintain a favorable reputation in the industry, and an appreciation for the tradeoff between price competition and liability exposure from product malfunction appear to be positive incentives for self-governing QA practices.

Quality Assurance is a critical element of the production of explosion-proof mining equipment. It is an activity that, once initiated, must not be compromised despite production demands regarding schedules, quotas, etc. A total QA program is quite comprehensive in that it imposes controls over all processes involved in producing an end product. Typically, a total QA program encompasses:

a. Procurement QA specifications--governing the kinds of material to be used.

b. Receiving inspections and certifications--to assure batch-to-batch consistency.

c. Materials control--governing contamination, shelf life, etc.

d. Production process control--to control the mixing of materials.

e. Quality assurance tests, or acceptance tests.

f. Storage, handling, and shipping controls.

In addition, all tools and instruments used in the QA program should be calibrated and traceable through records back to accepted standards. A total QA program approach is described in MIL-Q-9858A, and a more limited receiving inspection program is provided in MIL-I-45208A.

C.1 Incoming Materials

The MSHA (MESA) letter of April 22[5] (see Subsection II.A.4) requires that manufacturer's specifications be available for all glass or other window materials as well as related adhesives and their surface preparations. This means that materials and subassembly suppliers must furnish information on the use of the materials, installation procedures, and general performance requirements. For example, suppliers of adhesives and sealants must specify surface preparations and treatments appropriate to the specific enclosure application.

Typically, once the manufacturer has developed a design and identified an adhesive supplier, that supplier works with the manufacturer to draw up detailed procedures: surface treatment, mixing, applying, curing, storage, etc. The manufacturer writes up these procedures, which then form a part of his total QA program, and submits them to MSHA for approval. From then on the manufacturer need not conduct quality control tests on incoming adhesive batches, but merely certify that the incoming materials were of the proper manufacturer and formulation, and that all subsequent in-house procedures were properly followed.

In a similar manner each manufacturer develops his own acceptance standards for incoming glass and polycarbonate lenses. Glass lenses are checked for chips or cracks (MSHA requires defects greater than 1/32 in. [0.08 cm] in size to be rejected), and an occasional sample is impact tested for quality assurance. QA procedures for acceptance of polycarbonate tubes vary, for some manufacturers do their own annealing, while others rely on the supplier or another contractor to perform this service. Some manufacturers perform only a visual inspection of the tube surface. One company conducts a residual stress check by immersing the tube in a toluene-alcohol solution and checking the surface for crazing. All manufacturers surveyed subject tube samples drawn from the incoming lot to dimensional checks on length, diameters, roundness, temper (by impact testing), and gaging of thread tolerances, if applicable. Each manufacturer sets his own tolerances on these acceptance parameters.

Other subcontracted assemblies and subassemblies are also subjected to acceptance procedures. Castings and machined parts are checked for tolerance against the engineering drawings, which have had prior MSHA approval. On-the-shelf subassemblies are sometimes rechecked, depending on the time that has elapsed since received and whether there have been any subassembly engineering revisions which may cast doubt on whether the subassemblies are identical to others already in inventory.

C.2 Work-in-Process

There are no rigid requirements placed on quality control of production runs, and practices vary widely. In describing their policy one manufacturer explained that the QC inspectors first make a judgment as to how critical the assembly or subassembly is considered to be. In accordance with this judgment 100%, 20%, or 10% of the articles will be pulled off the line and inspected. This company's procedures call for epoxy cements to be mixed daily and disposed of after each day's production run. Records are kept as to when each epoxy batch was mixed.

Crouse-Hinds Co. places certain quality controls on its in-house production of its proprietary Portland-type cement, "Chico." Each premixed batch is checked in-house by a chemist for quality; the mix formulation is considered to be the important factor, for otherwise only water is added. There are no other assembly line checks of Chico.

C.3 Finished Units

Completed explosion-proof enclosure assemblies are subjected to a quality control inspection that varies among manufacturers. One manufacturer has a policy that (explosion-proof luminaire) finished goods are inspected on a 10% basis and that all are documented by a full time QA inspector on the shop floor. Other manufacturers contacted on this point have similar practices. What is essential, and indeed is suggested in the April 22 MSHA letter,(5) is some form of documentation on each finished unit. According to the April 22 letter, manufacturers are advised to "... have procedures for tracing the source of each window to permit recall of some, rather than all, of the applicants' enclosures in the event of in-mine failures."

There are two kinds of qualification tests performed on the complete enclosure structure. The methane explosion test (see Paragraph 18.62, Title 30, CFR) tests the flame gap capability of the unit and, to some extent, serves also as a structural integrity test. This qualification test is not performed on units taken off the assembly line. Only in the case of new designs or substantially modified existing designs is the methane explosion test required. Although some manufacturers have the capability to conduct this test in-house, ultimately MSHA in Triadelphia, West Virginia, has the responsibility to conduct these tests.

In addition to the methane explosion test, Paragraph 18.67, Title 30, CFR, requires a static pressure test to be conducted (by the manufacturer) on a specific enclosure design when required by MSHA. Here again, however, this test is not applied as a QA measure to units coming off the assembly line, but only to qualify a design. The static pressure is considered to be usually more stringent in verifying the structural integrity of the enclosure than the methane explosion test.

III. ACCEPTANCE OF ADHESIVE AND SEALANT MATERIALS

A. Introduction

The results of the mechanical property tests conducted at SwRI and summarized in Appendix A show that the representative adhesive and sealant products which have proved successful in underground mining operations to date, differ widely in their response to temperature and stress. For some of the materials, strength decreases with increasing temperature, while for others, strength increases with temperature. At the same temperature, a mechanical property may differ by as much as an order of magnitude from one material to another. In some materials, specific property measurements were found to be literally undefined as, e.g., the peel strength of Chico-2 and the tensile strength/elongation of GE RTV-108.

Moreover, explosion-proof enclosures themselves generally are complex structures, from the viewpoint of their stress distributions and failure modes under possible damage scenarios. This is particularly true of the adhesive bondlines themselves, where stress distributions due to core shrinkage/expansion, environmental effects, and thermal and mechanical loading simply cannot be calculated or duplicated in laboratory coupon tests in any practical sense. Although the measured mechanical properties of the sealants and adhesives clearly relate, in general, to the failure resistance of the explosion-proof enclosures into which they are incorporated, it is not clear as to the relative importance of each property, or even as to what stress/temperature profile the materials are subject during failure.

In view of these considerations, it is unrealistic to assign meaningful minimum performance standards for the adhesive and sealant products that may be candidates for inclusion in a Qualified Products List. At least two other alternatives, however, suggest themselves. Both approaches depend not upon the material properties, in terms of minimum allowed values, but rather require that properties simply should be well-defined for all candidate materials according to specified uniform test procedures (such as those used in the present study). These tests would be carried out under the authority of MSHA, and the results published in what will be called here a Characterized Products List (CPL).

The first approach is to require manufacturers of luminaires and other explosion-proof enclosures to analyze their designs carefully from the point of view of temperature and state of stress within sealants and adhesives, then select only such sealants or adhesives which are capable of withstanding the anticipated stress/temperature conditions. The weakness of this approach is that it is totally unreasonable to expect luminaire manufacturers to have the capability or resources to carry out such analyses. Moreover, even were this procedure followed, there would be no guarantee that the luminaire would survive the actual conditions imposed upon it, which might differ from those assumed for purposes of stress calculations.

Thus, it appears that a more prudent course to follow in attempting to qualify luminaires would be as follows. Manufacturers, having access to material property data for all candidate sealants and adhesives (the CPL), would use their own best judgment in consultation with the adhesive suppliers in choosing materials in terms of their individual luminaire designs. The test of acceptability would then be to determine whether the luminaire as a structure is capable of surviving reasonable tests of simulated operational conditions. Three different loading cases are suggested: an explosion test, a constant internal pressure following a prolonged period of time with the luminaire lamp turned on, and finally, a constant internal pressure following a prolonged period of time with the lamp turned on while exposed to an artificial acid mine water chemical environment.

This chapter outlines a recommended framework whereby adhesives and sealants proposed for structural use in explosion-proof enclosures are to be characterized by manufacturers, and qualified for use in particular structural configurations through tests performed by MSHA. The properties of characterized adhesives and sealant materials, as developed by their suppliers, should be published by MSHA, to provide luminaire manufacturers the opportunity to optimize their structures by choosing adhesives/sealants best suited to their design, knowing that all materials were subject to identical characterization tests.

The term "structural use" should be interpreted rather liberally here, and applies to cementitious materials intended to adhesively-bond or seal lenses, electrical umbilical and other appurtenances within or outside the enclosure, even if the structural performance requirement is small. The objective of the recommended framework is to ensure that each adhesive/sealant approved for use in an explosion-proof enclosure

(a) has a thermo-structural performance which will exceed particular use requirements

(b) is properly used and applied

(c) has adequate tolerance to all expected environmental influences.

There are many brands and varieties of adhesives and sealants currently marketed and which are candidate for structural use in explosion-proof enclosures. It appears, therefore, highly desirable that MSHA, as the cognizant Federal certification agency, develop formal procedures for characterization of adhesives and sealants to be used in enclosures, and for testing structures incorporating these materials. Once an adhesive/sealant has been characterized, its manufacturer has a continuing obligation to certify each batch of the material sold for enclosure manufacture, as is discussed in Chapter V.

B. Application for Characterization Acceptance

Before an enclosure design is approved by MSHA for manufacture and sale, any adhesive or sealant product used to retain lenses or for other structural use (as interpreted above) should be characterized by the manufacturer and accepted by MSHA for the intended kind of use. In this context, acceptance should be understood to mean that the characterization of the material has been performed according to the standards required by MSHA. Only adhesives and cements which are commercially manufactured and marketed should be considered for acceptance. Only the product manufacturer (applicant) should be permitted to apply for product acceptance, and his request should be made to the Approval and Certification Center, at MSHA in Triadelphia, W. Va. The application is to contain all the supporting information outlined in Section III.D-F of this report, and the product may be subjected to such additional MSHA evaluations as it deems necessary. MSHA, of course, should treat all information submitted, including the fact of submission itself, as proprietary.

Upon product acceptance by MSHA, the adhesive/sealant applicant will be given notice of this status, and any conditions to be placed upon sales or use (labeling of potential hazards, shelf life, use proscriptions, identifying markings, etc.) will be defined. The product acceptance and inclusion in the Characterized Products List (CPL) may be made public by MSHA, and the acceptance may be transferred by the manufacturer to another agent (fabricator, distributor, licensee, etc.) with MSHA approval. MSHA should reserve the right to revoke acceptance of a product and to require its removal from underground mines should the product be found at any later date to be: unsafe for mine use; in non-conformance with the description given in the application; or, improperly labeled.

C. Applicant-Furnished Acceptance Data

The responsibility for establishing the technical data in support of the application for acceptance will fall solely upon the product manufacturer (applicant), who will supply all that is requested to MSHA. However, MSHA should reserve authority for conducting certain specialized evaluations as described later in the chapter, as well as to verify manufacturer qualification data, when deemed advisable.

Mechanical property characterization of materials should require the following tests:

1) Tensile properties

2) Lap shear properties

3) Peel strength

4) Hardness

These tests will be carried out by the manufacturer according to standard, accepted procedures (Appendix A), and the results provided to MSHA.

There are two broad categories into which cementitious materials may fall which are candidate for explosion-proof enclosure use. The first of these is use as a sealant, where the product is to be used in such a way that it is not required to support or transmit any significant stresses or loads. For example, a product which is used as a barrier to protect against water seepage into the enclosure from around a lens, where the lens is backed up by a retaining ring, would be considered to be used as a sealant. Because they must maintain adhesive contact to their substrate surfaces during expansion and contraction that comes as a result of differential thermal or swelling expansion, sealants must possess some adhesive capacity. Sealants are normally (but not always) soft, compliant materials that may swell or shrink to accommodate environmentally induced forces (hygrothermal effects), and possess adhesive characteristics only to the extent that the bondline is maintained intact under action of these secondary forces.

The secondary use category is that of an adhesive. An adhesive is considered here to be a material used to bond two materials together and which is capable of reacting and transmitting all structural and secondary (environmental) forces imposed upon it during equipment operation. An adhesive may also have all characteristics of a sealant, but it is distinguished from a sealant in that the lens is held in place primarily with the adhesive. Although adhesives should be more compliant (of lower modulus) that the substrate to which they adhere (such as the lens or the metal frame), they have much higher adhesive and cohesive strength properties than sealants.

The emphasis in discussing sealants vis-a-vis adhesives is on structural use. A given product may be classified either as a sealant, or as an adhesive, or as both; while certain kinds of mechanical performance may be the same for both categories, some will differ markedly (i.e., sealants, in contrast to adhesives, generally have negligible tensile strength). Classifying materials into these two broad categories offers the manufacturer of explosion-proof structures guidance as to necessity for structural reinforcement in design.

C.1 Sealants

Most sealant materials for use in explosion-proof enclosures are single component, room temperature vulcanizing (RTV) silicones: commonly known as RTV's. Indeed, it is recommended that this should be the only category of sealants considered for characterization, unless other candidate compounds are shown to be comparable to the RTV's in terms of environmental tolerance. (One exception to this suggested policy is noted below.) The reasons for this recommendation are as follows:

1. The elastomeric* nature of RTV silicones gives it the compliant qualities required to accommodate dimensional changes due to differences in thermal expansion coefficients between the lens and its housing.

2. RTV silicones are considerably more resistant to the effects of heat and cold than organic sealants/adhesives (epoxies, polyurethanes, polyesters, acrylics), and they heat age and embrittle at a much lower rate. They generally retain their properties relatively well out to about 200°C (392°F).

3. RTV silicones have good chemical resistance in that they tend not to be affected by moisture or by weak acids and bases. Although they are not tolerant of toluene, xylene, or chlorinated solvents, they are to oils.

4. The elastomeric nature of cured RTV's provides some measure of shock isolation to the lens.

5. Although their strength and adhesion properties are far below those of most organic adhesives, they are adequate for many properly designed joints, and their elongation properties are generally superior to those of organic adhesives.

It appears proper to make one exception at this time to the recommendation above that only RTV silicones be included in the sealant category, and this is the inorganic Portland cement compound known as Chico™.** This material is commercially available, and has been successfully used in luminaires and other explosion-proof enclosures for years. It is especially compounded to control thermal expansion properties and is used in design applications where it is subject to compression forces only. Because of the unique chemistry and historical use of this sealant relative to others, this is one case in which a specific trademark is recommended for acceptance. However, it must only be permitted in design applications where it cannot be subjected to tensile and shear loadings.

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*An elastomer is a macromolecular material which is capable of substantial deformation at ambient temperatures, but which will recover to its original size and shape after removal of load.

**Manufactured by the Crouse-Hinds Company, Syracuse, New York. See Chapter II.B.3.

Mechanical property characteristics from tests conducted at SwRI for a typical RTV sealant (G.E. RTV-108) and Chico-2 are given in Appendix A, along with a description of the test procedures which were used. Comments regarding these recommended test standards are given in subsection III.D. following.

C.2 Adhesives

At present, practically all adhesives used for structural purposes in explosion-proof luminaires are two-part epoxies. However, other classes of adhesives under continuing development may be able to meet the use standards required of these adhesives, and therefore no restriction should be placed upon adhesive chemistry for purposes of acceptance.

D. Mechanical Property Characterization

Test conditions recommended for mechanical strength characterization are defined in Appendix A; following are certain considerations involved in carrying out the tests.

The specimens used in the ASTM D 638 tests for strength and percent elongation may either be molded or machined from sheet stock. The specimen design designated as "Type IV" should be used; this specimen has a gage length, width, and thickness of 3.30 cm, 0.635 cm, and 0.406 cm, respectively. Average values supplied MSHA should be based on five specimens per condition, and the range in values should also be reported.

The shear strength tests per ASTM D 1002 may use any of the adherends suggested in the specification: brass, copper, aluminum, steel, corrosion-resistant steel, or titanium. Data should be supplied for each adherend for which qualification is sought. "Steel" will be considered applicable to weldable or cast steel for purposes of this test qualification. The total elongation of the specimen length between the grips should be measured at rupture, or calculated from the head displacement rate and the loading time to failure. The load at failure divided by the total extension at failure gives a measure of specimen compliance; this value should be reported along with the other data called for under ASTM D 1002. Adherend surfaces should be prepared using customer-supplied procedures, nothing more elaborate. The report to MSHA will provide average and range data based on five specimens per condition, and the report is to include proper descriptions of all failed specimens, i.e., whether adhesive, cohesive, or adherend.

Clad aluminum adherends may be used in the tear test per ASTM D 1878 instructions, although the applicant may, at his option, substitute another metal adherend having thin alloy composition of the applicable enclosure design detail. In such a case, the applicant must demonstrate that the substitute adherend leads to a valid test (adherend must be capable of being bent through any angle up to 90° without breaking). Just as in the case of the shear strength tests above, the surface preparation for the D 1878 specimens must accurately follow customer-supplied instructions.

Insofar as the characterization tests for mechanical performance are concerned, a given adhesive or sealant may qualify as acceptably characterized only with certain adherends and not with others. If the applicant should develop improved or different surface preparation procedures, the adhesive/sealant must be recharacterized using the new procedure(s) for all substrates of interest. Customers must then be furnished suitable surface preparation instructions.

E. Physical Property Characterization

In addition to the mechanical performance data required by virtue of the foregoing discussion, each applicant should furnish the following property data as appropriate. Unless a particular ASTM standard is prescribed, the applicant should be free to furnish data based on his own test procedures provided a detailed written procedure is furnished by MSHA.

Property	Standard
Chemical name,* composition & tolerance	-
Mix ratio by weight	-
Mix ratio by volume	-
Solids content	-
Percent volatiles	-
Density (cured state)	ASTM D 1505
Gel time	-
Viscosity	ASTM D 1084 or D 2556
Pot life	ASTM D 1338
Tack	ASTM D 3121[a]
Cure time	ASTM D 1144
Shelf life	ASTM D 1337

(a) For pressure sensitive adhesives only

The applicant may decline to furnish certain of the test data requested above by submitting justification to MSHA establishing irrelevance. The MSHA will treat as confidential any portions of the data package submitted by the applicant which the applicant indicates are to be considered proprietary.

The applicant should provide flammability test data and toxicity information showing compliance with the acceptance criteria below, which are drawn from Reference 15. This information, as in the case of all applicant-furnished technical data, should be obtained by professional, technically competent persons. The MSHA should reserve the right to require additional tests, to review test reports, and to witness testing.

*Organic chemical components should be named according to the current rules of the International Union of Pure and Applied Chemistry. Inorganic chemicals and minerals should be named according to the current conventions of the Chemical Abstracts of the American Chemical Society.

The potential flammability hazard of a product should be determined by one or more of the following tests on the uncured or precured product:

Test No.	Type of Test	ASTM Standard
1	Ignition Temperature	ASTM D 1929
2	Noncombustibility	ASTM E 136
3	Flame Spread	ASTM E 162 or E 84

An adhesive or sealant product whose ignition temperature (by Test 1) is less than 300°F (149°C) should not be taken underground. A product rated as noncombustible (by Test 2) may be used without quantity limitation in mines, provided it meets the toxicity criteria. The test for noncombustibility need not be made on a product commonly accepted as being noncombustible or on a material for which ignition temperature is determined (by Test 1). Sealants and adhesives should have a flame spread index (by Test 3) of 25 or less.

The applicant should provide information (or assurance that such information is on file) on uncured product toxicity, including inhalation, ingestion, skin, eye, sensitization, carcinogenic hazards. A toxic product is a material capable of causing bodily harm by chemical action. The toxicity hazard should be under "normal" use conditions. Where Threshold Limit Values (TLV) are not published, the applicant should provide corresponding and appropriate toxicity information. The TLV's for chemical substances are those adopted by the American Conference of Governmental Industrial Hygienists, 1976. It is recommended that U.S. Department of Labor Form OM8 No. 44-R1387, "Material Safety Data Sheet" be completed and accompany each application to MSHA for product qualification.

A product which in the uncured state or during cure presents an inhalation, ingestion, skin, eye, sensitization, carcinogenic, teratogenic or mutagenic hazard, should bear a label stating the hazard and personal protection necessary. The wording and method of labeling should be similar to that given in ANSI Z129.1-1976. Products containing more than one percent of the hazardous chemicals listed in NFPA Code 49-73, Health Hazard Category 2 and 3, should be labeled to show the chemical and the hazard. The labeling should be similar to that given in ANSI Z129.1-1976.

Products containing more than one percent of the hazardous chemicals listed in the Toxic Substance List (U.S. Department HEW) and/or in NFPA Code 49-73 Health Hazard Category 4 having a lethal dose (LD_{50}) of 50 mg/kg or less should not be taken underground.

F. Environmental Tests

In addition to the performance data called for under Sections III.D and III.E which are to be furnished by the applicant, all sealants and adhesives should be characterized by appropriate tests for environmental susceptibility. It is recommended that such tests, as outlined below, be conducted at MSHA by MSHA personnel. The principal reason for this is that certain items of equipment are required which, although not particularly costly, are not commonly found in the laboratories of sealant/adhesive manufacturers. Although MSHA could require applicants to provide the needed data, it would be somewhat unreasonable to expect all suppliers to invest in specialized equipment that would be used rarely and then only to satisfy a narrow market segment. Furthermore, since the manufacturer would conduct such tests on a very infrequent basis, there would likely be a lack of continuity in the skills of the laboratory staff conducting the tests.

F.1 Sealants

In the case of sealants it is not appropriate to evaluate environmental attack effects in terms of strength degradation, for strength is not a relevant parameter. Rather, it is sufficient to evaluate the tendency of the product to become embrittled or reverted (gummy) over time and with exposure to hostile mine chemistry environments. The following simple test procedure is recommended as an environmental evaluation criterion for sealant products submitted for qualification.

A small "poker chip" wafer of material about 0.30-0.65 cm (1/8-1/4 in.) thick is immersed in the acidic simulated mine drainage solution developed by the Environmental Protection Agency[1,3] and discussed earlier in Chapter II of this report. The formula for this solution is to one liter of 0.01N H_2SO_4 add the following:

$CaSO_4$	$\cdot\ 2H_2O$	0.344g
$MnSO_4$	$\cdot\ H_2O$	0.024g
$Al_2(SO_4)_3$	$\cdot\ 18H_2O$	0.186g
$FeSO_4$	$\cdot\ 7H_2O$	0.997g
$MgSO_4$	$\cdot\ 7H_2O$	0.246g

The solution is to be maintained at a temperature of 70°C (158°F); this represents an exposure in two weeks equivalent to about a one year exposure at an ambient temperature of 23°C.* After 14 days' exposure, the chip is removed, dried, and its hardness measured at room temperature. Evaporation of the solution during the 14 days in the oven is minimized by maintaining the humidity level at 50% RH or greater. The hardness of this specimen is then compared with the hardness of an identical specimen which experienced no environmental exposure. These environmental embrittlement data are to be published by MSHA together with the foregoing manufacturer-furnished mechanical and physical property results, in order to assist manufacturers in choosing sealants most resistant to environmental degradation.

F.2 Adhesives

Materials presented for acceptance as characterized adhesives should also be subject to the environmental embrittlement test recommended above. In addition, they must be tested with respect to the integrity of the

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*This equivalency follows from a time-honored rule of thumb in chemical kinetics, which states that the rate of any reaction approximately doubles with a temperature increase of 10°C. If ΔT is the temperature increase in degrees Celsius, t_2 the time for a reaction to occur under ambient temperature conditions, and t_1 the time required at temperature ΔT above ambient, then $t_2/t_1 = 2^{(\Delta T/10)}$.

adhesive bond under exposure to mine water chemistries. The following test procedure is recommended for all (not sealants). It does require certain specialized equipment, and the test suggested was not part of the current test program. Limited subsequent investigation may be needed in order to refine and optimize the procedure and its interpretation.

The test is an adaptation of the "slow strain rate" test, for stress corrosion susceptibility in metals, wherein a specimen is subjected to a very slowly increasing tensile load while exposed to a hostile environment. The interaction of the environment with the increasing strain can be used to yield a rapid, comparative measure of environmental susceptibility. The proposed adaptation makes use of the ASTM D 1002 lap shear joint, identical to that used by the applicant in developing his data package for MSHA (see Appendix A). Also, the test is cyclic, as depicted in Figure 2, to simulate the cyclic thermal expansion/contraction that a joint is likely to experience due to on and off lighting requirements.

The test procedure may be outlined as follows:

1. The average head displacement rate, R, is to be calculated from the formula $R = \overline{\delta}_o/5x10^5$, where $\overline{\delta}_o$ is the (average) total specimen elongation in inches at failure from applicant's test report for ASTM D 1002 lap shear tests conducted at 70°C. The constant in this expression represents a time scale of approximately six days, in seconds. With reference to Figure 2, the actual head displacement rate, k, is then computed as three times R. The timing circuit for the load mechanism is to be adjusted to the following settings: $t_1 = \overline{\delta}_o/50k$ seconds, $t_2 = \overline{\delta}_o/100k$ seconds. These values are determined such that in the absence of all rate and environmental degradation effects, failure would occur at 100 cycles of load, at a specimen extension of $\overline{\delta}_o$ inches, and in a time of $5x10^5$ seconds (5.8 days). Note from Figure 2 that the local displacement loading rate is $\pm k$, but the average rate is R.

2. The specimen is to be attached to the load train at either end by mechanical grips of the same type as used for the lap shear tests conducted under ASTM D 1002 by the applicant. The entire specimen and the load train are to be surrounded by a stainless steel canister whose contents can be heated by means of strip heaters in contact with the outer surface of the canister, and can be controlled through a temperature probe placed in the fluid in close proximity to the joint overlap. The canister is then to be filled with the acidic simulated mine drainage solution described earlier, and the solution is to be brought to a temperature of 70°C (158°F). The canister should be checked periodically during the test to insure that the liquid level does not drop so as to expose any part of the test specimen. A period of 30 minutes should elapse between reaching equilibrium temperature and test startup, to allow the specimen to achieve thermal equilibrium. A strip chart and pen recorder should be provided so that a continuous time history of the load cell output can be made during the test.

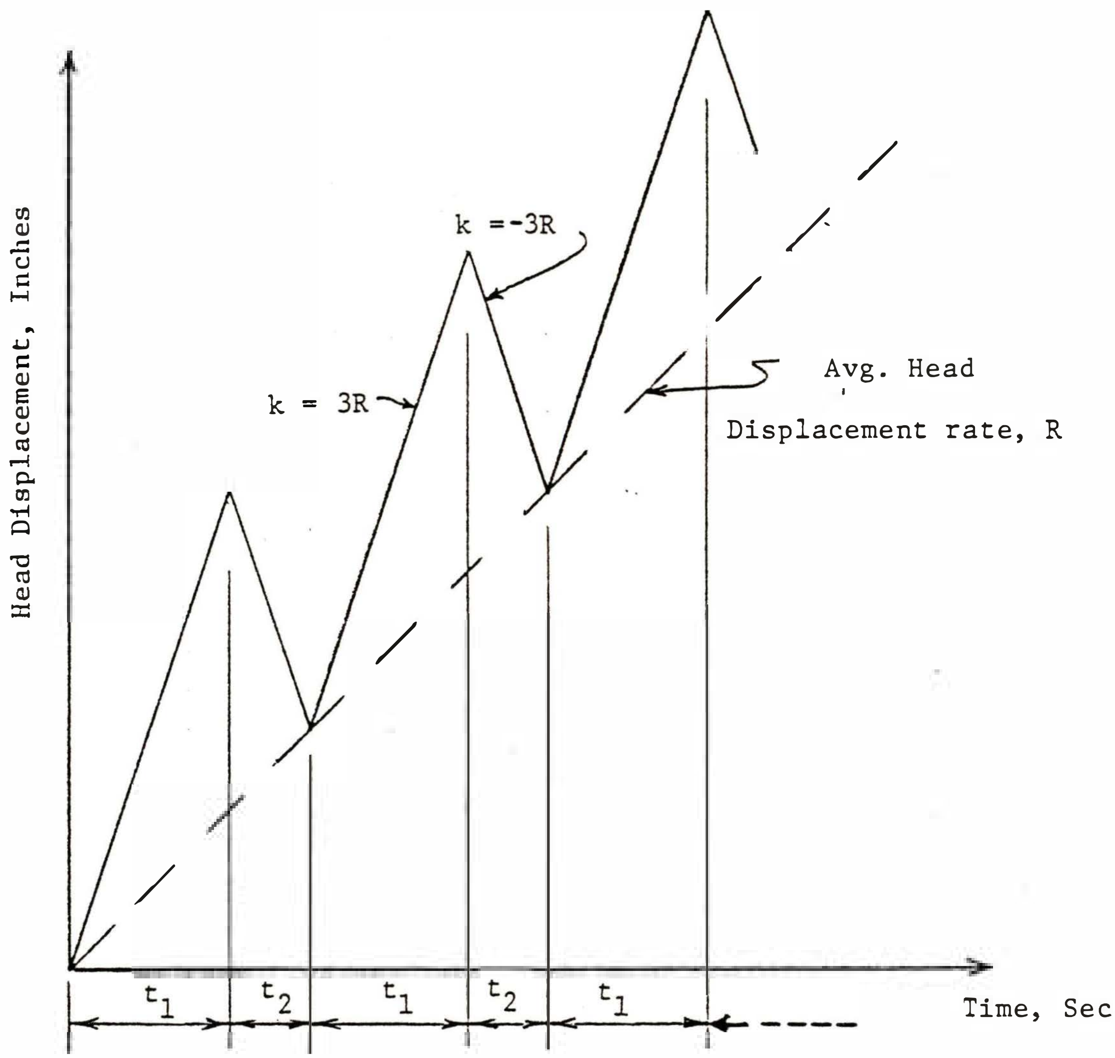

Figure 2. Ratchet loading sequence for recommended environmental susceptibility test for adhesives.

3. The test is to proceed uninterrupted until failure. The specimen is then removed from the canister and load train, dried, and the failure mode (adhesive, cohesive, or adherend) is to be described on the data sheet. The load in pounds at failure is also to be recorded; if the load is found to have been decreasing immediately prior to rupture, the highest load achieved during the final load cycle is to be used. The time-to-failure, number of cycles, and the average and the actual head displacement rates (R and k) are also to be recorded.

4. The ratio of the load at failure, as described above, to the average static failure per ASTM D 1002 at 70°C is to be computed for each test.

Results of these tests also should be published by MSHA as discussed previously.

G. Luminaire Acceptance Tests

It is recommended that three types of tests be carried out in order to qualify a luminaire system for acceptance by MSHA. These tests, which are to be conducted on actual prototype structures, fabricated in all respects to final drawings being submitted to MSHA for approval, are discussed in the following sections. In all cases, tests carried out under Paragraphs 18.62 and 18.67, Title 30, CFR, are to include the procedural modifications given in MSHA memorandums of 18 February and 22 April, 1977.

G.1 Explosion Test

It is recommended that all luminaire designs be tested for flame gap and structural capabilities according to Paragraph 18.62, Title 30, CFR. This test already is required by MSHA, and so does not constitute an additional criterion for acceptance.

G.2 Static Pressure Test

It is recommended that all luminaire design prototypes be subjected to a static pressure test, which is a modification of Paragraph 18.67, Title 30, CFR. In particular, the light source in each enclosure will be turned on and run continuously for a period of fourteen (14) days prior to the static test. The aim here is to assess the ability of the sealant/adhesive to withstand long-term thermal exposure. Immediately following this, a static pressure test will be carried out as per Paragraph 18.67, Title 30, CFR, using a gage pressure of 150 pounds per square inch.

G.3 Static Pressure Test, Mine Environment

It is recommended that all luminaire design prototypes be subjected to a pressure test similar to that described above, but carried out under humidity controlled environmental conditions. In this case, the luminaire light source will again be turned on and run continuously for a period of fourteen (14) days prior to the static pressure test. However, the luminaire during this time will be contained within an environmental chamber maintained at 20°C, with a 90% relative humidity environment. The moisture in the environment will be the acidic simulated mine water drainage solution developed by the U.S. Environmental Protection Agency, as described elsewhere in this report. Following this exposure, the luminaire again is subjected to a static gage pressure of 150 pounds per square inch.

IV. SEALING AND BONDING OF LENSES

From a quality assurance (QA) standpoint, a properly designed mechanical attachment of the lens to the enclosure is normally preferable to a bonded attachment. This is because (a) extreme care must usually be taken in preparing the surfaces to be bonded, and (b) the mechanical bond possesses full strength immediately upon assembly and is almost without exception stronger than the bonded joint. There are, however, other considerations which mitigate the exclusive use of mechanical attachments. Under internal pressure loadings as encountered in an explosion, the peak stresses in the lens are likely to be less (perhaps significantly less) if there is a sealant or adhesive between the lens and the restraining enclosure structure, than if such a bonding layer is absent. Such materials act as a cushion or foundation for the brittle glass. Moreover, an adhesively bonded lens may add to the structural rigidity of the enclosure as compared to the enclosure without the lens; increasing the rigidity lessens the stresses to which the lens may be subjected. Again, however, from the QA standpoint, enclosure designs using adhesive bonding for lens emplacement should be avoided when possible.

There are as many (indeed, more) bonding procedures as there are lens/substrate combinations and applicable adhesives on the commercial market. Because of this variety of conditions, recommendations of the adhesive supplier with regard to surface preparation should be followed scrupulously. It is possible to monitor the necessity of a particular surface preparation step by following its effect on bond strength in an adhesion test. As a general guideline, however, because strength can be highly sensitive to certain steps in surface preparation, it is recommended that all steps suggested by the supplier be strictly followed, or hard test data be furnished to MSHA justifying the exception. Such a policy would be entirely compatible with the April 22, 1977, MESA (now, MSHA) letter(5) which states that the "Adhesive formulator's procedures for use of the adhesive... (and the manufacturer's) certification that the adhesive shall be used in the exact manner prescribed by the formulator."

In general, the surface preparation of an adherend is the same regardless of what adhesive is used. The only differences arise when a primer or coupling agent or adhesion promoter is also used. In such cases, a match must be made of the interfacial agent to the adherend and the adhesive.

The following sections outline problem areas and general procedures for several substrates found in explosion-proof enclosures, including aluminum, steel, brass, glass, and polycarbonate.

A. Surface Preparation for Aluminum

Both chemical cleaning (etching) and mechanical abrasion (fine abrasive) are possible. The former, however, results in higher reliability.

One method which has been found to be satisfactory with both epoxy and urethane adhesives is as follows:

1. Degrease in a vapor bath of trichloroethylene.

2. Etch for 20 minutes at 66°C with a solution of 65.4 weight percent water, 26.9 weight percent sulfuric acid, and 7.7 weight percent sodium dichromate dihydrate ($Na_2Cr_2O_7$ $2H_2O$). Note: A fresh solution is necessary.

3. Wash with distilled water.

4. Dry at 66°C for 10 minutes.

5. Unprimed parts should be used within three hours.

B. Surface Preparation for Steel

Because of the wide variation in steel compositions, this adherend can be a special problem. For example, mild steels respond nicely to degreasing and abrasion, while stainless steels require degreasing, cleaning with detergent, and an acid etch.

Perhaps the two most common problems are corrosion on the surface prior to bonding and disruption of bonding due to water ingression to the interface. This means that although initial adhesion may be good, it can deteriorate rapidly in use.

Surface preparation for steels, then, is a critical factor. Also, primers or adhesion promoters find greater application here than on other metallic substrates.

The following procedure omits acid etch, rinse and dry steps, which are not necessary on mild steel.

1. Wipe and vapor-degrease with trichloroethylene (TCE) or perchloroethylene (PCE).

2. Grit blast.

3. Degrease again.

4. Dry.

5. Use immediately after drying.

C. Surface Preparation for Brass

Brass and other copper alloys pose a problem in good adhesive bonding due to the rapid formation of oxide coatings. There is a commercial product which intentionally produces a tightly-adhering black-oxide coating to which the adhesive forms a bond ("Ebonol C Special," Enthane Co., New Haven, Connecticut).

There are several other acid etchants which are easier to produce from commonly available materials than the above. A process using one of these follows:

1. Vapor-degrease.

2. Etch for 1 to 2 minutes in a solution of 50 weight percent concentrated hydrochloric acid, 20 weight percent ferric chloride ($FeCl_3$), and 30 weight percent water.

3. Rinse with distilled water, dry and use as soon as possible.

D. Surface Preparation for Glass

Generally speaking, glass provides a good bond capability with many sealant and adhesive materials. Excellent adhesion is afforded by epoxies as well as acrylics, unsaturated polyesters, and polyvinyl butyral.(16) Cleanliness is the most important factor in bonding to glass. Abrasion (fine-grit blasting or #400 grit paper) can be a supplement. If a sizing is present on the surface, such as in glass fibers/cloth, it must be removed by a heat treatment at 450°C for 24 hours.

A general procedure is:

1. Clean with a solvent [alcohol, acetone, trichloroethylene (TCE)].

2. Dry and keep dry prior to use.

Note: The adhesive for glass should not embrittle with age because of thermal expansion of the substrates.

Coupling agents have found great utility in forming adhesive bonds to glass and will improve reliability of the bond. Various organofunctional silane coupling agents are commercially available to enhance adhesion with both thermoplastic and thermosetting resins.

E. Surface Preparation for Polycarbonate

Adhesives which cure at room temperature are preferred when bonding polycarbonate to metals owing to the differences in thermal expansion of the two substrates. As a rule, most adhesives tend to embrittle polycarbonate lenses with time, and for this reason mechanical attachment (such as threading the ends of a polycarbonate tube in the case of fluorescent luminaires) or solvent-bonding systems are preferable.(17) However, when adhesive bonding is indicated, the adhesive choice should be made with full regard to the temperature and water chemistry environments to which the adhesive will be exposed.

Both cleaning and abrasion are recommended for polycarbonate surfaces as follows:

1. Wipe clean with alcohol or a hydrocarbon (hexane, heptane, naptha or toluene).

2. Abrade with 200-grit sandpaper.

3. Scrub with abrasive cleanser.

4. Rinse with alcohol, distilled water, and dry.

V. RECOMMEND QUALITY ASSURANCE PROCESSES

A. Approaches

The establishment of appropriate quality assurance (QA) standards is a goal which may have several approaches. The ultimate objective is to ensure that enclosure manufacturers design and build units from proper materials, using reliable fabrication procedures, so that reasonable confidence is secured that each unit will perform satisfactorily in the field.

The approach developed in this report is to recommend standards of materials and enclosure performance, and design QA procedures to provide reasonable assurance that accidental explosions can indeed be contained. This approach, of course, leads to additional regulation not only of the enclosure industry, but of supplying industries as well. The degree of regulation required depends upon

(1) The acceptable risk level that enclosures in the field will indeed be able to contain explosions,

(2) The degree to which the infusion of new technology is allowed to be inhibited through imposition of controls on designs and materials,

(3) The level to which free competition within supplying industries is to be restricted.

In an effort to guarantee that no accident will ever result from a faulty enclosure (whether the fault lies with component suppliers, the manufacturer, the field installer, or through improper or unusual field use), it is possible to carry regulation to the point that enclosures are severely overdesigned. Although such an approach may provide the desired level of safety assurance, it necessarily would throttle the infusion of new technology and the exercise of competitive free enterprise mentioned above. The other extreme, of course, would be to impose no QA requirements on the enclosure units. This approach is equally unacceptable for precisely the opposite reasons as those just mentioned.

What is needed then, is an intermediate level of QA regulation, one that can maximize, in some subjective sense, all three parameters of safety, technology, and competition. This is the path taken here. In this Chapter is outlined an approach to QA that MSHA may take to regulate and to approve explosion-proof enclosures. It will become obvious as the plan unfolds that no attempt has been made to quantify precisely every element of the QA process. Implementation of this process, as in the case for any other sensible process, requires the exercise of good judgment.

B. QA of Sealant and Adhesive Products

In nearly all cases the enclosure manufacturer must purchase his sealants/adhesives from an outside supplier. One important element of the QA process is the allowable means by which this acquisition of supplies is to be accomplished. At one level, the manufacturer may be permitted to purchase products that are approved by MSHA, i.e., that appear on a "Characterized Products List" (CPL).* This method gives the manufacturer a great deal of flexibility to make product substitutions and to select supply sources that are low in cost and that meet his delivery requirements. On the other hand, it provides no assurance or certification of performance characteristics, nor does it enable the manufacturer to establish a shelf-life reliably. After all, his source of purchase could be the manufacturer, a distribution center, a surplus stock warehouse, another business having excess stock of the product, or any other source. The age or storage treatment of the product cannot be assured from the time when the product leaves its point of manufacture and distribution. Thus, despite its apparent advantages, this approach to materials acquisition without a rigorous incoming materials QA program is not recommended, for it does not permit sufficient control over the quality of the sealants/adhesives used in the manufacture of enclosures. If, on the other hand, a sufficiently rigorous materials receiving QA program were established for acceptance of materials purchased in this manner, this approach may be acceptable. However, the amount of materials testing that would be required of the enclosure manufacturer to offset the vagaries of his incoming materials might be forbidding.

As an alternative approach, the manufacturer could be required to have a statement of certification from the supplier with each lot of materials he procures. A certification, for purposes of definition, is a manufacturer's warranty that the accompanying product lot has the stated properties. Certification may be provided with or without accompanying data, and most adhesive/sealant manufacturers will supply certifications with or without data free of charge on all minimum orders. A manufacturer's certification of a product already approved by MSHA and on their Characterized Products

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*See Chapter III.A.

List should be sufficient to permit that product to be used directly in the manufacture of enclosures without further in-house testing to verify properties. The drawback to this approach is that it requires the product to be purchased directly from the manufacturer; other sources such as local distributors are not in a position to provide the needed certification. Understandably, enclosure manufacturers would not like to have this requirement imposed upon them without other options available.

In some cases it may be possible for the enclosure manufacturer to purchase materials from a manufacturer who will provide certification to specifications promulgated, e.g., by the MSHA. Most suppliers, however, will not accommodate such purchase requests unless the order is very large so that the additional cost can be justified. Moreover, because of increasing sensitivity to product liability, the trend among product manufacturers is toward avoidance of certification of properties and to certify only that the product is made with consistent procedures and therefore may be considered to be the same as prior lots of the same product. This approach places the burden of establishing or confirming properties on the user.

It is recommended here that first the MSHA establish a Characterized Products List (CPL), for sealants and another for adhesives, using as guidelines the standards proposed in Chapter III. The enclosure manufacturer should be permitted to use only materials that appear on one of these lists and may substitute one sealant product for another, and similarly for adhesives, subject to complete retesting of the structure using the new sealant/adhesive. The manufacturer may not, however, use a sealant to replace an adhesive (or vice versa) in a design which was approved for an adhesive unless the substitute product appears on both the adhesive and the sealant CPL. The manufacturer has two basic options for purchasing his sealant and adhesive products. He may buy directly from the manufacturer and be furnished a certification statement with data attesting to the fact that the product meets the required minimum performance standards on each lot purchased. Alternatively, he may purchase from any source of his choosing, but must conduct such materials acceptance tests as suggested by the manufacturer and approved by the MSHA to ensure freshness, shelf life, and properties of the lot. This option, then, requires that the manufacturer furnish the enclosure manufacturer and the MSHA with a written statement of those specific tests and procedures which it considers necessary to establish lot quality and age when purchased through another source.

It is recommended further that manufacturers of sealants and adhesives be required to maintain at least a minimum quality assurance program with respect to these products. In particular, it is recommended that MIL-I-45208A ("Inspection System Requirements") be the required minimum standard. This and other Military and Federal Specifications can be ordered through:

Commanding Officer
Naval Publications and Forms Center
5801 Tabor Avenue
Philadelphia, Pennsylvania 19120

The primary technical scope of this Specification is defined under Section 3: REQUIREMENTS. A heading outline of this Section is as follows:

- 3.1 Contractor Responsibilities
- 3.2 Documentation, Records and Corrective Action
- 3.3 Measuring and Test Equipment
- 3.4 Process Controls
- 3.5 Indication of Inspection Status
- 3.6 Government Furnished Material
- 3.7 Nonconforming Material
- 3.8 Qualified Products
- 3.9 Sampling Inspection
- 3.10 Inspection Provisions
- 3.11 Government Inspection at Subcontractor or Vendor Facilities
- 3.12 Receiving Inspection
- 3.13 Government Evaluation

This particular Specification is a less comprehensive version of MIL-Q-9858A ("Quality Program Requirements"), which may be used in whole or in part rather than MIL-I-45208A. Whereas MIL-I-45208A is confined to inspections and testing requirements, MIL-Q-9858A also sets controlling standards for work operations and manufacturing processes; as such it is more applicable to complex systems as opposed to products. It should be mentioned that some sealant and adhesive manufacturers already deliver products certified to MIL-Q-9858A, and hence by implication to MIL-I-45208A.

C. QA of Explosion-Proof Enclosures

At the present time there are no detailed QA procedures promulgated by the MSHA with regard to explosion-proof enclosures. Title 30 of the Code of Federal Regulations, in Part 18 specifies in Section 18.20 only that

> "MESA (now MSHA) will test only electrical equipment that in the opinion of its qualified representatives is constructed of suitable materials, is of good quality workmanship, based on sound engineering principles, and is safe for its intended use."

Although this may provide adequate general guidance for qualifying a design by prototype testing, it does not give the needed protection for the production of enclosures. This is given in Section 18.6(K).

It is recommended that manufacturers of explosion-proof enclosures be required to develop and to maintain QA programs of at least a minimum standard. A survey of the industry in connection with this report showed the industry to be uneven in regard to QA standards. Some manufacturers have comprehensive, well regulated QA programs that are managed by professionally trained people, whereas others are significantly lacking in this important respect. It is recommended that manufacturers be required to meet the requirement of FED-STD-368 ("Quality Control System Requirements") as a <u>prerequisite</u> to Certification by the MSHA. This Standard establishes minimum requirements for a quality control system to be provided and maintained by a contractor. The system includes the methods, procedures, controls, records, and maintenance of the system to provide verification of product compliance with contract requirements. This Standard, which can be ordered through the Naval Publications and Forms Center at the address given in the preceding section, prescribes criteria according to the following outline:

- 5.1 Detailed Requirements
- 5.2 Organization
- 5.3 Inspection Status
- 5.4 Measuring and Test Equipment
- 5.5 Sampling Plan
- 5.6 Inspection Stations
- 5.7 Records
- 5.8 Drawings, Specifications, Charges
- 5.9 Preparation for Delivery
- 5.10 Written Procedures

The best way to ensure adoption and compliance with the provisions stated in FED-STD-368 is for each qualified enclosure manufacturer to develop a written QA manual. Such a manual would incorporate directly or indirectly all the FED-STD-368 requirements, as well as whatever policies for internal use the manufacturer deems appropriate. It also specifies the procedures for bonding lenses into the enclosures. Such procedures may range from the very specific (see Chapter IV of this report) to the rather general, by deferring to the product's recommended application procedures. Such manuals are frequently considered to be proprietary to the company, although of course current copies (controlled or uncontrolled) must be made available to appropriate officials of the MSHA.

Although there should be no single prescribed format for the QA manual, for purposes of illustration and guidance it might be structured along the following lines.

ORGANIZATION

- Define Infrastructure
- Define Lines of Authority and Communication
- Describe Pertinent Activities
  - QA
  - Purchasing
  - Receiving Inspection
  - Materials Control
  - Inspection and Testing
- Personnel Training/Certification

EQUIPMENT CALIBRATION

- Internal Procedures
- Vendor Audits

RECORDS

Drawings, Specifications, and Changes
Customer Warranties
Customer Complaints
Nonconforming Material
Inspection Status

D. Discussion

This chapter contains several recommendations that have the effect of regulating both the product suppliers and the equipment manufacturers. The ultimate objective of these recommendations is to provide some measure of protection to persons working in underground mines, and to the public at large, from loss as a result of accidental explosions. Although regulation will make it more difficult for disreputable or unscrupulous enterprises to manufacture and market explosion-proof enclosures or the adhesives/sealants that are used therein, no amount of regulation will ensure their exclusion. By making it more difficult through increased regulation for such enterprises to compete economically, competition is reduced, high caliber smaller organizations find it harder to compete, and the extra cost of regulation is passed on to the mining industry and, ultimately, the public.

In recognition of these tradeoffs, the recommendations form what are considered to be a prudent program of quality assurance that is reasonable, yet not excessive. This program consists of the following major elements. The first is for the MSHA to establish two Characterized Products List (CPL): one for sealants and one for adhesives, as defined in Chapter IV. The prime responsibility for including new products on the CPL's lies with the enclosure manufacturer, working in cooperation with the product manufacturer to develop the performance data required of MSHA. The development and maintenance of the CPL's places a technical and administrative burden on MSHA which it must plan for in order to handle effectively.

The second recommendation is that purchased adhesive/sealant products are either to have accompanying certifications with data, or the enclosure manufacturer is to undertake acceptance tests following receiving inspection. The objective is to help ensure lot-to-lot consistency of the product. Of the two options, the first in practical fact requires the enclosure manufacturer to purchase his products directly from the manufacturer, thus limiting his opportunities to work with local suppliers or to buy at discounted prices. Over the next few years it is expected that manufacturers will continue to move away from certification of their products to performance specifications, for reasons related to product liability. The second option provides the manufacturer with more freedom of purchasing choice, but requires him to conduct acceptance tests on each lot of product purchased.

The third recommendation is to require the product manufacturer to establish a QA program in conformance with MIL-I-45208A or MIL-Q-9858A. The purpose of this recommendation is to give the MSHA some control over the quality and consistency of manufacturing operations used in the production of sealants and adhesives.

The fourth recommendation is to place a QA requirement on the enclosure manufacturer, through conformance with FED-STD-368. Most if not all manufacturers now have QA programs, although they are quite variable within the industry. This requirement would place an acceptable minimum standard on the quality assurance function.

Finally, the fifth recommendation requires the manufacturer to develop and publish a QA manual that is acceptable to MSHA. Here again, several manufacturers already comply with this recommendation.

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10. "Electrical Apparatus for Potentially Explosive Atmospheres. Part 1, General Requirements," British Standard No. B55501, Part 1, 1977 (European Standard Number EN 50 014).

11. Personal communication with Mr. Roger King, U. S. Bureau of Mines-Bruceton, on February 7, 1979.

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13. Personal communication from Mr. L. R. Cooper, Head of Instrument Research Branch, National Coal Board, Mining Research and Development Establishment, England, March 13, 1979.

14. Personal communication from staff of Dr. Horst Ruter, Institute for Geophysics, West Germany, dated March 6, 1979.

15. "Interim Fire and Toxicity Criteria for Acceptance of Products Taken into Underground Mines," MESA Draft No. 2, March 22, 1977. (A third draft is pending as of the time this report was written, but is not expected to be issued before the end of calendar year 1979.)

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APPENDIX A

MECHANICAL PROPERTY CHARACTERIZATION OF ADHESIVES

This Appendix contains results obtained from various mechanical characterization tests on the following five sealants and adhesives:

Name	Type	Manufacturer	City, State
Armstrong T-900	Epoxy	Armstrong Products Co.	Warsaw, IN
Chico-2	Portland	Crouse-Hinds Co.	Syracuse, NY
Dolphon CB-1078	Epoxy	John C. Dolph Co.	Monmouth Junction, NJ
GE RTV-108	Silicone	General Electric Co.	Waterford, NY
Scotch-Weld 2216	Epoxy	3M Co.	Saint Paul, MN

These products were chosen for evaluation because they are rather widely used in the manufacture of explosion-proof luminaires and because they represent a variety of chemistries and physical properties. The purpose of these tests was to establish ranges of mechanical properties which are found typically in products which are currently being used successfully in mine equipment. All specimen fabrication and testing were done at SwRI unless otherwise noted.

A. Tensile Test Data

Tensile specimens of the various products were cast in open-face silicone rubber molds to the geometry called for in ASTM 638, Type IV. This specimen is of a "dogbone" configuration, 4.5 in. overall length, with a gage section of width 0.25 in. and length 1.30 inches. The specimen width at the tab ends is 0.75 inch. The specimen ends were wrapped with thin brass strips, then gripped using standard wedge grips in conjunction with a screw-driven Instron tensile test machine. The loading rate was 0.05 in./min., and autographic load-time charts were made during each test. No strain gaging or extensometry was used; rather, specimen elongation was computed from loading time-to-failure. The following expression was derived for estimating the gage section strain at failure, ε_f, from the total specimen elongation in inches (between grips) at failure, δ_f:

$$\varepsilon_f = \frac{\delta_f}{L_g\left[1 + \frac{2L_t}{L_g(\frac{W}{w} - 1)} \ln\left(\frac{W}{w}\right)\right]}$$

where w is the specimen width in the gage section (nominally 0.25 in.), and W is the specimen width at the ends (nominally 0.75 in.). L_g and L_t are, respectively, the length of the straight sided portion of the specimen (nominally 1.30 in.) and the length of the transition region from the end of the straight sided gage section to the beginning of the straight sided region of the grip region (nominally 0.6 in.). Inserting these nominal dimensions into the formula, there results the relation:

$$\varepsilon_f = 0.5104\ \delta_f$$

This expression was used in computing the failure strains presented in Table A.1.

No tensile tests were conducted on the GE RTV-108 because it is an extremely flexible and soft material, and it was impossible to acquire valid data on the equipment used. Some difficulties were encountered in testing the Chico, for just the opposite reason. This material is highly brittle, and frequently broke when the wedge grips were locked onto the ends.

B. Lap Shear Test Data

Lap shear specimens, consisting of 6061 aluminum adherend strips bonded together with the various products being evaluated, were tested to determine bond strength in shear. The specimens were fabricated and tested in accordance with ASTM D 1002. The adherends were prepared by the following five-step procedure:

(1) Sand aluminum with 320 grit sandpaper.

(2) Wipe clean with acetone.

(3) Apply Pasa-Jell 104 for surface treatment; allow Pasa-Jell to stand for 10 minutes.

(4) Wash clean with distilled water.

(5) Oven dry for 20 minutes at 140°F.

All products were mixed per the data sheet specifications supplied by the manufacturer, and all cure cycles were at room temperature. No procedures other than those specified were used to enhance strength or adhesive properties. Panels (from which the specimens were cut) were laid up and cured with 0.030-in. shims around the edges in an effort to achieve some degree of bondline thickness control. There was some variation in bondline thickness, and this could have been reduced. However, the general approach was to fabricate specimens without the use of sophisticated laboratory techniques, to simulate specimen quality that might be found in a typical factory shop that is not normally involved in developing adhesive bonding techniques.

Specimens were tested in a screw-driven Instron testing machine at a crosshead rate of 0.05 in/min. No tests were made with the GE RTV-108, since this product is an aerobic material and the interior of a wide bondline can not cure due to lack of contact with air. Thus, it is not possible to manufacture lap specimens of this product per ASTM D 1002, although it would be possible to make individual specimens up to about 0.25 in. in

TABLE A.1

TENSILE TEST RESULTS

Spec. No.	Test Temp. (°F)	Spec. Thickness (in.)	Spec. Width (in.)	Max. Load (lb)	σ_u (psi)	ε_f (%)
ARM-1	75	0.146	0.266	186	4790	1.28
ARM-2	75	0.152	0.292	192	4330	1.17
ARM-3	150	0.145	0.247	53	1480	9.03
ARM-4	150	0.155	0.253	41	1050	8.52
ARM-5	150	0.142	0.272	45	1170	7.76
ARM-6	150	0.137	0.295	58	1440	12.76
CHICO-2	75	0.141	0.231	30	921	0.61
DOL-1	75	0.132	0.243	4	514	30.11
DOL-2	75	0.134	0.248	3.4	413	33.28
SCO-1	75	0.134	0.256	53	1550	29.45
SCO-2	75	0.134	0.279	27	722	28.38
SCO-4	75	0.132	0.260	21	612	33.69
SCO-5	75	0.132	0.302	75	1881	28.12
SCO-3	150	0.132	0.271	11	308	10.36

NOTE: ARM = Armstrong T-900
DOL = Dolphon CB-1078
SCO = Scotch-Weld 2216

width. Attempts to fabricate lap shear specimens with Chico were abortive due to lack of adequate bond to the aluminum adherends. Chico is a water base compound, and chemical action is required for a proper bond. Test data from the three products evaluated are given in Table A.2.

TABLE A.2

LAP SHEAR TEST RESULTS

Spec. No.	Test Temp. (°F)	Spec. Width (in.)	Overlap Length (in.)	Max. Load (lb)	τ_u (psi)
ARM-1	75	0.922	1.037	365	382
ARM-2	75	0.914	1.008	350	380
ARM-3	150	0.938	0.916	1520	1769
ARM-4	150	0.920	0.944	1030	1186
ARM-5	150	0.932	1.027	830	867
ARM-6	150	0.925	1.015	1225	1305
DOL-1	75	0.941	0.965	295	325
DOL-2	75	0.924	0.933	192	223
DOL-3	150	0.930	0.942	70	80
DOL-4	150	0.929	0.946	45	51
DOL-5	150	0.914	0.954	51	58
DOL-7	150	0.964	0.970	13.5	14
SCO-1	75	0.908	0.854	730	941
SCO-2	75	0.922	1.072	1095	1109
SCO-3	150	0.952	0.975	180	194
SCO-4	150	0.935	0.880	247	300
SCO-5	150	0.954	0.857	130	159
SCO-6	150	0.939	1.087	368	361

NOTE: ARM = Armstrong T-900
DOL = Dolphon CB-1078
SCO = Scotch-Weld 2216

C. Peel Strength Test Data

The T-Peel test, described in ASTM D 1876, was used to evaluate the relative resistance of the products to this type of loading. The adherends were 6061 aluminum, as in the case of the lap shear specimens previously described. The same cleaning and specimen preparation procedures were used here as described earlier.

Specimens were tested in a screw-driven Instron testing machine at a crosshead rate of 10 in/min. No tests were made on the GE RTV-108 or the Chico products, for reasons having to do with specimen preparation as described in the foregoing section. The test data are tabulated in Table A.3.

TABLE A.3

PEEL STRENGTH TEST RESULTS
(All tests conducted at 75°F)

Spec. No.	Spec. Width (in.)	Planimeter Reading (in^2)	5" Avg. Load (lb)	Avg. Peel Strength (lb/in)
ARM-6	1.05	0.26 (a)	1.66 (a)	1.58
ARM-7	1.03	0.39 (b)	2.00 (b)	1.94
DOL-1	1.04	9.06	18.10	17.40
DOL-2	1.04	8.98	18.00	17.30
DOL-3	1.08	6.06	12.10	11.20
DOL-4	1.01	4.87	9.74	9.64
DOL-5	1.05	5.19	10.40	9.90
DOL-6	1.06	6.94	13.90	13.10
SCO-1	1.00	7.28	14.60	14.60
SCO-2	0.979	8.73	17.50	17.90
SCO-3	0.995	7.22	14.40	14.50
SCO-4	1.03	7.77	15.50	15.00
SCO-6	1.03	8.09	16.20	15.70
SCO-7	0.974	8.10	16.20	16.60

(a) Tear length = 1.57 in.
(b) Tear length = 1.95 in.

NOTE: ARM = Armstrong T-900
DOL = Dolphon CB-1078
SCO = Scotch-Weld 2216

D. Shore Hardness Test Data

Product hardness was determined by Shore "A" and Shore "D" measurement per ASTM D 2240. Shore "A" is used for soft plastics and is usually conducted with a rebound-type scleroscope, although a mechanical indentor appropriately calibrated may be used. Shore "D" is used for determining the hardness of harder plastics and employs a mechanical indentor. The Shore "D" tests were conducted at SwRI, and the Shore "A" tests at an outside laboratory. Specimens were cast into "poker chip" configurations, nominally 1.375-in. diameter and 0.140-in. thick.

Tests were conducted on specimens before and after exposure to the mine water chemical solution described in Chapter II.A.2. Exposure consisted of immersing a specimen in a small glass vessel filled with the solution, then maintained at a temperature of 70°C (158°F). Values shown in Table A.4 are averages of three readings. Table A.5 gives a qualitative comparison of the specimens before and after environmental aging.

TABLE A.4

SHORE HARDNESS TEST RESULTS

		No Environmental Aging		No Environmental Aging	
Product	Type	Shore A	Shore D	Shore A	Shore D
Armstrong T-900	Epoxy	N/A	87	97	75
Chico-2	Portland	N/A	86	N/A	80
Dolphon CB-1078	Epoxy	83	N/A	89	50
GE RTV-108	Silicone	30	N/A	42	6
Scotch-Weld 2216	Epoxy	N/A	52	94	48

Note: Environmental conditioning consisted of immersing specimen in solution of artificial mine water (See Chapter 2.A.2) for 14 days at 70°C (158°F).

TABLE A.5

PHYSICAL APPEARANCE OF SPECIMENS
AGED IN ACIDIC MINE-DRAINAGE SOLUTION

Product	Before Aging	After Aging
Armstrong T-900	Medium gray, very smooth	Deep yellow, bumpy surface
Chico-2	Medium gray	Brownish-yellow, very brittle
Dolphon CB-1078	Black, rubbery	Dull yellowish-black, stiff
GE RTV-108	Clear/translucent, rubbery	Light yellow, rubbery
Scotch-Weld 2216	Deep gray, smooth	Greenish-yellow, semi-smooth

APPENDIX B

ESTIMATE OF TEMPERATURE GRADIENTS THROUGH LUMINAIRE LENSES

As stated in Chapter II.A.2 of this report, Federal regulations impose a maximum external surface temperature limit of 150°C (302°F) on explosion-proof enclosures. The sole exception to this requirement currently is that the internal temperature of polycarbonate lenses, used, e.g., in luminaires, is 240°F (116°C). As mentioned in Chapter II.B.4 of this report, there is a basis for concern that, left unregulated, the inside temperature of glass lenses may become excessive during normal operating conditions. First, tempered glass will lose its temper given sufficiently high temperatures and exposure times. Temper loss, in turn, lowers the inherent strength of the lens and promotes warpage (due to unsymmetric temper) which may induce edge rotations with consequent debonding, gaps, and crack growth in adhesives and sealants. Second, excessive temperatures on the inside lens surface may cause excessive heating of adhesives and sealants, which may then be susceptible to failure.

It is very difficult to make realistic calculations of the inside temperatures on a lens used on a luminaire, for the temperature is highly dependent upon such design parameters as: kind and power rating of the lamp; the geometry of the enclosure; and the enclosure materials. However, a convincing argument can be advanced to support the contention that certain luminaire designs may lead to unsafe temperature conditions. This argument is based on a simple model for estimating the temperature gradient across a typical glass lens. The following equation was developed for estimating the temperature on the inner surface of a glass lens, T_i, from the known temperature on the outer surface, T_o. The model was developed from elementary theory of conductive and convective heat transfer:*

$$T_i = T_o + 0.1\ t\ L\left(\frac{T_o - T_a}{L}\right)^{1.25}$$

Here, T_a is the ambient temperature (°F), t is the lens thickness (in.), and L is the "size" of the lens (in.), e.g., the diameter in the case of a circular lens.

As an example, if T_o = 302°F (the maximum allowable under Title 30 of the CFR), T_a = 42°F, t = 5/8 in., and L = 4 in., the equation predicts

$$T_i = 302 + 46 = 348°\text{F}$$

*This equation results from equating the heat flux coming to the inner surface of the lens, $kA\,(T_i - T_o)/t$ to the heat flux leaving the outer surface by free laminar convention, $hA(T_o - T_a)$. Here, k is the thermal conductivity coefficient for glass, and h is the heat transfer coefficient, $0.29\,[(T_o - T_a)/L]^{0.25}$, from page 219 of: Holman, J. P., HEAT TRANSFER, McGraw-Hill Book Co., Inc., New York, 1972.

Thus, a temperature gradient through the lens thickness on the order of 50°F (10°C) may be expected. It could, however, be higher due to heat buildup inside the enclosure; this heat would be removed through the metal structure (which has a much higher conductivity than glass). These temperatures nonetheless are sufficiently high to impair the mechanical performance of some adhesive materials, such as epoxies, especially if local hot spots are present. On the other hand, this temperature estimate puts the temperature on the inside surface of the lens within the performance limits of glasses used in these applications.

In view of this analysis, it is recommended that the enclosure manufacturer submit to MSHA data from thermocouple surveys made on all prototypes which contain bonded lenses to confirm that (1) the operating temperature on the inside of the lens is within safe limits for the particular lens material, and that (2) the temperature around the edge on the interior surface is within allowances for that product as specified by the product manufacturer.

APPENDIX C

LUMINAIRE VENDORS

Crouse-Hinds Co.
1347 Wolf St.
Syracuse, NY 13221

Contact: Mr. Garrett S. "Gary" Yarbrough
Manager of Engineering
Construction Materials Division
315/477-7000

Ensign Electric Division
Harvey Hubbell, Inc.
914 Adams Avenue
P. O. Box 820
Huntington, WV 25712

Contact: Mr. Richard "Dick" Jimison, Manager
Mechanical Design & Engineering
Systems
304/529-3311

Joy Manufacturing Company
325 Buffalo St.
Franklin, PA 16323

Contact: Mr. Ed Warner
Director of Engineering
814/437-5731

McJunkin Corporation
P. O. Box 513
Charleston, WV 25322

Contact: Mr. H. P. "Mac" McJunkin
Director of Engineering &
Manufacturing
304/348-5211

Mining Controls, Inc.
P. O. Box 1141
Beckley, WV 25801

Contact: Mr. Woody Dacal, President
304/252-6243

Mine Safety Appliances Co.
600 Penn Center Boulevard
Pittsburgh, PA 15235

Contact: Mr. Bob Havener
Product Line Manager
412/273-5177

National Mine Service
3001 Koppers Building
Pittsburgh, PA 15219

Contact: Mr. Ed Able
Product Manager
412/281-0688

Service Machine Company
6072 Ohio River Road
P. O. Box 8177
Huntington, WV 25702

Contact: Mr. James H. Nash
President
304/736-8933