"A STUDY OF MISFIRES IN MINING"

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ABSTRACT

A misfire results when explosives fail to detonate as planned during a mine blast. Accidental detonation of misfires is a frequent cause of personal injury, equipment damage, and lost production. In an effort to minimize these problems, the Bureau of Mines investigated the causes of misfires, methods for detecting misfires, and procedures for their disposal. During this investigation, input was obtained from explosives suppliers, mining companies, blasting contractors, blasting consultants, and governmental agencies. Additional data were obtained through detailed analysis of blasting accidents involving misfires.

The greatest number of misfire accidents are caused by drilling into bootlegs in underground metal and nonmetal mines. Improper disposing of misfires is the second most frequent accident category, and some accidents are due to impact initiation of explosives in the muck. Misfires are usually caused by misunderstanding, improper use, or some failure of the initiation system. Other causes are cutoffs, insufficient firing current, inadequate priming, improper explosive storage, and damage to the initiation system. Visual inspection is still the only available method for detecting misfires. Disposal of misfires in underground mines is generally by refiring; at surface mines, they are usually dug out during the mucking operation. Extreme care must be exercised when digging out misfires.

INTRODUCTION

It is difficult, if not impossible to determine how frequently misfires occur. When operators are asked, they usually reply, "Rarely, if ever, do we have a misfire." The truth is, however, that misfires are fairly common, and they are a major cause of accidents and increased mining costs. In a recent visit to a surface coal mine, five borehole casts were observed on the highwall, one still containing explosives.

The investigation of two underground coal mine accidents revealed that misfires were very common. Explosives were found in the broken coal as well as in bootlegs in the face at one mine, where the company attributed the primary cause of the misfires to cold temperature storage of water gels. In the second accident, a misfire (which increased the burden for the next hole) resulted in a blow out, coal dust ignition, and eight fatalities. It should be noted that the misfire, while a major factor in the dust ignition, was not the only factor involved.

Because many people feel that misfires reflect the quality of their work, they are reluctant to report them. In addition, the increased use of noncap-sensitive blasting agents with lower shock sensitivity has generated an attitude of indifference about misfires and many feel there is no need to report them. Noncap-sensitivity means that a blasting agent is insensitive to a No. 8 strength detonator. Some manufacturers produce detonators of higher strength that will initiate some blasting agents. Because of these two factors, it is rare that a misfire that does not involve an injury is ever reported.

This paper discusses the effects of misfires on mining operations in terms of safety and increased mining costs. The causes, detection, and disposal of misfires are also examined. Typical accident examples are included. Discussions with explosives suppliers, mining companies, blasting contractors, blasting consultants, MSHA (Mine Safety and Health Administration, U. S. Department of Labor) inspectors and state mining agencies provided valuable information.

EFFECTS OF MISFIRES ON MINING OPERATIONS

A misfire has two basic effects on an operation: one is the safety hazard a misfire presents and the other is the increase in mining costs.

SAFETY

To most people, a misfire primarily represents a safety hazard. With the increasing use of noncap-sensitive blasting agents, the possibility of accidental initiation is reduced. Thus, the concern for safety is diminishing. However, based on HSAC (Health and Safety Analysis Center) data there are still many injuries sustained due to misfire accidents. In a 4-year period (1978-81), 41 misfire accidents in mining resulted in 46 injuries and 2 fatalities (Table 1). A detailed look at these accidents reveals that the majority of misfire accidents (73 percent) occur in underground mines, with 54 percent in underground metal/nonmetal mines. These numbers are not surprising because it is not the total amount of explosives used, but the number of shots or holes fired that provides the opportunity for misfires. In addition, visibility in underground mines is generally poor, so detection of misfires is hampered to some degree. In underground metal/nonmetal mines, most accidents (86 percent) were due to improper handling or drilling into misfired explosives: in underground coal mines, most accidents (75 percent) were due to undetonated explosives that were initiated during the mucking operation.

The remaining 27 percent of misfires occur in surface mines and are divided fairly evenly between metal/nonmetal and coal. In metal/nonmetal mines, most accidents (67 percent) were due to improper handling and drilling into the misfire. All surface coal mine accidents were due to undetonated explosives in the muck. The differences in these mining operations may be responsible for some of the differences in accident causes. For example, coal mining operations are frequently single pass and do not subdrill, whereas metal and nonmetal operations are generally multiple bench and subdrill.

The three main causes of accidents are improper handling, drilling, and initiation of explosive in the muck. The two basic problems that occur in improper handling of misfires are (1) returning too soon to the blast site after trying to refire a misfire and (2) rough handling of explosives and detonators when removing them from the muck or borehole. Each operator should develop procedures for handling misfires and these procedures should be based on the explosives and devices used at that particular mine with input from suppliers and manufacturers. Most drilling accidents in underground mines are caused by drilling into bootlegs either by accident or to ease collaring of the hole. Improving inspection techniques and drilling practices could eliminate these accidents. Undetonated explosives in the muck pile represent the most difficult problem. The situation could be improved by frequently checking the muckpile during the mucking operation and by checking for explosives in conveyance and at the crusher.

Misfires can be a secondary cause of ignitions in a gassy mine by causing a subsequent hole to be blown out. The occurrence of a misfire in a gassy mine can thus contribute to a major mine disaster.

COST

Misfires that result in an accident with injuries, fatalities, and/or equipment damage involve obvious costs; however, there are other costs due to misfires that are not so obvious. Because the effect of a misfire will vary greatly, operators should conduct probable cost analyses of misfires at their mines. Those who do will place greater emphasis on practices to avoid misfires.

In addition to the cost of disposal of the misfire, there are the direct costs in drilling, explosives, primers, detonators, and labor. For some operations, these expenses alone could be in the hundreds of dollars. In some underground mines, the failure of a "cut" hole could result in the loss of the entire round.

The handling of boulders that require secondary breakage is another cost factor. Increased digging time and greater wear and damage to equipment (especially bucket teeth) result in lower productivity and higher maintenance costs. Misfires frequently are the cause of high bottom, which results in reduced production and higher maintenance costs on mucking equipment. In addition, haulage vehicles traveling over rough terrain will increase the haulage cost and vehicle maintenance. Often, these humps must be drilled and blasted, which constitutes another cost.

The misfiring of one hole will increase the burden on a later hole, causing cratering with excessive flyrock and overbreak. Flyrock is a leading cause of personal injury and equipment damage. Overbreak may extend beyond the burden for the first row of holes for the next shot. This can cause problems in drill setup for the next shot. Overbreak at the final pit wall could produce ground control problems with very high cost and even loss of ore.

It is obvious that misfires can be very costly when all factors are considered. The cost of taking care of a single misfired hole is considerably more than generally realized. For one misfired hole in a surface mine of 9-inch diameter, 50-foot depth, loaded with AN-FO and disposed of by washing, the cost can exceed $250. In an underground mine, a single misfired hole of 2-inch diameter, 12-foot depth, loaded with AN-FO, and disposed of by refiring, can cost $30. It was assumed that refiring the misfired hole in this example contributed no further fragmentation.

CAUSES OF MISFIRES

During the preparation and initiation of blasts, there are many aspects that may result in misfires. The most frequently stated cause of misfires is the incorrect use of the initiation system, a problem common to all initiation systems. The lack of understanding by blasting personnel of how the system works is a major contributing factor to misuse of the initiation system. High turnover rates of blasting personnel and changes from the standard blasting pattern are the main sources of initiation system error. Unless the blasting personnel have a full understanding of the initiation system, even minimal changes in a shot can result in poor blast performance and misfires. Simply adding an extra hole to a shot or including secondary blasting in with a production shot can be a problem. More complex changes such as addition of in-the-hole delays or decks have produced disastrous results in terms of misfires.

Damage to the initiation system or explosives column is another common source of misfires. Rock movement that produces cutoffs and poor work practices on the blast site are causes of damage to the initiation system. Damage can often occur while shoveling in stemming, and stepping on wires, cords, or tubes. Even driving over the initiation systems is not uncommon at some mines. Damaged systems and poor hookups can cause current leakage in electrical blasting. Current leakage can result in random misfires throughout the shot. The power source in electrical blasting, which can be the cause of misfire, should be checked for adequate capacity for the circuit and for weak batteries, and be in good working condition. The wiring in or hookup of a shot, regardless of the initiation system used, is a very important part of blasting.

It is important that all initiation systems be checked after the hookup. The method of system checkout depends on the system used. All electrical hookups should be checked with a blasters meter. All shots should be checked visually. To accomplish this, good housekeeping and neat and consistent hookup practices are helpful.

Rock movement may cut off the explosives columns and result in misfired explosives. Uplift, as well as horizontal displacement, is a factor in cutoffs. An area surface coal mine may have 100 or more holes drilled and loaded, which are then divided into 4 or 5 shots. Where rock movement is general uplift with little or no horizontal movement, the uplift can damage loaded holes waiting to be wired in for the next shot.

Geology is another factor that plays a major role in causing cutoffs. Fractures, faults, joints, and bedding planes are all zones of weakness that may cause burden movement to occur in much shorter times than considered normal. The use of decking and multiple primers is sometimes advantageous to avoid cutoffs. Rock falling from the walls of the borehole can cause bridging and explosives column separation.

Hole blockage can also be the result of careless work habits, such as workers knocking material into the hole. Rapidly loaded cartridged products will often bridge, particularly in holes that are partially filled with water. Careless work practices are often due to the rush placed on the blasting crew to get the shot off by a given time.

The proper use of delays is very important in preventing cutoffs. The longer the delay between holes, the greater the probability of cutoffs. Shorter delay times are needed when surface delays are used. If longer delay times are required for fragmentation and rock displacement, in-the-hole delays should be considered. Many systems or combinations of systems are available to meet delaying requirements.

Poor priming practices frequently cause detonation failure. Each product has minimum priming requirements. Even when proper priming is used, if the primer sinks into the mud at the bottom of the hole or water enters a hole loaded with non-water resistant products, a misfire can occur. Many operators of surface mines using larger diameter blast holes place the primer at the floor level, and not at the bottom of the hole in the subdrilled region. In the event of a misfire, the more sensitive primer and detonator are more easily retrieved.

Proper storage is also an important factor in avoiding misfires. Improper storage can alter the performance of many products. The sensitivity of some products is dramatically reduced by low temperature storage, which can result in malfunctioning. Malfunctioning of explosives products is usually due to improper storage rather than quality control problems in manufacturing, which are rare. Hydrostatic pressure as well as compression from the firing of adjacent holes has caused some products to lose sensitivity and misfire. If misfires are to be avoided, the blaster must have a complete understanding of the products and conditions under which they can be used. This information is available from the supplier.

DETECTION OF MISFIRES

Sometimes misfires are obvious, sometimes they are not. Each shot must be checked for misfires before mucking is begun. When the explosive is laying on the muck, detection of a misfire is no problem. However, when the explosive is buried in broken rock, visual detection is unreliable.

There are a number of clues that may indicate a misfire. Most operations have standardized blasting practices that have fairly uniform results from each shot. A change from the norm could indicate misfires. In surface mines where the shot can be observed from a safe location, watching and listening to the shot is worthwhile. A change in the sound--louder or quieter--may indicate misfires. Ejection of stemming, cratering, and flyrock may result from too much burden, due to earlier holes misfiring.

In surface and underground operations, the muck pile profile can reveal areas of possible misfires. Muck laying mostly to one side of the shot, less displacement than expected, abnormal backbreak, and humps and valleys in the muck pile can all be due to misfires. Change in fragmentation is a very good indicator of possible misfires. Boulders across the top of the muck pile are easy to see and could indicate misfires. Operators of loading equipment should be aware that boulders uncovered in lower sections of the pile also may be the result of misfires. This is common where multiple decks are used.

Multiple priming can be used to minimize misfires although this method is generally not used because of additional costs. However, considering the cost of misfires, perhaps multiple priming should be considered more frequently. A double-trunkline or loop system must be used with detonating cord systems. Even with the two paths of detonation, all of the cord should be consumed in the blast. Finding detonating cord in the muck is a strong indication of a misfire.

In underground mines, detection is hampered by poor lighting. It is difficult for the loader operator to spot explosives in the muck. Checks for explosives in the muck should be made before and during the mucking operation. Every bootleg must be examined carefully for misfires. A misfire may have occurred even though there is no cap legwire or tubing protruding from the hole. Lifter holes are of particular concern because they slope downward, are often water filled, and it is easy for loose material to fall into them. These conditions promote misfires. In addition, lifter holes are the most difficult to relocate and check for misfires.

DISPOSAL OF MISFIRES

There are two basic methods used to dispose of undetonated explosives: one method is to recover and destroy the explosives, the other is to detonate the misfire in place. Any explosive product removed from a misfire is considered damaged and must be destroyed in a safe manner. The manufacturer is the best source of information on destroying an explosive product. Many water-based products do not burn readily and are difficult to destroy. The most common method used to dispose of misfires is in-place detonation. This is good practice in underground mines where flyrock is less of a problem. In many operations, the disposal of misfires is the only blasting that is done on shift, and this creates blast area security problems.

When the original initiation system is still intact, it can be used to refire the charge except with cap and fuse blasting. When a misfire results with cap and fuse blasting, the blaster should never relight the fuse because the fuse may have been shortened, causing unexpected premature initiation, or the fuse may be damaged and could produce a hang-fire. With cap and fuse blasting repriming is essential.

Misfires are occasionally refired in surface mines, in which case flyrock is a major consideration. Because of reduced burden on the missed hole, violent flyrock may result. Normally, removal of the explosive load is recommended in surface mines. Mucking out a misfire must be done with caution, with the minimum number of personnel in the area, and under the supervision of a competent person.

Removal of stemming and explosives from blastholes is more difficult in vertical holes than in horizontal holes. Two common techniques used are washing material out with water or blowing it out with air. When the main charge is AN-FO, washing with water has an advantage because water will destroy the AN-FO. This can take much more water than expected if the total charge is to be destroyed. When repriming of the hole is planned, the use of water is a disadvantage; it is better to blow out the stemming with air. Also, air has an advantage in that it is generally readily available in many mines. Recent changes in drilling (hydraulic) have limited the availability of air in some mines. The disadvantage of air is that it blows dirt and duet into the atmosphere, creating poor working conditions around the hole. When the explosive is to be recovered, both air and water may redeposit the charge in fractures around the bore hole. This may create more of a problem than if the charge is left and dug out during the mucking operation.

The removal of an explosive charge by firing a nearby charge is another technique that has been used. With this method, the danger of drilling into the misfire is always present. In blasts with angled holes, such as a Vee cut, or where hole length-to-burden ratios are high, this technique should not be used. This method is not recommended and should be used only as a last resort. When this technique is used, recovery and disposal of the explosive most still be performed in a safe manner.

If explosives from a misfire must be stored, all detonators should be removed and stored separately. Explosives and detonators removed from a misfire should not be stored with other explosives or detonators.

REGULATIONS

Many regulations apply to misfires. Federal regulations affect the entire industry, but there are also state and, in some locations, county regulations. Most mines have their own company safety procedures. Regulations for handling misfires specify the waiting time after a suspected mis fire, inspection of the face or muckpile, and approved disposal methods. Regulations can vary greatly from agency to agency and even by commodity. An example of such a variation in the Federal regulations is the waiting time for misfires that occur with electric detonators. The minimum waiting period for underground bituminous and lignite coal mines is 5 minutes, underground anthracite is 30 minutes, and underground metal and nonmetal is 15 minutes. Regulations will not be covered in detail here, but it is important for blasting personnel to know and understand all the regulations that apply to their mine.

EXAMPLES OF MISFIRE ACCIDENTS

The following case histories provide some enlightenment concerning misfires. They are examples of the type of misfires that occurred between 1976 and 1980.

1. One hundred holes of a 251 hole shot misfired. There were no injuries and the cause wee not determined. However, it took 11 days to dispose of all of the misfires.

2. A crusher operator, standing in the doorway of the crusher control room, was struck by flyrock when misfired explosives in the muck detonated in the jaw crusher. The operator's right elbow and a arm were broken.

3. In an underground operation, the driller and shift boss were discussing the next shot in a stope. It was decided to drill one hole in the footwall to remove the high bottom on one side of the stope. The shift boss was standing in front of the drill, using his light to spot the hole location. After drilling about 6 inches, a misfire was intersected and detonated. The full force of the explosion hit the shift boss in the head. He was pronounced dead on arrival at the hospital.

4. A blaster found a large number of misfires when he returned to the site where a burn cut round had been fired with cap and fuse. He made several attempts to refire them, but by the end of the shift there were still misfired holes remaining in the face. This was reported, and the next shift driller was informed of the misfires. The driller decided he could avoid drilling into the misfires if he used a Vee cut. Flyrock hit his chest, arms, and legs when he drilled into a misfire.

5. A 14-hole shot with 3 decks per hole was fired. All of the top decks misfired. The cause of the misfire could not be determined. There were no injuries. However, the shot had to be mucked out on a nonproduction basis, with each bucket load visually checked for explosives before it was hauled to the crusher.

6. While drilling a large boulder for secondary blasting, a misfire was drilled into. The driller was thrown 10 feet into the air and required 9 hours of reconstructive surgery.

7. While boulders were being pushed to a storage area for secondarary breakage, an explosion occurred. The windshield of the loader was shattered.

8. Three miners trimmed an existing fuse and lit it with a match. They then retreated to a safe location. After a 3-minute wait, one miner stated that he had heard the cap fire, so they returned to the site. Seeing smoke coming from the hole, one miner pulled out the burned fuse and threw it back from the face and started mucking. The misfire exploded, killing him.

SUMMARY AND CONCLUSIONS

Misfires are more common than most people believe. Misfires represent major cost items in many mines in terms of both human suffering and real dollars. As stated earlier, from 1978 through 1981 there were 41 documented misfire accidents in mining that resulted in 46 injuries and 2 fatalities. Misfire accidents are caused by improper handling of known misfires, drilling into misfired explosives or undetonated explosives in the muck being initiated. It is impossible to determine or even estimate the number of misfires that occur annually where fortunately no injuries are involved. The cost of a single misfired hole in surface mining can be in excess of $200 not including possible lost production or higher maintenance costs.

Most misfires are due to some problem with the initiation system such as failure to make a connection, a broken lead or simply not understanding the initiation system. Other causes of misfires are cutoffs, inadequate priming, and malfunctioning of the explosives due to improper storage.

Detection of a misfire is no problem if none of the holes detonate. However, if a few holes or portions of a single hole fail to detonate, detection of the misfire can be very difficult. In these cases, visual inspection of the muck pile for undetonated explosives and boulders or other muck pile irregularities that suggest possible misfires is the most reliable detection method.

Disposal of detected misfires is accomplished by removing the explosives with water washing or air flushing, repriming and reshooting or by detonating a nearby charge. Detonating a nearby charge can be very dangerous and is not recommended.

The best way to avoid misfire accidents and costs is to eliminate their causes. This can be done by knowing the characteristics of the explosives, delays, and initiation system, proper blasting design, taking care in loading the shot and hooking up the initiation system, and good housekeeping practices at the blasting site.

Table 1. - Misfire accidents in mining from 1978 through 1981

Accident cause	Incidents	Fatalities	Injuries	Incidents	Fatalities	Injuries
	Surface coal			Surface metal/nonmetal		
Improper handling	0	0	0	3	0	4
Drilling into misfired explosives	0	0	0	1	0	1
Undetonated explosives initiated during mucking	4	0	6	1	0	1
Undetonated explosives in muck initiated by other sources	1	0	1	1	0	1
Subtotal	5	0	7	6	0	7
	Underground coal			Underground metal/nonmetal		
Improper handling	1	0	1	8	1	11
Drilling	1	0	2	11	1	10
Undetonated explosives initiated during mucking	4	0	2	1	0	1
Undetonated explosives initiated by other sources	2	0	2	2	0	3
Subtotal	8	0	7	22	2	25
Total	13	0	14	28	2	32

PROCEEDINGS
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