How To Cut Downtime And Extend Cable Life

Surface mining cable care and maintenance

ANACONDA BRAND

General Cable

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contents

"Colossal" is the best word to characterize modern surface mining operations—both in terms of scope and size of equipment. A fact which has placed growing importance on ensuring a continuous flow of current to these massive mining machines. This has become even more important given today's highly competitive economic environment.

Anaconda® Brand mining cables have been designed to reduce cable-related downtime, as this factor represents a serious impact to mine profitability. In operations of these magnitudes, every minute of downtime is very expensive, and once lost, can never be recovered. This has led us to assemble considerable information and know-how over the years on how such downtime can be minimized.

This booklet represents a timely updated body of knowledge for surface mining. It reduces our recommendations to simple procedures that can readily be passed on to all your operating personnel.

A companion piece is available on underground mining cable care and maintenance.

The Huge Cost of Cable Downtime Today

Reliable performance of modern trailing cables is essential to low-cost coal mining. The unscheduled interruption of production, resulting from cable failures, costs much more than is generally realized. Lost tonnage, interest, depreciation, overhead and labor costs associated with this kind of downtime can surpass the initial investment in cable.

Obviously, it has become vitally important in today's mining operations to minimize downtime through proper handling and maintenance of cables. In order to do this most effectively though, an understanding of the design of trailing cables and an awareness of their optimum performance limitations can be of great value.

Design of Surface Mining Cables

Surface mining with large electric shovels began in the early 1920s. At that time, shovel cables were relatively small in size, insulated with natural rubber and protected only with coverings of asphalt-impregnated cotton braid or a spiral wire armor.

Over the years, conductor sizes increased greatly along with growing shovel capacities. But at the same time, many sophisticated advances took place in polymeric insulating and jacketing materials, as well as in stranding and shielding techniques.

General Cable played a leading role in pioneering these advances, which have lead to cables such as the highly engineered, tough, flexible design shown in Figure 1.

Here is a brief description of each of the components:

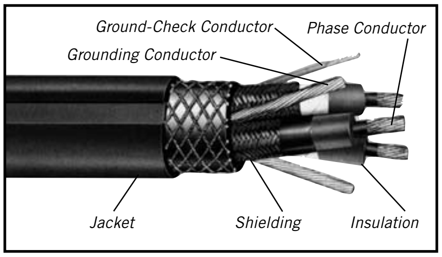

Figure 1

Jacket

Chlorinated Polyethylene (CPE) is now the standard for a tough, flexible jacket. In addition to superior tensile strength and abrasion resistance, it has a wide thermal range from 90°C down to -50°C.

CPE possesses natural resistance to ozone, making it especially suitable for high-voltage applications.

Even so, a common problem with jackets occurs when excessively long lengths of the cable are put on a hitch and dragged with a caterpillar. The jacket will normally tear under the load. Ways of avoiding this are described under the "Proper Care and Maintenance Greatly Reduces Downtime" section.

Shielding

Remember that an ungrounded shield is dangerous and should be treated as an energized conductor. The shield must be grounded at least at one end and preferably at two or more locations. It is recommended that shields be grounded at all cable terminations and splices. Stress cones should be installed at all high-voltage shield terminations.

The well-known functions of the shield include:

1. To obtain symmetrical radial stress distribution within the insulation and to eliminate, for practical purposes, longitudinal stresses on the surface of the insulation or jacket

2. To provide a definite capacitance to ground for the insulated conductor, thereby presenting a uniform surge impedance and minimizing the reflection of voltage waves within the cable run

3. To reduce the hazard of shock and danger to both life and property

Reliable performance of modern trailing cables is essential to low-cost coal mining.

Tests have shown that the copper/textile braid shield is mechanically superior to a full copper braid.

Shielding (con't)

Shielding wires have also been found to perform another function, especially important where ground continuity is essential. In constructions where grounding conductors are laid in the cable, in contact with the shield throughout the length of the cable, ground continuity is assured through the infinite number of parallel paths provided.

There are two types of flexible shielding which have become associated with surface mining:

1. Full copper braid
2. Copper/textile braid

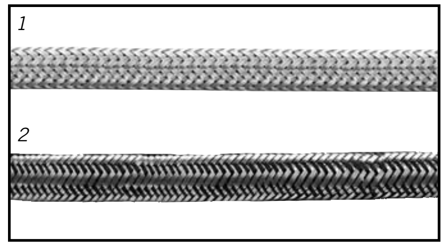

Figure 2

Tests have shown that the copper/textile braid shield is mechanically superior to a full copper braid. This is largely because the individual wires cross over threads instead of other wires. (Figure 2)

The problems that develop with shielding systems are generally related to kinks in the semi-conducting tape which cause stress points, leading to dielectric breakdown over a period of time. The best protection is to observe the minimum bending radii recommended by Insulated Cable Engineers Association (ICEA).

Grounding System

Grounding conductors and shielding wires cannot be separated from each other when considering effective ground impedance because together they form the total grounding system.

As a result, little change occurs in the grounding system impedance after individual components have suffered extreme flex fatigue. In fact, it has been shown that the grounding system will continue to function long after phase conductor failure renders the cable inoperative.

The function of the grounding system, theoretically, is to carry fault current and simultaneously limit the resulting voltage drop in the grounding circuit external to the grounding resistor to not more than 100 volts. This means that the fault current flowing in the grounding conductors and shield wires, all connected in parallel, multiplied by the resultant impedance cannot exceed 100. Where the maximum fault current is limited by a grounding resistor, it seems that the parameters for sizing the grounding conductors are thereby defined.

Even though the grounding system might be considered fail-safe, continuous ground monitoring is required by Federal law to ascertain continuity through connections and to assure solid terminations.

Ground-check conductors are included in trailing cables to facilitate this ground monitoring. Premature flex fatigue of these ground-check conductors has been virtually eliminated by the application of a heavy wall of polypropylene insulation that prevents kinking. In cases where the ground-check conductor is much smaller than the phase conductor, its flex life is best improved by increasing the insulation wall thickness. The objective is to derive maximum resistance to kinking.

Insulation

Ethylene Propylene Rubber (EPR) insulation is now standard in mining cables, and has helped reduce insulation thickness by one third, while nearly doubling typical breakdown voltage.

Ethylene Propylene Rubber has excellent mechanical properties over a temperature range of -60°C to +90°C. Within this range, EPR has high tensile strength, resistance to tear, abrasion, and compression cut. In addition, it is flexible and easy to repair, making it well suited for rugged mining environments.

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Conductor Stranding

Mining cable conductors are stranded to provide both flexibility and flex life. The flex life of a particular construction is the number of times it can be bent back and forth before the strands fatigue. Flex life or resistance to flex fatigue is a function of stress. The relationship is nonlinear, especially in the low-stress portion of the curve. (Figure 3) Theoretically, at some point on the curve below you could increase the flex life by a factor of 10 simply by reducing the stress by one half, however operating at very low-stress levels can be impractical.

Flex fatigue in any portable cable is a certainty and just a question of time. To prolong the time before it happens, the important thing is to balance the tensile load among the individual conductors as uniformly as possible.

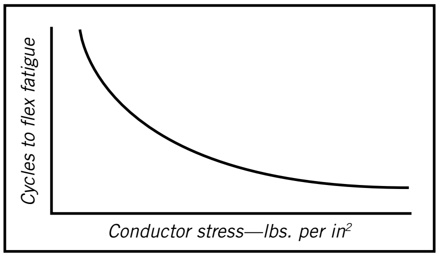
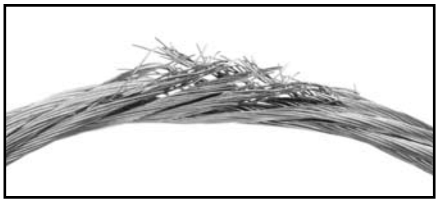


Figure 3

Manufacturers' recommended minimum bending radii and maximum tensile loads are calculated with this in mind. Exceed them, and you will greatly accelerate failure rates. In which case, the percent reduction in flex life exceeds the percent increase in operating limitations by a large margin.

The recommended Insulated Cable Engineers Association (ICEA) minimum bending radii is as follows:

- Braid-shielded portable cable—8 times the cable diameter
- Nonshielded portable cables—6 times the cable diameter
- Flat nonshielded cables—6 times the minor dimension



The control sample was flexed continuously for a specified number of cycles over a given bending radius, under specific tension, until only a few strands remained unbroken.

The second sample was flexed the same number of cycles over the same bending radius, but the tension weight was reduced by one half. As can be seen, reduction of tension greatly reduced strand breakage.

The third sample was again flexed the same number of cycles using the same tension as with the control sample. However, a bending radius two and one-half times larger was used. Increasing the bending radius practically eliminates strand damage.

Increasing the bending radius practically eliminates strand damage.

Cable breakdowns are neither mysterious nor unaccountable, and almost without exception the cause can be traced.

How Surface Mining Cables Fail

Cable breakdowns are neither mysterious nor unaccountable, and almost without exception can be traced to one or more of the following causes:

1. Excessive tension
2. Mechanical damage
3. Current overload
4. Improper splicing and termination techniques

Excessive Tension

Many cable failures are the direct result of excessive tension. A cable that has been "stretched" no longer has the balanced construction that is so vital to long life. Tension on the conductors subjects the individual wires in the strand to compression and shear. These thin wires are then damaged and will break more easily when bent or flexed.

Tension also elongates the conductor insulation. The elongated insulation is then vulnerable to compression cutting. It will rupture more easily when it is crushed against the stranded conductor during runovers. The insulation will also have a tendency to creep over the conductor at a splice.

Jackets under tension lose a considerable part of their resistance to mechanical damage. A jacket under tension is much more likely to be cut or torn. Stretching also causes the copper conductors to take a permanent set. Of course the insulation and jacket are stretched as well, but they will return to their original length when the tension is removed. This difference in the properties of rubber and copper when subjected to tension will cause the conductors to be wavy and fail prematurely.

Mechanical Damage

This is one of the most prevalent sources of trailing cable failures. Factors initiating mechanical damage include cutting, compression (crushing), punctures and abrasion.

In extreme cases of mechanical damage, the failure is instant and the cause can be assigned on the spot. Many times, however, the cable components are merely "injured" and become latent failures. At that point, it may be more difficult to pinpoint the exact cause and to take remedial action.

Current Overload

The temperature of the conductors, insulation and jacket are, of course, elevated when cables are subjected to an electrical load. The resistance of the copper is increased, voltage drop in the cable is increased and therefore, a reduced voltage is supplied to the machine. As a result, the machine calls for even more current which adds further to cable heating.

Current Overload (con't)

A trailing cable's insulation and jacket materials exhibit maximum resistance to physical abuse at the rated conductor temperature of 90°C or less.

The ability of these components to withstand damage decreases as the temperature increases. Conditions which normally cause few cable failures suddenly become a problem. At elevated temperatures, the jacket has lost much of its resistance to cutting, crushing, tearing and abrasion.

When cables are used with one or more layers wound on a reel, the ampacities should be derated as follows:

No. of Layers	Multiply Ampacities By
1	0.85
2	0.65
3	0.45
4	0.35

Figure 4

The section of the cable that remains on the reel is most likely to be damaged by electrical overload. Layering on the reel hinders ventilation and heat dissipation. (Figure 4) Continued exposure to elevated temperatures will age the jacket, making it hard and brittle, and causing crazing or cracking upon subsequent reeling.

Improper Splicing and Terminating Techniques

Over the years, much work has been done to improve both splicing materials and techniques. The following items have been found to be primarily responsible for unsatisfactory splice service:

1. Ending up with a grounding or ground-check conductor which is shorter than the power conductors
2. Semi-conducting residue on the insulation surface that was not removed
3. Gaps, voids or soft spots in the insulation tape build-up
4. Improper termination of shielding system, leaving inward-pointing projections
5. Damage to factory insulation by improper removal of shielding systems
6. Excessive slack in one or more individual conductors
7. Splice has low tensile strength and is easily pulled in two
8. Individual wires are damaged during application of connector
9. Splice is too bulky—will not pass through cable guides or over sheaves
10. Improper application of the outer covering allowing water to enter the cable interior

By choosing a cable with an adequate current rating, avoiding excessive tension and mechanical damage, and using proper splicing techniques, it is not unreasonable to reduce cable-related downtime by more than 50 percent. This will, of course, translate into increased production and profits.

A trailing cable's insulation and jacket materials exhibit maximum resistance to physical abuse at the rated conductor temperature of 90°C or less.

The best means of minimizing the occurrence of harmful situations is a workable cable maintenance program.

Proper Care and Maintenance Greatly Reduces Downtime

The cable failure mechanisms described in the previous section are usually brought into play by one or more of these common surface mining situations:

1. Rock falls and slides
2. Runovers by pit equipment
3. Dragging
4. Improper splicing

The best means of minimizing the occurrence of these harmful situations is a workable cable maintenance program. This program should not be limited to a few "Dos and Don'ts," but must consist of a series of good cable practices that become a habit and fit naturally into the daily mining routine.

An Effective Program

There is no magic formula for cable maintenance that fits all conditions. The following basic outline suggests an approach that can be applied at any operation:

1. Choose a cable design that is consistent with voltage, safety and expected performance
2. Maintain a record of causes of cable failures
3. Educate operating personnel to recognize the limitations of a portable cable
4. Take remedial action based on records and education. Records will point to what made the cable fail. Education will help explain why the cable failed.

Effective maintenance begins with choosing the most suitable cable construction obtainable for the application. *Economic considerations alone are a poor substitute for sound engineering.* Cable manufacturers like General Cable supply an abundance of data to serve as a guide, but the following should be emphasized in choosing a cable type and size:

1. Safety
2. Current-carrying capacity
3. Voltage drop
4. Ambient temperature—for example, extreme summer heat
5. Mechanical strength
6. Unusual conditions that might require a special cable construction

The second step in a good maintenance program is analysis of performance. An accurate record must be maintained and should include:

1. The date of installation
2. Record of removal for repairs
3. The cause of each failure

Information on number 3 is the most important of all.

An Effective Program (con't)

An accurate record of causes of failure will point out those areas where maintenance is most urgently needed. This record will also indicate the effectiveness of any remedial action that might be taken. Experience is a good teacher and can be most useful in setting up a program; but experience can be greatly enhanced by an accurate record. There is too great a tendency to classify practically every failure under "improper handling by operating personnel."

There should be mutual understanding between the cable manufacturer and mining operator concerning the physical and electrical limitations of a cable. Such an understanding will prove to be one of the most rewarding steps in the entire program. Cable manufacturers like General Cable can offer valuable assistance in training programs designed to instruct operating personnel in good cable practice.

Rock Falls and Runovers

Falling rock and runovers are responsible for approximately 50 percent of all cable failures, calling for a concentrated maintenance effort. Cables subjected to rock falls and runovers by heavy equipment are damaged by impact and crushing.

Trailing cables have, on occasion, exhibited outstanding resistance to mechanical damage, but to a large degree their ability to withstand impact and crushing is limited by the following:

1. The concentration of impact on a small area of cable—a rock striking the jacket surface, sharp-edge-first, can do more harm than a larger rock landing flat-side-down.

2. The position of the conductors at the point of impingement—the most vulnerable is when one conductor rests directly over another. The metal conductors serve as blunt cutting edges, and under severe impact, will initiate breaks or ruptures in the insulation.

3. The physical characteristics of the jacket and insulation—relatively speaking, jackets have the properties found in tire treads. High-voltage insulations are approximately one-half to two-thirds as tough as the jackets.

4. Flexible shield and grounding conductors are, of necessity, constructed with small-diameter wires—when subjected to impact or crushing, they are readily deformed and easily broken. For example, an individual shielding wire has a breaking strength of approximately 4 lbs.

Damage to cable components by rock falls and runovers are all potential blowout points. Cuts in jackets provide entrances for water to penetrate the cable. Deformed or injured copper wires accelerate fatigue breaks. Insulation with compression breaks will rupture electrically.

Maintenance suggestions that require repetition are:

1. Move cables into the clear during blasting.

2. Position cables in the pit where the possibility of them getting hit by rock slides from the spoil bank or highwall is minimized.

3. Provide vehicles and areas of heavy traffic with adequate lighting during nighttime operation. Cables should be kept visible at all times.

4. Either bury cables or provide arched runways at vehicle crossings.

There should be mutual understanding between the cable manufacturer and mining operator concerning the physical and electrical limitations of a cable.

While it is true that no splice is as good as a new cable, the use of quality materials and proven techniques can dramatically improve the service life of a spliced cable.

Dragging

It is quite possible to avoid jacket tearing and other cable injuries caused by dragging—instead of putting a single loop on a caterpillar hitch, you should pull the cable into more loops, thereby shortening the length of each pull.

Proper Splices

While it is true that no splice is as good as a new cable, the use of quality materials and proven techniques can dramatically improve the service life of a spliced cable. A good splicing has the following characteristics:

1. High tensile strength—the splice cannot be easily pulled in two
2. Balanced conductors—equal tension on each conductor
3. Small outside diameter—the splice can be passed easily through existing cable guides
4. Low electrical resistance
5. Adequate insulation
6. High resistance to fatigue
7. A covering that is capable of keeping moisture from entering the cable interior

Preparation of Cable for Splicing

In preparing cable ends for splicing and terminating, there are certain steps that require special attention and technique to insure against premature failure. These are listed below:

1. Cable ends should always be cut carefully and squarely.
2. The outer jacket should be removed without damaging shield tapes or braid by the following procedures:
   a) Ring jacket circumferentially through approximately 80 percent of the jacket thickness.
   b) Holding knife at an angle, cut the jacket longitudinally in such a manner so that repeated traverses of these cuts will only have penetrated approximately 80 percent of the jacket thickness.
   c) Using pliers, grip the edge of the jacket and pull in the direction of the slant cut. If the jacket does not readily tear at the cut, a knife may be used with tension applied to the jacket, still avoiding damage to the underlying shield tapes or braid.
3. Thoroughly clean jacket on both ends of the splice to obtain good adhesion between the factory jacket and the completed splice jacket.

Making the Splice

1. Stagger the conductors so that the finished splice will have the smallest possible diameter, and so that all reconnected conductors will be of equal length. (Figure 5)

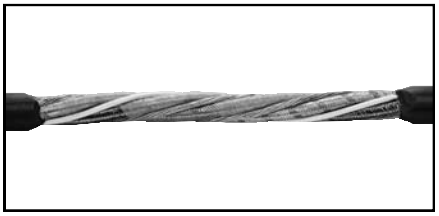


Figure 5

2. Cut the shield wires at the point of termination carefully. A smooth shield edge is essential in preventing premature splice failure.

3. Remove the semi-conducting insulation shield, if present, to within approximately 1/4" of the end of the metallic shield. Improper termination of shield components is one of the major causes of splice failure.

4. Pencilling of the insulation requires a 360° perpendicular cut through all but the last 1/16" of insulation, and at a predetermined distance from the conductor end. This distance is directly dependent on the type of connector and type of cable insulation. Pencil and smooth the taper before removing the short section of insulation from the conductor. This buffer technique, illustrated in Figure 6, protects the conductor surface against undue abrasion and scoring.

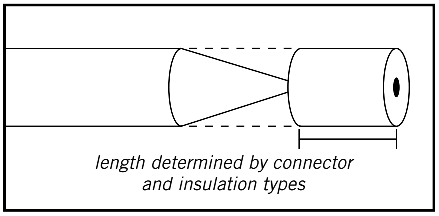


Figure 6

5. Any traces of semi-conducting residue remaining on the conductor or surface of the insulation must be removed. Normally a lintless cloth slightly dampened with cleaning solvent will suffice. (Note: Semi-conducting insulation shield materials are generally not used on mining cables rated less than 8000 volts)

6. Reconnect the conductors, being careful not to damage the individual wires. (Figure 7)

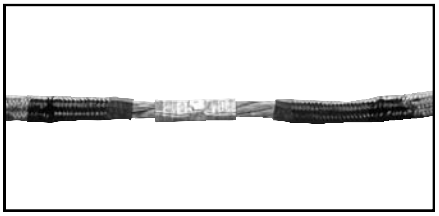


Figure 7

Re-Insulating the Joint

At this stage, the ultimate electrical integrity of the cable joint will be in direct relationship to the skill of the splicer. If the individual fails to properly address any phase of the operation, failure could result. Areas requiring strict attention to details are:

1. Application of a semi-conducting tape over the conductor connector must result in a smooth contour. (Figure 8) Insulation putty can assist in this, as well as seal against moisture.

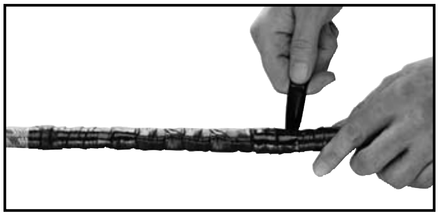


Figure 8

At this stage, the ultimate electrical integrity of the cable joint will be in direct relationship to the skill of the splicer.

By adopting these practices, cutting cable-related downtime by more than 50% isn't at all unreasonable!

Re-Insulating the Joint (con't)

2. The high-voltage insulating tape should be applied half-lapped, introducing uniform stretch as specified by the tape manufacturer. (Figure 9)

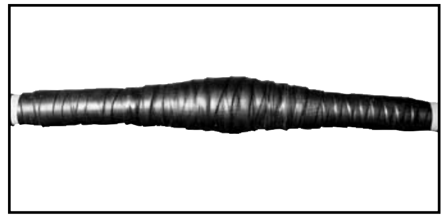


Figure 9

3. Frequent rolling of the work with a concave tool, screwdriver shank or other round object helps to eliminate any entrapped air which could otherwise ionize if sufficient voltage gradient is impressed across it.

4. Wrap insulating tape to approximately 1/4" from cable semi-conducting component. The space allows for proper transition between materials in reshielding. For proper metallic shielding, a tinned, all-copper braided tape is recommended for proper conductance.

Re-Jacketing the Completed Splice

Attempting to rebuild the cable as close to its original condition as possible includes consideration of the jacketing material. Uncured thermosetting rubber tapes have been used for this purpose with considerable success. (Figure 10) It should be vulcanized in a molding press for best results.

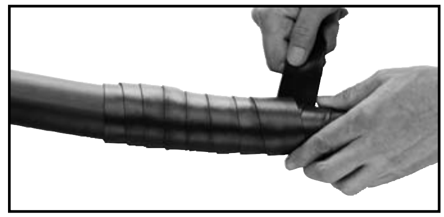


Figure 10

The Finished Job

A well-made, permanent-type splice with a vulcanized covering approaches all the above characteristics, with good resistance to fatigue being the most difficult to achieve. As voltage ratings increase, the margin of safety will be on the decrease. Therefore, it is essential that every aspect of the installation be precisely engineered and supervised by capable individuals. The same applies to pre-fabricated splicing devices.

Summary of Ways to Cut Cable Downtime

Following is a summary of the steps which have proven effective in prolonging cable life:

1. Prevent twisting or kinking of cable during installation—a kinked conductor is a damaged conductor.
2. Avoid excessive tension.
3. Use the largest-size cable possible for the application. Take advantage of the extra tensile strength and current-carrying capacity of the next larger size. It is more economical in the long run.
4. Keep runovers to a minimum. Any form of crushing is a potential source of rupture in the insulation and jacket.
5. Remove damaged sheaves, guides and rollers. Make certain cable guides are large enough for splices to pass through freely.
6. Repair cut or crushed cable even if a blowout has not occurred.
7. Provide a spare cable. Remove cable with temporary repairs and make permanent repairs. This will pay off, especially in wet pits.
8. Keep water out of the cable interior.
9. Keep a record of what caused failures. It will point out where steps must be taken for more effective maintenance.

By adopting all the pre-mentioned practices, cutting cable-related downtime by 50 percent isn't at all unreasonable!

Here's the information in tabular form:

Guide To Trailing-Cable Maintenance

Causes of Damage	Evidence of Damage	How to Avoid Damage
Excessive Tension	1) Cable necked down resembling an hourglass in shape 2) Jacket creeping back from temporary splice 3) Grounding conductor pulled in two 4) Cable kinked or jacket torn where pulling hitch is attached	Keep proper tension on trailing cable reel. (1, 2, 3) Pull the cable into several loops (rather than a single long length) when moving. (4)
Mechanical Damage	1) Short sections of cable crushed or flattened to a larger diameter 2) Excessive abrasion, cable grooved or shows uneven wear 3) Gouges, cuts and punctures	Move cables into the clear during blasting. (1) Position cables in the pit where there is the least possibility of their getting hit by rock slides from the spoil bank or high wall. (1) Provide vehicles and areas of heavy traffic with adequate lighting during nighttime operation. (1) Either bury cables or provide arched runways at cable crossings. (1) Replace broken sheaves or broken guides. (2, 3)
Current Overload	1) Blistered jacket 2) Tinned copper conductor wires turn to a blue-black color	Choose a cable with an adequate current rating. Consult cable manufacturer or mining machine manufacturer for recommendations. (1, 2) Avoid unnecessary earth covering of long lengths of cable. (1, 2)
Temporary Splices and Terminations	1) Bare conductors exposed in a temporary splice 2) Open grounding or ground-check conductor 3) Kinked cable	Carry insulating tapes back over the original conductor insulation, and replace temporary splices with permanent splices as soon as possible. (1) Connect these smaller conductors approximately 1/4" longer than the power conductors in all splices and terminations. (2) Balance the conductors in all splices and terminations so that there will be an even stress on all conductors. (3)

General Cable would be glad to work closely with you to reduce cable-related downtime in your own mining operation.

How General Cable Helps You Cut Downtime

General Cable would be glad to work closely with you to reduce cable-related downtime in your own mining operation. To do this, we have three separate areas of competence we can lend to your situation:

1) Anaconda® Cables

We've long been the leading supplier of portable cables designed for reliable operation in the toughest of mining environments. And we're still pioneering advances!

2) Field Assistance

We've learned a lot from years of providing engineering assistance right at the mine site. Experience which we're happy to share with you at your own locations. We can even train your personnel in proper cable care!

3) Mining Cable Test Lab

We believe no other supplier can offer you the services of a facility like this. Located at Marion, Indiana USA, we have all the test equipment necessary to simulate actual conditions in a mine. But with one important difference—our Portable Cable Lab can test a cable to destruction in a fraction of the time it would take under normal field conditions. Yet we can accurately extrapolate the results, in terms of the type of end-use the cable is expected to receive.

Thus, the laboratory can give you fast, reliable advice on your problems with trailing cable life. It can help you with correct recommendations on which cables to select. And of course, it has helped General Cable immeasurably in the past in designing cables that are in-tune with the realities of the mine site. The following chart describes common types of failure, and the lab tests we can perform to induce such damage.

Cable Damage Source	Cable Tests for Simulating Service Damage
Excessive tension and wire fatigue:	• Tension reeler • Flexing machines • Torsion bending machine
Mechanical damage:	• Compression cut machine • Abrader • Free-fall impact (crusher) • Pile driver (repeating impacter)
Electrical stability:	• Current overload test • Cyclic aging • EMA • ac life endurance test • dc proof test
Flame and heat resistance:	• Flame test • Air oven • Electrical overloads
Splices and terminations:	• Mechanical and electrical tests
Environment:	• Chemical- and oil-resistance • Oven aging • Weather sunlight

4 Tesseneer Drive,
Highland Heights,
Kentucky 41076-9753

Phone:	1.888.593.3355
Fax:	1.800.335.1270
International Tel.:	+1.859.572.8000
International Fax:	+1.859.572.8058

www.generalcable.com

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