Jackleg drill injuries

by C.C. Clark, D.J. Benton, J.B. Seymour and L.A. Martin

Abstract ■ The U.S. 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. The results indicate that jackleg drills are involved in more groundfall accidents in underground metal mines than any other drill, and jackleg-drill-related injuries are most prevalent at the face in the course of installing initial ground support. Practical mechanized alternatives to jackleg drills for drilling and bolting under incomplete support in narrow underground openings have not yet been realized. Small, versatile mechanized bolting equipment needs to be developed to address jackleg-drill-related accidents and improve safety at mines where jackleg drills are being used.

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Introduction

Jackleg drill is a generic name for a handheld, rotary, percussion rock drill equipped with an attached reaction leg to provide stability and thrust (Fig. 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. Jackleg drills 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). Jackleg drills typically weigh 46.7 kg (103 lb), but the weight can approach 54.4 kg (120 lb) after being 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 up to 1.83 m (6 ft) deep in rock.

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Application. Jackleg drills are primarily used in underground mines when the size of the orebody, the ground conditions or the mining method does not permit large openings to be mined with mechanized equipment, for example, in narrow vein mining. They 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).

With drill bits attached to hollow steel bars called drill steels, the jackleg drill is used to drill holes in rock by rotary percussion drilling. It can then be used to install various types of ground support components, depending on the ground conditions and the specific ground support measures needed: for example, expansion-anchor rockbolts or resin-grouted rockbolts using the drill's rotary-motion feature, or friction-type Split Set rockbolts using the drill's percussion, or hammer-motion, feature. As shown in Fig. 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 like wire mesh and shotcrete that are in turn used to retain small, loose material between the bolts (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 by exerting hand, leg and body pressure while the drill is in operation (Helander and Peay, 1982; Lavender and Marras, 1990; Clark, 2012). The operator and operator skill are integral components of the drilling process.

Jackleg drill accident data

Historically, the jackleg drill has been 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 Spokane Research Laboratory of the U.S. National Institute for Occupational Safety and Health (NIOSH) to address jackleg-drill-related injuries. This paper provides a review of jackleg drill usage and accidents based on injury statistics collected from the U.S. Mine Safety and Health Administration (MSHA) and analyzed in four of the most recent of the NIOSH studies.

The broadest of the studies addressed all U.S. metal, nonmetal and coal mines and sorted the information into a subset of mines known to use jackleg drills, based on at least one jackleg drill incident being reported to MSHA. MSHA defines "reportable injury" as including all incidents requiring medical treatment or resulting in death, 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. The "mine jackleg drill" (MJLD) data set 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 1999-2009 (Coleman, Martini and Brune, 2010). A third study addressed only U.S. underground metal mines (UGMM; *n* = 80) for 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 2006-2010 (Seymour et al., 2012, 2013). UGMMF is thus a subset of UGMM, focusing on mines with difficult ground conditions and eliminating mines where control of ground was not a significant safety concern.

Figure 1

Jackleg drill in operation (Clark, 2012).

Jackleg drill usage

Mines using jackleg drills. From the MJLD data set, a total of 59 mines reported at least one jackleg drill incident to MSHA from 2003 through 2012. Metal mines accounted for 54 percent, or more than half, of the incidents, while coal mines accounted for 31 percent and nonmetal mines for 15 percent. The average per year was 18 mines. On a yearly basis, metal mines consistently accounted for the majority (Fig. 2). A peak occurred in 2007, with 26 mines reporting at least one jackleg drill incident, of which 69 percent were metal mines.

Incidents involving jackleg drills. From the MJLD data set, 483 incidents involving jackleg drills were reported to MSHA from 2003 through 2012. Of these, 91 percent occurred at metal mines, even though metal mines made up only 54 percent of the overall mines, while about 6 percent occurred at coal mines and less than 3 percent at nonmetal mines. The average per year was 48 incidents. On a yearly basis, the vast majority of the incidents occurred at metal mines (Fig. 3). Although jackleg drills are in widespread use across the mining industry, jackleg-drill-related accidents are clearly more prevalent in metal mines.

Figure 2

Number of active mines known as using jackleg drills, by year from 2003 through 2012 (Benton, 2014).

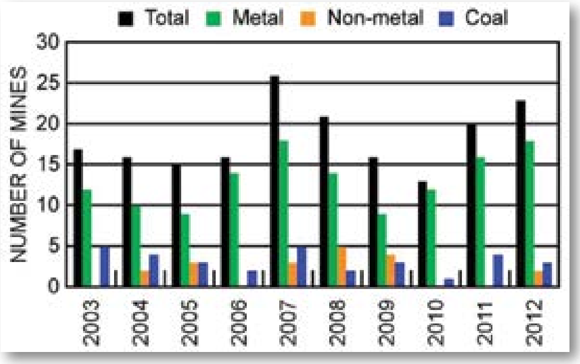


Figure 3

Number of incidents involving jackleg drills at active mines, by year from 2003 through 2012 (Benton, 2014).

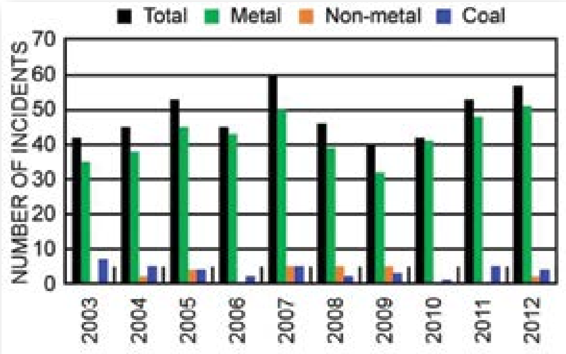


Table 1

Groundfall fatalities and injuries for metal mines.

Type of injury	MM (%)	UGMM (%)	UGMMF (%)
Fatality	10.4	50.0	63.6
Nonfatal day lost (NFDL)	9.6	13.0	14.5
No day lost (NDL)	13.9	15.9	18.7

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/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 others	7.7	8.7	8.4
All sources	100.0	100.0	100.0

Distribution of jackleg drill use and injuries. Most of the active underground metal mines in the United States are located in the West. As a result, the majority of incidents involving jackleg drills also are in western states. The top seven states with the most jackleg-drill-related incidents during 2003 through 2012 were all western states (highlighted in yellow in Fig. 4), and Montana, Idaho and Nevada together accounted for about 70 percent of the total incidents.

Jackleg drill accidents

Operating jackleg drills. The primary sources of injury for jackleg drill operators are fall of ground; machinery, including pinches and strains; and slips or falls. When using a jackleg drill in an underground mine, there is always a risk of injury from a fall of ground while operating the drill. Factors that contribute to increased risk include improper ground control measures, such as inadequate scaling or removal of loose material; poor worksite preparation, including general messiness; insufficient lighting; oily and watery, and thus slippery, floors; broken and uneven footing; and awkward use of the drill in an extended position as a result of an oversized mine opening. The last situation is more common in difficult ground conditions, where ground support must be installed shortly after the underground opening is created (Vorster and Franklin, 2008). In this stage of mining, miners are likely to have increased exposure to groundfall hazards because they may be drilling and bolting under incomplete support, without the benefit of overhead protection from a 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 may be gained by analyzing the available MSHA accident data in the context of how a jackleg drill is used during the mining cycle. Several factors were examined in the four NIOSH studies covered in this paper, including groundfall accidents and injuries, the activity taking place at the time of the groundfall incident, the type of drill being used, the location in the mine where the accident occurred, the actual source of the injury and the part of the operator's body that was injured, as specified in the MSHA accident narrative.

Groundfall accidents and injuries. From the MM data set, groundfall accidents caused 10.4 percent of the fatalities, 9.6 percent of the nonfatal day lost (NFDL) injuries and 13.9 percent of the no day lost (NDL) injuries at active surface and underground metal mines in the United States from 1999 through 2009 (Table 1).

Figure 4

Active underground metal mines in the United States in 2010 (Seymour et al., 2013), with states having the most jackleg-drill-related incidents in 2003-2012 in yellow (Benton, 2015).

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 groundfall hazards is particularly evident in the changing and often unpredictable ground conditions in which jackleg drills are most frequently used. According to Seymour et al. (2013), groundfalls are typically the leading cause of fatalities and a significant source of injuries in underground metal mines. The UGMM data set, which considered only U.S. underground metal mines from 2006 through 2010, showed marked increases in the groundfall accident statistics, with groundfall accidents causing 50 percent of the fatalities and 13.0 and 15.9 percent, respectively, of the NFDL and NDL injuries (Table 1). The risks are further increased when focusing on underground mines with difficult ground conditions and eliminating mines where ground control is not a prevalent problem. The UGMMF data set indicated that groundfall accidents caused 63.6 percent of the fatalities and 14.5 and

18.7 percent of the NFDL and NDL injuries, respectively, in U.S. underground metal mines from 2006 through 2010.

Table 2 shows that the percentage of injuries caused by groundfall incidents increased from 3.5 percent for the MM data set, which covered all metal mines, to 16.5 percent for the UGMMF data set, which covered underground metal mines with at least one reported groundfall accident. Although the risks associated with groundfall hazards depend on a host of factors specific to the mine site, such as the mineral commodity, mining method, ground support, geology and ground conditions, a comparison of the MM, UGMM and UGMMF results indicates increased risks from groundfall accidents in underground metal mines, particularly those where groundfall incidents have been previously reported.

Activities associated with groundfall injuries. Although jackleg drills are used for drilling and the installing of ground support in nearly all phases of mining, most jackleg-drill-related injuries occur in the production phase. After blasting the ore at an active mining face, a flurry of activity typically ensues, including scaling of loose rock, installing of ground support, mucking or removal of ore and debris, drilling of holes for the next blast round, and charging of the holes with explosives. The UGMM study found that 93 percent of the groundfall incidents in underground metal mines occurred in this production phase or during the drill-blast-muck mining cycle. Table 3 shows bolting as the activity with the highest percentage, 38 percent, of injuries caused by groundfalls, followed by scaling with 17 percent, drilling with 12 percent and blasting with 10 percent. Fatalities caused by groundfalls were evenly distributed across bolting, scaling and machine maintenance with 28.6 percent each, followed by drilling with 14.3 percent. Bolting and drilling, the activities that would typically involve a jackleg drill, accounted for 50 percent of the total groundfall injuries.

Table 3

Activities associated with groundfall injuries in underground metal mines, from the UGMM data set.

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	0	0	21	6
Handling*	7	3.0	0	0	5	2
Machine maintenance*	7	2.0	2	28.6	3	2
Inspection*	6	2.0	0	0	2	4
Setting posts*	3	1.0	0	0	3	0
Hanging	5	2.0	0	0	2	3
Mucking*	2	1.0	0	0	1	1
Traveling	7	3.0	0	0	6	1
Other/not classified	23	9.0	0	0	13	10

*Operator data only – no contractor data.

Type of drill associated with groundfall injuries. From the UGMM data set, 104 groundfall accidents occurred in U.S. underground metal mines from 2006 through 2010 that involved drilling equipment. Because the type of drilling equipment was not specified for 48 percent, or almost half, of these accidents, it is difficult to determine the relative use of jackleg drills in comparison with other types of drills. However, the available data do indicate that jackleg drills were being used during at least 46 percent of these groundfall accidents, and jackleg drills were involved in 89 percent of the groundfall incidents for which the drill type was known (Clark et al., 2016). The jackleg drill is therefore associated with more groundfall accidents in underground metal mines than other types of drilling equipment.

Over the years, the design and components of jackleg drills have seen little change. Unlike a mechanized drill, whose operator is protected beneath a canopy, the jackleg drill's operator is still exposed to potential groundfall hazards. Consequently, the problems and risks of injury associated with operating jackleg drills are not new and have been previously investigated by others. For example, Oitto (1975) noted that jackleg drills caused more injuries than any other type of rock drill in U.S. underground metal and nonmetal mines in the 1973-1974 period. Of the 575 injuries from rock drills that were reported, 55 percent involved jackleg drills.

Location of jackleg drill accidents. From the MJLD data set, 483 groundfall accidents involving jackleg drills occurred at U.S. metal, nonmetal and coal mines from 2003 through 2012. Figure 5 shows that 61 percent, or the majority, occurred at or near the active mining face. For 28 percent, or almost a third, the location was not clearly identified, with 22 percent noted as "other" and 6 percent as "unknown." "Other" and "unknown" are official MSHA designations that cannot be specified further. Accident narratives can sometimes provide additional information, but distinct locations are typically not mentioned with these categories. The remaining 11 percent occurred in either inclined (4 percent) or vertical (4 percent) shafts, at intersections (2 percent) or in underground shop areas (1 percent). Most jackleg-drill-related injuries occur in the production phase of mining, so it is reasonable that most of these accidents would happen at the face.

Jackleg drills 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 drilled, the majority of these jackleg-drill-related groundfall incidents more than likely occurred while ground support was being installed under incomplete cover. As seen in Table 3, bolting has the highest percentage of injuries caused by groundfalls.

Sources of injuries to jackleg drill operators. From the MJLD data set, MSHA reported 483 incidents of jackleg-drill-related injuries at U.S. metal, nonmetal and coal mines from 2003 through 2012. Figure 6 shows that 39 percent, the highest, were caused by falling objects, and most of the remaining injuries were caused by other striking, either flying material or moving objects (21 percent) or by overexertion (20 percent).

An analysis of the size distribution of these falling objects in the form of groundfalls and rock bursts (Biswas and Zipf, 2003; Clark et al., 2011) is presented in Fig. 7. From 1999 through 2004, 65 percent, or the majority, of the groundfalls that occurred in underground metal mines consisted of small rocks weighing less than 11.3 kg (25 lb). The remaining 35 percent involved much larger material: slabs (26 percent), massive rocks (5 percent), and rock bursts (4 percent). While these large falls of ground were responsible for 75 percent of the groundfall fatalities, the vast majority of the small rock falls (81 percent) resulted in NDL injuries. Nonetheless, these small falls of ground can easily cause serious injuries to unprotected miners, as evidenced by 19 percent of these small groundfalls resulting in fatalities or NFDL injuries. As noted by Lacerda (2004), a 11.3-kg (25-lb) rock that has fallen 3.1 m (10 ft) has an impact with force of 3.4 kN (767 lbf). Small groundfalls 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).

Injuries to jackleg drill operators. From the MJLD data set, the types of injuries suffered by jackleg drill operators in the 483 incidents that occurred at U.S. metal, nonmetal and coal mines from 2003 through 2012 are shown in Fig. 8. Most of the injuries are roughly spread among three major categories: skin damage, 44 percent; injuries to bones and teeth, 24 percent; and joint and muscle injuries, 22 percent. Skin damage occurred in the form of abrasions, lacerations, punctures, and contusions. Serious injuries – such as amputation or enucleation; concussion (cerebral); crushing; dislocation; hernia or rupture; or cerebral hemorrhage – were relatively rare at 7 percent, and eye injuries were even more scarce at 1 percent. The natures of these injuries are again typical for smaller falls of ground.

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 realized because the proposed technologies do not meet the functional requirements to fully 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

Figure 5

Locations of jackleg-drill-related ground fall incidents, 2003-2012 (Benton, 2015).

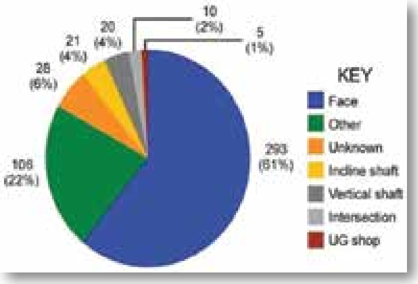


Figure 6

Sources of jackleg-drill-related injuries, 2003-2012 (Benton, 2014).

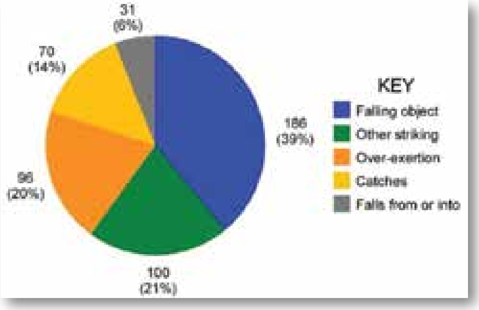


Figure 7

Sizes of groundfalls in underground metal mines, 1999-2004 (Biswas and Zipf, 2003; Clark et al., 2011).

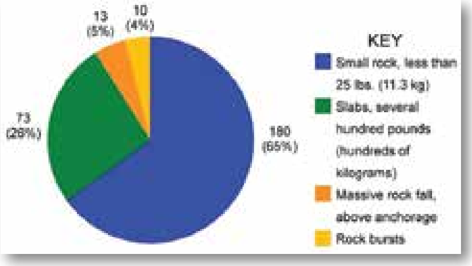
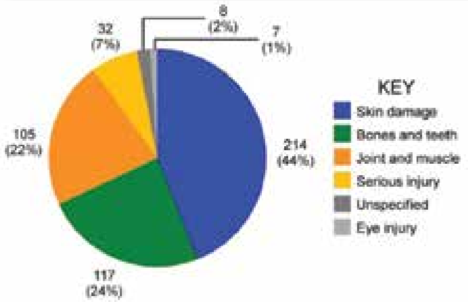


Figure 8

Nature of jackleg-drill-related injuries, 2003-2012 (Benton, 2014).



ahead of the machine, and (2) bolters 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 from those for jumbos in terms of drill boom flexibility and groundfall 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. J.H. Fletcher & Co. is developing a version in conjunction with Stillwater Mining Co. that protects the operator under a canopy, yet is also able to operate in areas 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-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

From the analysis of jackleg drill usage and accidents, the following conclusions were drawn:

1. Jackleg-drill-related incidents predominantly occur at metal mines in the western United States, with Montana, Idaho and Nevada accounting for a majority of the accidents involving jackleg drills.
2. Groundfalls are the leading cause of fatalities and a significant source of the injuries in underground metal mines. The risk of groundfall injuries increases significantly in underground metal mines with difficult ground conditions.
3. Most groundfall accidents occur during the production cycle. Bolting and drilling, typical activities involving jackleg drills, accounted for about half of the groundfall injuries.
4. Jackleg drills are involved in more groundfall accidents in underground metal mines than any other drill. Most of these jackleg-drill-related accidents occur at the face and are caused by small falls of ground. The vast majority of these small groundfalls 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 jackleg drills 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. ■

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