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JACKLEG DRILL USAGE AND ACCIDENTS

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ABSTRACT

National Institute for Occupational Safety and Health NIOSH is conducting research on jackleg use and related accidents in underground metal mines. This paper provides an analysis and overview of jackleg drill usage, accidents, operational characteristics, and alternatives, based on information from injury reports, legacy research, stakeholder input, and published literature. Jackleg drills are involved in more ground fall accidents in underground metal mines than any other drill. Jackleg-related injuries are most prevalent at the face in the course of installing initial ground support. Alternatives to jacklegs for drilling and bolting under incomplete support in narrow underground openings are not yet available. Small mechanized bolting equipment needs to be developed to address jackleg-related accidents and improve safety at mines where jacklegs are being used.

JACKLEG DRILL

Description

The term “jackleg drill” is a generic name for a class of *handheld*, *rotary*, *percussion* rock drills that are equipped with an attached reaction leg to provide stability and thrust for the drill (Figure 1). All of the drill and leg controls are located near the operator’s handle at the rear of the head portion of the drill. Jacklegs are classified according to the bore size of their pneumatic pistons which normally range from 6.03 to 8.26 cm (2.375 to 3.25 in) [Kurt, 1982; Clark, 2012]. Jacklegs typically weigh 460 N (103 lbs), but their weight can approach 535 N (120 lbs) after they are fitted for operation with drill steel and air and water hoses [McKibbin and Clark, 2001]. In underground mines, jackleg drills are commonly used to drill 3.8-cm (1.5-in) diameter holes 1.83 m (6 ft) deep in rock.

Application

The jackleg drill is primarily used in underground mines when the size of the ore body, the ground conditions, or the mining method do not permit large openings to be mined using mechanized equipment (e.g., narrow vein mining). Jacklegs are used to drill blast-holes for explosives and also holes for installing ground support. These versatile drills are used in nearly all phases of mining including exploration, development, production, and maintenance [Kurt, 1982; Williams et al., 2007; Chen and McKinnon, 2012].

The jackleg is used to drill holes in rock using drill bits attached to hollow steel bars called drill steels (rotary percussion drilling). After the hole is drilled, the jackleg can be used to install different types of ground support components, depending on the ground conditions and the specific ground support measures that are needed. For example, the jackleg can be used to install expansion-anchor rockbolts or resin-grouted rockbolts using the drill’s rotary-motion feature. On the other hand, the jackleg can also be used to install friction-type Split-Set™ rockbolts using the drill’s percussion (hammer-motion) feature. As shown in Figure 1, various washer-like bearing plates can be installed along with these bolts to provide additional ground support and to help secure surface control products, such as wire mesh and shotcrete that are in turn used to retain small, loose material between the bolts [Clark, 2012].

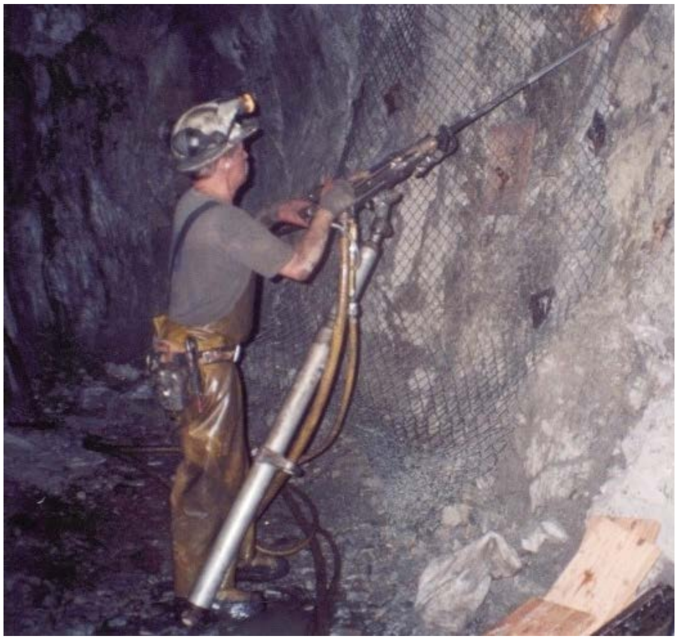

Figure 1. Jackleg drill in operation (after Clark, 2012).

Operation

The handheld jackleg drill combines a rotating percussive drill element with an integrated hinged thrust leg. Efficient use of these components requires skill, strength, coordination, and stamina. As a result, operating the jackleg drill can be extremely labor-intensive, particularly for an inexperienced user. The drill operator controls the drill’s rotational speed and feed leg thrust through modulation of the hand controls. In addition, the operator must also balance the drill’s roll, pitch, and yaw through the exertion of hand, leg, and body pressure while the drill is in operation [Helander and Peay, 1982; Lavender and Marras, 1990; Clark, 2012]. In short, the operator and the operator’s skill are integral components of the drilling process.

JACKLEG DRILL ACCIDENT DATA

Historically, the jackleg drill has proven to be a rugged and reliable means of drilling relatively shallow holes in rock. Although this practical drill has been used widely throughout the mining industry, a pattern of accidents and resulting injuries have been associated with its use. Over the years, several studies have been conducted at the NIOSH Spokane Research Laboratory to address these injuries. This paper provides a review of jackleg drill usage and accidents based on injury statistics that were collected from the Mine Safety and Health Administration (MSHA) and analyzed during four of the most recent of these NIOSH studies.

The broadest of these four studies addressed all U.S. metal, non-metal, and coal mines and sorted this information into a subset of mines that were known to use jackleg drills, based on at least one jackleg drill incident[1] being reported to MSHA. This data set, called Mine Jackleg Drill (MJLD) covers the period 2003-2012 and includes 59 mines (n=59) [Benton, 2014; 2015]. A second study addressed all U.S. underground and surface metal mines (MM; n=289) for the period 1999-2009 [Coleman et al., 2010]. A third study addressed only U.S. underground metal mines (UGMM; n=80) during the period 2006-2010 [Signer, 2011], and a fourth study addressed only U.S. underground metal mines where at least one fall of ground incident occurred (UGMMF; n=46) during these same years (i.e., 2006-2010) [Seymour et al., 2012; 2013]. The data from this fourth study is thus a subset of UGMM, eliminating mines where control of ground is not a significant safety concern and instead focusing on mines with difficult ground conditions.

JACKLEG DRILL USAGE

Mines Using Jackleg Drills

From 2003 through 2012, a total of 59 mines reported at least one jackleg drill incident to MSHA (MJLD data set). As shown in Figure 2, metal mines accounted for over half (54%) of these mines, with coal mines (31%) and non-metal mines (15%) accounting for the remainder.

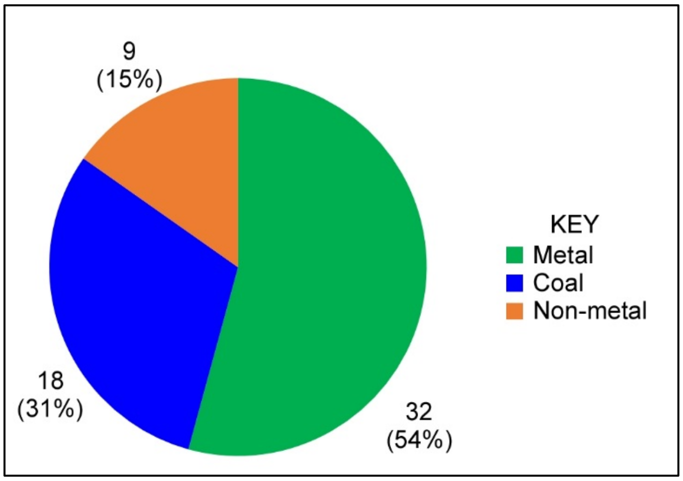

Figure 2. Number of known active mines using jackleg drills, by material class, from 2003 through 2012 (after Benton, 2014).

During this time period, an average of 18 mines per year reported incidents involving jackleg drills. For each of these years, metal mines consistently accounted for the majority of the mines that were known to use jackleg drills (Figure 3). According to this data set, the peak use of jackleg drills occurred in 2007, with 26 mines reporting at least one jackleg drill incident. Again, most of the mines using jackleg drills that year were metal mines (69%).

Incidents Involving Jackleg Drills

From 2003 through 2012, 445 incidents involving jackleg drills were reported by MSHA (MJLD data set). A preponderance (91%) of these jackleg-related incidents occurred at metal mines (Figure 4), even though metal mines accounted for only 54 % of the U.S. mines using jackleg drills during this time period. In comparison, about 6% of the reported jackleg accidents occurred at coal mines, and less than 3% of these incidents happened at non-metal mines.

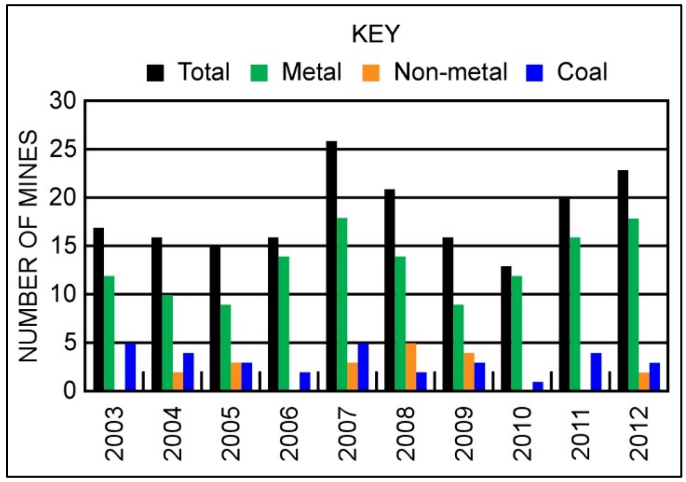

Figure 3. Number of known active mines using jackleg drills per year from 2003 through 2012 (after Benton, 2014).

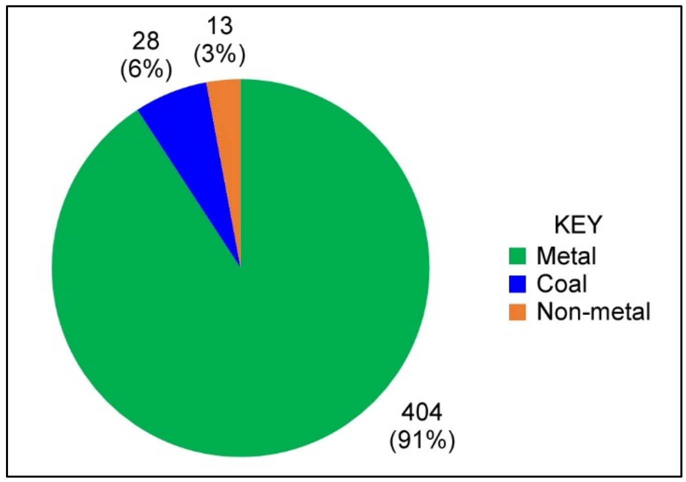

Figure 4. Number of jackleg-related incidents, by material class, at active mines from 2003 through 2012 (after Benton, 2014).

From 2003 through 2012, an average of 48 incidents involving jackleg drills occurred per year at U.S. metal, non-metal, and coal mines. As shown in Figure 5, the vast majority of these incidents occurred each year at metal mines. Although the use of jackleg drills is widespread throughout the mining industry, jackleg-related accidents are clearly more prevalent in underground metal mines.

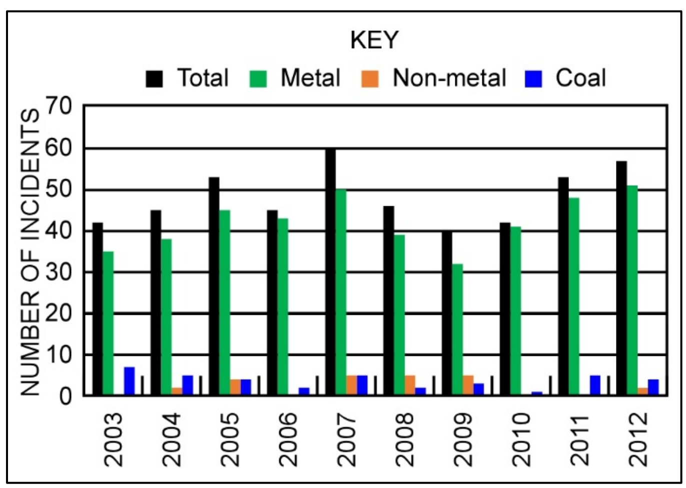

Figure 5. Incidents involving jackleg drills per year at active mines from 2003 through 2012 (after Benton, 2014).

[1] As defined by MSHA, the term "reportable injury" includes all incidents that require medical treatment, or result in death, or loss of consciousness, or inability to perform all job duties on any workday after the injury, or temporary assignment, or transfer to another job. Injuries involving "first-aid only" are not reportable.

Distribution of Jackleg Drill Use and Injuries

Most of the active metal mines in the United States are located in the west (Figure 6). As a result, a majority of the incidents involving jackleg drills also occur in western states. As shown in Figure 7, the top seven states with the most jackleg-related incidents from 2003 through 2012 were all western states. In fact, Montana, Idaho, and Nevada accounted for about 70% of the total incidents involving jackleg drills that were reported by MSHA during this time period.

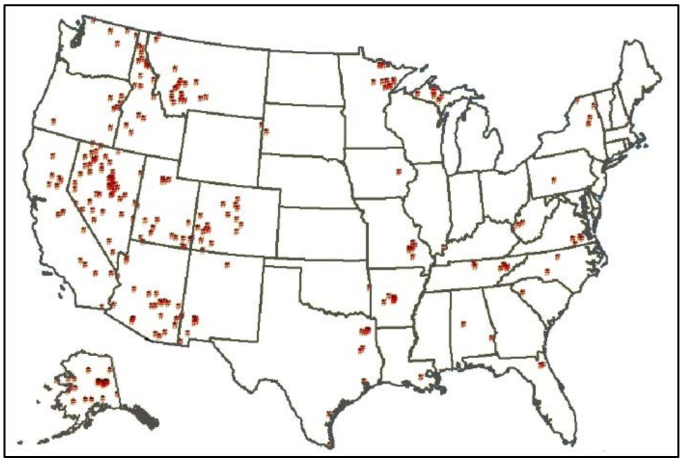

Figure 6. Active metal mines in the United States, 2009 (after Coleman et al., 2010).

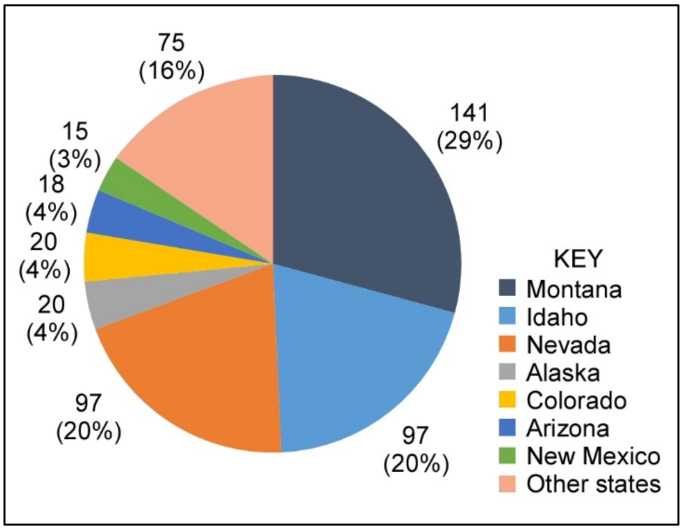

Figure 7. Top seven states with the most jackleg-related incidents at active mines from 2003 through 2012 (after Benton, 2015).

JACKLEG DRILL ACCIDENTS

Operating Jackleg Drills

The primary sources of injury for jackleg drill operators are falls of ground, machinery (pinches, strains, etc.), and slips or falls. When using a jackleg drill in an underground mine, there is always a risk from falls of ground *while* operating the machinery. Additional factors that contribute to an increased risk of injury include: improper ground control measures (inadequate scaling or removal of loose material), poor worksite preparation (general messiness), insufficient lighting, oily and wattery (slippery) floors, broken and uneven footing, and awkward use of the jackleg drill in an extended position as a result of an over-sized mine opening. This latter situation is more common in difficult ground conditions, where ground support must be installed shortly after creation of the underground opening [Vorster and Franklin 2008]. During this stage of mining, the miners are likely to have an increased exposure to ground fall hazards because they may be drilling and bolting under *incomplete support*[2] without the benefit of overhead protection provided by the canopy and/or reach of a mechanized drill or bolter.

Although the exact extent of any of these hazards is difficult to quantify, further insight can be gained by analyzing the available MSHA accident data in the context of how the jackleg is used during the mining cycle. Several factors were examined during the four NIOSH studies mentioned in this paper, including: ground fall accidents and injuries, the activity taking place at the time of the ground fall incident, the type of drill being used, the location in the mine where the accident occurred, the actual source of the injury, and finally the part of the operator's body that was injured as specified in the MSHA accident narrative.

Ground Fall Accidents and Injuries

From 1999 through 2009, ground fall accidents caused 10.4% of the fatalities, 9.6% of the non-fatal day lost (NFDL) injuries, and 13.9% of the no day lost (NDL) injuries at active surface and underground metal mines in the United States (Table 1). Normally, the risks of accidents and injuries associated with falls of ground are much greater in underground mines than at surface mines. This increased exposure to ground fall hazards is particularly evident in the changing and often unpredictable ground conditions, where jacklegs are most frequently used.

Table 1. Ground Fall Fatalities and Injuries for Metal Mines.

Type of Injury	MM (%)	UGMM (%)	UGMMF (%)
Fatality	10.4	50.0	63.6
Non-Fatal Day Lost (NFDL)	9.6	13.0	14.5
No Day Lost (NDL)	13.9	15.9	18.7

If only underground metal mines are considered, the ground fall accident statistics increase markedly. For example, ground falls are typically the leading cause of fatalities and a significant source of the injuries in underground metal mines (Seymour et al., 2013). From 2006 through 2010, ground fall accidents in U.S. underground metal mines caused 50% of the fatalities and accounted for 13.0% and 15.9% respectively, of the NFDL and NDL injuries (Table 1).

The risks associated with ground fall accidents again increase significantly by eliminating mines where ground control is not a prevalent problem and instead focusing on underground mines with difficult ground conditions. From 2006 through 2010, ground fall accidents caused 63.6% of the fatalities, 14.5% of the NFDL injuries, and 18.7% of the NDL injuries in U.S. underground metal mines, where at least one fall of ground was reported by MSHA (Table 1).

As indicated in Table 2, the percentage of injuries caused by fall of ground incidents increased significantly from 3.5% for all metal mines to 16.5% for underground metal mines with at least one reportable ground fall accident. Obviously, the risks associated with ground fall hazards depend on a host of factors that are specific to a particular mine site, such as the mineral commodity, mining method, ground support, geology, and ground conditions. Nevertheless, a comparison of the results from these three NIOSH studies (MM, UGMM, and UGMMF) indicates that the risk of injury from ground fall accidents increases significantly in underground metal mines, particularly at mines where ground fall incidents have been previously reported.

Activities Associated with Ground Fall Injuries

Although jackleg drills are used for drilling and installation of ground support in nearly all phases of mining, most jackleg-related injuries occur during the production phase. After blasting the ore at an active mining face, a flurry of activity typically ensues, including scaling

[2] Awaiting installation of bolts, mesh, shotcrete, etc.

of loose rock, installation of ground support, mucking or removal of ore and debris, drilling holes for the next blast round, and charging the holes with explosives. The UGMM study concluded that 93% of the ground fall incidents in underground metal mines occurred during this production phase or during the drill-blast-muck mining cycle. As indicated in Table 3, bolting was the activity that had the highest percentage (38%) of injuries caused by ground falls, followed by scaling (17%), drilling (12%), and blasting (10%). Fatalities caused by ground falls were evenly distributed between bolting, scaling, and machine maintenance at 28.6% each, followed by drilling at 14.3%. Bolting and drilling, the activities that would typically involve a jackleg drill, accounted for 50% the total ground fall injuries.

Table 2. Sources of Reportable Injuries for Metal Mines.

Source of Injury	MM (%)	UGMM (%)	UGMMF (%)
Handling Materials	34.7	27.6	26.8
Fall of Ground	3.5	14.4	16.5
Slip or Fall of Person	21.1	16.5	16.0
Machinery	12.4	13.3	13.8
Hand Tools	13.2	10.0	9.5
Powered Haulage	7.4	9.5	9.0
All Other	7.7	8.7	8.4
All Sources	100.0	100.0	100.0

Table 3. Activities Associated with Ground Fall Injuries in Underground Metal Mines (UGMM).

Activity	Number	%	Fatals	%	NFDL	NDL
Bolting	103	38.0	2	28.6	41	60
Scaling	46	17.0	2	28.6	30	14
Drilling	32	12.0	1	14.3	19	12
Blasting	27	10.0			21	6
Handling*	7	3.0			5	2
Machine Maintenance*	7	2.0	2	28.6	3	2
Inspection*	6	2.0			2	4
Setting Posts*	3	1.0			3	
Hanging	5	2.0			2	3
Mucking*	2	1.0			1	1
Traveling	7	3.0			6	1
Other/Not Classified	23	9.0			13	10

*Operator data only—no contractor data.

Type of Drill Associated with Ground Fall Injuries

From 2006 through 2010, 104 ground fall accidents occurred in U.S. underground metal mines that involved drilling equipment. Unfortunately, the specific type of drill, which was being used for drilling or bolting at the time of the incident, was only mentioned in the MSHA accident narratives for 52% of these cases (Table 4). Because the type of drilling equipment was not specified for almost half (48%) of these accidents, it is difficult to accurately determine the relative use of jackleg drills in comparison with other types of drills.

Table 4. Equipment Used for Drilling/Bolting during Ground Fall Accidents (UGMM, operator data only).

Type of Drill	Number	%	% Known
Jackleg	48	46	89
Other	6	6	11
Known	54	52	100
Unknown	50	48	
Total	104	100	

However, the available data does indicate that jackleg drills were being used during at least 46% of these ground fall accidents (Table 4). Furthermore, jackleg drills were involved in 89% of the ground fall incidents, where the specific type of drill was identified (i.e., the known cases listed in Table 4). As a result, the jackleg drill is undoubtedly associated with more ground fall accidents in underground metal mines than any other type of drilling equipment. Over the years, the design and the components of jackleg drills have changed very little. Unlike mechanized drills where the operator is protected beneath a canopy, the jackleg operator is still exposed to potential ground fall hazards. Consequently, the problems and risks of injury associated with operating jackleg drills are not new and have been previously investigated by others[3].

Location of Jackleg Drill Accidents

From 2003 through 2012, 480 ground fall accidents involving jackleg drills occurred at U.S. metal, non-metal, and coal mines (MJLD data set). As shown in Figure 8, the majority (61%) of these jackleg-related incidents occurred at or near the active mining face. For almost a third (28%) these incidents, the location of the accident was not clearly identified and merely noted as other (22%) or unknown[4] (6%). The remaining 11% of these ground fall incidents involving jackleg drills occurred in either inclined (4%) or vertical (4%) shafts, at intersections (2%), or in underground shop areas (1%). Most jackleg-related injuries occur during the production phase of mining; therefore, it is reasonable that most of these accidents would happen at the face.

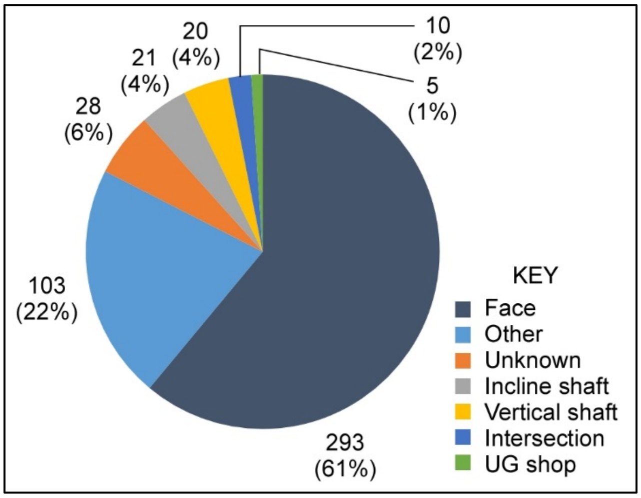

Figure 8. Location of jackleg-related ground fall incidents (after Benton, 2015).

Jacklegs are typically used to drill blast holes for explosives or holes for installing ground support. In underground metal mines, ground support is normally installed before the next blast round is drilled. Since the underground opening is supported while the blast pattern is being drilling, the majority of these jackleg-related ground fall incidents more than likely occurred while ground support was being installed under incomplete cover. As noted in Table 3, bolting has the highest percentage of injuries caused by ground falls.

Sources of Injuries to Jackleg Drill Operators

From 2003 through 2012, MSHA reported 483 incidents involving jackleg-related injuries at U.S. metal, non-metal, and coal mines (MJLD data set). As shown in Figure 9, the highest percentage of these injuries were caused by falling objects (39%), whereas most of the remaining injuries were caused by other striking by flying material and moving objects (21%) and over-exertion (20%).

An analysis of the size distribution of these falling objects in the form of ground falls and rock bursts is presented in Figure 10. From 1999 through 2004, the majority (65%) of the ground falls that occurred in underground metal mines consisted of small rocks weighing less

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3 Oitto [1975] reported that jackleg drills caused more injuries than any other type of rock drill in U.S. underground metal and non-metal mines for the period 1973-1974. Of the 575 injuries from rock drills that were reported, 55% involved jackleg drills.

4 "Other" and "Unknown" are official MSHA designations that unfortunately cannot be specified further. Accident narratives can sometimes provide additional information, but distinct locations are typically not mentioned with these categories.

than 9.33 kg (25 lbs). The remaining 35% of these ground falls involved much larger material—slabs (26%), massive rocks (5%), and rock bursts (4%). While these large falls of ground were responsible for 75% of the ground fall fatalities, the vast majority of the small rock falls (81%) resulted in NDL injuries. Nonetheless, these small falls of ground can easily cause serious injuries to unprotected miners, as evidenced by 19% of these small ground falls resulting in fatalities or NFDL injuries. As noted by Lacerda [2004], a 9.33-kg (25-lb) rock that has fallen 3.1 m (10 ft) impacts with a force of 3.4 kN (767 lbs-force).

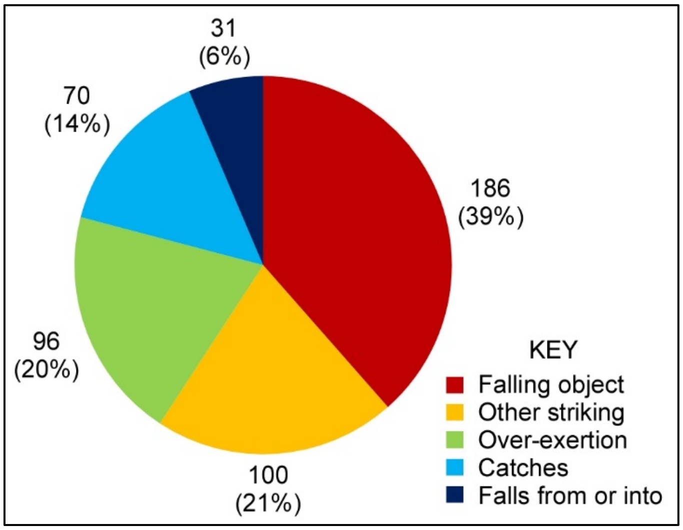

Figure 9. Sources of jackleg-related injuries, 2003-2012 (after Benton, 2014).

Small ground falls typically occur between traditional ground support components such as bolts, plates, mats, or trusses. These small falls of ground are usually prevented by extensive scaling or the installation of additional surface support elements such as wire mesh and shotcrete [Clark et al., 2011].

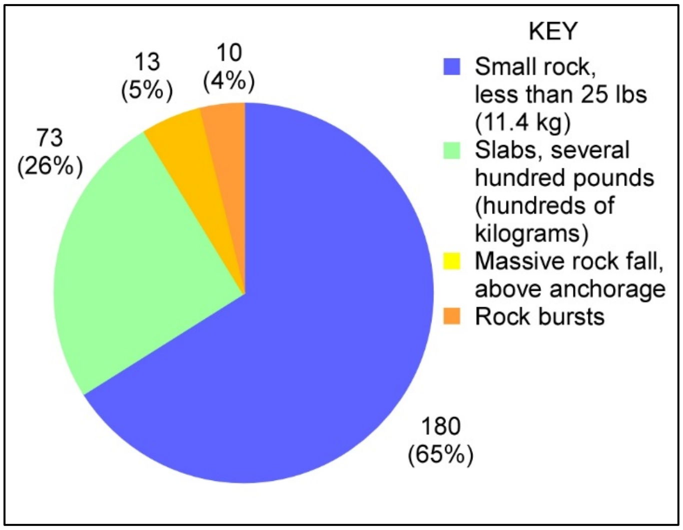

Figure 10. Size of ground falls in underground metal mines, 1999-2004 (after Biswas and Zipf, 2003; Clark et al., 2011).

Injuries to Jackleg Drill Operators

The type of the injuries suffered by jackleg drill operators is shown in Figure 11 for the 483 jackleg-related incidents that occurred at U.S. metal, non-metal, and coal mines from 2003 through 2012 (MJLD data set). Most of these operator injuries are roughly spread among three major categories—skin damage (44%), injuries to bones and teeth (24%), and joint and muscle injuries (22%). Skin damage occurred in the form of abrasions, lacerations, punctures, and contusions. Serious injuries[5] were relatively rare (7%), and eye injuries were even more scarce (1%). The nature of these injuries is again typical for smaller falls of ground.

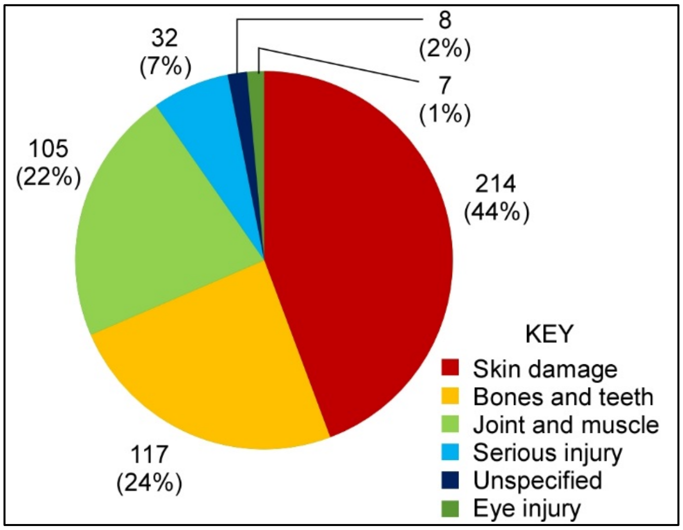

Figure 11. Nature of jackleg-related injuries, 2003-2012 (after Benton, 2014).

JACKLEG DRILL ALTERNATIVES

Viable mechanized alternatives need to be developed for jackleg drills to address the accidents and injuries associated with its use. However, the jackleg drill is a difficult tool to replace because it is not only used for drilling blast holes for explosives and holes for installing ground support, but also for a variety of miscellaneous repair and utility applications. To effectively replace the jackleg drill, these alternative machines need to be practical, reliable, and versatile; capable of being operated on broken or uneven ground; and able to be easily transported through narrow openings in underground mines. Practical mechanized alternatives have not yet been implemented because none of the proposed technology can meet the functional requirements and replace the efficiency, and flexibility provided by the jackleg drill.

Mechanized equipment for drilling involves two types of machines: (1) jumbos for drilling blast patterns immediately ahead of the machine, and (2) bolters designed for drilling and installing rockbolts and wire mesh along irregular surfaces and at odd angles to the excavation.

Several specialized mini-jumbos have been developed for drilling blast patterns in narrow underground openings [Walker, 2014]. However, these machines predominantly drill into a vertical face along a horizontal orientation aligned in the same direction as the mining advance, and they are not designed to install rockbolts or other types of ground support at other orientations.

In the case of small-scale mechanized bolters, the choices are less clear and much more limited. The design requirements for these machines are significantly different than jumbos in terms of drill boom flexibility and ground fall protection. The drill boom must be able to articulate to access the roof and walls of the mine opening, and the unit must be equipped with an overhead canopy to protect the operator. Prototypes of small-scale bolters are being developed for installing ground support in narrow underground openings. For

[5] Injuries in the form of amputation or enucleation; concussion (cerebral); crushing; dislocation; hernia or rupture; joint, tendon, or muscle damage; cerebral hemorrhage; or multiple injuries.

example, Fletcher is developing a version of this bolter in conjunction with the Stillwater Mining Company that protects the operator under a canopy and yet is still able to operate in areas, which were previously accessible only to jackleg drills [Kendall and Ferster, 2014]. Several other companies are developing self-propelled, self-contained drilling platforms for narrow vein mining, including Aramine, Atlas Copco, Boart Longyear, CMAC (a division of Thyssen), and Sandvik [Walker, 2014].

Because of their ease of transport and versatility, the use of jackleg drills is likely to continue, particularly for miscellaneous repair and rehabilitation, installation of secondary infrastructure, and utility applications.

CONCLUSIONS

1) An analysis of MSHA accident data indicates that jackleg-related incidents predominantly occur at metal mines in the western U.S. with Montana, Idaho, and Nevada accounting for a majority of the accidents involving jackleg drills.

2) Ground falls are the leading cause of fatalities and a significant source of the injuries in underground metal mines. The risk of ground fall injuries increases significantly in underground metal mines with difficult ground conditions.

3) Most ground fall accidents occur during the production cycle. Bolting and drilling, typical activities involving jackleg drills, accounted for about half of the ground fall injuries.

4) Jackleg drills are involved in more ground fall accidents in underground metal mines than any other drill. Most of these jackleg-related accidents occur at the face and are caused by small falls of ground. The vast majority of these small ground falls result in NDL injuries and usually damage the jackleg operator's skin, bones and teeth, or joints and muscles.

5) Jackleg drills are used more safely and effectively in mine openings that are sized for the use of handheld equipment. Although larger mine openings are useful for mechanized drilling and mucking equipment, they create problems for the installation of ground support with jackleg drills.

6) Although alternatives to jacklegs are frequently used for drilling blast holes, alternatives are not readily available for drilling and bolting under incomplete support in narrow underground openings. Small mechanized bolting equipment needs to be developed to address this safety problem.

ACKNOWLEDGEMENTS

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Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

REFERENCES

Benton, D. [2014]. Jackleg Drill: Usage at Underground Mines. *Ground Control Branch Strategic Planning Document*, NIOSH Internal Report, 11 pp. (unpublished)

Benton, D. [2015]. Jackleg Drill: Safety Research Potential. *Ground Control Branch Strategic Planning Document*, NIOSH Internal Report, 10 pp. (unpublished)

Biswas, K. and Zipf, R.K. [2003]. Root Causes of Groundfall Related Incidents in U.S. Mining Industry. *Proceedings of the 22nd International Conference on Ground Control in Mining*, Morgantown, WV, pp. 335-343.

Chen, S., and McKinnon, R. [2012]. Cut-and-fill narrow vein mining at Great Basin's Hollister Mine. *Mining Engineering Vol. 64, No. 4,* Society of Mining, Metallurgy, and Exploration, pp. 69-72.

Clark, C. [2012]. Miner's Jackleg-Drill Alternatives. *Ground Control Branch Strategic Planning Document*, NIOSH Internal Report, 72 pp. (unpublished)

Clark, C., Stepan, M., Seymour, J., and Martin, L. [2011]. Early Strength Performance of Modern Weak Rock Mass Shotcrete Mixes. *Mining Engineering Vol. 63, No. 1*, Society of Mining, Metallurgy, and Exploration, pp. 54-59.

Coleman, P., Martini, L., and Brune, J. [2010]. Safety and Health in U.S. Mines, 1999-2009. NIOSH Internal Report, 43 pp. (unpublished)

Helander, M., and Peay, J. [1982]. A Human Factors Research Program for Underground Metal and Non-Metal Mines. *Proceedings of the Human Factors Society--26th Annual Meeting*, DOI: 10.1177/154193128202600423, pp. 379-388.

Kendall, W., and Ferster, M. [2014]. Development of Mechanized Ground Support Installation Equipment for Improved Safety in Narrow Vein Mine Conditions. *33rd International Conference on Ground Control in Mining*, ICGCM, Morgantown, West VA, pp. 185-187.

Kurt, E. [1982]. Conventional Small Drilling Equipment. *Underground Mining Methods Handbook, W. Hustrulid (Ed.)*, SME-AIME, New York, pp. 999-1033.

Lacerda, L. [2004]. Shotcrete and Other Surface Support Liners. *Preprint No. 04-36, SME Annual Meeting* Feb 23-25, Denver, CO: Society of Mining and Mineral Exploration, 6 pp.

Lavender, S., and Marras, W. [1990]. An electromyographic analysis of an ergonomic intervention with the jackleg drill. *Applied Ergonomics, Vol 21 No.2*, Butterworth & Co. Ltd, pp. 90-100.

McKibbin, R., and Clark, C. [2001]. Prevention of Drilling and Bolting Injuries - Project Accomplishments 1999-2001. NIOSH Internal Report, 10 pp. (unpublished)

Oitto, R. [1975]. Analysis of Injuries Involving Jackleg Rock Drills Underground, 1973-1974. *MESA Information Report 1024*, United States Department of the Interior. Washington, D.C., 16 pp.

Seymour, J., Martin, L., Clark, C., Tesarik, D., and Stepan, M. [2013]. An Analysis of Recent MSHA Accident Data for Underground Metal Mines Using Backfill. *Preprint No. 13-061, SME Annual Meeting,* Feb 24-27, Denver, CO: Society of Mining and Mineral Exploration, 9 pp.

Signer, S. [2011]. Assessment of Ground Control for Underground Metal Mines. *Ground Control Branch Strategic Planning Document*, NIOSH Internal Report, 10 pp. (unpublished)

Vorster, B., and Franklin, D. [2008]. Immediate Ground Support, After Development or Stope Face Exposure, Can Prevent Falls of Ground. *SAIMM Narrow Vein and Reef 2008*, Sun City RSA, the Southern African Institute of Mining and Metallurgy, 20 pp.

Walker, S. [2014]. Mining Machines for Small Spaces. *E&MJ*, Engineering and Mining Journal Jacksonville, FL, USA, Retrieved from http://www.e-mj.com/features/, 10 pp.

Williams, T., Brady, T., Bayer, D., Bren, M., Pakalnis, R., Marjerison, J., and Langston, R. [2007]. Underhand Cut and Fill Mining as Practiced in Three Deep Hard Rock Mines in the United States. *Proceedings of the CIM conference exhibition*, Montreal, CAN, pp. 1-11.