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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

in	inch	rpm	revolution per minute
ft/min	foot per minute	wt pct	weight percent
pct	percent		

NOVEL COAL-CUTTING BITS AND THEIR WEAR RESISTANCES

By Lung Cheng,[1] Israel Liebman,[2] Aldo L. Furno,[3]
and Richard W. Watson[4]

ABSTRACT

Based on earlier tests that showed steel to be much more likely to cause frictional ignition than tungsten carbide, the Bureau of Mines redesigned coal-cutting bits to reduce the hazard of face ignitions. Two bit designs--a mushroom-shaped bit with a conical shank and a dovetail bit with a rectangular shank--are described, as well as bit wear tests conducted in the laboratory and in an operating coal mine. In laboratory tests, for 1/8-, 1/4-, and 1/2-in-deep cuts and cutting speeds of 280, 500, and 660 ft/min, the mushroom bit had significantly longer tip wear life than the conventional bit; the dovetail bit was also superior to the conventional bit. Results of in-mine tests on the mushroom bit agree well with laboratory results. In-mine tests of the dovetail bit are underway.

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[3]Supervisory physical scientist.
[4]Research supervisor.
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INTRODUCTION

The increasing use of coal- and rock-cutting machines in the mining industry has increased the frequency of face ignitions. These ignitions and possible subsequent methane explosions can be initiated by hot particles, sparks, or molten material produced by the frictional impact of the machine cutting bits (picks) on hard inclusions in the coal face (1-2).[5] Although frictional ignitions in coal mines have been attributed to a wide variety of causes, about 90 pct of the incidents reported involved the cutting bits of mining machines (3).

At present, methane ignitions at the coal face are reduced by use of face ventilation or methane drainage systems. However, such methods are not always adequate when methane face emission is unusually high, or when methane feeders are encountered. Other means of minimizing the occurrence of frictional face ignitions include the use of water sprays to cool the bit trace (3, 4). The present report deals with the concept of redesigning the cutting bit to reduce the ignition hazard. Two new bits--a conical-shank and a rectangular-shank bit--have been developed and tested for wear resistance.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Dr. Welby G. Courtney for sharing with us his field experiences on bit testing, to L. Garner McDonald for his efforts in analysis of tip materials, and to Jerome Leff and Richard Pro for their assistance in carrying out the tests. We appreciate the cooperation of Carmet Minetool Products Division, Kings Mountain, N.C., in helping to fabricate the nickel-bonded and mushroom bits, and that of Jim Walter Resources, Inc., Birmingham, Ala., in allowing us to conduct the in-mine tests with the assistance of No. 7 Mine personnel.

TWO NOVEL BITS

Tests have been conducted by many investigators to determine the incendivity of a number of metals when frictionally impacted against hard rock materials in flammable methane-air environments (5-7). Such tests conducted by the Bureau of Mines were used to quantify the incendivity of metals used in the construction of cutting bits (8-9). By taking pure iron to be unity, the incendivity of tungsten carbide used as coal cutter tips was shown to be less than 0.1, whereas the incendivity of commercial carbon steels ranged from 3 to 9. Thus, it appeared that the steel shank rather than the tungsten carbide tip was primarily responsible for face ignitions.

Two common cutting bits currently used on coal mining and road-heading machines are conical-shank (plumb-bob) bits and rectangular-shank (chisel-type) bits. Figures 1 and 2 show examples of these bits; the tungsten carbide cutting tips are cemented into steel shanks. Based on the Bureau of Mines findings, a change in bit design was made to protect the steel shank from contact with the face during cutting. For this purpose, the tip cross section has been enlarged at its junction with the shank, so as to partially mask the adjacent shank surface, thereby protecting the shank from exposure at the point of impact. The novel designs are referred to as a mushroom tip (fig. 1) and as a dovetail tip (fig. 2). The dovetail design provides two lateral interfaces formed by inwardly slanting

[5] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

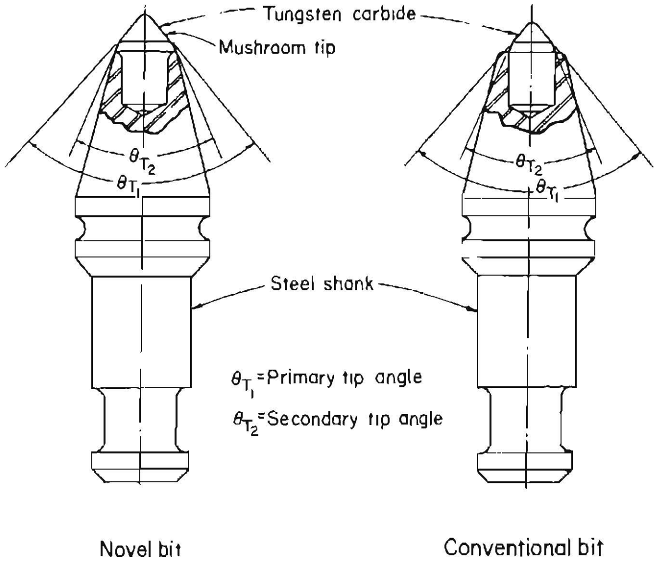

FIGURE 1. - Comparison of tip designs for conical-shank bits.

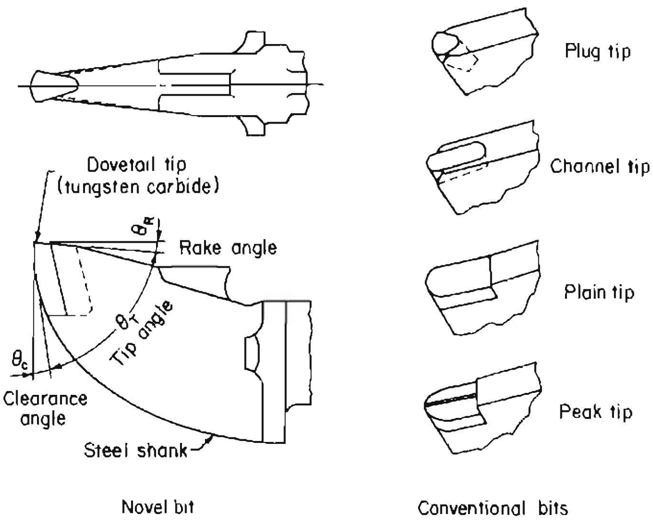

FIGURE 2. - Comparison of tip designs for rectangular-shank bits.

planes that prevent the tip from being ripped away or twisted inside the shank recess during cutting.

In both the new and conventional bits, the cutting tips are composed of tungsten carbide granules bonded together with either cobalt or nickel; the shanks are made of carbon steel. Prototypes of the two bits are shown in figure 3. Both bit designs can be used with conventional mining machines. The cutting geometry utilizing these bits in rotary cutting, as with ripper and shearer machines, to rip a coal face is illustrated in figures 4 and 5.

Although the novel designs have a good potential for decreasing the face ignition hazard, it was recognized that, for practical purposes, the bits would not be useful to the mining industry unless their life was comparable to that of conventional bits. Accordingly bit wear tests in the laboratory as well as in an operating coal mine were conducted to compare wear resistance of the novel and conventional bits.

BIT WEAR

Rotary cutting is commonly used for coal and rock cutting with conical- and rectangular-shank bits. In metal cutting with metal-cutting bits, the metal departs at the edge of the bit tip, whereas rock cutting, more precisely termed rock crushing, is carried out by the clearance face of the cutting bit. During sumping and shearing with the mining machine, a thrust force builds up between the clearance face of the bit tip and the target face, with tangential crushing and abrasion of these faces. A wear flat, i.e., a worn surface, develops on the clearance face on both the rectangular-shank and the conical-shank bit, especially when the conical-shank bit is not self-rotating (fig. 6). If there is a hard inclusion in the target, there is impact crushing and abrasion as well, causing impact wear at the summit of the tip and the clearance face, particularly when the cutting speed is high.

The total wear rate of a cutting bit can be defined as the loss of metal volume or increase in size of the flat area per unit of cutting time, total slide distance, or number of impacts on the target surface. The reciprocal of the wear rate is the wear resistance. The wear resistance of rock-cutting bits depends on the state of cutting, such as the depth of cut and cutting speed, and

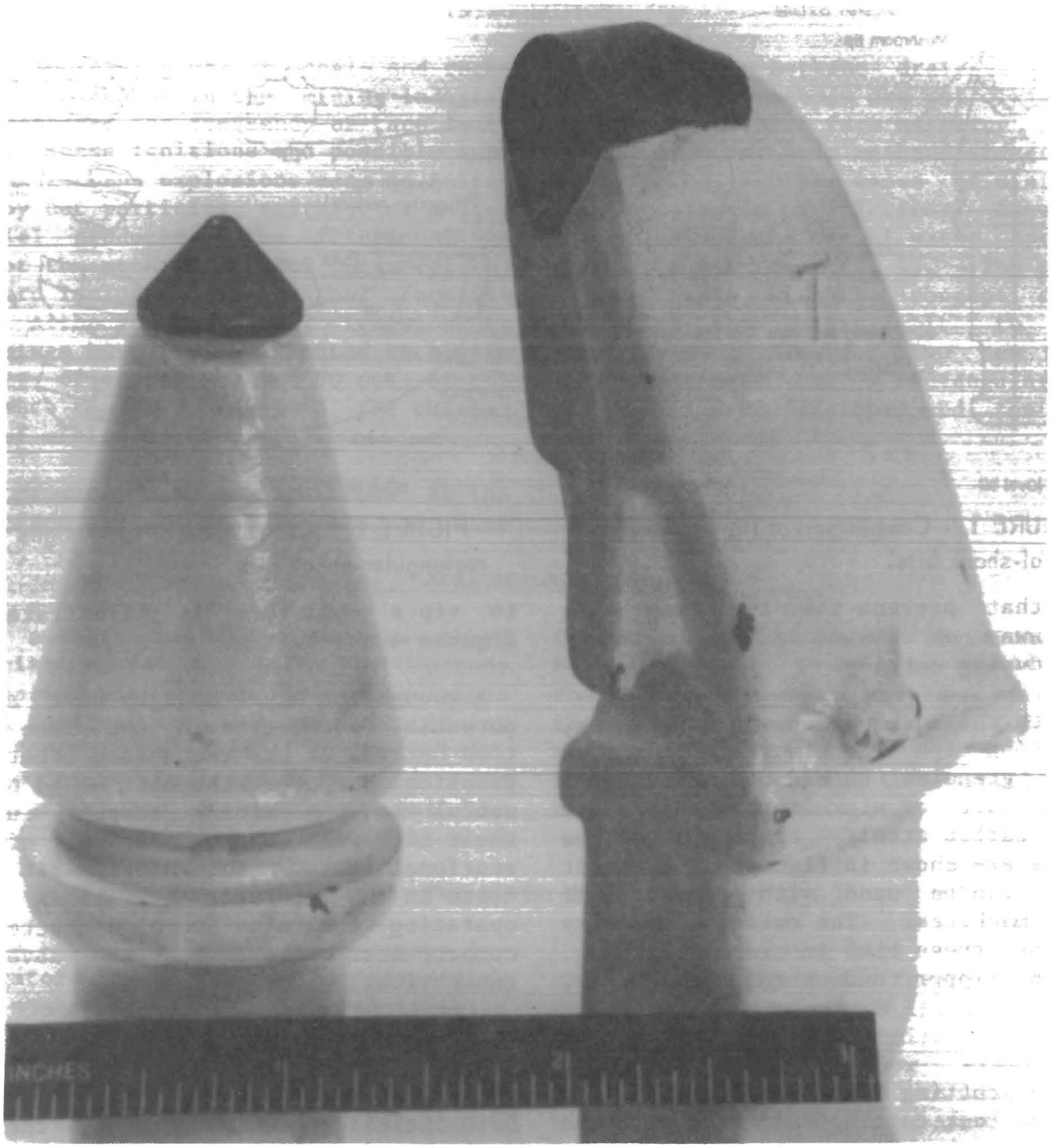

FIGURE 3. - The mushroom bit (left) and the dovetail bit (right).

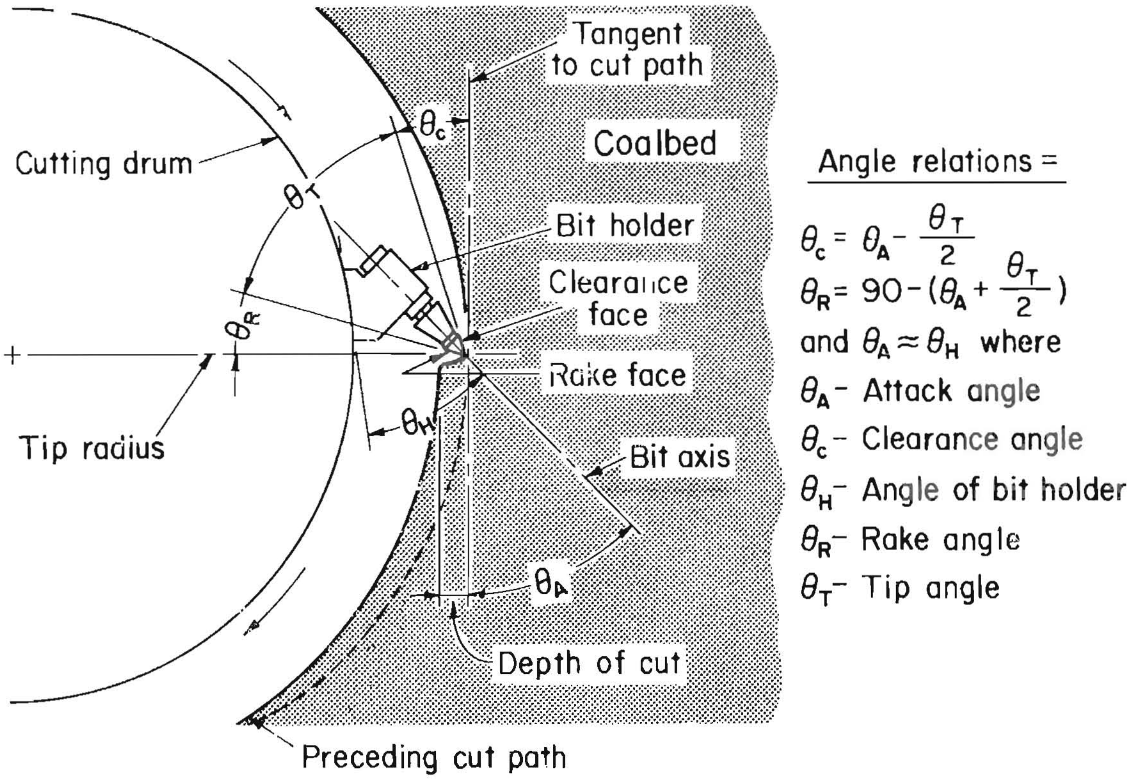

FIGURE 4. - Cutting geometry of conical-shank bits in rotary cutting.

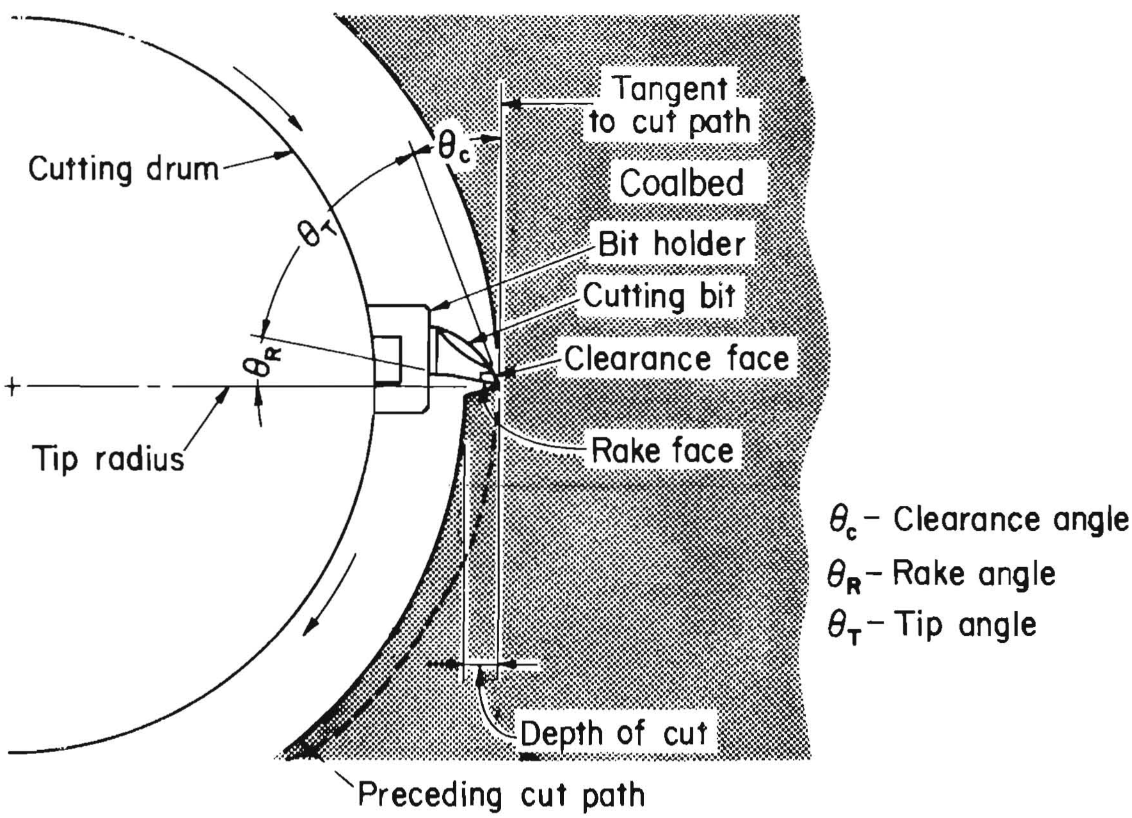

FIGURE 5. - Cutting geometry of rectangular-shank bits in rotary cutting.

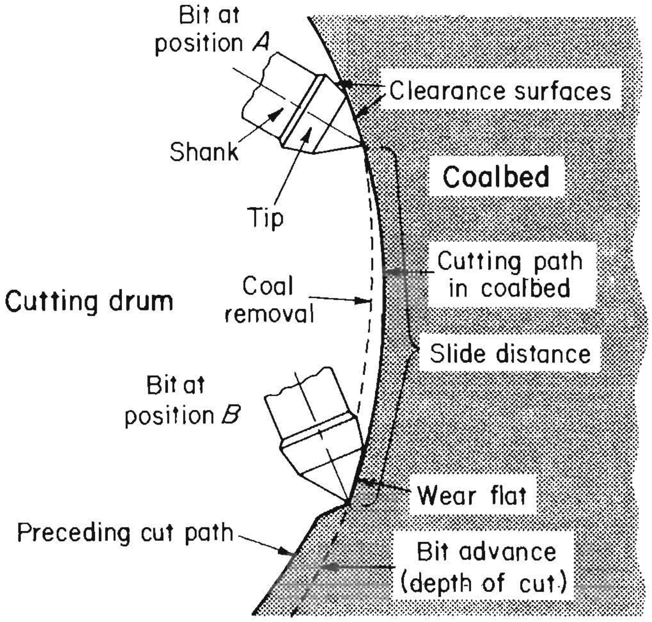

FIGURE 6. - Schematic illustrating the development of the wear flat in rotary cutting.

on the physical properties of the bit and target. For a specific bit and target material, the bit wear rate should depend only on the state of cutting. Since rock fragmentation between tip and target surfaces occur in discrete events, the interaction between them can be separated into various stages. For instance, Fairhurst and Lacabanne (10) distinguish stages as (1) crushing of irregular surfaces, (2) elastic deformation of rock, and (3) pulverization of rock at the contact point. Thus, different tip geometries should interact differently in the various fragmentation stages, and consequently different wear rates should result at the wear flat.

The American Society for Testing and Materials (ASTM) promulgated a test method on the abrasion resistance of cemented carbide through a measurement of weight loss of a flat specimen held by a specified fixture immerged in a slurry bath (11). However, the method cannot be used to assess the wear resistance of cutting bits because it does not take into account the effect of tip geometry and the state of cutting.

In quantifying bit wear, we compared the wear resistance of different bits in terms of the total number of impacts or the total slide distance required to wear the bit tip to the point where the flat extended to the steel shank. With this degree of wear we expect a marked increase in the incendivity of the cutting bit owing to the exposure of the steel shank.

Field tests made to compare the wear resistance of various bits require that all of the bits be mounted on the same cutting drum and tested at the same time in order to assure that each bit type experiences the same cutting history. After a certain cutting time, comparisons between the bit types can be made in terms of the observed severity of bit wear for each type of bit tested. This was done for the in-mine tests.

LABORATORY TESTS

Four conical-shank bits were tested: (1) a cobalt-bonded bit with $\Theta T_1 = 80°$ and $\Theta T_2 = 50°$ (ΘT_1 = primary tip angle, ΘT_2 = secondary tip angle; see figure 1); (2) a nickel-bonded bit similar in shape to bit 1; (3) a cobalt-bonded double-angle bit with $\Theta T_1 = 90°$ and $\Theta T_2 = 50°$, so called because of the more apparent change in tip angles; and (4) the novel mushroom bit, which was cobalt-bonded with $\Theta T_1 = \Theta T_2 = 80°$. Bit 1 was used as a standard for comparing relative bit wear. All of the bits were 4-13/16 in. in overall length and had a total exposed tip length of 3/8 in, with no appreciable difference in other dimensions. Two types of rectangular-shank bit tips were also tested; both were cobalt-bonded and had the same overall length of 5-1/2 in. One of these bits, a plug tip (fig. 2), was selected as a standard; the other was the novel dovetail bit.

The cobalt content in cases of cobalt bonding was about 11 wt pct for the standard and the double-angle bits and 9 wt pct for the mushroom bits. The nickel bonding was done with an experimental mixture containing nickel and nickel-cobalt-chromium binders. The nickel-bonded bit had shown improved wear resistance in earlier laboratory testing (12).

A full-scale shearer drum was used in the laboratory tests; it had only one bit holder. All bits were trimmed to the same holdout length to ensure the same depth of cut. The target was hard rock, with a hardness of 65 on the Shore scale and a face height of 20 in (fig. 7). The bit holder was set straight without slant and skew, and the holder angle for the conical-shank bits was 45°. Three depths of cut (1/8, 1/4, and 1/2 in) and three drum speeds (21, 35, and 47 rpm) were selected. At the 20-rpm speed, which resulted in a cutting speed of 280 ft/min, the rigidity of the target, which weighed more than 1 ton, was sufficient to maintain uniform cutting throughout the entire cutting stroke. Thus, a good evaluation of abrasion wear of the bits was possible. The 47-rpm test (cutting speed of 660 ft/min) resulted in a severe percussion at the first impact with partial contact maintained thereafter; thus impact wear of the bits was primarily evaluated. The 35-rpm test (500-ft/min cutting speed) resulted in a mixed mode of impact and abrasion wear. Figure 8 shows two conical-shank bits that were exposed in cutting the same target for the same length of time. Each bit made

FIGURE 7. - Equipment used for measurement of wear resistances.

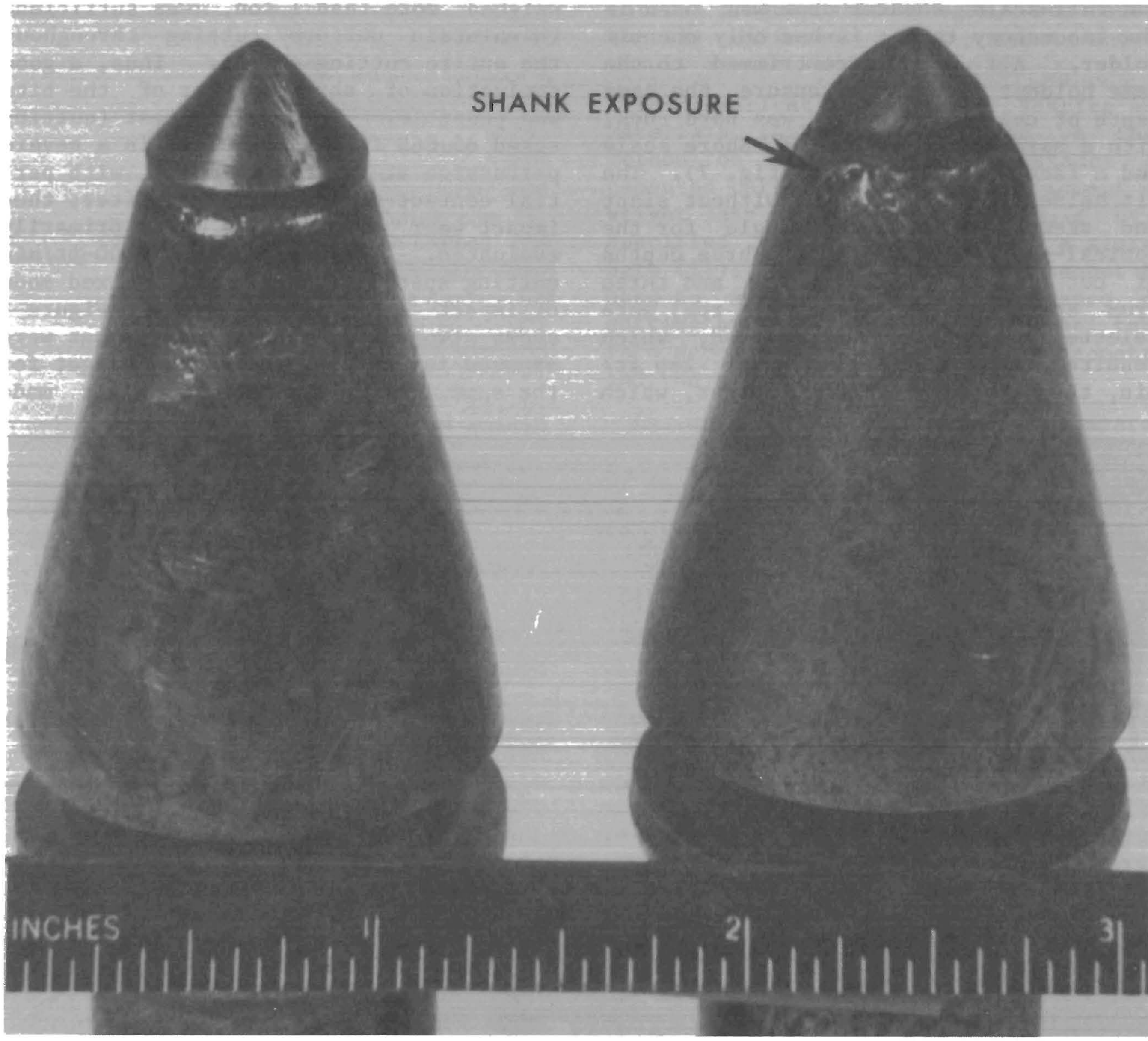

FIGURE 8. - Conical-shank bits after being exposed to cutting the same target for same length of time; mushroom bit (left) and standard bit (right).

200 impacts on the hard rock target, each impact cutting to a depth of 1/8-in. It will be noted that the standard bit shank where it joins the tip has undergone more wear than the mushroom bit shank. This would tend to make the standard bit more incendive and require earlier replacement. Figure 9 shows the difference between the dovetail bit and the standard plug-type bit after 200 impacts on the same type of stone.

Because of the uncertainty of self-rotation of the conical-shank bits during the tests, the bits were rotated manually in the bit holder every several cuts to ensure uniform wear around the bit tip. Since the depth of cut and cutting speed were well controlled, reproducibility of the wear resistance measurements was excellent. Test results are plotted in figure 10 for the conical-shank bits and figure 11 for the rectangular-shank bits

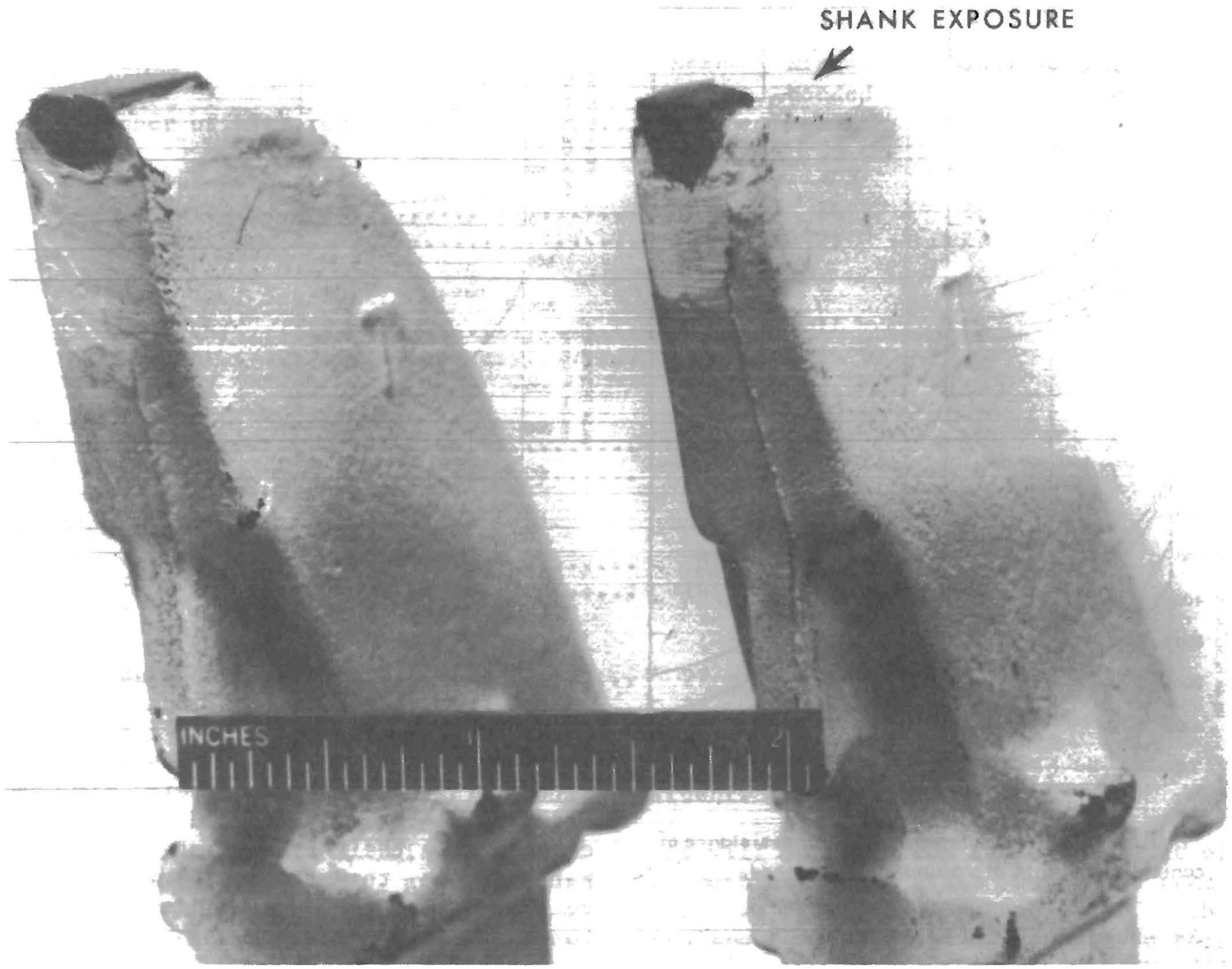

FIGURE 9. - Rectangular-shank bits after being exposed to cutting the same target for same length of time; dovetail bit (left) and standard bit (right).

in terms of the total slide distance and the number of impacts required to wear the bit tip to the point where the flat extended to the steel shank.

The laboratory tests with the conical-shank bits show that the double-angle and the mushroom bits have better wear resistance than the standard bits and the nickel-bonded bits over the range of cutting speeds and depths investigated. Furthermore the mushroom bit is superior to the double-angle bit at all cutting speeds and especially at the deeper cuts. No significant difference was observed between the nickel-bonded bit and the standard bit at the high cutting speed (fig. 10C), but wear resistance was slightly worse at the two lower cutting speeds (figs. 10A and 10B). The dovetail bit exhibited superior wear resistance at all speeds and depths of cut (figs. 11A-11C).

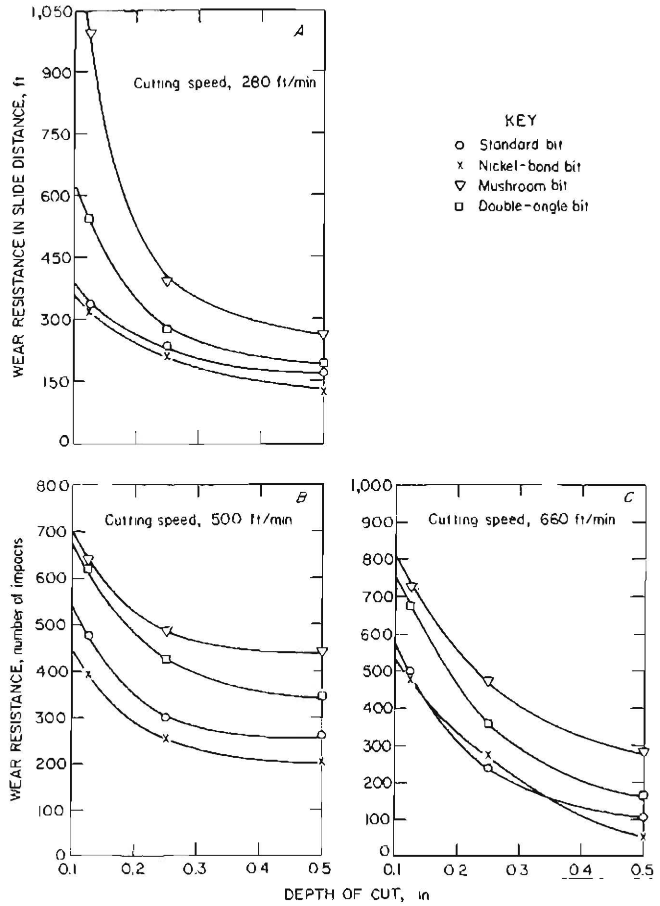

FIGURE 10. - Measurements of wear resistance of conical-shank bits at various cutting speed.

As regards bit fracture, the mushroom bit withstood the percussions of high-speed cutting in the ranges of cutting depth used but fractured at the low cutting speed and deep cuts. The

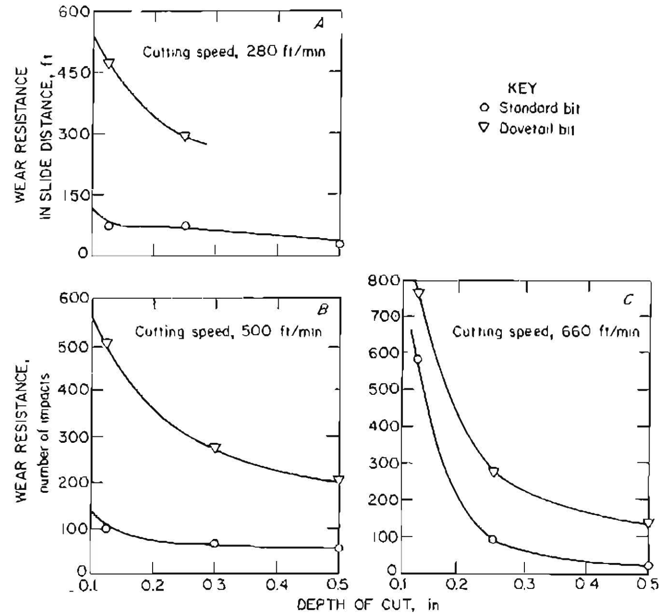

FIGURE 11. - Measurements of wear resistance of rectangular-shank bits at various cutting speed.

fracture usually occurred when an oblique wears flat, formed due to lack of self-rotation, was large enough to extend into shank steel. When that much wear occurred in other bits, their tip had already been greatly reduced in size, and consequently their shank steel received part of the thrust force during a deep cut, reducing the possibility of fracture. No bit fracture was observed in any of the tests with the dovetail bit design nor with the rectangular-shank standard bit.

IN-MINE TESTS

The purpose of in-mine tests was to confirm the laboratory results and to acquire information that might have been overlooked in the laboratory, where the cutting drum was real but the target was not. The tests were conducted in a commercial mine at a section where hard inclusions existed. They involved 100 standard bits, 89 nickel-bonded bits, 100 double-angle bits, and 100 mushroom bits. All of the bits selected had the same holdout length (from tip to shoulder), ±1/32 in. They were painted different colors and engraved with a code number for easy indentification. The tests were conducted on a Joy CM[6] continuous miner which holds approximately 100 cutting bits. The cutting drum was divided into four lateral regions, each laced with approximatly 25 bits of the same type.

Four test runs, which produced 200, 230, 300, and 340 tons of coal, were conducted. After each test run, the drum was replaced with fresh bits; the lacing pattern was rotated so that each bit type

[6]Reference to specific products does not imply endorsement by the Bureau of Mines.

TABLE 1. - Wear and fracture of conical shank bits observed in mine tests

	Standard	Nickel-bonded	Double-angle	Mushroom
Number of bits recovered	84	85	98	100
No apparent wear:				
Number	13	16	26	69
Percent	23	21	27	92
Slight wear apparent:				
Number	20	27	25	3
Percent	35	35	26	4
Medium wear apparent:				
Number	16	22	23	2
Percent	28	29	24	3
Severe wear apparent:				
Number	8	11	22	1
Percent	14	15	23	1
Bit fracture:				
Number	27	9	2	25
Percent	32	10	2	25

saw cutting action on all four sections of the drum. In the course of the four test runs, 22 bits were carried away with the raw coal and the remaining 367 bits were recovered for wear and fracture analysis. Four degrees of wear based on observation of the amount of metal removed from the shanks of the bits--no apparent wear, slight wear, medium wear, and severe wear--were established to quantify the results of the in-mine tests; a fifth category--fracture--was also used when applicable. The results are summarized in table 1, where the number and percentage of each of the four bit types are given for the four degrees of wear; the number and percentage of bits that were fractured are also presented. Figure 12 illustrates the four degrees of wear for the four different bit types, and figure 13 presents the data from table 1 in the form of a bar graph. The superiority of the mushroom bit over the standard bit is clearly evident.

As will be seen from table 1, 92 pct of the mushroom bits (that were not fractured) suffered no apparent wear. The double-angle bits were next best in this regard, with 27 pct showing no apparent wear; 21 pct of the nickel-bonded bits and 23 pct of the standard bits showed no apparent wear. In terms of fracture resistance, the double-angle bit was far superior to the other bit types, with only 2 pct of the bits suffering fracture; the nickel-bonded bit (10 pct fracture) was next best. The mushroom bit exhibited a relatively high fracture percentage (25 pct), and the standard bit was the worst with 32 pct fracture. It was noticed that fracture frequently occurred in several adjacent bits when the leading bit holder was either missing, loose, or misaligned.

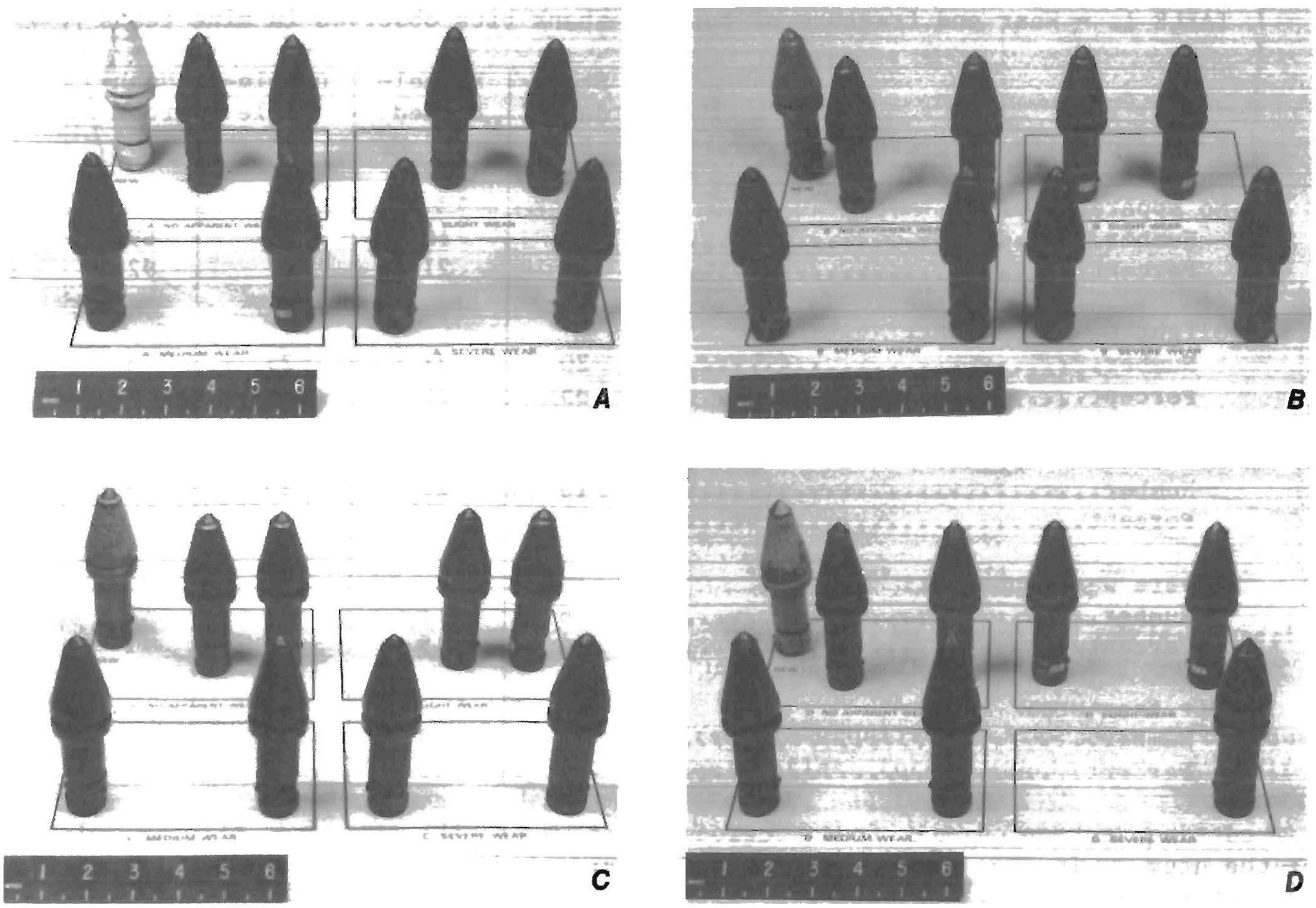

FIGURE 12. - Wear observed in mine tests: *A*, standard bits; *B*, nickel-bonded bits; *C*, double-angle bits; *D*, mushroom (novel) bits.

DISCUSSION

In regard to the test method used in the laboratory, the wear resistance curves in figures 10 and 11 should be hyperbolic. All the conical-shank bits have conical tips, and therefore the wear curves are fairly parallel. The detailed configuration of each tip is different; therefore each tip reacts differently to different cutting conditions and has its own wear resistance characteristics. In comparing the resistance curves of the nickel-bonded bit and the standard bit, one realizes that the difference between them is due to the different tip materials, which appear to react differently for abrading (fig. 10A) and impacting at the high speed (fig. 10C).

The major difference in tip geometry of the standard bits and the double-angle conical shank bits is the primary tip angle (θT_1). It follows that a decrease of 5° in both the rake angle and the primary clearance angle in conjunction with the 45° bit holder (fig. 4) promotes the protection of the shank from early exposure during cutting cycles, but to a lesser extent than with the mushroom bit. Therefore, it is to be expected that an increase of the primary tip angle of the mushroom bit from 80° to 90° would provide more shank protection than the present design. This requires further tests to verify.

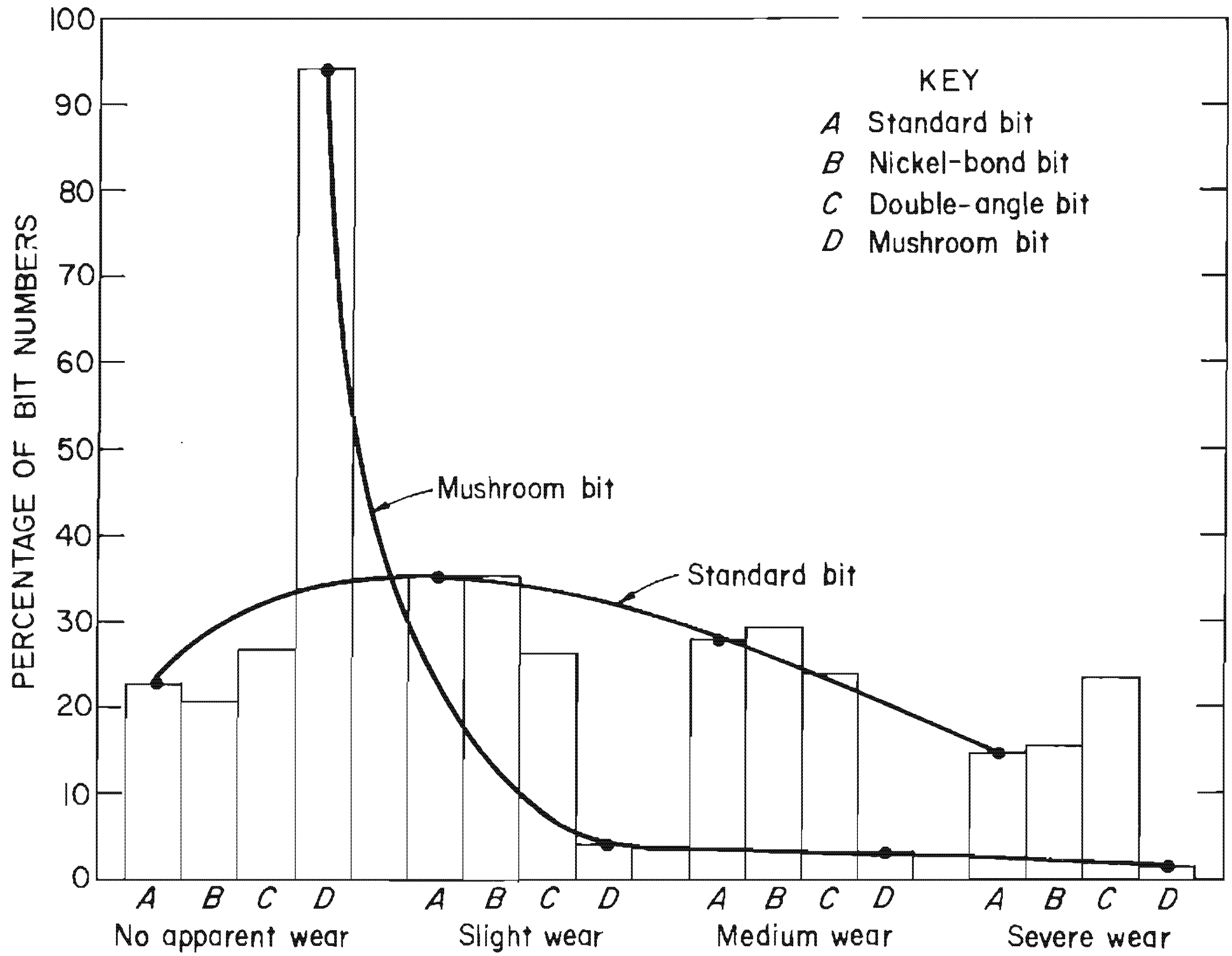

FIGURE 13. - Distribution of wear observed in mine tests.

Wear resistances were measured with dry cutting, and no consideration has been given here to the effect of water cooling and lubrication on bit wear, nor did this investigation deal with cutting efficiency or dust generation in relation to bit geometry.

The in-mine test results are in fair agreement with the laboratory results; i.e., the nickel-bonded bit was slightly worse than the standard bit, whereas the mushroom bit was much better than the standard bit and the double-angle bit but tended to fracture. It is to be expected that if cutting time is increased much more than in the present tests, the distribution pattern of wear for each bit type (fig. 13) would change and skew to severe wear.

As regards costs benefits, the cost of a cutting bit for coal mining is estimated to be 4.5 cents per ton of coal produced without including the time loss of replacement (13). The U.S. coal industry is paying $14 million each year for bits. It is estimated that the new bits will cost the same as the conventional ones and may double the usage life; thus, $7 million could be saved annually. Even more important is the potential contribution to coal mine safety, which cannot be measured in financial terms.

The frequency of fracturing observed for the mushroom bit is still a matter of concern. Modification of the geometry of the tungsten carbide insert, specifically increasing the radius of curvature at the junction of the cap and stem of the mushroom, could increase the mechanical strength of the unit with a corresponding increase in resistance to fracture. An increase in the cobalt content of the bit tip might also increase its fracture resistance for cutting hard rocks.

CONCLUSION

Two bit designs--a mushroom-shaped bit with a conical shank and a dovetail bit with a rectangular shank--are described, as well as bit wear tests conducted in the laboratory and in an operating coal mine. In laboratory tests, for 1/8-, 1/4-, and 1/2-in-deep cuts and cutting speeds of 280, 500, and 660 ft/min, the mushroom bit had significantly longer tip wear life than the conventional bit; the dovetail bit was also superior to the conventional bit. Results of in-mine tests on the mushroom bit agree well with laboratory results.

Since these tests were primarily aimed at comparing the wear resistance of the mushroom bit to that of the double-angle bit and the standard bit, it is perhaps premature to draw a conclusion as to the potential benefits of the novel bits in terms of their anti-incendive character. Courtney (3) and Watson (4) described the potential ignition hazard of worn cutting bits. If we assume that new or slightly worn bits are not particularly incendive, and conversely that bits with moderate to severe wear or fractured bits are highly incendive, then the data of table 1 indicate that only 28 pct of the mushroom bits fall into the incendive category, whereas 47 pct of the double-angle bits and 61 pct of the standard bits fall into this category (14). On this basis, the mushroom bits are clearly superior to the other bit designs. Further laboratory and in-mine tests will be required to establish the validity of this conjecture. However, the results of the in-mine tests of the mushroom bit were encouraging enough to lead us to believe that we are on the right course. In-mine tests on the dovetail bit are underway, and test results will be reported later.

With regard to tip geometry designed to improve the bit life, the present mushroom tip and dovetail design can be adapted to heavy gage bits, and also for any improved tip metals other than the tungsten carbide now widely used.

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