Pennsylvania Coal Association

Bituminous Coal Mine Safety Act

Section 334 Industry Studies

Final Report

March, 2012

Sections 334 (b) and (c) of the Pennsylvania Bituminous Coal Mine Safety Act (BCMSA), 52 P.S. § 690.334(b) and (c), contain provisions concerning certain studies that were to be performed pertaining to electrical issues. These include studies related to the potential use shielded cables in certain applications, more sensitive ground fault detection and studies related to enhancing the safety of underground direct-current machine cables.

The Pennsylvania Coal Association (PCA) formed a committee with representatives of a number of operators, including representatives from higher seam longwall mines, and mines that rely on continuous miners in thinner seams and larger and smaller operations. That Committee met several times and also communicated through email and telephone discussions. The committee initiated inquiries in the following areas:

- Higher resistance grounding with more sensitive ground fault detection for section power centers.
- Shielded cables for use with section power centers to supply 600 Volt AC power to permissible and non-permissible equipment that moves with the section.
- Ground wire monitors to monitor the grounding connection between a battery and off-board portable equipment that moves with the section, i.e. direct current equipment. .

HIGHER RESISTANCE GROUNDING WITH MORE SENSITIVE GROUND FAULT DETECTION FOR SECTION POWER CENTERS.

The Pennsylvania Bituminous Coal Mine Safety Act, Section 332(4) requires that the power center grounding resistor limit ground fault current to 25 Amperes or less. A similar MSHA standard, 30 CFR 75.901(a), also requires the grounding resistor limit ground fault current to 25 Amperes or less. The MSHA Program Policy Manual for 30 CFR 75.900 recommends that the ground fault detection device be adjusted to operate at not more than 50 percent of the current rating of the grounding resistor. At the present time, standard mining industry power centers are equipped with a grounding resistor(s) that limit ground fault current to 15 Amperes. The ground fault detection devices are commonly adjusted to operate at approximately 5 Amperes.

The PCA committee agreed that increasing the resistance rating (decreasing the current rating) of the grounding resistor would offer a significant increase in the safety of the power system. This change would limit the amount of energy available in all ground faults that could occur in the power system. Any decrease in the current rating of the resistor would also require a decrease in the setting of the ground fault detection relays. This enhancement to underground section power centers offers the potential to increase the safety of the power center, the equipment powered from it as well as the trailing cable. The committee was concerned that lowering the setting of the ground fault detection relays would result in nuisance tripping.

The committee investigated manufacturers of ground fault relays and section power centers. They found the following original equipment manufacturers to be suitable sources for this equipment:

Ground Fault Relays	**Section Power Centers**
Bender 700 Fox Chase Coatesville PA 19320 304-255-7438	Intermountain Electronics 12005-1/2 Virginia Blvd. Ashland, KY 41102 877.543.9199
Littelfuse, Inc. 8755 West Higgins Road Chicago, IL, 60631 773-628-1000	Line Power Manufacturing P.O. Box 8200 Bristol VA 24203 276-466-8200
Bender-SMC Electrical Products P.O. Box 880 Barboursville WV 25504 304-736-8933	Bender-SMC Electrical Products P.O. Box 880 Barboursville WV 25504 304-736-8933

The above lists are not the only possible sources for this equipment

Testing was initiated in two underground longwall mines. This proved successful in that it did not appear to generate unacceptable nuisance tripping of the equipment. Testing was then initiated in two underground non-longwall mines, which was also was successful. At this point larger scale testing was begun. Full power centers were ordered with current limiting grounding resistors rated at three, one and/or 0.6 Amperes. The setting of the ground trip relays was varied and the lowest value that could be reliably maintained without nuisance tripping was determined to be 0.300 Amperes. As of this date there are 15 safety enhanced section power centers in service in Pennsylvania underground coal mines. The ground fault detection relays in all of these power centers are currently set to trip at 0.300 Amperes.

This testing program has demonstrated that higher resistance rated (lower current rated) grounding resistors with more sensitive ground fault relays is practical, commercially available and provides a significant enhancement to the safety of miners, working in a section power center, the equipment powered from it and handling the trailing cable.

SHIELDED CABLES FOR USE WITH SECTION POWER CENTERS TO SUPPLY 600 VOLT AC POWER TO PERMISSIBLE AND NON-PERMISSIBLE EQUIPMENT THAT MOVES WITH THE SECTION.

PCA invited the major suppliers of underground mining cable, AmerCable and General Cable, and the two leading cable repair shops located in the state, Global Mine Services and RC Kadyk to participate in this portion of the study.

There was extensive discussion of the type of laboratory testing that was necessary to determine if the use of shielded cables was feasible on underground mine equipment with cable reels. Such discussions focused, in part, on the tests that would involve bending and manipulating shielded cables. The cables other jurisdictions such as the United Kingdom of Great Britain, Australia and Canada were discussed, as well as American shielded cable. A testing protocol was developed, including identification of the types and sizes of cables to be tested, as well as the potential availability of cable to be tested.

One of the manufacturers, General Cable, had testing equipment that appeared suitable for the testing, although that equipment had not been used for several years. They offered to rehabilitate the equipment and perform the testing at one of their out of state manufacturing plants. The test cables were identified and obtained from both cable manufacturers, General Cable and AmerCable. Some of those cables were built to specifications used in other countries. The upgraded test equipment was thought to be suitable and the testing began.

Unfortunately there was a problem regarding plant visitation privileges which delayed the testing. Initially it was believed that the technical representatives of the competing cable companies would be given access to the other manufacturer to witness and participate in the testing, but this was ultimately not permitted by the cable manufacturer because of concerns over the protection of proprietary information and trade secrets. As a result, both companies agreed to do independent testing. AmerCable had to build its own test equipment. While this issue caused a delay, it resulted in a more comprehensive laboratory test program. The focus of the testing was to simulate the use of the cables on reeled equipment. The test equipment was developed to perform multiple flexing of the cable until failure was reached. The concern is that the use of reeled cables, under tension, with the occurrence of continual flexing of the shielded cable would damage the shielding. This damage results in unshielded sections of the cable and ground faults.

AmerCable Inc. Tiger®brand Shielded Shuttle Car Cable Testing

Test Objective:

To determine what shielded shuttle car cable(s) designs could be used in Pennsylvania mines as acceptable substitutes for the current non-shielded cables being used.

Design Criteria:

Cable must be capable of withstanding approximately 25,000 cycles on a machine designed to represent reeling and de-reeling of cables on shuttle cars (Shuttle Car Simulator). This was estimated to be approximately equal to 3 months of flexure in the mine.

Test Parameters:

The sheaves were 8" outside diameter and the tension was maintained at 100 lbs +/- 10%. These values were based on the practical experiences of the PCA committee members and AmerCable technical staff. The conductor temperature was approximately 75°C in a 25°C ambient. Seventy-five degrees Celsius was used instead of 90°C since this is the approximate temperature of shuttle car cable in free air, as opposed to temperatures down in the reel. The power conductors were wired in series to apply current. The machine was set to shut down when a power conductor experienced fatigue failure, or when the ground check or a grounding conductor broke. Also, a ground fault monitor was used to determine if/when a braid shield wire broke and penetrated the insulation. This too was set to shut down the machine at that moment.

Background on Test Cables:

The cables selected by the PCA committee were representative of shielded cables being used in the U.S., shielded shuttle car cables being successfully used in other countries; and a control sample of both non-shielded Type GGC and copper braid shielded Type SHD-GC.

The following cables were tested:

- **Tiger® brand standard #2AWG 3/C Round Type GGC**

  This was selected to establish base line data for what is probably the most commonly used shuttle car cable in the U.S.

- **Australian Type 275 CPE**

  This sample was labeled TR1069 and uses the standard #2 3/C Round GGC assembly, but with semi-conductive rubber insulated grounds and a semi-conductive rubber inner jacket layer. It had an AmerCable standard Extra-Heavy-Duty (EHD) Chlorinated Polyethylene Rubber (CPE) outer jacket layer.

- **Australian Type 275 TPU**

  This sample was labeled TR1067 and has the same design of the cable assembly, but with a Thermoplastic Polyurethane (TPU) semi-conductive inner jacket layer; and an EHD TPU outer jacket material.

- **British Standard BS 6708 Type 11**.

  This cable had three copper/nylon individually braided shielded power conductors, and one individually shielded pilot (ground check) conductor equal in size to the power conductors. This cable had no bare copper grounding conductors in the interstices. The copper braid shielding over all four conductors is made to the British requirement and has enough mass to carry any fault current that might occur during a failure. The specification BS 6708 contains dc resistance requirements for the braid shields in parallel.

- **Tiger® brand standard #2AWG 3/C Type SHD-GC**

  This sample was a standard commercially available American design.

- **South African Type RSA 41.5**

  This cable had two 35mm^2 conductors in a Flat Type GGC construction a Hypalon rubber jacket. It was a brand new style of semi-conductive shielded flat DC shuttle car cable designed by AmerCable for coal mines in the Republic of South Africa.

Laboratory test results for each of these cables are shown below. The performance is recorded in cycles to failure or, if no phase to ground failure occurred, the target was approximately 25,000 cycles. Each cycle consists of a full traverse (down and back) of the Shuttle Car Simulator trolley.

Diagrams of the above cables and pictures of the test equipment and cable samples are in Appendix A of this report.

AmerCable Inc. Test Results

Cable Description	Cycles	Comment
#2AWG 3/C Round Type GGC	25,565	no failure
Australian Type 275 CPE	11,250	cable became kinked and had to be taken off of the machine
Australian Type 275 CPE	25,000	no failure
Australian Type 275 TPU	272	semi-conductive TPU cracked
British Standard BS 6708 Type 11	25,000	no failure
#2AWG 3/C Type SHD-GC	3,512	braid wire broke and penetrated the insulation
South African Type RSA 41.5	10,800	phase conductor wire broke and penetrated ground

Discussion:

Of the shielded cables, the British spec BS-6708 metallic shielded cable and the Australian Type 275 clearly performed the best on this test. They both performed equally to the most common shuttle car cable in the U.S., that being the #2 AWG 3/C Round Type G-GC non-shielded cable built to the Insulated Cable Engineers Association (ICEA) S-75-381. The ICEA spec SHD-GC was the second worst on this test, and hence will in all probability be a very poor performer in very small radius reeling applications at the mines. When used on larger diameter reels and guider sheave wheels, it should perform better.

A brand new style of semi-conductive shielded flat shuttle car cable for DC was designed by

AmerCable for coal mines in the Republic of South Africa. The first sample did quite well. Changes to the construction have been made, but no additional samples were tested on the Shuttle Car Simulator. While a work in progress this construction is considered to have good potential, even at 10,800 cycles to failure. The semi-conductive shielding performed its task and tripped the circuit breaker when one of the individual wires of the power conductor broke and penetrated the insulation.

General Cable Shielded Shuttle Car Cable Testing

After extensive technical discussion between the PCA committee and General Cable technical staff a laboratory test protocol was developed. General Cable had previously built testing equipment and this equipment was in line with the needs of the PCA to test cable; however the equipment had not been used for testing for several years. General Cable offered to rehabilitate the test equipment and perform the testing at their Marion, Indiana cable factory.

The testing equipment consisted of two apparatus to test cables – each subjecting the cables to different forces. The first tester, the "Flex Testing" apparatus, held a cable sample under tension and flexed the cable through an angle of 180°. Cables are periodically checked for shorts and opens in the various conductors. The test is performed for 10,000 cycles on round cables and for 20,000 cycles on flat cables. After the test is completed the test cable is dissected and the cores and shields are examined for individual wire breakage.

The second test simulated the operation of a mine shuttle car. This test used a stationary piece of cable on a traversing carriage. Four sheaves create a double "S" bend in the cable as it cycles over a 15 foot distance and the cable is tensioned with air pressure of 100psi (±10 psi). Round cables are cycled to a count of 7,500 and flat cables to 8,000. Again the samples are periodically checked for shorts and opens and upon test completion, the test cable is dissected and the cores and shields are examined for individual wire breakage.

The suitable candidate cables for test were identified and obtained. Those cables were #2 AWG, three conductor, 2 kV cables as described below:

- Round G-GC (non-shielded)
- Round G-GC (with a semi-conductive rubber inner jacket)
- Round SHD-CG (with a nylon and copper braid shield)

- Flat G-GC (non-shielded)
- Flat G (with a semi-conductive rubber inner jacket)

The test equipment was upgraded and thought to be suitable to perform the testing and the testing was begun. General Cable developed the cable designs, created the manufacturing work instructions and then manufactured sample cables for testing and the testing commenced. A problem was discovered late in the testing of the General Cable sample cables. A wear issue was discovered late in the process when certain test results were simply unbelievable. This wear issue invalidated all previous tested samples. The test equipment had to be redesigned, in some cases new cable samples had to be produced, and the testing restarted.

By March of 2010 General Cable had tested four of the five cable candidates that they had agreed to test. While the last sample cable was being manufactured an issue was discovered with the shuttle car simulator's gear box. In order to extend the life of the gearbox to complete the testing, it was agreed to reduce the cycle time of the shuttle tester. This caused a delay as the testing that had occurred there had taken place at much slower cycle speeds than expected because of this gear box issue. This continued until it was realized that the gearbox had to be changed as it was pending a catastrophic failure. Testing of the last sample was delayed until the gear box could be replaced. Once the gear box was replaced the final cable sample was tested. To provide comparable data, the last cable was tested at the same "slower" cycle speed as the other cables.

Once this final cable sample was tested, data from the cable tests were evaluated, analyzed and presented to the PCA.

- Ground conductors in metallic shielded cables performed poorly in the flex test.

- Ground conductors with a semi-conductive shield performed poorly in the shuttle car simulator test.

- Wire breakage in both power and ground check conductors was approximately equal in all 3 round cables tested.

- Metallic shield wire breakage (discovered in the shuttle car simulator test) would likely lead to premature phase-to-ground shorts.

Two flat cables were tested, a #2 AWG, four conductor, type W and a #2 AWG, three conductor, type G with a semi-conductive inner jacket acting as a shield. The tests on these cables revealed:

- Little difference was found between the two cables with respect to power conductor wire breakage.

- Ground conductors in the type G with the semi-conductive shield surrounding did not hold up well.

Following a meeting with PCA, General Cable determined that the laboratory tests needed to be performed again to validate the data presented and alleviate questions raised about the testing by the PCA. General Cable was tasked with retesting the following cables:

- #2 AWG, three conductor round 2 kV Anaconda cable (type G-GC)

- #2 AWG, three conductor round 2 kV Anaconda cable with a semi-conductive inner jacket shield (type G-GC).

- #2 AWG, three conductor flat 2 kV Anaconda cable with a semi-conductive inner jacket shield (type G).

At this time, General Cable had developed two new cable designs. The General Cable designs were modifications to standard cable designs, a round 2 kV #2 AWG three conductor type G-GC Anaconda cable with an inner jacket layer of semi-conductive rubber and a flat 2 kV #2 AWG three conductor type G Anaconda cable also with an inner jacket layer of semi-conductive rubber.

After the retesting, PCA advised that there was little benefit in further laboratory testing and CONSOL has agreed to test both of the new cable designs in a mine.

Representatives from CONSOL, R.C. Kadyk, and General Cable met to discuss the in mine testing. CONSOL agreed to field test the new round type G-GC and flat type G General Cable designs with the semi conductive inner jacket (from here on referred to as "safety enhanced" cable). R.C. Kadyk requested a quote for 4,000 feet of the round cable so that adequate quantity of the cable would be available for a meaningful test. CONSOL did offer to look into modifying equipment using round cable to accommodate flat cable to facilitate the testing of the flat cable.

Both the BMX and Enlow Fork mines use a "CONSOL Spec" type W cable (a standard type W cable with a semi-conductive layer over the ground wire) shuttle car cable. BMX Mine agreed to install a length of the new safety enhanced round cable on a shuttle car. When this cable was to be removed from service, BMX Mine agreed to test the new flat safety enhanced cable.

BMX Mine tested the round safety enhanced cable in their mine. The cable operated for three weeks. When the cable was taken out of service it had 5 splices/taped spots on it. Reports stated that on the first day of operation the cable was pulled around the rib and torn in two. Mine personnel spliced the cable and reported that the cable appeared to be more difficult to splice then a standard cable. The cable was returned to R.C. Kadyk's shop for inspection.

In September CONSOL requested that General Cable provide splicing recommendations and procedures for the enhanced cables. General Cable, working in conjunction with TE Connectivity was tasked to develop procedures for splicing three cables: three conductor flat type G (2 kV); three conductor round type G-GC (2 kV); and four conductor round type W cable (also 2 kV).

General Cable's new enhanced #2 AWG four conductor round type W cable was placed in service on a shuttle car at CONSOL's Enlow Fork Mine. Service life of the cable was typical of shuttle car cable life at the mine. The cable had one splice in it, the remainder of the jacket was in good condition. Delving deeper, the splice was well made but mine personal noted that splicing the cable took longer than normal to complete due to the jacket being difficult to strip. The cable performed as designed; a failure in the cable generated enough fault current to trip the breaker. From a safety point of view, the cable met the expected goals. From a cable repair point of view, the cable under performed. General Cable was contacted and asked to start a root cause investigation as to why the cable was so difficult to strip.

Investigation by General Cable revealed that the stripping problem was caused by inconsistent application of talc between the conductor insulation and the inner semi-conductive jacket. Sections of the cable that had adequate talc applied were significantly easier to strip then sections lacking enough talc. Without a proper amount of talc applied to the core, the inner jacket bonds to the phase insulation during the curing process making the cable difficult to strip.

Several measures were taken by the Marion plant to ensure proper manufacture of this new product. An audible alarm was tied to a visual alarm on the equipment applying the talc; A visual aid showing proper talc application was placed at the operator work station; and a refresher training course was conducted for all operators.

At this time, in mine testing is still being conducted. CONSOL wishes to continue to test the #2 AWG four conductor type W safety enhanced cable. The cable is on order

Additional information is included in Appendix B.

Illinois Mines using Shielded Cable

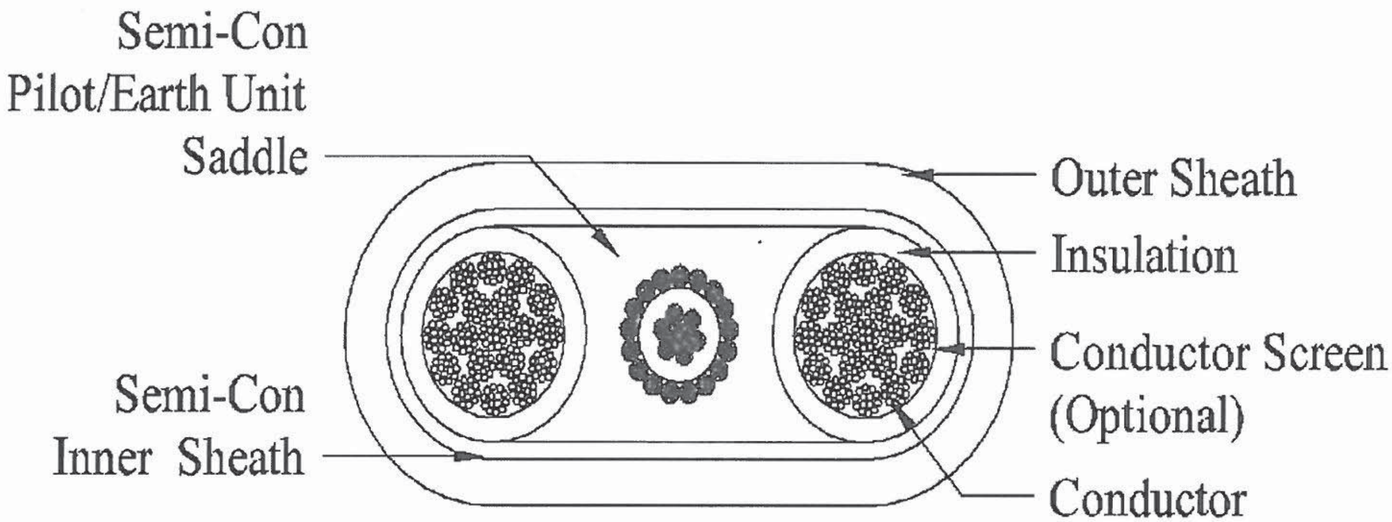
It was brought to the attention of the PCA committee that there are operating coal mines in Illinois using shielded cable for all face equipment powered from their section power centers. The committee was able to confirm that five mines are using shielded cable for all face equipment. Each of these mines is operating all face equipment at 995 VAC. Only one mine is operating cable reel shuttle cars. The committee was unable to gain any specific knowledge regarding cable life, splicing issues or shield deterioration. The lack of concrete information on the use of shielded cables in Illinois, prevents any meaningful comparison or analysis for the purpose of this report.

Finding

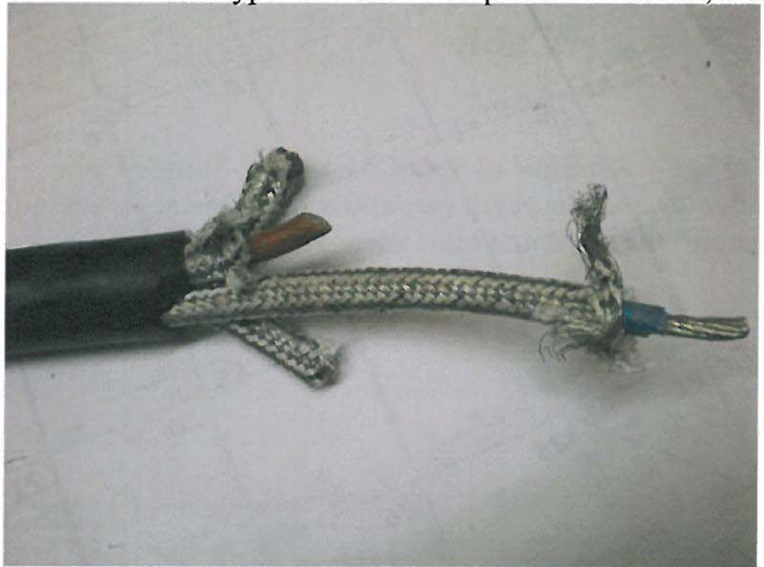
As a result of all the above information, at this time, the PCA committee finds that shielded cables available for use in Pennsylvania underground coal mines could not be expected to provide reasonable service.

Appendix A
AmerCable

Flat DC Shuttle Car Cable for Republic of South Africa DC Shuttle Cars
Pilot is the small central conductor and the earth (grounding conductor) is stranded around the insulated pilot wire.



British BS 6708Type 11: 3 screened power conductor, 1 screened pilot



Description: 3-phase 4-core. Three power cores and one pilot core having the same nominal cross-sectional area, each having a protective metallic screen, laid around an elastomeric centre, sheathed overall. The combined screens shall function as the cable earth conductor

U.S. Type G-GC: 3 non-screened power conductors, 2 earthing conductors, and one pilot per Insulated Cable Engineers Association S-75-381/NEMA WC-58


U.S. Type SHD-GC 2kV: 3 copper/nylon braid screened power conductors, 2 earthing conductors, and one pilot wire per ICEA S-75-381/NEMA WC-58.

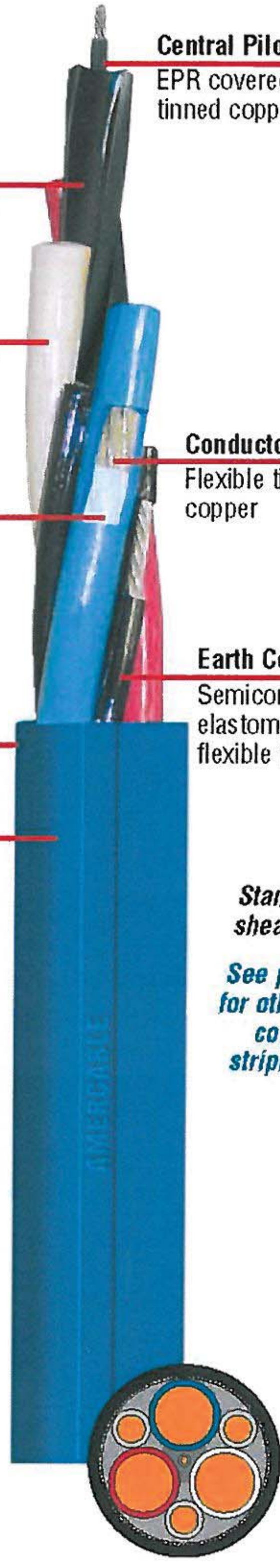
Type 275
Mould-cured CPE Sheath • 1.1kV

Summary

Used for shuttle cars or other equipment with cable reels.

AmerCable Mining Cable meets or exceeds AS/NZS 1802 Standards.

Highly flexible construction with abrasion resistant CPE sheath. Available in colours and stripes.



Central Pilot Core
EPR covered extensible tinned copper

Cradle Separator
Semiconductive elastomer

Insulation
Ethylene-propylene rubber (EPR) R-EP-90

Conductors (3)
Flexible tinned copper

Separator Tape
Polyester

Earth Conductors (3)
Semiconductive elastomer covered flexible tinned copper

Core Assembly Screen
Semiconductive elastomer

Sheath
Reinforced mould-cured heavy-duty thermosetting elastomer sheath

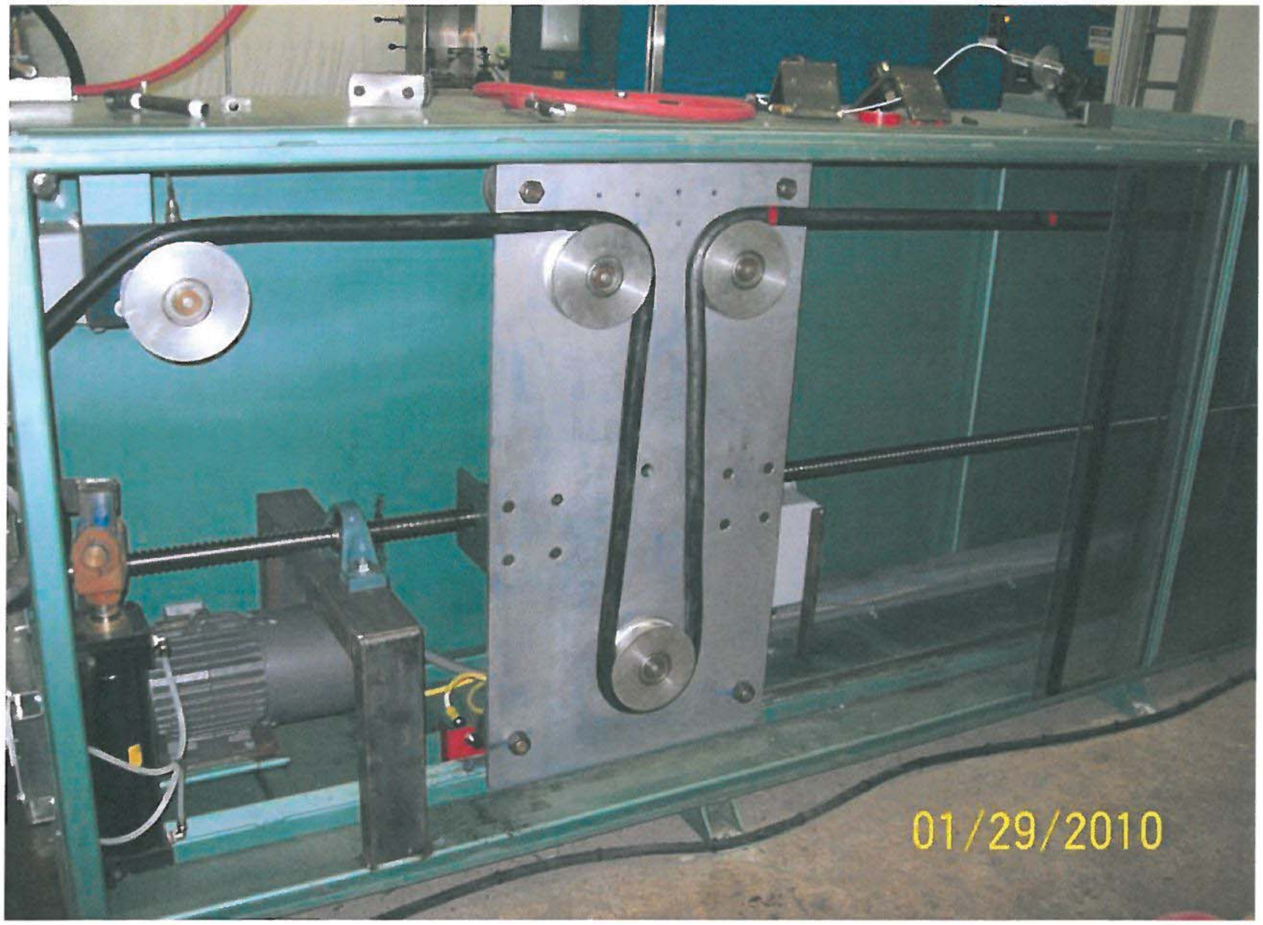
Cable identification via permanent marking

Standard cable sheath is black.

See pages 17-18 for other available colours and striping options.

All materials in AmerCable Australia's mining cables are lead free.

Put the Power of AmerCable in your Mine



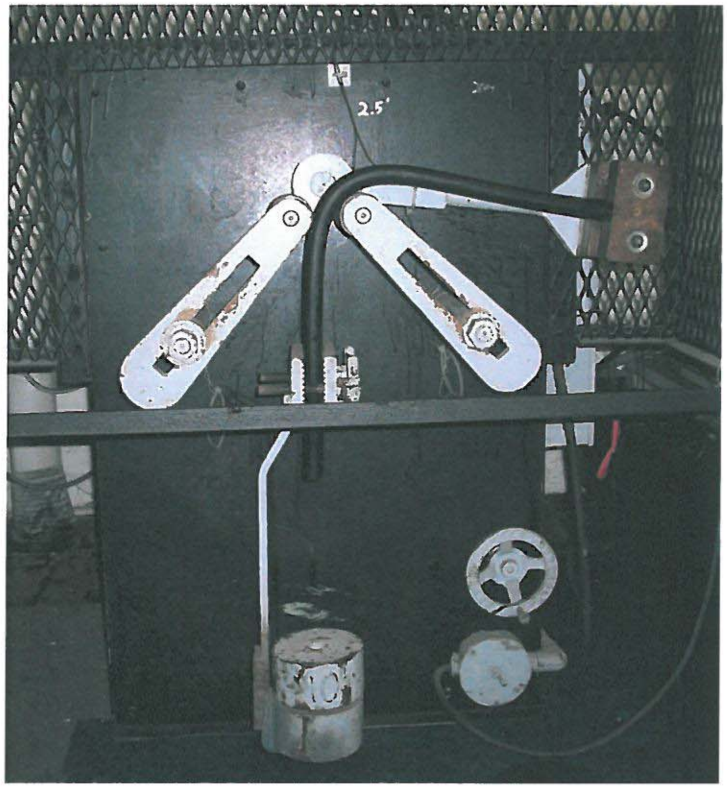
Shuttle Car Simulator

Australian Type 275, first sample kinked

Standard SHDGC with broken shield wires. Also, note the wide spacing of the braid wires after only 3,512 cycles.

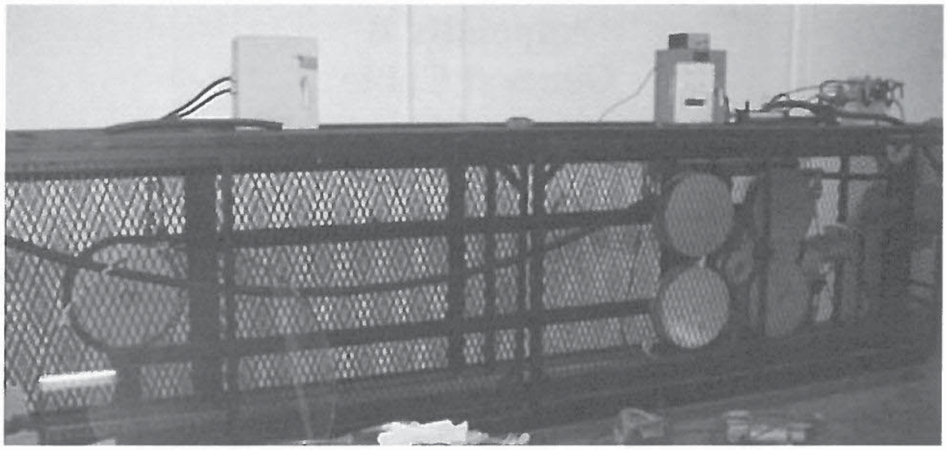
SHDGC shield wires penetrated the insulation causing the trip.

Appendix B
General Cable



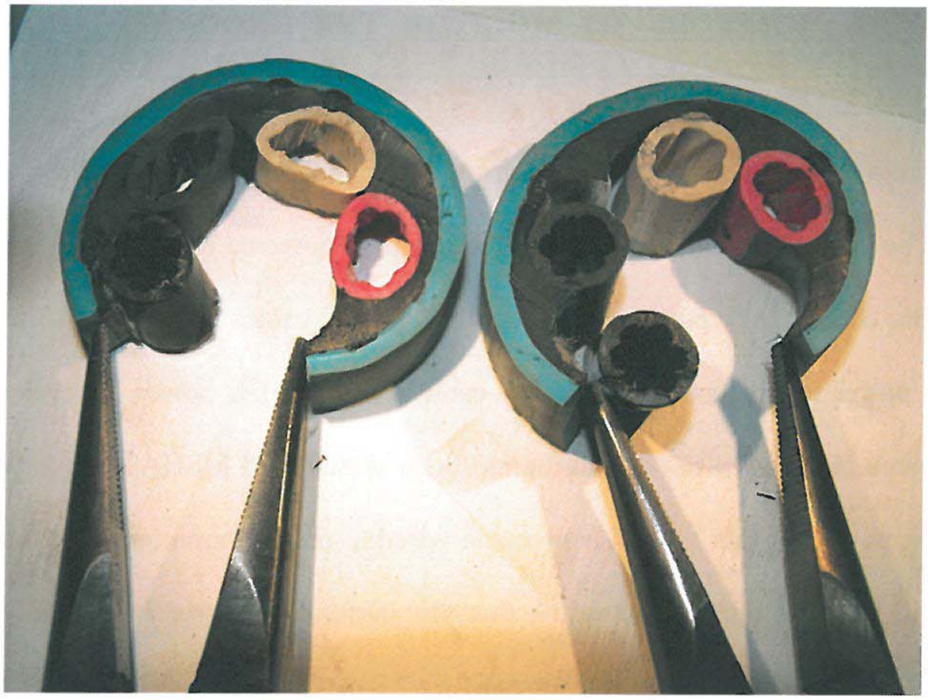
Flex Testing

- Cable is flexed under tension through an angle of 180°
- 10,000 cycles for round cables
- 20,000 cycles for flat cables
- Samples periodically checked for shorts & opens
- Dissection for the examination of wire breaks



Shuttle Car Simulator Testing

- 7,500 cycles for round cable and 8,000 cycles for flat cables
- Samples periodically checked for shorts and opens
- Dissection for the examination of wire breaks
- Test utilizes a stationary piece of cable on a traversing carriage
- Four sheaves create a double "S" bend of the cable as it cycles over a 15' distance
- Cable tension air pressure:100 PSI ±10PSI



From the photo it can be seen that the cut cross sections of two cable samples behave very differently when they are spread apart with the pliers. The "without talc" section on the left, shows that the phase insulation is bonded to the semi-conductive jacket

GROUND WIRE MONITORS TO MONITOR THE GROUNDING CONNECTION BETWEEN A BATTERY AND OFF-BOARD PORTABLE EQUIPMENT THAT MOVES WITH THE SECTION.

The Pennsylvania mining industry evaluated ground wire monitors for use on direct current (DC) equipment. The use of portable and/or mobile equipment powered by DC cable is not common but a few mines occasionally power equipment through DC cables. There are a limited number of mines that power equipment through a DC cable where the DC power is developed from an AC power source in a power center/distribution box. A standard MSHA accepted ground wire monitor can be powered from the AC source and wired to provide monitoring of the DC ground connection. In fact it is our understanding that this currently required by the Bureau of Mine Safety through their equipment approval process.

A second method is to power equipment through a DC cable where the DC power is developed from an ungrounded battery. An example is a power take off (PTO) that provides power to a power center carrier. The carrier is powered by DC motors. The cable connecting the carrier to the PTO includes a conductor that is connected to the battery case at one end and the power center carrier frame at the other. The circuit breaker protecting this cable is interlocked to trip the circuit breaker if any plug is opened. The circuit is also protected against overload and short circuit. The power center carrier is only energized to relocate the unit after high voltage AC power is removed from the power center. A second example is powering a longwall monorail cable handling system after longwall cables have been de-energized as part of a longwall section power move.

We obtained the following list of companies that offer MSHA accepted ground wire monitors for use in underground coal mines.

American Electric, Inc.
P.O. Box 710
Beckley WV 25802
304-255-7438

American Mine Research, Inc.
12187 North Scenic Highway
Rocky Gap VA 24366
276-928-1712

Gai-Tronics Corporation
400 East Wyomissing Avenue
Mohntown PA 19540
800-492-1212

Line Power Manufacturing Corporation
P.O. Box 8200
Bristol VA 24203
276-466-8200

Mining Controls Incorporated
P.O. Box 1141
Beckley WV 25802
304-252-6243

Pemco Corporation
P.O. Box 1319
Bluefield VA 24605
276-326-2611

Bender-SMC Electrical Products
P.O. Box 880
Barboursville WV 25504
304-736-8933

None of these manufacturers have an approved ground wire monitor that is rated for use on battery powered equipment. There are no MSHA-approved direct current powered ground wire monitors. A DC powered monitor would be required as the AC power is de-energized in the above examples.

American Electric, Inc. was the only manufacturer that was willing to work with us to develop a DC ground wire monitor. We set up a test area at Marion Engineering in Fairmont, West Virginia. Several prototype units were tested and each one failed. Attempts to modify existing MSHA accepted monitors by Marion Engineering also resulted in failure.

Caterpillar (Bucyrus) initiated a project to develop an MSHA accepted DC ground wire monitor. After several months they determined that a plug interlock circuit extended to the load is the current state of the art in this area.

The technical difficulty associated with developing such a monitor, the need to avoid grounding the battery and a limited market for this type of equipment are significant reasons that no such monitor is commercially available.

Our finding is that a DC ground wire monitor is not practical at this time.