Technology News

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Breakthrough in Roof-Bolt Drilling Technology

Provides 200 to 400 Times Greater Bit Life

Problem

Roof bolting is a slow, expensive, and absolutely necessary mining activity. Roof-bolting activities also account for the largest percentage of lost-time injuries in underground coal mines. Dull bits result in the application of excessive force, which bends drill steel; and changing starter and finisher steel was the most significant source of injuries associated with roof bolting. The tungsten carbide (WC) roof-bolt drill bits currently used in American, Canadian, and Australian coal mines are capable of drilling only one or two 4-ft holes and then they are resharpened once or twice to drill another one or two holes. Often, in medium-hard rock formations (sandstone), as many as 20 to 30 bits may be required to drill a single 4-ft hole.

Objective

To compare the performance, longevity, and cost of newly developed polycrystalline diamond compact (PDC) roof-bolt drill bits against WC bits.

Research and Background

Diamonds for industrial use have been scarce throughout history and continuous attempts have been made to produce synthetic diamonds. The first synthetic diamonds were manufactured in 1953. Economically produced synthetic diamonds are 1 to 10 μm in size, but in this size range, they are totally unsuitable for industrial applications. In 1972, General Electric Co. developed a process to sinter the artificially developed, minuscule diamond particles into usable products. In this process, several layers of diamond-particles-and-cobalt mixture are overlaid on WC substrates and sintered at 2,350° F and 1,000,000 psi. The final product is known as PDC. Today, PDC's are available in many shapes, but their size is limited to 3/4 in, or less, in length or diameter, because pressures greater than 1,000,000 psi are required to manufacture larger PDC's. At present, diamond and PDC are the hardest and strongest commercial materials available for wear surfaces. The PDC used in this study had a hardness 3.61 times greater than that of WC.

Development

Since 1979, the U.S. Bureau of Mines' Twin Cities Research Center has engaged in research to put PDC's to use in the mining industry. In 1983, Hanson demonstrated that diamond-coated bits reduce the risk of methane ignition in coal mines. In 1987, Pliss showed that PDC's can enhance the life of coal-cutting tools by a factor of 3.5. In 1988, Sundae demonstrated that it is possible for a conical PDC bit to cut more than 10,000 ft of very abrasive rock and show no sign of wear on the bit tip, while a similar WC bit wears off completely after cutting 2,500 ft. A similar test with a spherical PDC bit gave similar results.

Field Testing

During the fall of 1991, a midwestern coal company asked the Bureau for technical assistance to help them minimize roof-bolting costs. The Bureau, in cooperation with a PDC manufacturer and a drill bit manufacturer, who had recently designed and fabricated a PDC-coated roof-bolt bit, which was ready for field testing, conducted a field test to demonstrate the feasibility of using PDC roof-bolt drill bits. The PDC and WC bits used in this investigation are shown in figure 1.

Discussion of Results

Past research by the Bureau and the manufacturer's literature suggest that the PDC inserts are brittle and highly susceptible to fracture because of thermal and mechanical stresses and impact loading. Therefore, a decision was made to test the PDC-coated roof-bolt bits with normal 80 psi water pressure and half the rotational speed and thrust required by WC bits. During the first field trial, a single PDC bit drilled 401 holes and showed no sign of wear, abrasion, oxidation streaks, or fracture. Because of these preliminary test results, a decision was made to conduct additional tests, with the remaining bits in other nearby mines in the southeastern Utah coalfields. All four of the test mines contain similar roof-rock formations, i.e., shale, mudstone, and sandstone.

During field testing, mine No. 2 was not able to maintain 80 psi water pressure with an in-line pump and a new, 150-hp pump was installed, which boosted water pressure to 200 psi. This change in water pressure doubled the bit life, but caused the bits to plug with clay around the tips. To avoid this problem, cutting speed was increased from 300 to 450 rpm.

Quartz-size analysis of mine No. 2 roof rock shows that quartz grains were cut through at 300 rpm, but full grains of quartz were removed at 450 rpm. The latter enhanced the penetration rate significantly and increased bit life. This mine was previously able to drill only 10 ft with a WC bit; with a PDC bit, a bit life of 4,500 ft was achieved. With further refinements in drilling techniques, this mine is currently drilling up to 6,000 ft per PDC bit. The test results in table 1 show similar increases in bit life for mines No. 3 through 5.

After completion of initial trials in the Utah mines, tests were conducted in four eastern mines with massive sandstone roofs, designated No. 6 through 9. The compressive strength of sandstone in these mines varied from 27,000 to 28,000 psi and the quartz content from 70 to 85 pct. Two of the test mines, No. 6 and 7, are located in West Virginia coalfields and the other two, No. 8 and 9, are located in Pennsylvania coalfields.

The first two sandstone roof mines usually experienced WC bit life of 2 to 10 ft. The test results in table 1 and figure 2 show that with the use of PDC bits, mine No. 6 was able to drill 1,400 ft, and test mine No. 7 was able to drill 500-1,080 ft during the first trials. Mines No. 8 and 9 were able to drill 6 to 8 in. in the sandstone with a single WC bit, but with the PDC bits, they were able to drill 98 and 72 ft.

A 400-times increase in bit life will drastically reduce the injuries associated with roof bolting by reducing the time a driller is exposed when changing drill bits, and performing other activities associated with roof bolting. Table 1 shows that despite much higher costs of PDC bits, each mine operator was able to reduce bit cost by as much as 50 pct and to realize additional savings in labor and other material costs, such as drill steels.

Why It Works

At present, very little is known about the fatigue behavior of PDC under prolonged cyclic loading; therefore, it is difficult to explain why the PDC bits have a life expectancy 400 to 500 times greater than that of WC bits, when their hardness is only 3.6 times greater. The PDC bit has a larger surface area for heat dissipation and the grain size of synthetic diamond appears to be somewhat smaller than that of WC, but none of the differences in physical properties can adequately explain the phenomenal longevity of PDC bits.

Special Instructions for Use of PDC Bits

With proper application, this technology is capable of even greater bit life. The test results in table 1 show that three of eight mines were able to achieve optimum life for PDC bits. To achieve this in general use, mine operators are urged to motivate their miners to follow the special instructions outlined below. The roof-bolt drillers should be clearly warned that these bits are very brittle, and to avoid premature bit fracturing, it is absolutely necessary to take the following precautions:

1. Maintain cutting speed between 450 and 480 rpm, thrust between 2,000 and 3,200 lb, and water pressure between 200 and 300 psi. Any increase in cutting speed above 500 rpm or drop in water pressure below 180 psi will cause the PDC to fracture because of frictional heating, i.e., uneven expansion of WC and cobalt in the transitional layers of the PDC bit tip. Any increase in thrust above 3,200 lb will cause the bit to shatter. Many times, the PDC bits were lost because miners failed to turn the water on, or because of a sudden drop, below 180 psi, in water pressure. Miners are urged to continuously monitor cutting speed, thrust, water pressure, and penetration rate, and not put the drill into reverse gear.

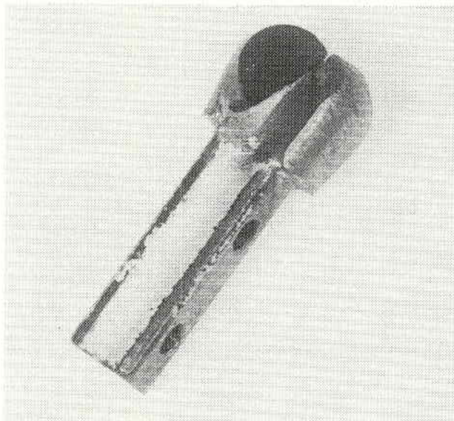
2. To obtain higher penetration rates and avoid bit failure, all holes should be collared or started with WC bits.

3. It is absolutely necessary to firmly secure the bit to its steel rod with two roll pins. The roll pins should be inspected after drilling five or six holes and be replaced promptly when needed.

4. Caution should be exercised when using PDC bits in roof rock that contains voids, clay pockets, fissures, large cracks, or other openings.

For More Information

A Bureau report on the use of PDC bits is being prepared. To obtain additional information contact: Laxman S. Sundae, U.S. Bureau of Mines, Twin Cities Research Center, 5629 Minnehaha Avenue South, Minneapolis, MN 55417-3099, phone (612) 725-4783.


PDC Roof drill bit

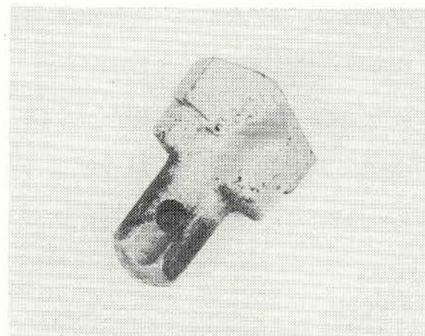

WC Roof drill bit

Figure 1.—Test bits.

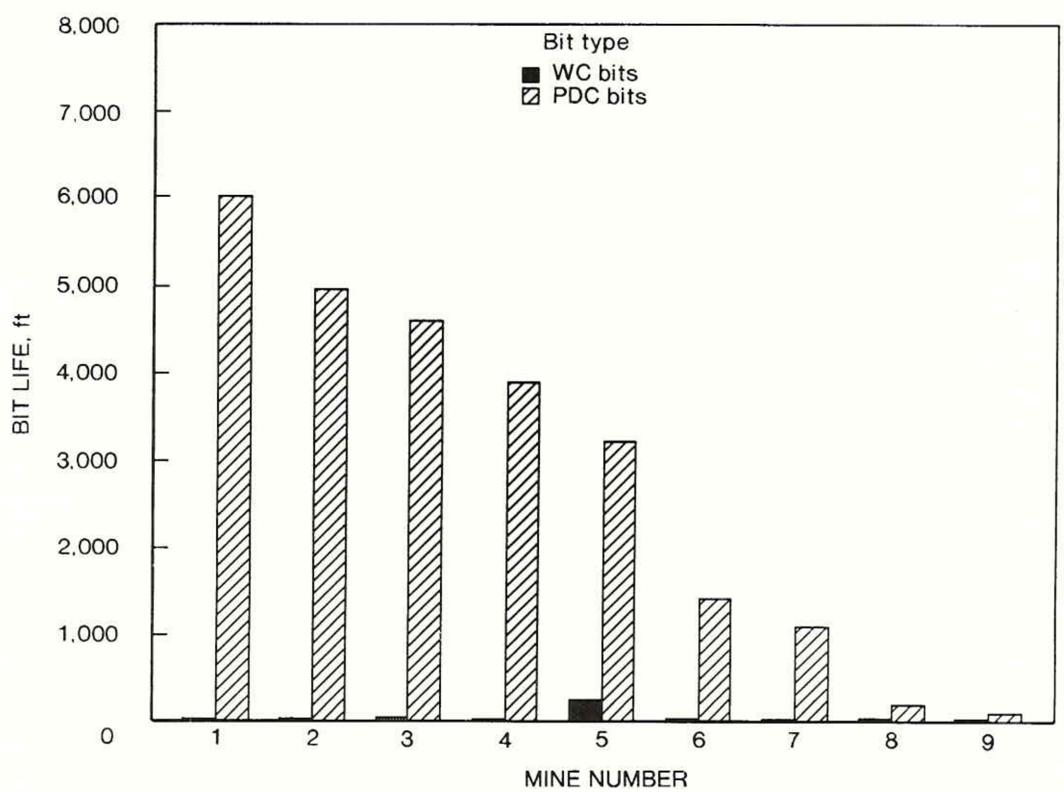


Figure 2.—Comparison of WC and PDC bit life in nine coal mines.

Table 1.—Performance and cost effectiveness of WC and PDC bits in nine coal mines

Mine	Mine location	Roof rock type	Properties of roof rock		Bit life, ft (bit cost, per foot)	
			Compressive strength, psi	Silica content, pct	WC	PDC
1	Emery Co., UT	SL, silty SS, SS	NA	16	10 ($0.14)	4,500-6,000 ($0.04)
2	Carbon Co., UT	Siltstone, SS, MS ..	6,369	NA	5-10 ($0.14)	1,560-4,940 ($0.03)
3	Emery Co., UT	SL	32,540	12	16-31 ($0.13)	2,492-4,604 ($0.06)
4	Emery Co., UT	MS, SS	NA	NA	18 ($0.11)	3,900 ($0.04)
5	Carbon Co., UT	Dolometric shale ...	8,000-10,000	35	96-244 ($0.02)	816-3,192 ($0.04)
6	Wyoming Co., WV	Interbedded mudstone, SS.	NA	NA	10 ($0.21)	1,400 ($0.10)
7	Indiana Co., PA	Dark grey SS	NA	85	2-3 ($1.30)	500-1,080 ($0.16)
8	Cambirra Co., PA	SL, SS	28,412	85	[1]6-7 ($2.00)	98 ($1.50)
9	Greenbrier Co., WV ...	SL, SS	27,320	70	6-8 ($2.10)	72-88 ($1.59)

MS Mudstone.
NA Not available.
PDC Polycrystalline diamond compact.
SL Shale.
SS Sandstone.
WC Tungsten carbide.
[1]Value in inches.