Determining the Root Causes of Flame Cutting and Welding Fires in Underground U.S. Coal Mines

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Abstract

One of the predominant causes of fires in underground coal mines is flame cutting and welding. These fires can lead to major events such as the explosion that occurred on January 22, 2003 in an airshaft being constructed at the McElroy mine. Six contractors were inside the shaft at the time of the explosion and the explosion fatally injured three and seriously injured three [MSHA 2003]. Understanding the root causes of these fires and explosions will help prevent these types of events from occurring in the future. Fires and explosions require fuel, oxygen and an ignition source (heat). These three items are referred to as a fire triangle. The control of these three items in flame cutting and welding operations is required to prevent fires and or explosions. United States Department of Labor, Mine Safety and Health Administration (MSHA) Reports of Investigation (ROI), MSHA Mine Accident, Injury, and Illness Reports, and the MSHA Mining Industry Accident, Injuries Employment, and Production Data Base were analyzed and interviews and observations with mine workers and welders were conducted to determine the root causes of coal mine fires and explosions caused by flame cutting and welding operations. This paper will discuss the root causes and potential means to reduce the number of fires and resulting fatalities and injuries caused by or due to flame cutting and welding.

Introduction

One of the goals of NIOSH is to enhance the safety of mine workers by preventing disasters caused by fires and explosions. To prevent and reduce the number of fires and explosions from occurring in underground coal mines, one must understand the nature of their initiation and identify the root causes. Small underground coal mine fires can lead to larger uncontrolled fires if not extinguished quickly.

Of the four major sources of fires in underground coal mines (electrical, friction, flame cutting and welding, and spontaneous combustion), flame cutting and welding operations are probably the easiest to manage. There is always a person present who can ensure that the heat source is used only when the fuel can be controlled and accidental ignitions can be extinguished immediately. Fires related to flame cutting and welding are normally a result of human failure to prepare and protect the work site [Hartman et al. 1997].

Major fires and explosions have been reduced over the last few decades at coal mines in the United States. With respect to flame cutting and welding fires, Pomroy and Carigiet reported that 16% of the 164 underground coal mine fires from 1978 – 1992 were caused from flame cutting and welding operations [Pomroy et al 1992]. Conti reported that 14% of the 76 underground coal mine fires from 1991-2000 were caused from flame cutting and welding operations [Conti et al. 2005]. Even though there has been a slight reduction in flame cutting and welding fires, over the last few decades, 14% is still too high and the goal is to have zero fires and explosions.

Any fire or explosion in an underground coal mine is a potential disaster. Underground coal mines are confined in space and the ventilation system is required to provide a constant supply of breathable air and dilute and renders harmless any explosive or toxic gas and dusts. The ventilation system can play a major part in the occurrence of fires and explosions and in their prevention, since it can carry combustion products, hot smoke particles, or provide dilution of the explosive gasses in confined spaces. After an underground coal mine fire or explosion occurs, the mine air composition and ventilation flow quantities may change. It is difficult to predict the direction and quantity of airflow in areas with active fires or where ventilation controls have been destroyed.

Methodologies for Determining Root Causes

The root causes of mine fires and explosions caused by flame cutting and welding fires were determined by analyzing MSHA Reports of Investigation [MSHA 2003, MSHA 1992, MSHA 1999] from three recent major accidents, MSHA Mine Accident, Injury, and Illness Reports from 1995 to 2005, the MSHA Mining Industry Accident, Injuries Employment, and Production Data Base [MSHA 2006], and by conducting interviews with mine workers and welders and through observations of flame cutting.

MSHA Reports of Investigation

A formal Report of Investigation is required for all fatal accidents. MSHA District Managers determine if Reports of Investigation will be filed for other non-fatal or non-injury investigations based on factors such as the need to inform the industry of case-specific facts or public interest.

MSHA Accident, Injury and Illness Reports

Mine operators are required by 30 CFR §50.10 to immediately contact MSHA when an accident occurs. After notification of an accident by the mine operator, the MSHA District Manager will decide whether to conduct an accident investigation and will promptly inform the operator of his or her decision. If MSHA decides to investigate an accident, it will initiate the investigation within 24 hours of notification. Accidents pertaining to flame cutting and welding include: an unplanned ignition or explosion of gas or dust, an unplanned mine fire which is not extinguished within 15 minutes of discovery, and an injury or death due to flame cutting or welding operation.

In addition to immediately reporting accidents, 30 CFR §50.20 requires mine operators to prepare and submit a Mine Accident, Injury, and Illness Report, MSHA Form 7000-1, for each accident, occupational injury, or occupational illness at the mine. An occupational injury is any injury to a miner which occurs at a mine and for which medical treatment is administered, or which results in death or loss of consciousness, inability to perform all job duties on any day after an injury, temporary assignment to other duties, or transfer to another job. Occupational illness means an illness or disease of a miner which may have resulted from work at a mine or for which an award of compensation is made [CFR].

When MSHA investigates an accident, Accident Investigation Data Forms, MSHA Form 7000-50 series, are completed by MSHA inspectors to document their findings. These forms are entirely independent from MSHA Form 7000-1; however both sets of forms can be on record with MSHA if MSHA had performed an investigation.

MSHA Mining Industry Accident Injuries Employment and Production Data Base

NIOSH's Surveillance and Statistics team accessed MSHA Mining Industry Accident, Injuries Employment, and Production public data base from 1995-2005 to identify injuries that were caused by flame cutting and welding of underground mine fires and explosions. The information in this data base is entered from MSHA Form 7000-1 reports filed by mine operators.

Analysis of Flame Cutting and Welding Fires and Explosions

McElroy Mine Explosion

An explosion occurred on January 22, 2003 at the McElroy Mine (WV) at a shaft sinking site where contractors were attempting to remove corrugated, galvanized steel sheeting which was blocking access to the unventilated water ring being constructed. Three of the workers were fatally injured and three were seriously injured. The workers first cut an opening in the sheeting with an axe. This opening was large enough to allow the foreman to place a hand-held methane detector in the opening to test for methane gas. The reading obtained was 0.2%. After the methane reading, a mechanic starting cutting the sheeting with an oxygen-acetylene torch and an explosion occurred inside the water ring that had contained an explosive methane-air mixture.

MSHA determined that the root cause of the explosion at the McElroy mine was that the examination for methane was not adequate. An adequate examination would have required testing for methane in all areas that could have been affected by the used of cutting torch [MSHA 2003].

Blackville Mine Explosion

An explosion due to a welding operation occurred on March 19, 1992 at the Blackville No. 1 Mine, (WV) under the cap above the Production shaft, which resulted in the deaths of four persons (one mine employee and three contractors). The personnel underground were not injured by the effect of the explosion and safely exited the mine. Overcasts, cribs, stoppings, and the rotary dump in the underground area within 100 feet of the shaft were also severely damaged by the forces of the explosion.

According to MSHA, the causes of the explosion at the Blacksville No.1 Mine were as follows [MSHA 1992]:

1) The volume and velocity of air was not maintained in sufficient amounts to render harmless and to carry away explosive gases.
2) The approved ventilation system and methane and dust control plan for this mine was not followed in that a major change in ventilation was made without the approval of MSHA. A major ventilation change occurred when the production shaft was capped.
3) A change in ventilation was made which affected the split of air ventilating the Production shaft. A few miners continued to work underground. Miners were allowed to work in this environment before a certified person checked the changes in ventilation. Methane was being liberated inside the shaft and failure to adequately ventilate the area allowed an explosive methane-air mixture to accumulate undetected in the production shaft that was being capped.
4) Methane examinations were not being conducted at the capped Production shaft. Welding operations were conducted without examinations for methane having been made at any time.

Loveridge Mine Fire

An underground coal mine fire was discovered at 12:50 a.m. on June 22, 1999 inside the Loveridge No. 22 Mine, near and behind a permanent stopping separating the submains from a mined-out longwall pillared area. According to MSHA, a foreman found the fire while checking on a work site where flame cutting operations had been performed on the previous day shift. The foreman traveled to another section of the mine to obtain fire-fighting equipment and to report the fire. Four other foremen, including the shift foreman, joined him and attempted to put out the fire with three 20-pound fire extinguishers at the base of the permanent stopping but were not successful. Water was sprayed onto the stopping and an orange glow was still visible through holes in the bottom and both top corners of the stopping. The shift foreman then realized that there was a large fire on the inby side of the stopping, within the worked-out area, and sent one of the foreman to a nearby mine phone to inform all underground personnel to report to fight the fire. Seven additional mine workers who were underground at the time assisted in fighting the fire. Water was applied to the fire through the holes in the stopping; however, the conditions of the fire worsened and the mine was evacuated at 1:45 a.m. Management made the decision to seal the entire mine in order to minimize the spread of the fire.

According to MSHA, the cause of the mine fire at the Loveridge No. 22 mine was the failure to comply with 30 CFR §75.1106 (A diligent search for fire was not made during and after flame cutting operations, which were performed during the day shift) [MSHA 1999].

MSHA Mine Accident Analysis

MSHA investigation reports from 1995 – 2005 were examined in order to determine the root causes of fires and explosions caused by flame cutting and welding operations in underground U.S. coal mines during this time period. From the MSHA 7000-50 reports, thirty-one fires or explosions were the result from flame cutting and fifteen fires were the result from welding (Figure 1).

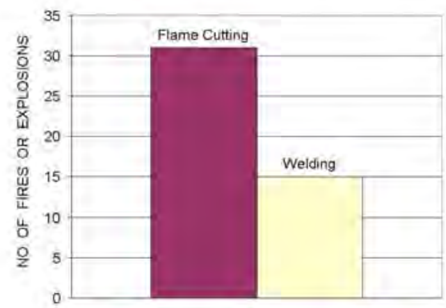


FIGURE 1. NUMBER OF FIRES OR EXPLOSIONS DUE TO FLAME CUTTING AND WELDING, 1995-2005

From the MSHA accident reports, the three causes of these fires or explosions, shown in Figure 2, were:

1) Hot slag or sparks ignited methane bleeders on the roof, ribs or floor (28 fires or explosions).
2) Hot slag or sparks ignited a methane build up (for example, in an air shaft or under a longwall pan) (9 fires or explosions).
3) Hot slag or sparks ignited coal dust on the floor of the mine (9 fires or explosions).

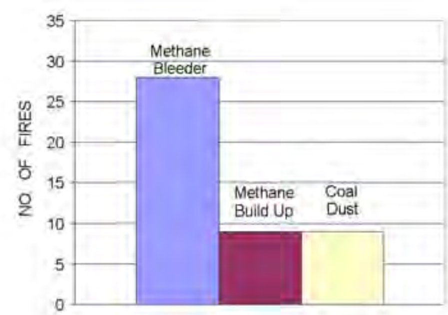


FIGURE 2. NUMBER OF FLAME CUTTING AND WELDING FIRES OR EXPLOSIONS WERE RECORED AS ACCIDENTS, 1995-2005

According to MSHA, 12 citations were issued for violations of safety standards that contributed to these accidents. These enforcement actions were issued under six different subparts of 30 CFR Part 75-Mandatory Safety Standards-Underground Coal Mines and 30 CFR Part 77-Mandatory Safety Standards, Surface Coal Mines and Surface Work Areas of Underground Coal Mines. Figure 3 shows the failures that contributed to these accidents, including:

1) Six citations for inadequate examination of methane.
2) Two citations for ventilation plan not followed.
3) One citation for inadequate search for fire.
4) One citation for inadequate rock dusting.
5) One citation for unusable fire extinguisher.
6) One citation for noncombustible barrier not installed.

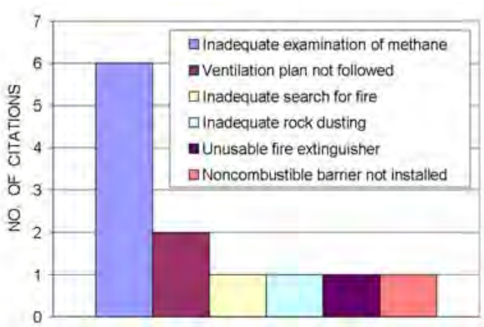
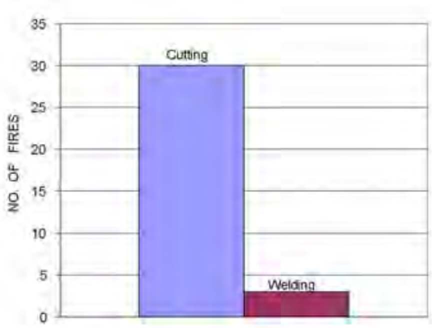


FIGURE 3. NUMBER OF CITATIONS FOR FLAME CUTTING AND WELDING ACCIDENTS, 1995-2005

Mining Industry Accident, Injuries, Employment and Production Data Base Analysis

Another problem with flame cutting and welding operations is personal injuries. The mining industry accident, injuries, employment, and production data base was examined from 1995-2005 to identify the number of personal injuries from flame cutting or welding activities [MSHA 2006]. From this data there were a total of thirty-three nonfatal injuries caused by flame cutting or welding (Figure 4).



GURE 4. NUMBER OF FLAME CUTTING AND WELDING FIRES THAT CAUSES NONFATAL PERSONAL INJURIES, 1995-2005

The numbers and causes of these injuries, shown in Figure 5 were:

1) 19 injuries resulted from sparks or hot slag.
   - Eleven of these injuries occurred when the mine worker was cutting in a position where hot sparks were able to fall into the worker's ear. For example, one of the mine workers was lying on their side next to a continuous miner, one under a cable tray, one was under a roller bearing on a conveyor system, and another was under a continuous miner cutting head cutting off bit lugs when hot sparks entered the mine worker's ear.
   - Five of these injuries occurred when the mine worker was cutting or welding and hot slag or a spark got behind the welding shield or cutting glasses.
   - Three of these injuries occurred when the mine worker was cutting and sparks or hot slag entered through openings in the shirt, gloves or boots. In one of these injuries, the mine worker was stretching to cut a top rail and a spark went down his shirt and burned him. In another injury, the mine worker was burning lugs off of a continuous miner when hot slag entered his boot. In the last injury, the mine worker was cutting a swivel pin out of a continuous miner when a piece of hot slag burned the oxygen hose behind the torch. The hose then caught fire burning the mine worker's hand.
2) Four injuries resulted from faulty or damaged torch hoses.
   - One set of welding hoses broke and caught fire burning the mine worker's left hand.
   - One set of hoses was cut when roof rock fell onto both the oxygen and acetylene hoses. The mine worker's left glove filled with the gases which were ignited by a spark, burning the worker's hand.
   - One set of hoses was damaged when a beltline headroller was being disassembled with a cutting torch. A piece of metal fell on the hoses, pulling the hoses away from the mine worker. The mine worker then examined the hoses without shutting off the torch. The hoses were damaged and leaking, causing them to catch fire and burn the mine worker's left finger and thumb.

    - One set of hoses got caught in a feeder breaker when a mine worker was using a torch to change a bearing on the tail roller. The torch hoses got caught in the breaker which pulled the small acetylene tank through breaker, causing it to explode and burning the mine worker.

3) Four injuries resulted from the improper handling of the torch.
    - One injury resulted when the mine worker was using a cutting torch to trim a piece of belt structure and caught his glove on fire.
    - One injury resulted when the mine worker completed cutting with a torch and then shut it off. The worker then used the torch to blow dust off of his safety glasses, which were hanging around his neck. The worker lost his balance and the hot torch touched his right eye burning his cornea.
    - One injury resulted when the mine worker used a cutting torch on a piece of metal lodged and under tension at the bottom of the feeder. When the hot metal suddenly released from under tension, it struck his arm and burned it.
    - One injury resulted when the mine worker's cutting torch went out due to the accumulation of debris at the end of the cutting torch tip. The mine worker shut off the torch, and used his left, glove-covered hand to clean the torch tip. The glove caught on fire and burned his left hand.
4) Three injuries resulted from methane gas ignitions.
    - Two injuries resulted when two mine workers were using cutting torches to a cut a longwall conveyor chain and a methane ignition occurred. An accumulation of methane gas under the conveyor ignited, burning both workers.
    - One injury resulted when the mine worker was flame cutting near the face inside a vertical shaft. The ventilation device, intended to ventilate the area in which the ignition occurred, was not within the 20-foot maximum distance required by the shaft sinking plan, allowing methane gas to accumulate in a roof void approximately thirty-four feet from the end of the ventilation tubing. One miner was burned.
5) One injury resulted from a leaky pressure gauge on an acetylene tank. The mine worker was flame cutting a conveyor chain on a continuous miner. Hot slag ignited the leak near the acetylene tank pressure gauge, burning the mine worker's face.
6) One injury resulted while the mine worker was flame cutting bolts from the center section of a scoop. Hot sparks caught lubricating grease on fire. The mine worker extinguished the grease fire with his left gloved-cover hand. The mine work burned his left hand.
7) One injury occurred while the mine worker was welding a toolbox latch. Oil located inside the toolbox caught fire, burning the welder.

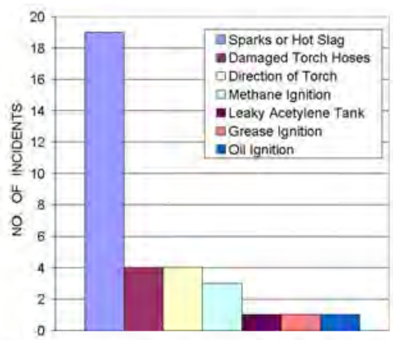


FIGURE 5. NUMBER OF FLAME CUTTING AND WELDING INCIDENTS THAT CAUSED PERSONNEL INJURIES, 1995-2005

Source: MSHA Mine Accident, Injury, and Illness Reports

The effects of these fires resulted in 11 burned ears, 11 burned hands, five burned eyes, four burned faces, one burned leg, and one burned arm (Figure 6).

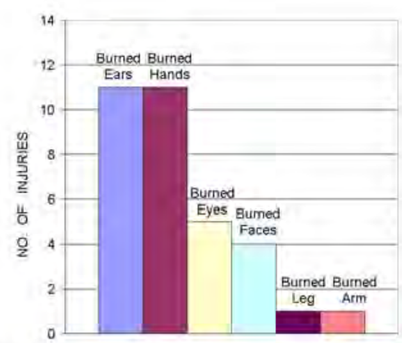


FIGURE 6. INJURED BODY PART FROM REPORTED FIRES, 1995-2005

Source: MSHA Mine Accident, Injury, and Illness Reports

Mine Worker Interviews

Several miners who perform flame cutting and welding operations were interviewed by NIOSH's researchers to gain insight into the root causes of fires caused by flame cutting and welding. One mine worker stated that taking adequate time to preparing and perform flame cutting and welding tasks was very important in preventing accidents and injuries. Some examples he gave on how to perform the flame cutting or welding job safely were: check the oxygen and acetylene tanks, gauges and hoses for leaks or damage, rock dust the area, have portable fire extinguishers in close proximity, and perform an adequate methane check. Another mine worker commented that having a helper or observer could prevent accidents and injuries. Working alone makes it difficult to detect hot spots from sparks and slag. Another mine worker stated that methane pockets from bleeders on the floor of the mine often accumulate under equipment, especially under longwall panlines. These methane pockets are difficult to detect with hand-held methane detectors and can result in fires or explosions when flame cutting or welding. The mine worker also stated that he had observed several small fires from flame cutting that were initiated while cutting off rusted bolts when relocating the conveyor systems. The mine workers all felt strongly that these small fires had the potential to lead to major fires or explosions.

Flame Cutting Experiments

Several flame cutting experiments were performed by an experienced miner at NIOSH's Lake Lynn Laboratory to observe the effects of hot steel particles on coal fines and grease. Coal fines and grease were placed on a steel sheet (1/8 in. x 2 ft. x 2 ft.) and the miner performed a flame cutting operation directly above (Figure 7).

FIGURE 7. MINE WORKER PERFORMING FLAME CUTTING OPERATION

This allowed sparks and slag to fall onto the coal fines and grease. Thermal images of the coal fines and grease were taken using an infrared (IR) camera. Figure 8 shows an image from the IR camera of the sparks and slag from the flame cutting operation falling onto the coal and grease. In this image, hot spots of 1600 ºF were observed.

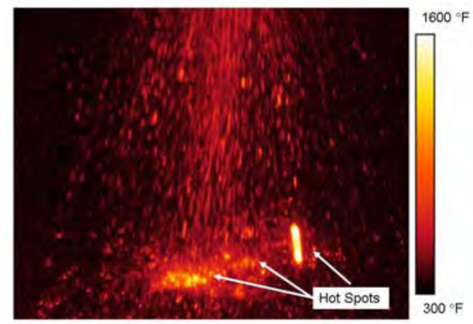


FIGURE 8. IR IMAGE OF IMAGE OF HOT SPOTS FROM FLAME CUTTING

Hot particles and slag from the flame cutting that came in contact with the coal fines and grease immediately ignited the grease**.** After several minutes, the flames from the grease appeared to be burned out and, to the naked eye, the fire appeared to be out; however, hot spots not visible by the human eye were detected by the IR camera. The highest temperatures observed with the IR camera approximately 15 minutes, after the end of the cutting operations, were between 200-300˚F degrees (Figure 9). These hot spots were monitored with the IR camera for a time period of approximately two hours and the temperature of the hot sports remained between 200-300˚F.

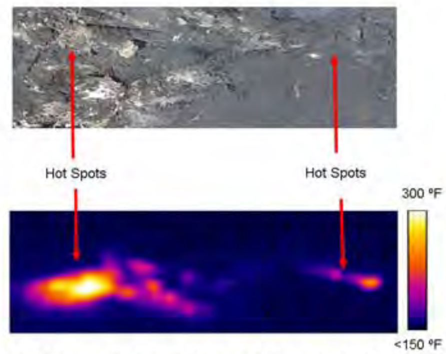


FIGURE 9. VISIBLE AND IR IMAGES OF COAL FINES AND GREASE 15 MINUTES AFTER FLAME CUTTING

A small fan with an average air velocity of 400 ft/min was then placed one foot in front of steel sheet that contained the coal fines and grease. This ventilation flow caused the temperature of the hot spots to increase, resulting in a re-ignition of the coal fines and grease. Without the use of the IR camera, it appeared that the fire was completely extinguished. This demonstrates that hot spots, hot enough to re-ignite coal and grease, can be invisible to the human eye and difficult to detect.

Root Causes of Fires and Explosions

From the MSHA Mine Accident reports that were analyzed, the major cause of fires and explosions due to flame cutting and welding was an inadequate examination for methane. While 30 CFR §75.323(a) specifies that tests for methane concentrations must be made at least 12 inches from the roof, face, ribs and floor, this distance requirement is not applicable to welding, cutting and soldering activities performed under §75.1106. MSHA's policy on §75.1106 clearly states that methane tests conducted under this section must be made in locations where methane is likely to exist, and in no case is cutting, welding or soldering permitted in an atmosphere that contains 1.0 percent or more of methane. Since the face, roof, ribs, floors and any fully or partially enclosed areas of an underground coal mine are locations where methane is likely to exist, methane tests must also be made at or near the surface of these areas (not 12 inches away), and within any enclosed areas that may be exposed to the above ignition sources MSHA [2004]. According to MSHA, additional ventilation may also be used to reduce the methane level in these areas where flame cutting and welding activities are occurring.

The root causes of mine workers not conducting adequate methane examinations include:

1) Methane checks are not being made close enough to surfaces where ignitable concentrations of methane may exist. Tests should be conducted in and around the immediate area where flame cutting and welding is conducted and where hot slag and sparks might fly. If necessary, a pump type methane monitor and probe should be used (Figure 10).

FIGURE 10. PUMP-TYPE METHANE MONITOR AND METHANE PROBE

2) The methane checks are not being performed throughout the entire area where hot sparks or slag may reach.
3) Improper use of methane detection instrumentation. When continuously monitoring for methane, the instrument needs to be located where the highest concentration of methane is likely to first accumulate within the area affected by the flame cutting or welding task.

From the MSHA Mine Injury reports that were analyzed, the other causes of accidents were as follows:

1) Unsafe acts such as not using appropriate personal protection equipment or using flame cutting and welding equipment in an unsafe manner.
2) The environment or physical workspace was not properly prepared, resulting in physical hazards remaining in the workspace.
3) Inspection of tools and equipment was not done prior to starting the task.
4) A diligent search for fire and hot spots in all potentially affected areas was not made during and after cutting operations.

In the author's opinion, the root causes of these accidents were as follows:

1) The area was not properly prepared. For example: adequate ventilation needs to be provided, methane checks need to be performed around the entire area prior and during the task, grease needs to be cleaned off of surface area prior to starting flame cutting and welding and a portable fire extinguisher should be located in close proximity of the work area.
2) Tools and equipment were not inspected prior to starting the task. A safety check of the tools and equipment must be performed prior to the start of each flame cutting or welding task.
3) The personal protection equipment must be chosen so that it is effective and also comfortable to wear.
4) If a search for fire was performed after the flame cutting or welding work ended and no hot spots were detected, it is possible that hot spots may have been invisible to the human eye and may have been missed.

Recommendations

Based on the data obtained, there are several recommendations for reducing the number of fire accidents and injuries caused by flame cutting or welding by addressing the root causes identified above.

1) The inspection doors on longwall panlines should be removed when available to allow methane pockets to be vented.
2) All persons (mine workers and contractors) who are required to conduct methane examinations during flame cutting and welding

operations should have regular training. This training should include:

- The proper calibration and use of methane detection instruments.
- Proper methods for tests of methane and the use of methane probes in conjunction with a methane pump.

3) All persons (mine workers and contractors) who are required to flame cut or weld should have regular training. This training should include:
    - A review of pertinent regulations pertaining to flame cutting and welding in underground coal mines. Some of these include:
        - o Welding, cutting or soldering must be done under the supervision of a qualified person.
        - o The qualified person must conduct a diligent search for fire during and after any welding, cutting, or soldering activity.
        - o Any welding, cutting or soldering shall not be conducted in air that contains 1.0 percent or more methane.
        - o Rock dust (240 pounds) or one portable fire extinguisher shall be immediately available during any welding, cutting or soldering activity.
        - o A diligent search for hot sports shall be made after flame cutting or welding. Hot spots can remain invisible and smolder for many hours.
    - Proper preparation of the area and good house keeping. Its appears that better fire protection to the work area around conveyor structures is needed when performing flame cutting or welding on these structures, since several small fires have resulted while relocating these structures.
    - Proper use of a torch. All persons required to use a torch should have regular training on torch operation and safety.
4) When the flame cutting or welding tasks are completed, additional rock dusting and water should be used in all areas where the task was performed in order to extinguish any remaining hot spots.
5) The oncoming shift section foreman should make an immediate inspection of the area where flame cutting or welding operations were performed and record that a check for fire and hot spots was made.
6) The proper use of personal protection equipment will help reduce the number of accidents and injuries. PPE that should be worn in areas of flame cutting or welding includes:
    - Flame-resistant gloves
    - Safety cutting goggles when flame cutting
    - Welder's helmets with full face shield when welding
    - Flame-resistant hood
    - Welder's apron
    - Metatarsal boots
    - Long-sleeved shirts and full length pants made from heavy, flame-resistant material.

    Based on the number of injuries to the ears and eyes, it appears that an ergonomically designed, custom-fit ear guard made from a fire-resistant material, and an ergonomically designed custom-fit welding shield and cutting glasses could reduce the number of injuries to these body parts.
7) Hoses must be routed such that they are protected from machinery, roof falls and sharp objects.
8) The use of thermal imaging (IR) systems to detect hot spots. In addition, there are several other uses for IR systems in an underground coal mine that can reduce the risks of accidents fatalities and injuries. These include: inspection of hot rollers during belt exams, power center inspections, brake inspections, hot hangers inspections on trolley wires, and mine rescue efforts.
9) New technologies are also being developed using IR for detecting methane gas emissions. NIOSH PRL has begun researching this technology at its ventilation gallery to evaluate its effectiveness for use in underground coal mines. In addition, this technology may be used on the surface in coal preparation plants and at gob vent holes. Manufacturers are considering developing intrinsically safe IR instruments for use in underground coal mines at this time.

Summary

Flame cutting and welding fires have accounted for approximately 15% of the reportable underground coal mine fires over the last 25 year period. These fires have led to major events such as the McElroy mine explosion on January 22, 2003, the Loveridge No. 22 mine fire on June 22, 1999, and the Blackville No. 1 mine explosion on March 19, 1992. One of the goals of NIOSH is to enhance the safety of mine workers by preventing disasters caused by fires and explosions. This paper identifies some of the root causes of fires and explosions and causes of injuries resulting from flame cutting and welding. These include the failure to detect hot spots (sometimes invisible to the human eye), inadequate methane checks of the entire area where hot sparks or slag can reach, failure to adequately prepare the work site and the improper use of personal protective equipment. Suggestions to correct these root cause failures include training in the use of methane measuring instrumentation and personal protective equipment and the use of infrared camera technology to search for hot spots.

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