Reducing the fire and explosion hazards of flame-cutting and welding in underground coal mines

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Abstract

One of the major ignition sources of fires and explosions in underground U.S. coal mines is flame cutting and welding. On May 20, 2006, a flame-cutting operation at the Darby Mine No. 1 led to an explosion that resulted in five fatalities. On Jan. 22, 2003, another explosion caused by flame cutting at the McElroy Mine resulted in three fatalities and three serious injuries. On June 22, 1999, a flame-cutting and welding operation at the Loveridge Mine caused a fire that required sealing the mine for an extended period. On March 19, 1992, an explosion initiated by welding at the Blacksville No. 1 Mine resulted in four fatalities. These examples of mine incidents demonstrate the need to conduct research to develop best practices for safely conducting flame cutting and welding in underground coal mines.

The National Institute for Occupational Safety and Health (NIOSH) conducted a study on fires and explosions in underground U.S. coal mines that were caused by flame-cutting and welding operations to determine the root causes of these types of incidents. The methodology included interviewing mining personnel who perform flame-cutting or welding operations in underground U.S. coal mines and visiting mines to observe these operations. In addition, MSHA reports of investigations and accidents statistics were analyzed. The findings were used to identify and compare differences between flame-cutting and welding practices and techniques in small and large mines, eastern and western mines, low-seam and high-seam mines, room-and-pillar and longwall mines, and between experienced miners and new miners. As a result of this study, best practices were developed to reduce the number of fires and explosions caused by flame cutting and welding. This paper provides a summary of this research.

Disclaimer: *The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.*

Introduction

Flame-cutting and welding activities in underground U.S. coal mines continue to be a major originator of fires and explosions. Seventeen reported fires or explosions in underground U.S. coal mines for the period 1990 - 1999 were initiated by flame-cutting and welding activities (DeRosa, 2004). In addition, from 2000 - 2007 six underground fires or explosions were reported that were attributed to flame-cutting and welding operations and caused injuries or fatalities (DeRosa, 2008). These fires occurred when hot sparks or hot molten metal came in contact with combustible materials, such as coal, oil, grease, clothing, rags, paper and aerosol cans. These explosions occurred when hot sparks or hot molten metal came in contact with flammable gases. The source of fuel for the majority of these incidents was methane gas. The Mine Safety and Health Administration's policy in 30 CFR §75.1106 states that methane tests must be done continuously in all locations where methane is likely to exist (MSHA, 2007).

In order to reduce the fire and explosion hazards caused by flame-cutting and welding operations in underground coal mines, a study to better understand the root causes of incidents and recommended best practices was completed by the National Institute for Occupational Safety and Health. The information from this study is presented here in the following format. In the first section of this paper, case histories are presented of major fires and explosions in underground U.S. coal mines that were caused by flame-cutting or welding operations. The second section of the paper identifies and discusses the root causes of fire or explosions associated with flame cutting or welding operations. Results of flame-cutting experiments performed at NIOSH's Lake Lynn Laboratory are presented in the third section of this paper. The paper concludes with recommended best practices and the conclusions of this research.

Darby Mine explosion

On May 20, 2006, an explosion occurred in a sealed section of the Darby Mine No. 1 in Kentucky, resulting in fatal injuries to five miners and injuries to one miner. A methane explosion occurred behind a block seal. MSHA determined that the explosion was caused by sparks that were generated by flame-cutting of a metal roof strap that passed above the seal (MSHA, 2006). Figure 1 shows the type of metal roof strap that was being flame-cut by an oxygen and acetylene torch at the time of the explosion.

Figure 2 shows the actual debris from a stopping, which was destroyed by the explosion. MSHA further determined that the incident occurred because the operator did not observe basic mine safety practices and critical safety standards were violated. Mine management failed to ensure that proper seal construction procedures were utilized in building seals, that safe work procedures were used while employees attempted to make corrections to an improperly constructed seal and that miners were adequately trained (MSHA, 2006).

McElroy Mine explosion

On Jan. 22, 2003, an explosion occurred inside an airshaft under construction for the McElroy Mine in West Virginia. Six miners were inside the shaft at the time of the explosion. The explosion fatally injured three miners and seriously injured three others. The miners were attempting to remove corrugated galvanized steel sheeting that blocked access to the unventilated water ring being constructed. Figure 3 shows the corrugated, galvanized steel sheeting after the explosion had occurred. After obtaining a reading of 0.2% methane on a handheld detector, the foreman directed the mechanic to cut the panning with an oxygen and acetylene torch. The mechanic ignited the torch and started to flame cut the panning. An explosion occurred when the torch cutting process ignited an explosive methane-air mixture contained inside the water ring. MSHA determined that the incident occurred because 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 use of the cutting torch (MSHA, 2003).

Loveridge Mine fire

On June 22, 1999, a mine fire was discovered in an approach to a worked-out area in a former belt conveyor entry in the Loveridge Mine in West Virginia. While checking the work site where a flame-cutting operation was completed at 2:00 p.m. on June 21, 1999, a foreman discovered the fire at approximately 12:50 a.m. on June 22, 1999. He observed an orange glow near a permanent stopping inby the location where the cutting operation had been performed. An attempt was made by mine personnel to extinguish the fire; however, the fire was so intense the mine was evacuated and sealed the next day. Four days after the mine was sealed, an explosion occurred that caused major damage to ventilation structures and mining equipment. Recovery of the mine started in July 2000, and required approximately one year to complete.

MSHA's investigation concluded that heated metal from the flame-cutting operation was the ignition source. Flame-cutting had been completed approximately 11 hours prior to the discovery of the fire. A heated metal spark from the cutting operation passed through an opening in the adjacent stopping, and coal and other combustible material within the worked-out area were most likely ignited. The root cause of this fire was that

FIGURE 1

Metal roof strap.

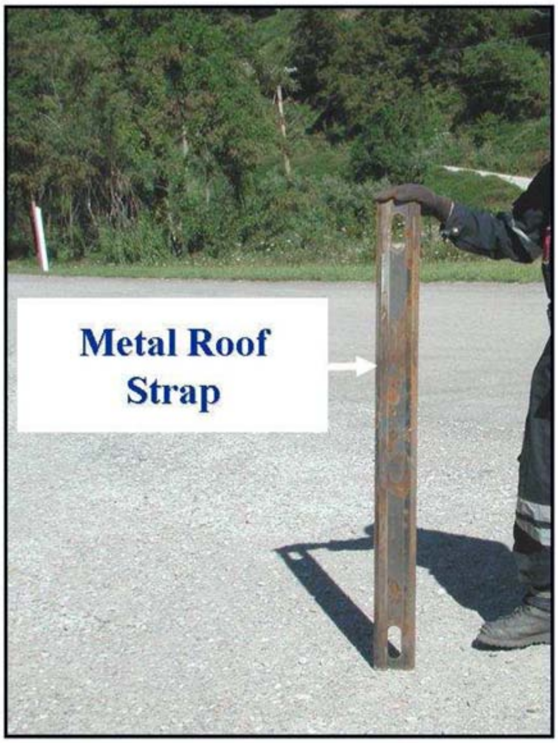


FIGURE 2

Debris from a stopping near the explosion in Darby Mine No. 1 (MSHA, 2006).

FIGURE 3

Corrugated, galvanized steel sheeting after the explosion in McElroy Mine (MSHA 2003).

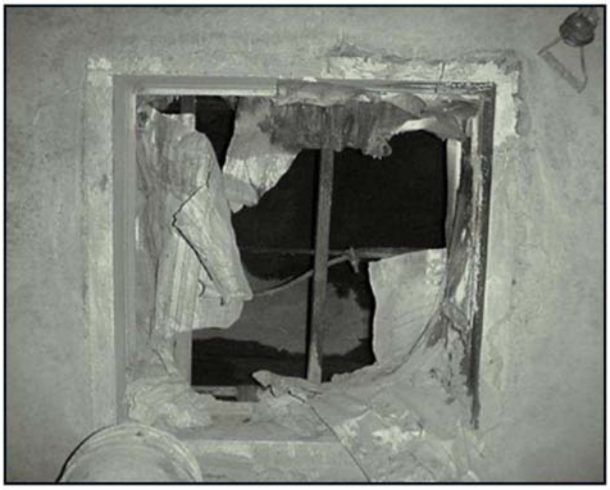
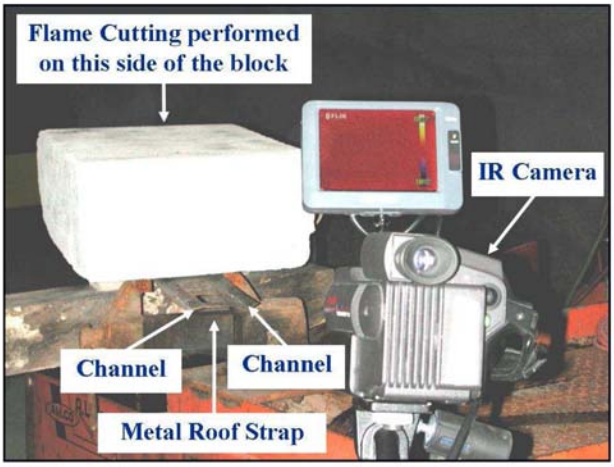


FIGURE 4

Setup of block and metal roof strap experiment.



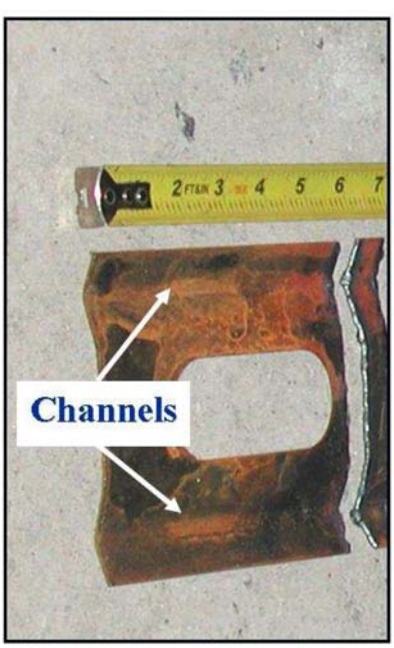
a diligent search for fire in all potentially affected areas was not made during and after the cutting operations (MSHA, 1999).

Blacksville No. 1 Mine explosion

On March 13, 1992, a cap was placed on a production shaft at the Blacksville No. 1 Mine in West Virginia, reducing the amount of intake air entering the shaft. On March 17, 1992, actions taken during installation of the casing caused further reductions in the amount of air entering the shaft. As a result from this reduced ventilation, methane within the explosive range (5%-15%) accumulated under the cap. On March 19, 1999, welding activities caused a methane explosion resulting in four fatalities and three injuries. MSHA's investigation determined that methane was ignited directly beneath the cap by sparks or an electric arc produced by the arc-welding operation that was in progress on top of the production shaft cap. The root cause of the fire was inadequate examination for methane (MSHA, 1992).

FIGURE 5

Close-up of the two channels on the metal roof strap.



Root causes of flame-cutting and welding fires and explosions

To reduce or prevent fires and explosions from occurring, one must understand the nature of their initiation and identify the root causes. In this study, the root causes of mine fires and explosions caused by flame-cutting and welding operations in underground U.S. coal mines were identified. MSHA Reports of Investigations (2006; 2003; 1999; 1992), MSHA Mine Accident Injury-Illness Reports and the MSHA Mining Industry Accident, Injuries Employment, Production Data Base (2008) from 1995 to 2007 were reviewed and analyzed. Ten working coal mines were visited to observe flame-cutting and welding operations, and interviews were conducted with approximately 100 mine workers who were involved in welding tasks. In addition, flame-cutting experiments were conducted at NIOSH's Lake Lynn Laboratory. The following root causes of fires or explosions from flame-cutting and welding operations in underground U.S. coal mines were identified:

1. Inadequate or improper methane examination and testing (30 CFR §75.1106).
2. Lack of a diligent search for fire during and after flame cutting or welding (30 CFR §75.1106).
3. Inadequate inspection of tools and equipment prior to cutting or welding (30 CFR §75.1106-5).
4. Improper procedures in preparing surfaces for cutting and welding, including degreasing and general cleaning (30 CFR §75.1106-4).
5. Inadequate ventilation of the work site (30 CFR §75 100).
6. Inadequate training of persons conducting the cutting and welding (30 CFR §75.1106-4).

Flame-cutting experiments

In order to gain a better understanding of the temperature histories of hot sparks, hot metal strips and hot molten metal, three sets of experiments were performed at NIOSH's Lake Lynn Laboratory. In each of these experiments the following parameters were utilized. An oxygen and acetylene torch was used to flame-cut a metal roof strap. An infrared (IR) camera with the appropriate instrumentation was used to obtain temperature histories of hot sparks and hot metal strips. In addition, a 6.35-mm (0.25-in.) thick metal strap, which was thicker than a metal roof strap, was flame-cut. The cuttings and hot molten metal from the cut dropped into a pan filled with float coal dust and grease to observe the effects of the hot molten metal on the float coal dust and grease. Float coal dust is defined as dust that passes a 75-µm (200-mesh) sieve. Float coal dust is easily transported by the mine ventilation system, can form an explosible coal cloud, and buildup on the floors, walls and roof.

Temperature histories of the hot sparks experiment

To conduct the experiment, a mine seal block was placed on top of the metal roof strap and the IR camera was positioned on the opposite side of the mine seal block where flame-cutting was performed. Figure 4

Table 1

Temperatures of hot particles.

Hot particle identification	Temperature of hot particle, °C/°F
1	747/ 1,377
2	742/ 1,368
3	760/ 1,400
4	500/ 932
5	762/ 1,404
6	587/ 1,089

shows this experimental setup. The metal roof strap was cut from underneath and hot particles traveled through the two channels located on the metal roof strap. Figure 5 shows a close-up of the two channels. Figure 6 shows the IR image of several hot sparks and Table 1 lists temperatures of some of the hot sparks identified in Fig. 6. These experimental results showed that flame cutting can produce hot sparks with temperatures much greater than 593° C (1,099° F), the minimum temperature required to ignite a methane-air mixture. It should be noted that the minimum temperature required to ignite a coal dust layer of less than 74 µm (-200 mesh) is 160° C (320° F) (Kuchta, 1985). Table 2 lists ignition temperatures of eight different coal layer samples.

Hot metal strip experiment

In this experiment, metal strips ranging from 1.27 to 3.75 cm (0.5 to 1.5 in.) were flame-cut from the metal roof strap shown in Fig. 7. The temperature histories of the hot metal strips were obtained by recording the temperature every 250 milliseconds using the IR camera. Figure 8 shows an example of the temperature histories of a 1.27-cm (0.5-in.) and a 3.75-cm (1.5-in.) metal strip following the cut. The 3.75-cm (1.5-in.) strip's temperature remained above 593° C (1,099° F) for 19 seconds, and the 1.27-cm (0.5-in.) strip's temperature remained

FIGURE 6

IR image of several hot particles.

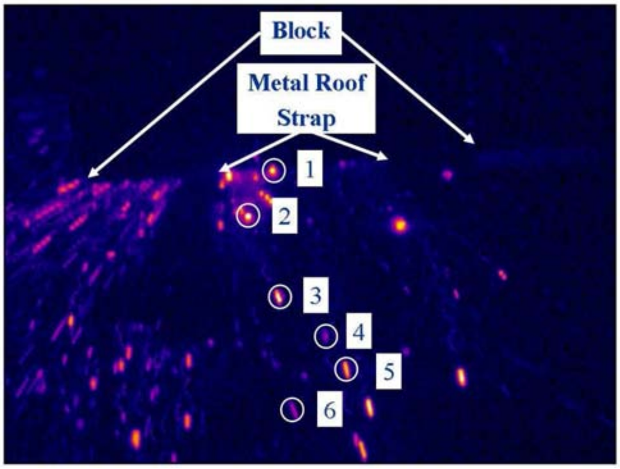


Table 2

Ignition temperature of coal layers (Kuchta, 1985).

Coal Identification	Ignition, °C/°F
Lignite, California	200/ 392
Lignite, North Dakota	180/ 356
Bituminous, Fox Hill, CO	180/ 356
Bituminous, No. 7 Illinois	160/ 320
Bituminous, Whitesburg, KY	190/ 374
Bituminous, Bruceton, PA	170/ 338
Bituminous, Pocahontas No. 3, West Virginia	220/ 428
Bituminous, Laramie No. 3, Wyoming	180/ 356

FIGURE 7

Metal roof strap prior to flame cutting individual strips.

FIGURE 8

Temperature histories of two hot metal strips following cutting.

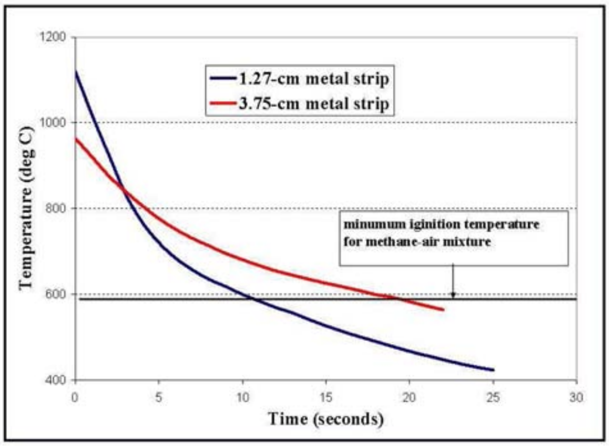


FIGURE 9

Setup for hot molten metal experiment.

about 593º C (1,099° F) for 10.5 seconds. The results from this experiment showed that these hot metal strips were capable of igniting a methane-air mixture.

Hot molten metal experiment

In this experiment, the effect of hot molten metal on float coal dust and grease was observed. Flame-cutting was performed approximately 1 m (3.3 ft) above the float coal dust and grease. The hot molten metal was allowed to fall directly on the float coal dust and grease. The temperatures of the metal, float coal dust and grease were recorded using the IR camera, shown in Fig. 9. The hot molten metal immediately ignited the grease. After several minutes, flames from the grease appeared to have self-extinguished. However, hot spots in the float coal dust were observed with a temperature range between 93-145º C (199-293° F).

These hot spots were not visible with the human eye and were only identified by using the IR camera. The IR camera was used to monitor the hot spots for approximately two hours. After two hours, a small fan was placed near these hot spots and air at a velocity of 2.03 m/s (6.66 ft/s) was passed over the hot spots. This air velocity was chosen since the air velocity in the belt entry must be at least 0.51 m/s (1.67 ft/s) and must not exceed 4.57 m/s (15 ft/s) when used to ventilate a working section (CFR). This ventilation caused the temperature of the hot spots to increase, resulting in re-ignition of the float coal dust and grease. The results from this experiment showed that hot spots can remain for several hours when not properly extinguished and can reignite if sufficient ventilation is provided (Hoffman, 1991).

Best practices to reduce fire and explosion hazards of flame-cutting/welding

The Code of Federal Regulations, 30 CFR §75.1106 requires the following: "All welding, cutting or soldering with arc or flame in all underground areas of a coal mine shall, whenever practicable, be conducted in fireproof enclosures. Welding, cutting or soldering with arc or flame in other then a fireproof enclosure shall be done under the supervision of a qualified person who shall make a diligent search for fire during and after such operations and shall, immediately before and during such operations, continuously test for methane with means approved by the secretary for detecting methane. Welding, cutting or soldering shall not be conducted in air that contains 1.0 volume per centum or more of methane." Rock dust (109 kg (240 lbs) minimum) or suitable fire extinguisher shall be immediately available during such welding, cutting or soldering, (30 CFR §75.1100-2(a)).

In addition to the CFR requirements, the following best practices are provided to reduce the fire and explosion hazards of flame-cutting and welding operations in underground coal mines. These best practices are based on the root cause analysis of fires and explosions caused by flame-cutting and welding operations in underground U.S. coal mines, observation of flame-cutting at operating coal mines, interviews with mine workers and flame-cutting experiments at NIOSH's Lake Lynn Laboratory and the MSHA report titled "Safety practices for welding and cutting operations" (Hoffman, 1981).

- Persons (mine workers and contractors) who are required to conduct methane examination during flame-cutting and welding operation should have training semi-annually. This training should include checks to ensure the methane detector device is properly calibrated by inspecting the date on calibration sticker and the proper use of methane monitors, with and without probes.
- Check for methane thoroughly and continuously during the flame-cutting and welding operations, and use a methane probe for hard to reach areas. Methane gas is colorless, odorless, tasteless, nontoxic, highly flammable and is lighter than air, so it can accumulate in areas such as roof cavities, get trapped underneath pan lines and other mining equipment. Ventilation should be adequate to provide dilution of any harmful gases or toxic vapors that may accumulate.
- Persons (mine workers and contractors) whose duties include flame-cutting and welding operations should have training semi-annually on the Code of Federal Regulations and State Regulations that apply to flame-cutting and welding.
- Use cold-cutting alternatives versus an oxygen and acetylene torch for cutting metals, when available. Several mines that were visited are using hydraulic cutters and punches. However, nonflame alternatives have limited application and cannot totally replace the use of flame cutting in underground coal mines.
- Have a helper observe the flame cutting and welding operations. This helper can continuously check for methane, immediately extinguish a fire and go for additional help if needed.
- Perform an equipment safety inspection prior to starting a flame-cutting and welding operation. When using an oxygen and acetylene torch:

1. Blow out the cylinder valves before attaching regulators.
2. Keep all grease (fingers, gloves) away from oxygen connections.
3. Never force connections.
4. Use the properly sized, clean cutting tips for the

operation.
5. Check connections for leaks.
6. Replace damaged hoses.
7. Open cylinder valves slowly.
8. Do not use acetylene at pressures higher than 9 psi.
9. Never lay acetylene bottles flat. They must remain vertical.
10. Ensure that flashback arrestors are installed.
11. Purge the oxygen and acetylene lines before lighting the torch.
12. When lighting the torch, point away from persons and combustibles.
13. Light the acetylene before opening the oxygen valve and do not re-light the torch on hot metal with the oxygen turned on.

- Have a fire hose hooked up and charged at the cutting/welding site. Thoroughly water down the surrounding area where all hot sparks and hot molten metal can reach prior to a flame-cutting and welding operation. This is one of the simplest and cheapest interventions to help reduce the risk of fire. After the flame-cutting and welding operation is completed, water down the area again.
- Wipe down equipment contaminated with coal dust, oil, grease or other combustibles prior to flame-cutting and welding operations.
- Apply rock dust to all adjacent areas prior to the flame-cutting and welding operation after the area has been watered down. Apply the rock dust liberally to cover the entire area where hot sparks or hot molten metal may be projected. Maintain an adequate supply of rock dust on hand to smother any fires that may flame up during the operation.
- Maintain accurate records of the flame-cutting and welding operations, including the following information:

1. Section and exact location(s) where the flame-cutting and welding operation was performed.
2. Item or items that were flame cut or welded.
3. The names of mine personnel that performed the flame-cutting and welding operation.
4. Time the flame-cutting and welding operation started.
5. Time the flame-cutting and welding operation was completed.
6. Special precautions should be taken to prevent fire or explosion and special instructions should be left for the oncoming shift personnel to monitor the site for hot spots.

- Use a thermal imaging camera to check for hot spots after the flame-cutting or welding activity is completed. The approximate cost for an IR camera that could be used for this application ranges from $5,000 - $8,000. As mentioned earlier, hot spots can remain undetected by the human eye and are only visible by an IR camera.
- Have the oncoming shift section foreman or a competent person inspect the area where flame-cutting and welding operations were performed and record that the site was re-inspected.
- Discuss flame cutting and welding operations at weekly safety meetings. Discuss any concerns related to this type of operation.

Conclusions

NIOSH conducted a research study on fires and explosions in underground U.S. coal mines caused by flame-cutting and welding operations. In this study, root causes of these types of fires were identified, flame-cutting and welding operations were observed and interviews were conducted with over 100 underground coal mine personnel whose duties included flame-cutting and welding operations. In addition, flame-cutting experiments were conducted at NIOSH's Lake Lynn Laboratory. As a result of this study, recommended best practices are provided for reducing fires and explosions from flame-cutting and welding. ■

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