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Some Design Factors for Windows and Lenses Used in Explosion-Proof Enclosures

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SOME DESIGN FACTORS FOR WINDOWS AND LENSES
USED IN EXPLOSION-PROOF ENCLOSURES

By Lawrence W. Scott¹

ABSTRACT

This Bureau of Mines report presents several factors that currently enter into the design, manufacture, and testing of windows and lenses used in explosion-proof enclosures. Emphasis is also given to the sealing concepts for lenses. 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 are also discussed.

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INTRODUCTION

For the past 5 years, Southwest Research Institute, San Antonio, Tex., through funding by the Bureau of Mines Coal Mine Health and Safety Program, has been analyzing several of the critical factors involved in the design of explosion-proof enclosures.² These include safety factors, weld quality standards, quality assurance standards, and reliability of enclosures with windows. The progress presented here is expected to be of considerable interest to the mining industry in general and to designers of explosion-proof enclosures in particular.

Title 30 of the Code of Federal Regulations (CFR), Part 18.2, defines 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 and cover(s), and (2) without ignition of surrounding methane-air mixtures or discharge of flame from inside to outside the enclosure."

Several different types of electrical equipment fall under this definition, including power enclosures, distribution boxes, splice boxes, and ballast boxes. This report is concerned primarily with power enclosures and luminaires, (lighting fixtures mounted on coal mining machinery). The windows and lenses built into luminaires are often fixed in place with adhesives and sealants and are generally subjected to more severe thermal environments than are other explosion-proof enclosures.

Windows in explosion-proof enclosures require careful design, fabrication, and installation. The designer

must be certain that the window or lens is adequate for the design conditions of the enclosure, particularly the dynamic pressure, temperature, point impact, thermal shock, and corrosive effect of the operational environment.

The windows and lenses discussed in this report are intended for use only in enclosures with window service conditions defined by

Maximum dynamic pressure (P_d) generated by an explosion of methane-air inside the enclosure.

Design pressure (P) equal to $P_d \times 1.5$ or 150 psig (1,034 KPa), whichever is greater.

Maximum temperature (T_d) generated by internal light source, equal to design temperature.

Pressure cycles generated by repeated explosions at design pressure and temperature.

Thermal shock generated by immersion of window at design temperature to water having a temperature between 59° F (15° C) and 68° (20° C).

Physical shock generated by point impact of an object with 8 ft-lb kinetic energy at the center of the window.

The windows and lenses discussed are subject to the following restrictions:

1. The operating temperature shall not exceed 302° F (150° C) on the exterior of the window.

2. The fluids contacting the surface of the window shall be only those typically found in an underground mine environment (that is, humid air, mine water, and lubricating and hydraulic oils used on mechanized equipment).

3. The total number of pressure cycles during the operational life of the enclosure shall not exceed 1,000.

²USBM contract H0377052, Analysis of Schedule 2G Enclosures; Bureau of Mines Technical Project Officer, Lawrence W. Scott.

MATERIALS

Windows and lenses should be fabricated only from materials suited for the operational environment encountered in mines. The suitability of a material is based either on documented extensive past experience, or on exhaustive evaluation by a materials testing laboratory in simulated mine environments. At present, glass and polycarbonate plastics are considered practical materials for fabrication of windows and lenses.

Glass

The chemical composition, casting process, and thermal treatment determine the physical, chemical, optical, and electrical properties of glass. Because of a very complex relationship among these variables, no single glass composition, casting process, or thermal treatment is considered superior to others. Thus, the designer is free to select the combination of fabrication parameters that best matches a specific set of product requirements.

The primary advantages of glass are its ability to retain its physical and optical properties under high ambient temperature, ultraviolet radiation, and humidity for a long period of time; to resist surface abrasion by rock particles; and to tolerate immersion in aqueous and organic solvents without initiation of stress cracking or corrosion. Glass windows can tolerate 100-percent relative humidity, temperature of 400° F (204° C), intense ultraviolet radiation, and continuous or intermittent immersion in basic or acidic water or organic solvents for indefinite periods.

The primary shortcomings of glass are its brittleness and low tensile strength. To compensate for these shortcomings, the design of the window seat assembly must provide, whenever feasible, protection against point contact with the metallic components of the enclosure and impact by rock fragments capable of fracturing the window. The protection against fracture initiated by point

contact is usually accomplished by inserting gaskets between the glass and metallic components of the seat assembly. Protection against breakage by impact is generally provided by an external shield in the form of a cage or plastic envelope, or by precompressing the glass window surfaces with thermal tempering or chemical ion exchange.

Because of their history of successful use in enclosures, the following glasses are practical for use as windows in enclosures: (1) Borosilicate glasses, (2) soda lime glasses, and (3) silica glasses.

Plastic

The high temperature, humidity, intensive ultraviolet radiation, and presence of vapors from petroleum-based oils tend to degrade rapidly the mechanical properties of plastic windows and lenses in explosion-proof enclosures. Some plastics deteriorate in lamp enclosure service faster than others, but even the most resistant ones age sufficiently to mandate their removal from service in less than 10 years. For this reason, a thorough engineering evaluation of plastic material must be conducted prior to its selection for service as a window in an explosion-proof enclosure. At present, polycarbonate plastic is considered practical for fabrication of windows and lenses for enclosures; however, Mine Safety and Health Administration (MSHA) policy limits the design temperature to 240° F (115° C). Industrial experience has shown that three other restrictions should be noted:

1. Contact with hydraulic oil and petroleum-based lubricants prohibited.
2. Low-ultraviolet (UV) environment (no more than 20-percent loss in luminaire output after one year of continuous operation).
3. Service life \leq 4 years.

DESIGN OF GLASS WINDOWS

The thickness of a glass window should be based primarily on the design pressure and only secondarily on the design impact resistance. The design pressure of the window should equal or exceed 150 psig or 1.5 times the maximum dynamic pressure generated by a methane-air explosion inside the enclosure, whichever is greater. For safety purposes, the calculated value of nominal tensile stress in the window at design pressure should not exceed 1,000 psig for annealed glass and 2,000 psig for tempered glass.

Windows may be fabricated by any acceptable commercial technique. Typical techniques are (1) cutting and grinding from plate stock or (2) pressing and grinding. The high- and low-pressure faces of the windows, except the bearing surface, should be polished and free from scratches and pits. Molds used for molding should have their surfaces polished. The bearing surfaces on plane, cylindrical, and dome windows should be flat within 0.010 inch. Ground surfaces should be finished with 220-micrometer or finer abrasive powder. The ground bearing surfaces of a pressed plane window should be located above the polished surface of the window to minimize the stress rise at the boundary line between the ground and polished surfaces. All sharp corners should be chamfered and free of chips exceeding 0.020 inch in size.

After grinding and polishing, the windows should be subjected to a thermal treatment. The thermal treatment for windows designed to serve in the annealed state should consist of subjecting them to the appropriate annealing procedure for that glass composition. The annealing procedure should be capable of

decreasing the residual stress in the window below 600 psi. The thermal treatment for windows designed to serve in the tempered state should consist of subjecting them to the appropriate tempering treatment for that glass composition. The selected tempering procedure should generate residual compressive stresses whose magnitude on the surface of the window exceeds 4,000 psi.

Unless information is available beforehand on the magnitude of the dynamic peak pressure generated by a gas explosion inside a selected enclosure design, the following design procedure should be followed:

1. Design the window assembly for 150-psig service.

2. Fabricate the window and window seat assembly, install them in the enclosure, and record the maximum dynamic pressure generated inside the enclosure by a methane-air explosion according to CFR 30, Part 18.62.

3. If the recorded pressure is less than 100 psig, the original design pressure of 150 psig is considered satisfactory. If the dynamic pressure exceeds 100 psig, the window must be redesigned to a new design pressure equal to 1.5 times the measured dynamic pressure.

4. If the window is to be used in a luminaire, an operational lamp test must be conducted to determine whether the temperature of the external window surface exceeds 302° F (150° C) when the enclosure is located in an ambient environment at 100-percent relative humidity and 100° F temperature.

DESIGN OF PLASTIC WINDOWS

The thickness of a plastic window should be based primarily on the design pressure and temperature, and secondarily on the design impact resistance. The design pressure of the window should

equal or exceed 150 psig or 1.5 times the dynamic pressure generated by a methane-air explosion inside the enclosure, whichever is greater. The calculated values of maximum nominal tensile and

compressive stresses in the window at design pressure should not exceed the nominal stress values for the selected plastic material composition and design temperature. At present, only polycarbonate plastics are qualified for window service. Maximum design values for this plastic are--

Grade--UV stabilized, clear
 Temperature--240° F (115° C)
 Tensile stress--1,100 psi
 Sheer stress--1,000 psi
 Compressive stress--1,500 psi

The window may be fabricated by (1) machining from plate or bar stock, (2) molding, or (3) extruding. Molded and extruded windows may require some machining to bring them in conformance with specified dimensions and bearing surface finishes. The high- and low-pressure faces of windows should have a finish of 32 rms³ or finer.

During the fabrication process, substances and fluids detrimental to plastics should be avoided. Windows fabricated by machining flat or bar stock should be annealed twice, once after rough machining and again when the window is completed. Windows fabricated by molding or extrusion should be annealed at least once, when all manufacturing operations have been completed. The annealing procedure must follow the

³rms (root mean square) is a surface roughness term, referring to relatively fine spaced surface irregularities, the height, width, and direction of which establish the predominant surface pattern. The rms average is obtained by squaring the height measurements of the peaks and valleys, taking the average of the squared values, and then extracting the square root of this average.

recommendations of the plastic supplier; however, the annealing temperature must exceed the maximum design temperature of the given plastic by at least 10° F.

Dimensions of finished plane windows with square edges should be within ±0.032 inch of nominal dimensions. The major diameter (or width and height) of finished plane and spherical windows with inclined bearing surfaces should be within ±0.020 inch of nominal dimensions. The thickness of finished windows should be within ±0.032 inch of specified nominal thickness. The diameter and wall thickness of cylindrical windows should also be within ±0.032 inch of specified nominal dimensions.

If either the peak pressure or window surface temperature is unknown, the designer should (1) design the window for 150 psig pressure and maximum allowable temperature for the plastic material composition, and (2) experimentally confirm the design values. The experimental confirmation should be conducted on an operational enclosure dedicated to the selected window design by--

1. Performing an internal explosion test according to Schedule 2G, Part 18.62 and recording the maximum internal dynamic pressure.

2. In the case of luminaires, performing an operational test by turning the lamp on inside the enclosure and recording the interior surface temperature of the window after 8 hours of continuous operation. If the recorded dynamic peak pressure multiplied by 1.5 is below 150 psig and the recorded surface temperature is below or equal to the maximum design temperature, the design is considered satisfactory.

SEALING AND BONDING OF WINDOWS AND LENSES

The windows and lenses used in explosion-proof enclosures, especially luminaires, are often held in place by sealants and adhesives and secured with a mechanical attachment.

There are two broad categories into which materials that are candidates for use in explosion-proof enclosures may fall. 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 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. Because they must maintain contact with their substrate surfaces, under conditions of expansion and contraction, sealants must possess some adhesive capacity. Sealants are normally soft, compliant materials that may swell or shrink to accommodate environmentally induced forces (hygrothermal effects) and that possess adhesive characteristics only to the extent that the bondline is maintained intact under action of these secondary forces.

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

Sealants

Most sealant materials for use in explosion-proof enclosures are single-component, room-temperature vulcanizing

silicones, commonly called RTV's. RTV's are widely used for the following reasons:

1. The elastomeric nature of RTV silicones gives them 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 temperature than are organic sealants and adhesives. They generally retain their properties relatively well up to about 200° C (392° F).

3. The elastomeric nature of cured RTV's provides some measure of shock protection for the lens.

4. These silicones have good chemical resistance in that they tend not to be affected by moisture or weak acids and bases.

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

Adhesives

At present, practically all adhesives used for structural purposes in explosion-proof enclosures are two-component epoxies. In general terms, epoxies are either one- or multi-component systems, depending upon whether the resin and hardener are blended together in a single system or stored separately. All epoxies are either basic resin systems or modified systems. 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 epoxies require elevated-temperature curing, and all two-component epoxies require careful mixing of the monomer and hardener. Epoxy adhesives have good high temperature performance and low shrinkage, but are very sensitive to formulation and application procedures.

Where a design calls for a true adhesive, several features aside from

adhesive strength should be considered in selecting the adhesive. Among these are (1) long-term tolerance to environmental factors without becoming brittle, (2) minimum shrinkage due to natural aging, (3) permanent barrier protection against water infiltration, and (4) acceptable level of emission of combustible decomposition products.

SURFACE PREPARATION OF ADHERENDS

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

There are as many bonding procedures as there are lens-substrate combinations and applicable adhesives on the commercial market. Because of this variety, recommendations of the adhesive supplier with regard to surface preparation should be followed scrupulously. In addition, the following general procedures for substrates found in explosion-proof enclosures, such as aluminum, steel, brass, glass, and polycarbonate, are recommended.

Surface Preparation for Aluminum

Although both chemical cleaning (etching) and mechanical abrasion (fine abrasive) are possible, etching results in higher reliability. An etching method that has been found to be satisfactory with both epoxy and urethane adhesives follows:

1. Degrease in a vapor bath of trichloroethylene (TCE).

2. Etch for 20 minutes at 66° C (150° F) with a fresh solution of 65.4 weight-percent water, 26.9 weight-percent sulfuric acid, and 7.7 weight-percent sodium dichromate dihydrate

($\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$). Note that 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 3 hours.

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 ingress to the interface. This means that although adhesion may be good initially, 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 TCE or perchloroethylene (PCE).

2. Grit blast.
3. Degrease again.
4. Dry.
5. Use immediately after drying.

Surface Preparation for Brass

Brass and other copper alloys pose a problem in good adhesive bonding owing to the rapid formation of oxide coatings. Although there is a commercial product that intentionally produces a tightly adhering black oxide coating to which the adhesive forms a bond (Ebonol C Special, Enthane Co., New Haven, Conn.).⁴

Several acid etchants are easy to produce from commonly available materials. 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.

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. 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 or cloth, it must be removed by a heat treatment at 450° C for 24 hours. A general procedure follows:

1. Clean with a solvent (alcohol, acetone, or TCE).
2. Dry and keep dry prior to use.

Coupling agents have found great utility in forming adhesive bonds to glass and will improve reliability of the bond. Various coupling agents are commercially available to enhance adhesion with both thermoplastic and thermosetting resins. Note that the adhesive for glass should not embrittle with age because of thermal expansion of the substrates.

Surface Preparation for Polycarbonate

Adhesives that cure at room temperature are preferred when bonding polycarbonate to metals, owing to the differences in thermal expansion of the two substrates. 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. 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, naphtha, or toluene).
2. Abrade with 200-grit sandpaper.
3. Scrub with abrasive cleanser.
4. Rinse with alcohol, rinse again with distilled water, and dry.

⁴Use of company and brand names is for identification purposes only and does not imply endorsement by the Bureau of Mines.

SUMMARY

Windows and lenses for use in explosion-proof enclosures require careful design, fabrication, and installation. The designer must be sure that the window or lens is adequate for its intended use and will tolerate an underground environment.

Although mechanical attachment of windows and lenses is preferred, adhesives and sealants are often used to secure windows in enclosures. Care must be taken when selecting an adhesive or sealant to insure that it can withstand

the environmental factors encountered in mines. Special attention should be given to the preparation of adherends to insure that a proper bond is obtained.

Finally, the design and testing suggestions discussed in this report are not all encompassing. The designer of windows, lenses, and enclosures should be cognizant of Schedule 2G of the CFR, which details performance of windows and lenses in such tests as the impact test and thermal shock test.

