Stronger Dozer Cab Windows: A Way to Improve Surge-Pile Safety

A Status Report

December 1, 1999

Mine Safety and Health Administration
U.S. Department of Labor

Background

Since November 1998, two bulldozers operators have died in separate coal surge-pile accidents. One accident occurred in Virginia, the other in West Virginia. In both cases the bulldozer fell into a hidden cavity above a feeder. In each case coal filled the cab when the windows of the bulldozer broke, or were pushed out of their gaskets. With these two accidents, 18 fatalities have now occurred at coal surge piles since 1980.

The Mine Safety and Health Administration set out, following the Virginia accident, to determine whether it was feasible to provide bulldozer-cab windows strong enough to resist surge-pile burial pressures. MSHA's Pittsburgh Technical Support Center explored possible solutions to the problem. These included installing stronger glass, or material such as polycarbonate, and/or providing supports to decrease the unsupported area of the glass in the windows.

This report summarizes the status of the option of strengthening the windows by installing high-strength glass - without additional supports. If feasible, this approach is considered preferable since adding supports would at least partially obstruct the operator's field of vision from the cab. The use of remotely-controlled equipment also appears to be a feasible alternative. This approach would remove the bulldozer operator from the potential danger and is being tried by at least two coal companies.

It is important to note that the purpose of strengthening the cab windows is to provide a "safe refuge" for the operator in the event of an accident, but this is just one element in an overall surge-pile-safety program. The overall focus of a such a safety program must be to minimize the development of hidden cavities and to ensure that equipment operators will not be exposed to the danger should a cavity develop.

Surge Pile Survey Results

For background information, MSHA conducted a survey of coal surge piles in February 1999. The purpose was to determine the number of surge piles and the number and type of mobile equipment used to move coal on the piles. The total number of surge piles reported at coal mines was 337, with at least one surge pile at 238 different operations. Approximately 600 pieces of mobile equipment were identified as being used on piles. Roughly 78% of the equipment was found to be Caterpillar bulldozers. The most common models were D9s (232 machines) and D8s (113 machines).

Burial Pressures

To determine the burial pressure that surge-pile-equipment cabs should be able to withstand, the surge pile accidents that have occurred over the last 20 years were examined. It appears that when a bulldozer had fallen into a hidden cavity, the amount of coal that came in on top of it varied from about 10 to 25 feet. It was also recognized that additional coal can come in on the dozer from two sources. While digging out

the buried dozer, additional coal may be disturbed and slide onto the dozer. Also, before it is discovered that an accident has occurred, additional coal may discharge from the stacker tube and accumulate on the dozer. A further consideration is that the rescue equipment itself can impose additional stress as it is used to dig-out the buried piece of equipment.
Considering these factors, it appears prudent to provide a cab which will safely withstand being buried to a pressure equivalent to a depth of at least 35 feet of coal. With a cab capable of withstanding this amount of pressure, it appears that all of the accident victims who have died as a result of coal pressure breaking in the cab windows would have had the opportunity to have been rescued.

The pressure created by a burial depth of 35 feet depends on the unit weight of the coal. Coal weights can vary from a low of approximately 60 pounds per cubic feet (pcf) for clean coal, to a high of about 80 pcf for raw coal. Using the higher unit weight value, the burial depth of 35 feet correlates to a pressure of about 20 pounds per square inch (psi). This is proposed as the burial pressure that the cabs of the equipment used on coal surge piles should be able to safely withstand.

Factor of Safety

From a burial-pressure standpoint, the windows represent the weakest area of a cab enclosure. To protect the equipment operator, the window glazing and mounts need to be designed to withstand the 20 psi burial pressure with an adequate factor of safety. The factor of safety allows for uncertainty in the conditions involved, and provides a measure of protection against factors that are difficult to quantify, such as the possibility of impact-type loading, stress concentrations from larger pieces of coal or rock, and pressure from the weight of rescue equipment. In the glass industry, a minimum safety factor of at least 2 is considered prudent in this type of application. Therefore, a prudent design for the equipment used on coal surge piles would be to provide a cab which is capable of preventing coal from entering the cab under a burial pressure of at least 20 psi, with a safety factor of 2.

Window Materials

Various glass and plastic manufacturers were contacted to attempt to identify a window material strong enough to resist a burial pressure of 20 psi with an adequate factor of safety. To support this level of pressure with a material of reasonable thickness, and without additional supports, it was found that chemically-strengthened glass, or a material like polycarbonate, would be required. A chemically-strengthened glass called Herculite II, which is manufactured by PPG Industries, was identified as a product with high bending strength. This material was developed for F-111 cockpit windows. To produce Herculite II, a special base glass containing lithium is cut to the required shape and then immersed in a bath of molten sodium nitrate. The glass is strengthened when the larger sodium ions displace the lithium ions, putting the surface of the glass into compression. Once treated, this glass has a modulus of rupture (unabraded) of over 60,000 psi, making it about 4 times stronger in bending than heat-tempered glass and significantly stronger than some other chemically-strengthened glass products.

Polycarbonate may also be a viable alternative but its use was not explored further at this time for two reasons. One concern is that the scratch resistance of polycarbonate may present a problem in a surge-pile environment. A second concern is that because it undergoes large deflections under loading, a polycarbonate window would have to be either rigidly held around the edges or a significant amount of edge overlap would need to be provided.

Window Mounting

In addition to having sufficient bending strength, to ensure that the window material will withstand the burial pressure, the glass must be adequately supported around the edge of the window opening. If the glass is held in a gasket, the gasket must be designed to allow the glass to overlap the edge of the cab opening by an adequate amount. The overlap must be sufficient to ensure that the glass will not pull through when it deflects, and that stresses high enough to cause cracking do not occur along the edge of the glass. Currently available gaskets only allow a minimal overlap of the glass - on the order of 1/8 of an inch - and will not accommodate glass thicker than 5/16 inch.

An alternative method of mounting the glass may be to use an adhesive bonding material, such as the material used to install automotive windshields. This method is currently being used by Caterpillar on some front-end-loader cab windows. How the bonding will hold up under the vibration loading that occurs during bulldozer operation has not yet been demonstrated.

Testing of High-strength Glass at PPG's Laboratory

To demonstrate and verify that the high-strength glass would support the burial pressure with an adequate factor of safety, laboratory testing was conducted at PPG's Aircraft and Specialty Products manufacturing plant in Huntsville, Alabama. The most critical condition was examined by testing the largest available dozer cab window (the rear window in a Caterpillar model D9R). The window is about 29 inches high and varies in width from about 43 inches across the top to about 45 inches across the bottom. A fixture was fabricated which duplicated the size of the opening in the cab and permitted the glass to be subjected to a uniform pressure using water and air pressure.

PPG engineers had recommended that a two-layer laminated glass be used. The strength of the full glass thickness would be designed to support the 20 psi pressure with a factor of safety of two. Furthermore, the inner ply of the window would be designed such that if the outer layer became damaged, the inner layer could still support the 20 psi loading. Thus the outer layer would provide a measure of protection against impact loadings.

A test was conducted on a window consisting of two 6-millimeter (mm) thick layers of Herculite II with a 1-mm thick polyvinyl butyral (PVB) interlayer. To represent worst case conditions, the glass was "simply-supported" around the edge of the test fixture, that is, it was simply resting on strips of rubber and a putty-type sealant. The glass overlapped the edge of the window opening by ½ -inch, which was the minimum overlap recommended by PPG.

The test was conducted in an environmental chamber with the temperature raised to 120 degrees Fahrenheit. This was done to simulate the conditions of operating the equipment on a pile on a hot, sunny day. The temperature of the glass itself was over 105 degrees. A strain-gage was installed to monitor the strain in the glass. The glass was loaded to a pressure of 40 psi and this pressure was held for two hours. The center of the glass deflected by about 1½ inches. No breakage of the glass occurred.

Testing on other glass samples had shown the importance of maintaining a cushion between the glass and the edge of the steel around the window opening. In a test where the glass was supported only on a bead of putty, the test sample eventually failed when the pressure on the glass squeezed the putty out allowing a high stress concentration in the glass where it contacted the uneven edge of the steel.

This testing demonstrated that Herculite II glass consisting to two 6-mm thick laminated layers can withstand a 40 psi pressure in the size windows found in bulldozers. Note that the largest window was tested and the results indicate that thinner glass could work on the smaller dozer windows.

MSHA Field Burial Demonstration

To demonstrate the use of the high-strength glass in a surge-pile bulldozer, a Caterpillar D9N was fitted with the glass and a full-scale burial test was conducted at the Federal No. 2 Mine, Fairview, WV. The bulldozer was prepared for the test in cooperation with representatives of PPG Industries and Caterpillar. The windows used in the demonstration were laminated, consisting of two 6-mm thick layers of Herculite II chemically-strengthened glass. The glass had been sized to provide a ½ -inch of overlap around the edge of the cab opening.

Caterpillar had the windows installed by Imperial Glass, a local glass installer out of Clarksburg, WV. The glass was bonded to the cab using Betaseal U-216, a two-component urethane adhesive used to install automobile windshields. Spacers or "buttons" were used within the adhesive to attempt to obtain a uniform adhesive thickness of about 5 mm. The adhesive was used because there wasn't a gasket available that could accommodate glass of this thickness. Since the glass was not held in place by a gasket, four layers of electrical tape were applied to protect the edges of the glass.

In the burial demonstration, the test dozer was positioned on the side of a pile of clean coal with the blade facing up the slope. The slope of the pile was about 35 degrees. A Caterpillar D11 bulldozer was then used to push coal over the edge of the pile and accumulate it on top of the test dozer. The test dozer ended up being buried in a 30-foot high pile of coal. When the dozer was dug out, the windows were undamaged. Instrumentation on the windows showed that for this burial condition the glass was subjected to stresses well below the level that it would take to break the glass. While the dozer wasn’t buried under the deepest part of the pile, the burial was considered to be representative of the conditions likely to be encountered in a typical burial accident.

Summary

Pushing coal on a surge pile is a potentially dangerous job. The danger comes from several factors: changing pile conditions; pushing coal at night and in adverse weather; time pressures; and the ever present possibility of the coal bridging over a feeder and creating a hidden cavity. While safety measures should be in place to minimize the formation of hidden cavities and to prevent equipment from being exposed to the danger of such cavities, as a back-up safety measure either the cabs of surge-pile equipment should be made strong enough to resist burial pressures, or remote-control equipment should be used. Coal companies are encouraged to implement one of these options to provide protection to their surge-pile equipment operators.

For the option of strengthening the cab windows, as described in this report, chemically-strengthened glass with a modulus of rupture (unabraded) of over 60,000 psi has been demonstrated to be capable of withstanding the pressure of 35 feet of coal, with a factor of safety of more than two. Other glass or polycarbonate products, capable of withstanding this amount of pressure, may also be available. Before a window product is installed in a piece of surge pile equipment, it should be demonstrated by testing that the material will withstand an ultimate pressure of 40 psi. The testing should also demonstrate that the method specified for mounting the window to the cab, whether it be by a gasket, an adhesive, or some other means, will provide adequate overlap and strength.

Coal companies are encouraged to work with glass and equipment manufacturers to upgrade the mobile equipment presently used on surge piles, and any new equipment that may be purchased for use in this application.

Contacts

For additional information on the testing and products described in this report, the following individuals can be contacted:

MSHA

- Mark Skiles, Director, Technical Support, Arlington, VA 703-235-1570
- John Fredland, Civil Engineer, Technical Support, Triadelphia, WV 304-547-2305

PPG Industries, Inc.

- Arthur Scott, Manager Securitect Products, Huntsville, AL 256-851-1023

Caterpillar Inc.

- Tom Ambrose, Regulations & Product Compliance Manager, Peoria, IL 309-675-5421

Komatsu America International Company

- Alex Vidakovic, Principal Engineer, USA Technical Center 847-970-3733