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THE STATE-OF-THE-ART IN CONTINUOUS MINING MACHINE BIT TECHNOLOGY

(BCR Report L-522)

By

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This research provides the results of a significant study of the current status of continuous mining machine bit technology and recommendations for improvements necessary to reduce dust generation. It gives direction for reducing dust generation by making recommendations dealing with the determination of bit performance and the development of new bit designs and material. The recommendations will be used to help direct the Bureau's machine parameter work. Surveys results are as follows: 1. The production of dust is not a major consideration in either the design or application of bits. 2. Limited test data were obtained with correlated bit design and respirable dust. 3. Mine operators generally believe that bit design is not a significant factor in dust production. 4. Because of apparent economic advantages, point attack bits are used on a majority of continuous mining machines in use today. 5. Good bit cost records are not generally available. 6. Although most coal companies interviewed are not involved in any test programs, they expressed willingness to cooperate in development of equipment or techniques for dust control.

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May 11, 1973

Mr. Frank Pavlich, Chief
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Section of Contracts, Building 20
Denver Federal Center
Denver, Colorado 80225

Dear Mr. Pavlich,

Submitted herewith is the Final Report, BCR Report No. L-522 on Contract No. H0220061, "Survey of Continuous Mining Machine Bit Technology."

The report summarizes the Phase I work, consisting of interviews with selected personnel from (1) bit manufacturing companies; (2) mining machinery manufacturing companies; and (3) coal mining companies.

The information and data obtained have been evaluated and recommendations for future research work are made.

Yours very truly,

John W. Igoe

John W. Igoe

JWI:RDS/bic

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FOREWORD

This report was prepared by Bituminous Coal Research, Inc., Monroeville, Pennsylvania, under USBM Contract No. H0220061. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of TCMRC, with Mr. K. Strebig acting as the technical project officer. Mr. F. Pavlich was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 22, 1972 to April 18, 1973. This report was submitted by the authors on May 11, 1973.

This technical report has been reviewed and approved.

Bituminous Coal Research, Inc.
Sponsored Research Program

The State-of-the-Art in Continuous Mining
Machine Bit Technology

I. INTRODUCTION

After many years of research, the occurrence of pneumoconiosis, black lung disease, among miners has been related to the mass of respirable coal dust to which mining personnel have been exposed. Congress passed Public Law No. 91-173 in 1969, which limited the dust concentration of respirable dust allowed in the mine working areas to 2.0 mg/m^3 as of December 31, 1972.

As a result of these restrictions, much work has been done in determining methods of either eliminating or suppressing respirable dust. The purpose of this project is to determine the state-of-the-art in continuous mining machine bit technology, particularly with regard to dust production.

The specific objectives of the project are:

1. To determine and recommend the need in the area of continuous mining machine bit design and manufacture so that respirable dust can be reduced during the fragmentation process.

2. To evaluate all factors of bit design, including bit length, strength, durability, cost per ton of coal mined, and the possibility of internal water flushing.

3. To evaluate all recommendations from both an engineering and economic standpoint.

The scope of the survey included visitations to bit manufacturers, mining companies, mining machine manufacturers, and consultants in order to determine what bits are the best available, why they are the best, and the level of acceptance of past and present bits by the mining industry.

In the presentation of this material, no reference will be made to specific companies or bit trade names. Instead, the bits are referenced to style numbers illustrated in Figures 1 and 2. References in the text to point attack bits will include plumb bob bits (Styles 1 through 9) and bullet bits (Styles 14 and 15). References to cutter bits will mean rectangular shank cutter bits, Styles 10 through 13.

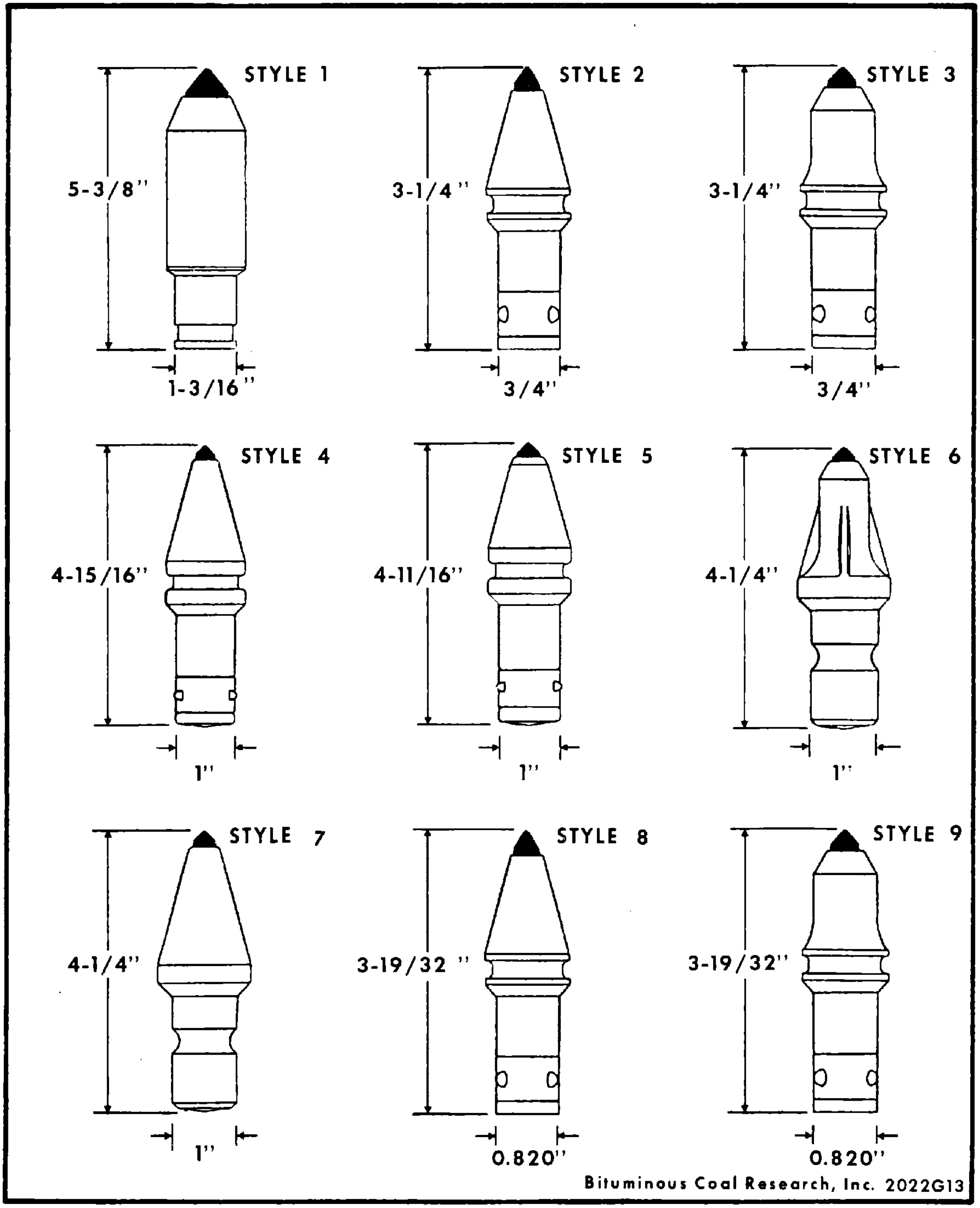

Figure 1. Illustration of Bit Styles

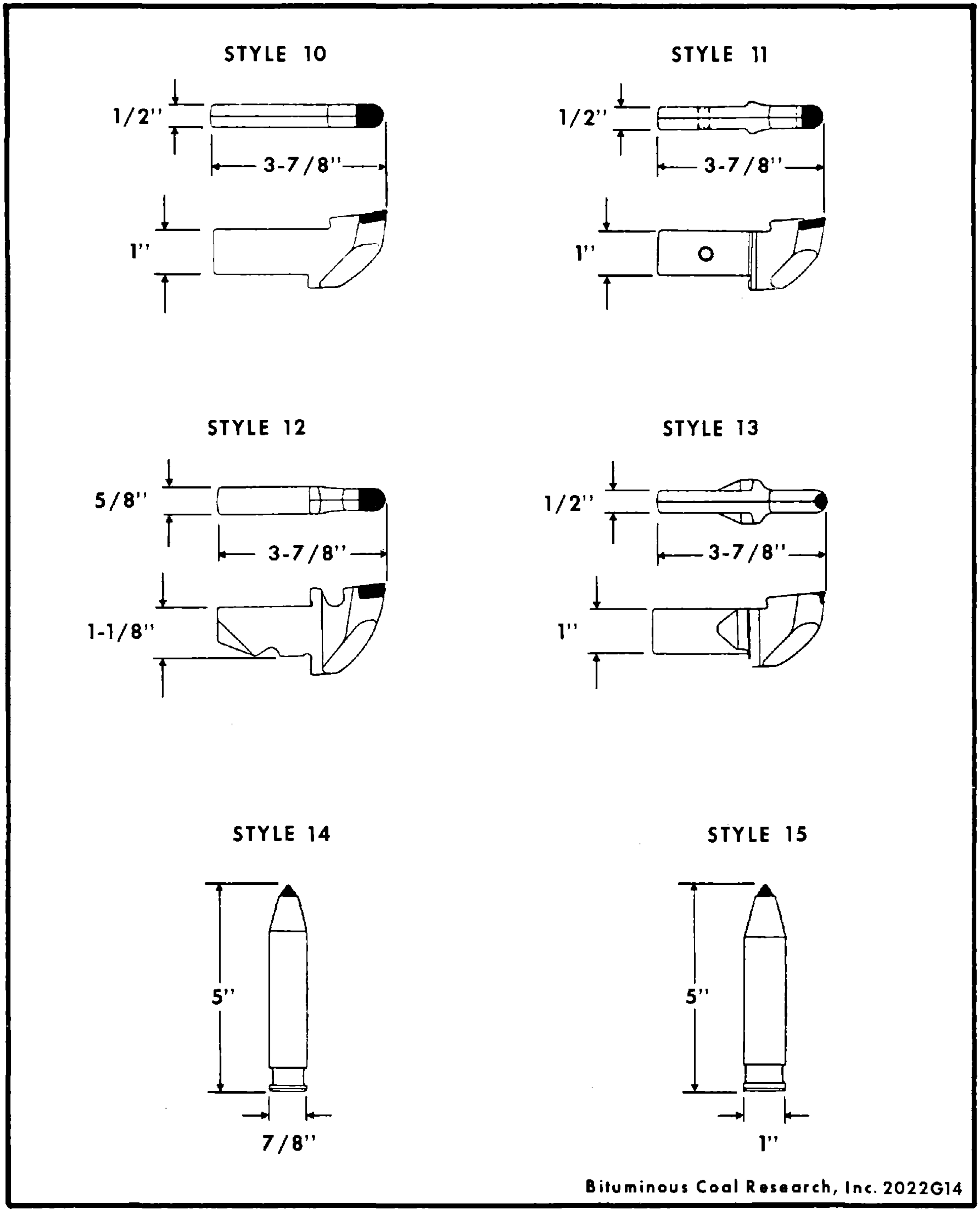

Figure 2. Illustration of Bit Styles (Continued from Figure 1)

II. STATEMENT OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

The information, test data, and opinions obtained during the survey indicate a wide variation in the results experienced by various operators in regard to bit design and bit application. The reasons for differences are:

1. Mining conditions between seams and between mines within a seam vary considerably,

2. The policies of various mining companies with respect to purchasing, equipment evaluation, and cost control methods are inconsistent,

3. Bit and mining equipment manufacturers' policies with respect to sales and to research and development programs most often reflect the coal companies' "wants" and not their "needs."

In addition, personal preferences of many mine operators and equipment manufacturers are based on work experience and are an important factor affecting opinions on both selection of equipment and mining techniques employed.

A. Summary of Results

The survey results, based on this information, test data, and opinions, can be summarized as follows.

1. The production of dust is not a major consideration in either the design or application of bits.

2. Limited test data were obtained which correlated bit design and respirable dust. The data showed that dust concentrations were consistently lower with Style 2 bits.

3. Mine operators generally believe that bit design is not a significant factor in dust production. They are concentrating their efforts on the use of auxiliary equipment such as sprays and ventilation to allay or remove the airborne dust rather than finding a bit design which may reduce dust production.

Even with these auxiliary methods, it is the opinion of most mine operators that the 2.0 mg/m^3 dust limit cannot be attained without seriously affecting the production and/or economic position of the companies.

4. Because of apparent economic advantages, point attack bits are used on a majority of the continuous mining machines in use today.

5. Good bit cost records are not generally available, and those mines that have data do not include as part of bit cost "change-out" time, maintenance cost, or other costs directly related to bits.

6. Most tests conducted by mining companies are informal and do not include controls, data collection, or formal reports.

7. Although most of the coal companies interviewed are not involved in any test programs, they expressed a willingness to cooperate in the development of equipment or techniques for dust control.

8. The coal companies feel that new equipment and/or mining technique development is basically the responsibility of the USBM and equipment manufacturers.

B. Conclusions

Based on these results, several conclusions were reached, as follows:

1. In spite of the opinion of the mine operators that bit design itself is not significant in controlling dust, we feel the limited test data available indicate that bit design could be a factor in reducing dust production.

2. There is no "best bit" design for use throughout the industry; rather, conditions in each mine dictate its "best bit" design.

3. The industry in general is not aware of the research now being carried out and therefore does not have the opportunity to implement the results of this work.

4. The reduction of dust production is not a factor in design of bits. Economic considerations are the prime factor. Many bit manufacturers base specific designs and their overall line on what their competitors are offering. This line of thought is reinforced by the mining company operators who agree that bit design cannot significantly reduce dust production.

5. Other factors, such as number of bits, bit speed, lacing patterns, have a significant affect on bit performance, particularly with respect to dust. Changes in bit design alone may not result in reduced dust generation.

C. Recommendations

Based on the results and conclusions outlined above,

1. Basic and applied research programs should be established in the areas of: (a) new mining techniques, such as combined hydraulic and machine mining; (b) cutting technology involving all types of bits, particularly with respect to rock, pyrites, and other inclusions encountered in coal seams; and (c) the influence of bit design on other machine cutting parameters, such as lacing patterns and bit speed.

2. Most published cutting research has been done using wedge-type tools. Research should be expanded to include the point attack bits.

3. Every effort should be made to disseminate the results of research to the industry and to encourage its incorporation into mining practices.

4. The mining companies and equipment manufacturers should become more involved in research and development programs, particularly those sponsored by the USBM. Underground tests should be conducted under controlled conditions to determine the effect of bit design on dust production and, if possible, to recommend a design which will reduce dust production to a minimum.

The material outlined in this section is discussed in more detail in other sections of this report.

III. SURVEY METHODS

In order to develop the information required under this contract, it was decided that personnel from a large cross section of the mining industry, including mining and manufacturing operations, would have to be interviewed. The basis for selecting the companies was as follows:

A. Mining Machine Manufacturers

Since there are only three major mining machine manufacturers; Joy, Lee-Norse, and Jeffrey, it was decided to interview personnel from each of these companies.

B. Bit Manufacturers

Of the approximately eleven bit manufacturers, seven can be considered major suppliers. It was decided to interview personnel from all seven of the major companies and from as many of the smaller companies as time would permit. Eight companies were interviewed; two others were contacted but did not want to participate.

C. Mining Companies

Since it was impractical to interview personnel from all the mining companies, the selection of appropriate organizations was based on the following criteria:

1. The selections were from those companies listed in the 1972 Keystone Coal Industry Manual.

2. Companies of various sizes, were selected based on the production figures listed in the Keystone Manual in order to obtain a complete cross section of the mining industry.

3. The mines were located in the major eastern coal producing states including Pennsylvania, Ohio, West Virginia, Kentucky, Illinois, Indiana, and Virginia, and included mining operations located in both high and low coal.

4. Only underground operations utilizing continuous mining equipment were considered.

Table 1 gives a summary of conditions at mines included in the survey, and Appendix A lists all organizations and personnel interviewed.

Each organization selected was initially contacted to obtain agreement to participate in the survey. If granted, a tentative meeting date was set and copies of a questionnaire forwarded, prior to the meeting, to the appropriate personnel to give them some indication of the type of information required and allow time to assemble data or other applicable information. Copies of the questionnaires used are shown in Appendix B.

TABLE 1. SUMMARY OF THE MINING COMPANIES INTERVIEWED SHOWING SEAMS AND ANNUAL PRODUCTION

Company	Mine	Seam	Average Height, Inches	Feet of Cover/ Grindability Index	1971 Production[+], Tons
Company A	Mine 1	Pittsburgh	63	315/62	1,873,000
	Mine 2	Pittsburgh	62	260/54	650,000
	Mine 3	Double Freeport	84	400/59	363,000
Company B	Mine 4	Pittsburgh No. 8	66	--/--	659,000
Company C	Mine 5,6*	Pittsburgh	76	500-1000/--	3,725,000
	Mine 7,8*	Pittsburgh	84	500-1000/--	3,348,000
Company D	Mine 9	Pittsburgh	78	200/--	955,000
Company E	Mine 10	Pittsburgh	84	500/--	810,000
	Mine 11	Lower Kittanning	39	500/--	226,000
Company F	Mine 12	Pittsburgh	78	100-1200/--	708,000
	Mine 13	Pittsburgh	72	300-350/--	938,000
Company G	Mine 14	Pittsburgh No. 8	60	400-700/50-60	826,000
Company H	Mine 15	Illinois No. 6	90	250/57	843,000
Company I	Mine 16	Illinois No. 6	84	650/--	--
Company J	Mine 17	Illinois No. 6	72	350/55	4,079,000
Company K	Mine 18	Illinois No. 6	87	300/52-53	1,170,000
Company L	Mine 19,20,21*	Illinois No. 6	80	200-700/59	5,235,000

* Information was obtained on two or more mines which could not be isolated to one particular mine.
-- Indicates information was not available.
+ Taken from the <u>1972 Keystone Coal Industry Manual</u> and rounded to nearest 1000 tons.

TABLE 1. SUMMARY OF THE MINING COMPANIES INTERVIEWED SHOWING SEAMS AND ANNUAL PRODUCTION (Continued)

Company	Mine	Seam	Average Height, Inches	Feet of Cover/ Grindability Index	1971 Production+, Tons
Company M	Mine 22	Illinois No. 6	93	740/50-55	1,860,000
Company N	Mine 23	Illinois No. 5	51	200/--	167,000
	Mine 24	Illinois No. 5	72	245/--	509,000
Company O	Mine 25	Freeport 6A	72	--/--	740,000
Company P	Mine 26	Freeport 6A and Pittsburgh No. 8	60	--/--	564,000
Company Q	Mine 27	Lower Freeport	42	300/105	1,115,000
	Mine 28	Lower Kittanning	45	450/100	
	Mine 29	Lower Freeport	42	500/105	472,000
	Mine 30	Lower Kittanning	54	600/95	770,000
Company R	Mine 31,32*	Freeport E and D	60	300/86	1,821,000
Company S	Mine 33	Lower Freeport	42	400/100	142,000
Company T	Mine 34	Lower Kittanning	42	100/--	65,000
Company U	Mine 35	Brookville A	60	200/105	490,000
Company V	Mine 36	Beckley	72	500/98-100	572,000
	Mine 37	Clothier	66	400/50	1,524,000
Company W	Mine 38,39*	No. 2 Gas	40	700/56	301,000

* Information was obtained on two or more mines which could not be isolated to one particular mine.
-- Indicates information was not available.
+ Taken from the <u>1972 Keystone Coal Industry Manual</u> and rounded to nearest 1000 tons.

TABLE 1. SUMMARY OF THE MINING COMPANIES INTERVIEWED SHOWING SEAMS AND ANNUAL PRODUCTION (Continued)

Company	Mine	Seam	Average Height, Inches	Feet of Cover/ Grindability Index	1971 Production+, Tons
Company X	Mine 40	Cedar Grove and Chilton	66	250/45	429,000
Company Y	Mine 41	Middle Coalburg	88	300/43	--
Company Z	Mine 42	Elkhorn	60	500/48-54	832,000
	Mine 43	No. 2 Gas	56	650/57-62	--
	Mine 44	No. 2 Eagle	52	800/50	124,000
Company AA	Mine 45	Imboden	72	1500/60	624,000
Company BB	Mine 46	No. 3 Elkhorn	55	50-1000/--	503,000
Company CC	Mine 47	Pocahontas No. 3	54	1300/--	1,661,000
Company DD	Mine 48	"C" Prime (Upper Kittanning)	42	300/--	308,000
	Mine 49	"B" Seam (Lower Kittanning)	44	600/--	595,000
	Mine 50	Upper Freeport	102	400/86	949,000
	Mine 51	Bakerstown	60	200/88-89	773,000
	Mine 52	Sewell	54	150-600/54	184,000
Company EE	Mine 53	Tiller	55	0-2500/78	874,000
	Mine 54	Jawbone and Tiller	168	0-2500/60-80	4,188,000

--Indicates information was not available.
+ Taken from the 1972 Keystone Coal Industry Manual and rounded to nearest 1000 tons.

It was originally intended that all interviews would include personnel from engineering, sales, purchasing, production, maintenance, and any departments directly involved in bit technology. During the actual interviews we were not able to talk with all these groups for various reasons including:

1. Some organizations did not include all of these departments, or the departments were combined in various ways.

2. The personnel were not available at the time of the meeting.

3. In any mining company the number of people who have information or experience concerning the performance or wear characteristics of bits is limited. The company representatives interviewed were from this select group.

The personnel interviewed at most mines were limited to mine superintendents, vice-presidents of operations, or similar administrative personnel. Since most mines are not organized to document bit information or data, their information was based primarily on personal experiences and observations. The administrative personnel, having the most overall knowledge and experience with operations, were best qualified to supply information for the survey.

The manufacturing companies generally appeared to have a more formal organization; as a result, the interviews usually included personnel from engineering, sales, and production. In any case an effort was generally made to obtain specific information from the proper personnel not in attendance either by phone during the meeting or by a follow-up letter or call.

The interviews were conducted using as a basis for discussion questionnaires designed for the type of organization in question. (See Appendix B) The questions covered the specific areas outlined in Section I of this report as well as other questions covering related areas such as dust control methods. However, the discussions were not limited to these specific questions but ranged over general areas such as operations, maintenance, the health law, mining equipment, and personnel problems.

The answers to the questionnaire and other general comments made during the interview were noted and later put in a report of the meeting. A copy of the meeting report was sent to the personnel interviewed for their review and modification as required. The reviewed copy was then kept on file at BCR as the official meeting report.

Information was also obtained from the following sources:

1. A literature search was conducted to determine what research has been carried out by various companies and/or research organizations not interviewed. Abstracts of the pertinent articles are presented in Section VI, and a bibliography of all articles is given in Appendix C.

2. A patent search was conducted to find any new or novel bit configurations that have been developed. Abstracts of several patents of new bits are presented in Section VI, and a list of all the patents reviewed is given in Appendix C.

3. Interviews were held with a limited number of personnel not directly in the mining or manufacturing phase of the mining industry. These included a metallurgical consultant, a consultant on lacing patterns, and a retired bit company executive who has developed a modified point attack bit.

4. The mining departments of all the major coal producing states were contacted concerning possible research and development programs being conducted by state agencies.

All the companies or personnel either contacted or interviewed are listed in Appendix A. The results of the contacts are presented in other sections of this report.

IV. BACKGROUND OF BIT DEVELOPMENT FOR MINING

Few accounts exist of mining methods in early days, and there is practically no record of bit development.

Archeologists believe that prehistoric man dug copper ore from crude trenches and washed gravel to mine gold. Findings in southeastern England indicate that Neolithic man used the antlers and shoulder bones of red deer as picks and shovels.

Later indications are that flint was mined to make tools, including those used in mining. The method believed to be used was to sink a pit, as much as 50 feet deep, and drive a drift.

The earliest recorded mining was done by the Egyptians in the torquoise mines of the Siani Peninsula, about 3400 B.C.

The first iron tools were probably made from meteors which struck the earth, but the origin of the use of iron tools is apparently unknown.

The Hopi Indians in northeastern Arizona mined subbituminous coal during the tenth century from two seams that outcropped in the Black Mesa area. Stone tools and pottery scrapers were used to remove the coal.

Up until the late 1800's, mining was largely a hand operation. In practically every field opened before 1840, the first coal was recovered by quarrying or strip mining--the operations being by pick and shovel and on a very small scale. New areas were opened as soon as mining became difficult or expensive. The coal was usually undercut three to five feet into the face, the miner lying on his side and using a pick. The coal was wedged down until explosives came into general use in the early 1800's.

Beginning about the middle of the 1800's, various pneumatically operated machines were developed in Great Britain. These machines used hammers and coal saws to cut the coal.

In both America and Europe there was much interest and activity in the development of mechanical coal cutters. In fact, the hard physical labor and low productivity of the man working with a pick and shovel had been of concern almost from the beginning of the industry. The first really practical machine was the English "Iron Man" developed by Firth of Leeds. The first chain cutter was installed in the Lochwood pit in Scotland in 1864 and is regarded as the ancestor of all the chain machines.

In spite of effort to mechanize mines, the pick and shovel remained king until about 1920. Up until this time, the main reason for the relatively slow development of mining machines was the lack of materials of sufficient strength for shafts, gearing, and other components, particularly cutting bits. Beginning in the 1920's, a large number of different machines were offered, particularly loading equipment. In 1922, the first all mechanical mine was opened at Oakland City, Indiana, signifying that the machine was really on its way.

Improvement in bits for both drilling and cutting was marked by the introduction during the 1920's of detachable bits for augers and the start of work on something better than the old quenched carbon bit for cutting. Although a beginning had been made on the throw-away bit, the main emphasis was on hard-surfacing and heat treating. Up until this time bits were generally forged by the blacksmith at the mine from 1 x 1/2 inch carbon steel bar. Resultant bits were pointed tools with 1 x 1 inch shanks.

Although improvements in mine machinery were made during the next two decades, it was not until the early 1940's, after more than half a century of trying, that the United States coal industry finally achieved full mining and loading with a single machine. This was made possible by the development of a bit utilizing a tungsten carbide tip. McKenna Metals Co., now Kennametal, Inc., is credited with pioneering this work, starting in 1941, and achieving commercial status in 1944. These bits were of the rectangular shank type, with broad, generally flat cutting faces.

Advances in metallurgy made possible machine components, as well as bits, of sufficient strength to permit the use of compact high horsepower electric drives in the cutting of solid coal. As a result, the capacity and economy of these machines have improved considerably.

The next, and last, significant change in bit design was the point attack or plumb bob bit introduced from England in the early 1960's. This is a round shank bit, normally utilizing a carbide tip, which tends to rotate as it cuts. This characteristic allows the bit to wear down while still maintaining a relatively sharp point. Theoretically, this extends its useful life and makes it more economical in terms of bit cost per ton of coal mined.

Both the original carbide tipped bit and the point attack bits have many variations, but the experience of the operators has been that no one design can be used in all mines.

At the present time no radical changes appear to be forthcoming in either bit designs or materials. Most operators agree that the present bits are adequate, and the next step in mining will probably be development of new mining techniques.

Economics has been the motivating force in the development of mechanized equipment. This has been especially true since the 1930's when unions became more powerful and started winning large economic gains for their members. The effect of mechanization can be seen in the following figures which reflect the increase in production per shift of a unit foreman and crew.

1. In 1910, 30 men and $10,000 in equipment produced 125 TPD.

2. In 1960, nine men and $300,000 in equipment produced 750-800 TPD.

3. In 1970, six men and $800,000 in equipment produced 1500 TPD.*

It is significant that the gains indicated above were made possible, to a great extent, by the development of better bits. Even today the efficiency of

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* The 1970 figures were projected in 1961 and may not be accurate.

a mining operation depends on the useful life of the bit. It would seem logical, therefore, that research and development of improved bits is an absolute necessity if mining efficiency is to increase.

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BCR wishes to acknowledge the assistance of the personnel from the coal companies, bit manufacturing companies, and machine manufacturers who were interviewed and supplied information used in this report.

V. ANALYSIS OF INFORMATION AND DATA FROM THE SURVEY

A. Mining Companies

An analysis of the information obtained during this survey indicates the mining companies are making every effort to comply with the Health and Safety Act. However, they are often frustrated in their efforts by the economic impact on operations, lack of information on new developments in dust control methods, and lack of reliable equipment for determining compliance.

It also became apparent that mining people feel it is impossible to separate the discussion of bits as related to dust control from other factors such as types of mining machines used, mine conditions, ventilation methods, operating personnel, and auxiliary equipment.

A discussion of specific areas of interest with regard to bit design is presented in the following sections.

1. Basis for Selection of Bit Design: As with most corporate policies, the primary basis for selection of bits is economics. The specific reasons given for use of a particular bit were:

a. The initial price of the bit,
b. Service provided by the supplier; i.e., (1) prompt delivery of bits and (2) technical help readily available to resolve problems related to bit quality or mining conditions.
c. The economics of operation, i.e., bit cost per ton of coal mined.

The order of importance of these considerations varied with different companies, but they are all directly related to the economics of operation.

The amount of dust produced by a specific bit design is given little or no consideration. This does not reflect apathy of the operators for the miners' health but their conviction that bit design itself is of little significance in controlling dust. They feel that all bits dull quickly and thus lose any advantage a design may have had initially. They think it is more practical to suppress the dust with auxiliary equipment such as sprays, scrubbers, and ventilating fans than to attempt to reduce dust production. Only if there is an obvious increase in dust will the use of a new bit be discontinued.

Until research and development work is undertaken to prove that bits can significantly reduce the respirable dust concentration, mine operators will continue to select bits which give minimum operating costs.

2. Industry Acceptance of the Point Attack Bit: Since their introduction to the American mining industry, point attack bits have been widely accepted, as indicated by the data presented in Tables 2 and 3. The 31 different companies listed, representing 54 mines, employ 390 continuous mining machines of various designs, and require approximately 43,500 bits. Point attack bits are used exclusively by 342, or 88 percent, of these machines. The remaining 58 machines include 23 which used cutter bits on the chains only; two which used them on the end cutters; two, at unspecified locations; and 31 (approximately 8 percent of the machines) used cutter bits exclusively.

TABLE 2. OPERATING PARAMETERS OF THE VARIOUS MINERS USED BY THE MINING COMPANIES

Company	Mine	Type and Number of Mining Machines	Head Speed, RPM	No. of Bits	Tons/Section, ROM
Company A	Mine 1	L.N. 38-Y (3)	56-58	84	540
		L.N. 455S	56-58	78	
		Joy 8CM	56-58	92	
		Joy 10CM (5)	56-58	120	
		Joy 12CM	--	--	
	Mine 2,3	L.N. 48	--	--	250
		L.N. 10 (Modified)	--	--	
		L.N. 484 (4)	56-58	92	
Company B	Mine 4	Joy 3CM	70	120	510
		Joy 8CM (2)	70	120	
Company C	Mine 5,6	Joy 1CM (23)	--	172	345
	Mine 7,8	Jeffrey Heliminer (6)	--	--	--
		Borers (3)	20-22	--	
Company D	Mine 9	Jeffrey 120M Heliminer (3)	--	72 (on chain)	138 (clean)
		2BT2 (4)	--	--	
		Joy Borer(6)	12	150	
Company E	Mine 10	L.N. 48H (2)	100	144	280
		Goodman Borer (5)	17-19	160	
	Mine 11	L.N. 32H	--	108	100
		L.N. 26H	--	140	
		L.N. 26H (3)	--	108	
Company F	Mine 12	Joy 1CM (6)	--	164	265

-- Dash indicates information was not available.

TABLE 2. OPERATING PARAMETERS OF THE VARIOUS MINERS USED BY THE MINING COMPANIES (Continued)

Company	Mine	Type and Number of Mining Machines	Head Speed, RPM	No. of Bits	Tons/Section, ROM
Company F	Mine 13	Joy 1CM (5)	--	260	355
		L.N. 45 (2)	--	240	
Company G	Mine 14	Joy 8CM (5)	70	138	615
		Joy 10CM	60	115	
Company H	Mine 15	L.N. 114 Hardhead (3)	--	88	433
		Joy 8CM	70	150	
		L.N. 48H	60	152	
Company I	Mine 16	Jeffrey	72.8	--	--
		Joy 10CM (5)	--	--	
		Marietta (9)	--	--	
		Goodman (18)	--	--	
Company J	Mine 17	Joy 10CM (6)	58	130-140	940
		Joy 12CM	58	130-140	
		L.N. 45E	--	130-140	
Company K	Mine 18	Jeffrey 120H Heliminer (2)	60	110	750
		Jeffrey 120H Heliminer (7)	60	172	
Company L	Mine 19,20,21	Jeffrey 120 Heliminer (2)	81	124	520
		Joy 10CM (2)	--	--	
		L.N. 481K (2)	765 fpm	160	
		L.N. 48H (4)	765 fpm	160	
		L.N. 45E (7)	765 fpm	160	
		L.N. 45CE (15)	765 fpm	160	

-- Dash indicates information was not available.

TABLE 2. OPERATING PARAMETERS OF THE VARIOUS MINERS USED BY THE MINING COMPANIES (Continued)

Company	Mine	Type and Number of Mining Machines	Head Speed, RPM	No. of Bits	Tons/Section, ROM
Company M	Mine 22	Joy 10CM (9)	60	108	530
		Jeffrey Heliminer (4)	60	108	
Company N	Mine 23	Joy 11CM (2)	--	124	400
	Mine 24	Joy 9CM	69	130	300
Company O	Mine 25	L.N. 45 (3)	81	116	--
		Jeffrey 120 Heliminer (3)	86	125	
Company P	Mine 26	L.N. 38 (4)	80	90	175
		L.N. 35 (2)	80	90	
		Jeffrey 120M Heliminer (3)	80	150	
		L.N. 28 (2)	80	90	
Company Q	Mine 27	L.N. 28E (6)	87	80	--
	Mine 28	Colmol	60	105	--
	Mine 29	L.N. 26H (5)	89	112	--
		L.N. 28H (2)	89	112	
	Mine 30	L.N. 35Y (7)	87	100	--
Company R	Mine 31,32	Joy 11CM (4)	69.5	108	168
		Joy 9CM (8)	69.0	140	
		L.N. 26 (6)	90	112	
		L.N. 28 (4)	89	100	
		L.N. 32 (3)	87	100	
		L.N. 35 (5)	87	100	
		L.N. 37 (2)	87	100	
		L.N. 38 (3)	87	100	
		Colmol (2)	76	75	

-- Dash indicates information was not available.

TABLE 2. OPERATING PARAMETERS OF THE VARIOUS MINERS USED BY THE MINING COMPANIES (Continued)

Company	Mine	Type and Number of Mining Machines	Head Speed, RPM	No. of Bits	Tons/Section, ROM
Company S	Mine 33	L.N. 26H (14)	78	112	--
		L.N. 28 (2)	78	112	
		L.N. 265 Hardhead (4)	60	112	
Company T	Mine 34	L.N. 26H	90	100	250
Company U	Mine 35	L.N. 256 Hardhead (3)	68	120	350
		L.N. 26H	98	120	
Company V	Mine 36	L.N. 455 Hardhead (2)	--	--	450
	Mine 37	L.N. 38 (3)	--	--	264
		L.N. 35 (5)	--	--	
		L.N. 265 Hardhead (3)	--	--	
Company W	Mine 38	L.N. 26H	--	140	805
	Mine 39	L.N. 26H (2)	--	140	285
Company X	Mine 40	Jeffrey 120L Heliminer	64	--	325
Company Y	Mine 41	Jeffrey 120H Heliminer (3)	--	--	--
Company Z	Mine 42	Joy 9CM	69	140	526
		Jeffrey 120M Heliminer	81	126	
	Mine 43	L.N. 35Y (2)	87.4	144	744
		Jeffrey 120M Heliminer	81	126	
	Mine 44	Jeffrey 120M Heliminer	81	126	135
		Jeffrey 120L Heliminer	52	123	
Company AA	Mine 45	L.N. 38Y (5)	87.4	104	425
		L.N. 37Y	87.4	104	

-- Dash indicates information was not available.

TABLE 2. OPERATING PARAMETERS OF THE VARIOUS MINERS USED BY THE MINING COMPANIES (Continued)

Company	Mine	Type and Number of Mining Machines	Head Speed, RPM	No. of Bits	Tons/Section, ROM
Company BB	Mine 46	L.N. 35Y (4)	75	84	350
		L.N. 10 (2)	81	120	
Company CC	Mine 47	L.N. 37X (7)	71	96	425
		L.N. 105 Hardhead (2)	--	100	581
Company DD	Mine 48	L.N. 28	75-90	126	167
		L.N. 32 (3)	75-90	126	
		L.N. 35	75-90	126	
	Mine 49	L.N. 28 (3)	75-90	110-120	--
		L.N. 26 (3)	75-90	110-120	
	Mine 50	Joy 8CM (3)	60	140	--
		Joy 10CM (2)	60	81	
		L.N. 48H (3)	60	100	
	Mine 51	Joy 11CM	69	--	270
		L.N. 32 (2)	--	--	
		L.N. 35 (3)	--	84	
	Mine 52	L.N. 32Cm (3)	87.4	64	160
Company EE	Mine 53	L.N. 28E (3)	--	--	300
		L.N. 32Y (2)	--	--	
		L.N. 35Y (2)	--	--	
	Mine 54	L.N. 37X	--	--	418
		L.N. 38H	--	--	
		L.N. 38Y (2)	--	--	
		L.N. 48H	--	--	
		L.N. 48Y	--	--	
		Jeffrey 120M Heliminer (2)	--	--	

-- Dash indicates information was not available.

TABLE 3. BIT STYLES USED BY THE VARIOUS MINING COMPANIES AND COST DATA

Bit Style	Bit Type	Company	Mine	Type and Number of Mining Machines Using the Bit	Initial Bit Cost	Bit Cost/ ROM Ton
No. 1	Plumb bob	Company N	Mine 24	Joy 9CM (52 bits/miner)	$8.40	--
		Company U	Mine 35	L.N. 265 Hardhead (3) (8 bits/miner)	--	$0.026
No. 2	Plumb bob	Company P	Mine 26	L.N. 28 (2)	0.87	0.078+
		Company Q	Mine 27	L.N. 28E (4)	1.02	0.041*
			Mine 29	L.N. 26H (4) L.N. 28H	1.02	0.041*
			Mine 30	L.N. 35Y (7)	1.02	0.034*
		Company R	Mine 31, 32	Joy 9CM (8) L.N. 26 (6) L.N. 28 (4) L.N. 32 (3) L.N. 35 (5) L.N. 37 (2) L.N. 38 (3) Colmol (2) (uses a Style 12 and Style 2)	1.03	0.07*
		Company U	Mine 35	L.N. 26H	1.07	0.026
No. 3	Plumb bob	Company E	Mine 11	L.N. 26H	1.10	--
		Company S	Mine 33	L.N. 26H	--	--

* Bit cost includes two or more bit styles which cannot be further separated.
-- Indicates information was not available.
+ Bit cost per ton of clean coal.

TABLE 3. BIT STYLES USED BY THE VARIOUS MINING COMPANIES AND COST DATA (Continued)

Bit Style	Bit Type	Company	Mine	Type and Number of Mining Machines Using the Bit	Initial Bit Cost	Bit Cost/ ROM Ton
		Company U	Mine 35	L.N. 265 Hardhead (3)	$1.07	$0.026
		Company W	Mine 38	L.N. 26H	--	--
		Company EE	Mine 54	Jeffrey 120M Heliminer (2)	1.05-1.10	0.015
No. 4	Plumb bob	Company D	Mine 9	Jeffrey 120M Heliminer (2)	--	0.087*
		Company L	Mine 19,20,21	Jeffrey 120 Heliminer (2) Joy 10CM (2) L.N. 481K (2) L.N. 45E (7) L.N. 45CE (15) L.N. 48H (4)	0.82-1.29	0.018(19 & 21) 0.090 (20)
		Company M	Mine 22	Jeffrey Heliminer (4) Joy 10CM (9)	1.46	0.00974
		Company N	Mine 23	Joy 11CM (2)	1.42	0.05
		Company O	Mine 25	Jeffrey 120 Heliminer	0.75-1.20	.002-.003*
		Company R	Mine 31,32	Joy 11CM (4)	1.42	0.07*
		Company Z	Mine 42	Jeffrey 120M Heliminer	1.56	0.10
		Company DD	Mine 51	Joy 11CM	--	--

* Bit cost includes two or more bit styles which cannot be further separated.
-- Indicates information was not available.
+ Bit cost per ton of clean coal.

TABLE 3. BIT STYLES USED BY THE VARIOUS MINING COMPANIES AND COST DATA (Continued)

Bit Style	Bit Type	Company	Mine	Type and Number of Mining Machines Using the Bit	Initial Bit Cost	Bit Cost/ ROM Ton
No. 5	Plumb bob	Company K	Mine 18	Jeffrey 120H Heliminer (9)	$1.43	$0.076
		Company O	Mine 25	Jeffrey 120 Heliminer	0.75-1.20	.002-.003*
		Company X	Mine 40	Jeffrey 120L Heliminer	1.57	--
		Company Y	Mine 41	Jeffrey 120H Heliminer (3)	--	--
		Company Z	Mine 43	Jeffrey 120M Heliminer	1.51	0.03*
			Mine 44	Jeffrey 120M Heliminer Jeffrey 120L Heliminer	1.51	0.21
No. 6	Plumb bob	Company Q	Mine 27	L.N. 28E (2)	1.15	0.041*
			Mine 30	L.N. 35Y (2)	1.15	0.034*
		Company Z	Mine 42	Joy 9CM	1.26	0.10
			Mine 43	L.N. 35Y (2)	1.22	0.03*
		Company DD	Mine 51	Joy 11CM L.N. 35 (2)	--	--
No. 7	Plumb bob	Company C	Mine 5,6	Joy 1CM (23)	1.25	0.10-0.14*
			Mine 7,8	Jeffrey Heliminer (5)	1.25	0.10-0.14*
		Company E	Mine 10	L.N. 48H	0.90	0.027*
		Company F	Mine 12	Joy 8CM L.N. 38 L.N. 45	--	--

* Bit cost includes two or more bit styles which cannot be further separated.
-- Indicates information was not available.
+ Bit cost per ton of clean coal.

TABLE 3. BIT STYLES USED BY THE VARIOUS MINING COMPANIES AND COST DATA (Continued)

Bit Style	Bit Type	Company	Mine	Type and Number of Mining Machine Using the Bit	Initial Bit Cost	Bit Cost/ ROM Ton
		Company H	Mine 15	L.N. 114 Hardhead (3) Joy 8CM	$1.30	$0.030
				L.N. 48H	1.11	0.007
		Company J	Mine 17	Joy 10CM (6) Joy 12CM L.N. 45E	1.27	0.034
		Company N	Mine 24	Joy 9CM (cutter wheels only)	1.19	--
		Company P	Mine 26	L.N. 38 (4) L.N. 35 (2)	1.10	0.078+
		Company AA	Mine 45	L.N. 38Y (5) L.N. 37Y	1.16	0.034
		Company BB	Mine 46	L.N. 35Y L.N. 10	1.21	0.020
		Company CC	Mine 47	L.N. 105 Hardhead (2)	1.05	0.023*
		Company V	Mine 37	L.N. 265 Hardhead (3)	0.90	--
				L.N. 38 (3)	1.08	--
				L.N. 35 (5)	1.08	--
		Company DD	Mine 48	L.N. 28	--	--

* Bit cost includes two or more bit styles which cannot be further separated.
-- Indicates information was not available.
+ Bit cost per ton of clean coal.

TABLE 3. BIT STYLES USED BY THE VARIOUS MINING COMPANIES AND COST DATA (Continued)

Bit Style	Bit Type	Company	Mine	Type and Number of Mining Machines Using the Bit	Initial Bit Cost	Bit Cost/ ROM Ton
			Mine 50	Joy 8CM (3) Joy 10CM (2) L.N. 48H (3)	--	--
			Mine 51	L.N. 32 (2) L.N. 35 (3)	--	--
			Mine 52	L.N. 32CM (3)	--	--
No. 8	Plumb bob	Company E	Mine 11	L.N. 26H (4)	$1.16	$0.105
		Company EE	Mine 53	L.N. 28E (3) L.N. 32Y (2) L.N. 35Y (2)	1.05-1.10	0.039
			Mine 54	L.N. 37X L.N. 38H L.N. 38Y (2) L.N. 48H L.N. 48Y	1.05-1.10	0.015
No. 9	Plumb bob	Company O	Mine 25	Jeffrey 120 Heliminer	0.75-1.20	.002-.003*
		Company P	Mine 26	Jeffrey 120M Heliminer (3)	1.10	0.078+
No. 10	Cutter	Company E	Mine 10	Goodman Borer (5)	1.05	0.027*
No. 11	Cutter	Company Q	Mine 28	Colmol	1.07	0.042*
No. 12	Cutter	Company D	Mine 9	2BT2 Borer (4) Joy Borer (6)	--	0.081

* Bit cost includes two or more bit styles which cannot be further separated.
-- Indicates information was not available.
\+ Bit cost per ton of clean coal.

TABLE 3. BIT STYLES USED BY THE VARIOUS MINING COMPANIES AND COST DATA (Continued)

Bit Style	Bit Type	Company	Mine	Type and Number of Mining Machines Using the Bit	Initial Bit Cost	Bit Cost/ ROM Ton
		Company E	Mine 10	Goodman Borer	$0.99	$0.027*
		Company F	Mine 12	Joy 1CM (6)	--	--
			Mine 13	Joy 1CM (5)	0.95-1.00	0.028*
		Company R	Mine 31,32	Colmol (2) (used with plumb bob style)	--	0.07*
		Company Z	Mine 43	L.N. 35Y (2) (24 bits on end cutters)	1.20	0.03*
No. 13	Cutter	Company C	Mine 5,6	Joy 1CM (23) (on cutter chains only)	0.96	0.10-0.14*
			Mine 7,8	Borers (3)	0.96	0.10-0.14*
No. 14	7/8" Bullet	Company A	Mine 1	Joy 8CM Joy 10CM (5) L.N. 38Y (3) L.N. 455S Hardhead	1.00	0.015
			Mine 2,3	Joy 12CM L.N. 48 L.N. 100L	1.00	0.044
		Company D	Mine 9	Jeffrey 120M Heliminer	--	0.087*
		Company E	Mine 10	L.N. 48H	0.70	0.027*
			Mine 11	L.N. 32H	0.94	0.119

* Bit cost includes two or more bit styles which cannot be further separated.
-- Indicates information was not available.
+ Bit cost per ton of clean coal.

TABLE 3. BIT STYLES USED BY THE VARIOUS MINING COMPANIES AND COST DATA (Continued)

Bit Style	Bit Type	Company	Mine	Type and Number of Mining Machines Using the Bit	Initial Bit Cost	Bit Cost/ ROM Ton
		Company G	Mine 14	Joy 8CM	$0.77	$0.050
		Company O	Mine 25	L.N. 45 (3)	0.75-1.20	.002-.003
		Company S	Mine 33	L.N. 26H (13) L.N. 28 (2) L.N. 265 Hardhead (4)	--	--
		Company T	Mine 34	L.N. 26H	1.11	--
		Company W	Mine 39	L.N. 26H (2)	0.96	--
		Company CC	Mine 47	L.N. 37X (7)	0.75	--
		Company DD	Mine 48	L.N. 32 (3) L.N. 35	--	--
			Mine 49	L.N. 26 (3) L.N. 28 (3)	--	--
No. 15	1" Bullet	Company C	Mine 7,8	Jeffrey Heliminer	--	0.10-0.14*
		Company G	Mine 14	Joy 10CM	1.30	0.018
		Company O	Mine 25	Jeffrey 120 Heliminer	0.75-1.20	.002-.003*
		Company Q	Mine 29	L.N. 26H L.N. 28H	1.13	0.041*
		Company V	Mine 36	L.N. 455 Hardhead (2)	1.00	--

* Bit cost includes two or more bit styles which cannot be further separated.
-- Indicates information was not available.
+ Bit cost per ton of clean coal.

One of the major reasons for this acceptance has been a major sales effort by bit manufacturers which stressed the advantages of the point attack design. The basic design concept of the plumb bob bit is that it rotates during operation and thereby maintains a sharp point at the tip, which theoretically gives the following advantages.

a. Increased tool life and, therefore, lower bit cost per ton.

b. More efficient operation due to increased fracturing of the coal.

c. Less rubbing action of the bit against the coal, resulting in less dust.

d. Lower power requirements.

e. Less shock on the machines, resulting in less machine maintenance.

The experience of the operators indicates that the success of this concept varies widely within the industry, ranging from estimates of zero percent of the bits rotating throughout their life to 100 percent, with the majority indicating at least 50 percent rotation. Examples of the wear patterns of bits are shown in Appendix D.

Inconsistency of bit performance has resulted in disagreement among the operators concerning the advantages of the point attack design over the cutter bit. For example, there were direct contradictions as to which design produced more dust; and the following advantages, based on a comparison of new bits, were claimed for both the point attack and cutter bits.

a. Less dust produced, based mainly on visual observations.

b. Greater penetration and larger size consist.

c. Longer bit life. (For the flat cutter bit, this is based on the ability to resharpen and reuse the bits on an average of three to four times; for the point attack bit it is based on the "self-sharpening" feature which allows its use to destruction.)

d. Better retention of the carbide tip.

The two points on which there was general agreement were (1) that after a short time the advantages of one type of bit over another rapidly diminish so that the main consideration should be ease and frequency of replacement; and (2) the point attack bit requires less "change-out" time than the cutter bit.

One opinion most frequently expressed was that the point attack design is the most economical to use. However, no information was available to substantiate this. This "cost-per-ton" data* listed in Table 3 vary from 1 cent to 14 cents per ton, and the data for the cutter bits compare very favorably with the point attack bit data. For the following reasons, however, the data cannot be considered reliable:

a. Many companies do not maintain accurate data or data in sufficient detail to isolate cost-per-ton figures.

b. In some instances different types of bits were included in one cost-per-ton figure. (These are noted in Table 3.)

c. In no case did anyone indicate that the cost per ton included any allowance for "change-out" time or other maintenance, exclusive of resharpening, that could be attributed to bit problems.

The main reason cited for not maintaining accurate cost data was that bit cost is a relatively small percentage of the total cost per ton, and the added expense of maintaining these records cannot be justified.

Another basis of comparison should be the tons of coal mined per bit. Except for the very limited data presented in Table 4, this information is not available. The limited amount of data and the considerable variation in values indicate that no valid conclusions can be reached with this information.

In most industrial applications a piece of equipment will not be utilized unless its operation has been explained by the manufacturer and is completely understood. In the case of the point attack bit there is an obvious lack of understanding of what causes the bits to rotate. In addition to simply "not knowing," the causes of rotation given by the operators included:

a. Vibration of the machine.

b. The unbalanced forces set up when the bit strikes the coal face regardless of the attack angle.

c. The friction forces of the cut coal as it falls past the bit.

d. The centrifugal forces set up by the rotation of the head and the resulting axial movement of the bit.

e. The vibration and thrust of the machine.

f. The oscillation of the head.

g. The conical shape of the bit.

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* "Cost-per-ton" figures are based on raw tonnage except where indicated. Information on clean coal was converted to raw coal by using percent reject figures supplied by the company.

TABLE 4. ROM* TONS MINED PER BIT

Company	Mine	Bit Style	ROM Tons/Bit
E	10	-	3.0
E	17	3	1.3
			2.8
		14	1.5
			5.6
F	13	12	6.0
J	17	7	32.4
N	23	4	30.8
R	31, 32	2	35.7
		7	29.1
AA	45	7	29.8
BB	46	7	61.6

* Run of mine or "as mined" coal including seam impurities.

h. The unbalanced forces set up when a bit, set at an angle of 5 to 10 degrees from the centerline of the machine measured in the horizontal plane, strikes the coal face.

Because of this lack of knowledge of the mechanics of rotation, there is also disagreement on what hinders or enhances rotation. Approximately 60 percent of the operators felt that water sprays enhance rotation by either washing out the bit holders or by the lubricating action of the fine coal slurry. Approximately 20 percent indicated sprays hindered rotation by promoting corrosion, caking, or washing the slurry into the holder. The remaining 20 percent had no opinion.

As indicated in Figures 1 and 2, there are many variations within the cutter bit and point attack bit designs. The most notable difference in point attack bits is between the plumb bob, Styles 1-9, and the bullet bit, Styles 14 and 15. Some companies have made comparisons between these styles and have listed the following advantages for the bullet bits:

a. Lower initial cost,

b. Less visible dust and therefore probably less respirable dust,

c. Faster "change-out" time than plumb bobs using a retaining pin,

d. Increased block life,

e. Decreased shank breakage (claimed for both the plumb bob and bullet types).

Except for item "a," there are no data to substantiate these claims; they are the personal opinions of the operators, based on their observations of mining operations.

From the data in Tables 2 and 3, 67 machines (20 percent of those machines using point attack bits), requiring approximately 7,439 bits, were equipped with bullet bits. Therefore, in spite of its higher initial cost, the plumb bob bit shows wider acceptance than the bullet. Again no information could be found to explain this observation.

It would appear, therefore, that the advantages or disadvantages of a bit depend primarily on its application rather than its design. Within the industry, changes made in the style of bit used are the result of revisions to mining equipment used; the introduction of a new bit and the associated sales effort; an attempt to eliminate a specific problem; and, in some cases, to reduce cost.

Generally, mining companies will change suppliers rather than bit types, in an effort to reduce cost without sacrificing performance.

In summary, the point attack bits have gained wide acceptance due to (1) the theoretical economic advantage of the self-sharpening design, even though operating data, as shown in Table 3, does not seem to substantiate this claim, and (2) the operators' lack of facilities and funds to conduct comparative tests on bit designs.

3. <u>Purpose and Results of Tests Conducted by the Mining Industry</u>: There is an obvious lack of test data available from the coal industry with regard to bit design. Many companies indicated they had conducted tests but that these were time studies or performance checks of equipment, and no data were kept nor formal reports written. However, some documented tests were conducted, and outlines of these tests are presented in this section.

It must be remembered that conducting controlled underground tests while maintaining production is extremely difficult. Many environmental conditions, such as temperature, humidity, seam conditions, and human factors, cannot be effectively controlled, making collection of meaningful data difficult. Therefore, the results of these tests should be considered as indicative of trends and not as precise conclusions.

An important observation from these tests is that the shortest and smallest diameter bit, Style 2 of Figure 3, appears to produce the least amount of respirable dust. Two independent tests produced the same results, indicating a strong correlation between dust production and bit size. If this correlation can be confirmed through further testing, it could help to establish a "best type" bit design for reducing dust levels.

Most of these tests do not relate specifically to bit design and are included for general information purposes.

a. <u>Tests Related to Bit Design</u>

(1) <u>Company Q Bit Survey Data</u>: Although not a formal test, a number of dust measurements correlated to bit types (Figure 3) were taken in four Company Q mines. The data were compiled and analyzed by BCR to determine whether the dust level, as determined by the average values for the readings taken, varied significantly as a function of the bit used. The results of this analysis, shown in Tables 5 and 6, indicate that the smaller bit (Style 2, Figure 3) does reduce the dust concentration as compared to the larger bits.

Since no effort was made to control test conditions, the data presented can only be considered indicative of a trend and no positive conclusions can be stated. Table 7 shows the operating parameters for the mining machines used when the dust readings were taken. There appears to be no correlation between these parameters and the average dust concentrations.

(2) <u>Comparison of 90 Degree and 60 Degree Tip Plumb Bob Bits</u>: Company M conducted tests to compare the cutting action of plumb bob bits using tips having included angles to 60 degrees and 90 degrees. Generally, the results of these tests were:

(a) A size consist analysis of the coal showed that 60 degree bits, Style 4, produced larger coal sizes than the 90 degree bits, Style 5, (Figure 4) and therefore probably less coal dust. (See Figure 5.) However, no dust samples were taken to substantiate this conclusion. The coal samples taken for the general mine average size distribution curve (Figure 5) were collected from a feeder from a 14,000 ton raw coal bin after the minus 6-inch ROM coal had been through a rotary breaker. This curve includes no plus 6-inch ROM material. When these samples were collected for the general mine average

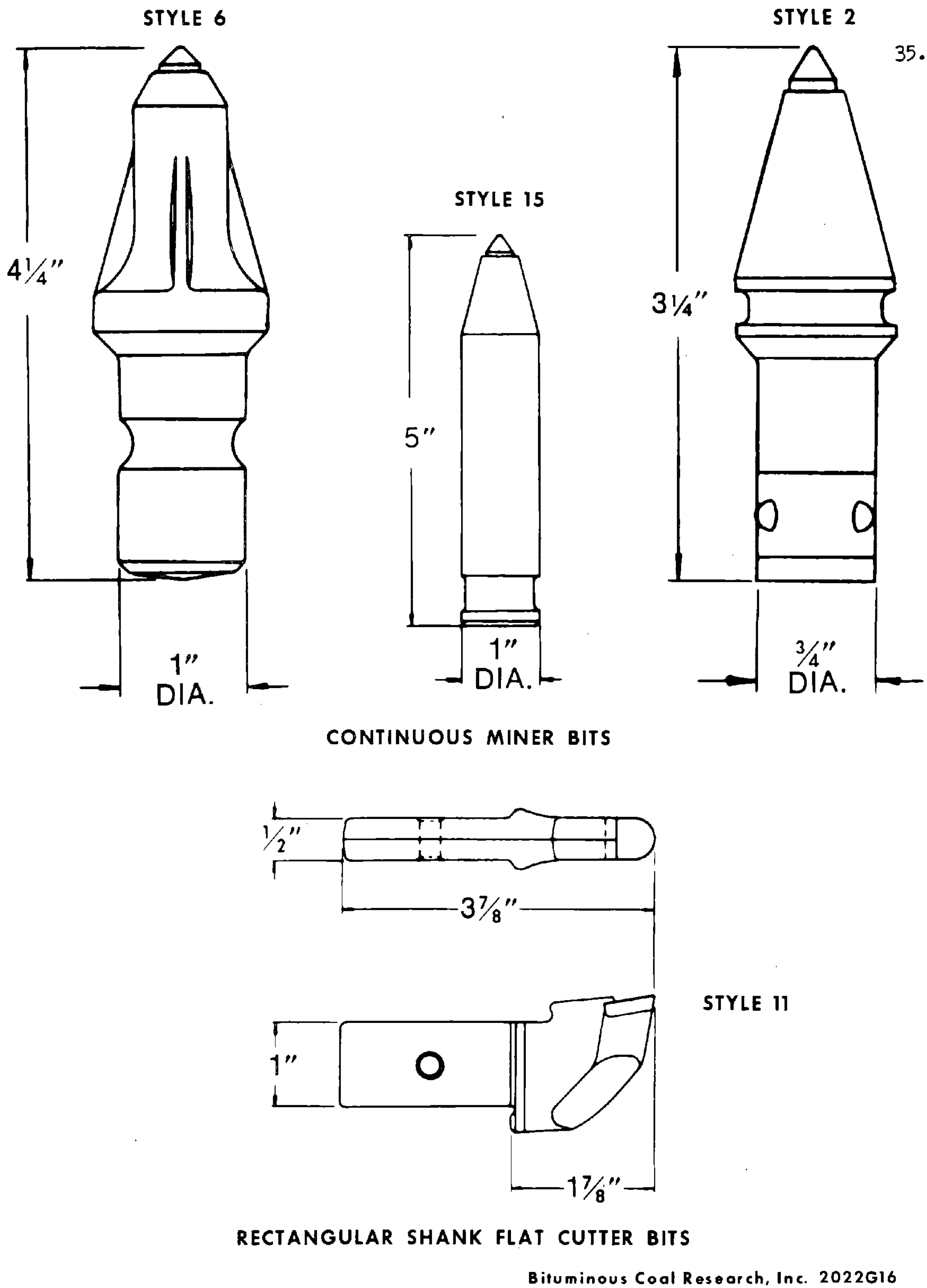

Figure 6. Bits Used in Company Q Dust Survey

TABLE 5. CORRELATION OF DUST TO TYPES OF MINERS AND BITS

Mine	Section	Type of Miner	Type of Bit	Bit Style No.	Average Dust Samples (10 samples for each average) (mg/m^2)*	Average for each Section (mg/m^2)
30	1	L.N. 35Y	Mini plumb bob	2	1.86 0.87 1.44 0.49	1.16
	2	L.N. 35Y	Mini plumb bob	2	1.64 1.31 1.26	1.40
	3	L.N. 35Y	Mini plumb bob	2	2.70	2.70
	4	L.N. 35Y	Mini plumb bob	2	0.88 0.95 1.16 0.70	0.92
	5	L.N. 35Y	Mini plumb bob	2	0.59	0.59
	6	L.N. 35Y	Finned plumb bob	6	2.13 1.11	1.62
	7	L.N. 35Y	Finned plumb bob	6	2.49 2.08 1.12 1.29 1.29 0.96	1.54
28	1	Colmol	Flat cutter bit	11	1.56 2.30 1.65 1.04	1.64
	2	Colmol	Flat cutter bit	11	1.30 1.70 1.97 1.42	1.60
	3	Colmol	Flat cutter bit	11	1.64 1.07 1.16	1.29
	4	Colmol	Flat cutter bit	11	0.82 0.47 0.34 0.40	0.51
	5	Colmol	Flat cutter bit	11	1.31	1.31
	6	Colmol	Flat cutter bit	11	1.86 1.62	1.74
	7	Colmol	Flat cutter bit	11	1.77 1.60 1.60	1.66
	8	Colmol	Flat cutter bit	11	1.39 1.28 1.84	1.50
27	1	L.N. 28E	Mini plumb bob	2	1.55 1.43 2.14 1.54	1.66
	2	L.N. 28E	Mini plumb bob	2	0.76 0.50 0.78 0.81 0.75	0.72
	3	L.N. 28E	Mini plumb bob	2	1.56 1.31 0.94	1.27
	4	L.N. 28E	Mini plumb bob	2	1.13 1.46	1.30
	5	L.N. 28E	Finned plumb bob	6	2.34	2.34
	6	L.N. 28E	Finned plumb bob	6	1.47 2.10 2.29	1.95
29	1	L.N. 26H	Mini plumb bob	2	1.77 1.13 2.03	1.64
	2	L.N. 26H	Mini plumb bob	2	1.29 1.97 1.84 1.48	1.64
	3	L.N. 26H	Mini plumb bob	2	1.54 1.56 0.93	1.34
	4	L.N. 26H	Mini plumb bob	2	0.93 0.87 0.70	0.83
	5	L.N. 28H	Mini plumb bob	2	1.31 1.19 1.49	1.33
	6	L.N. 28H	5" Bullet	15	2.09 1.87 1.13 0.75	1.46
	7	L.N. 26H	5" Bullet	15	1.12 1.94 1.10 1.16	1.33

* Expressed as equivalent MRE readings

TABLE 6. AVERAGE DUST CONCENTRATIONS FOR VARIOUS BIT STYLES

Mine	Bit Style No.	No. of Samples (Groups of 10)	Average Dust Concentrations (mg/m^3)
30	2	13	1.22
	6	8	1.56
28	11	24	1.38
27	2	14	1.19
	6	4	2.05
29	2	16	1.38
	15	8	1.40
Combined Mines	2	43	1.27
	6	12	1.72
	15	8	1.40
	11	24	1.38

TABLE 7. OPERATING PARAMETERS OF THE VARIOUS MINERS

Type of Miner	Head Speed RPM	No. of Bits	No. of Sprays
L.N. 26H	89	126	22
L.N. 28E	87	80	16
L.N. 28H	89	112	20
L.N. 35Y	87	100	21
Colmol	60	105	12

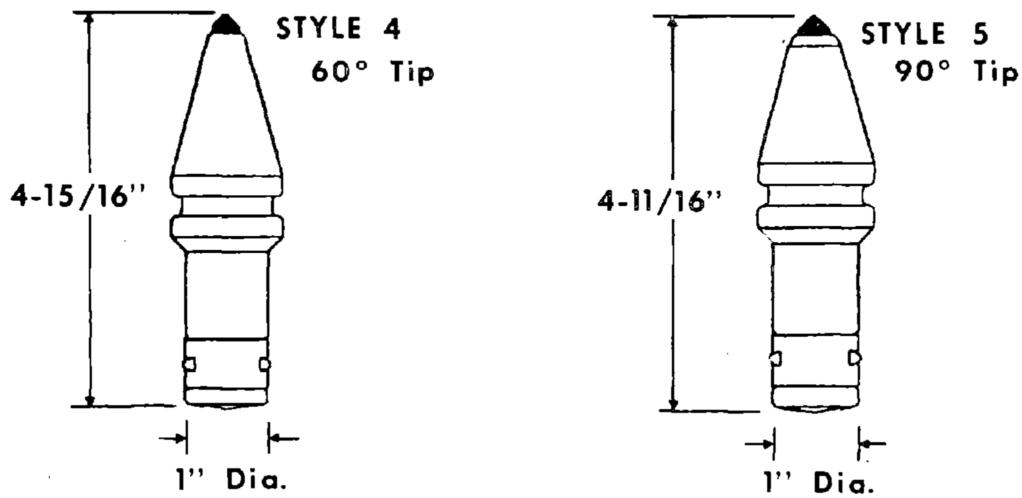

Figure 4. Point Attack Bits Used in Company M Cutting Tests

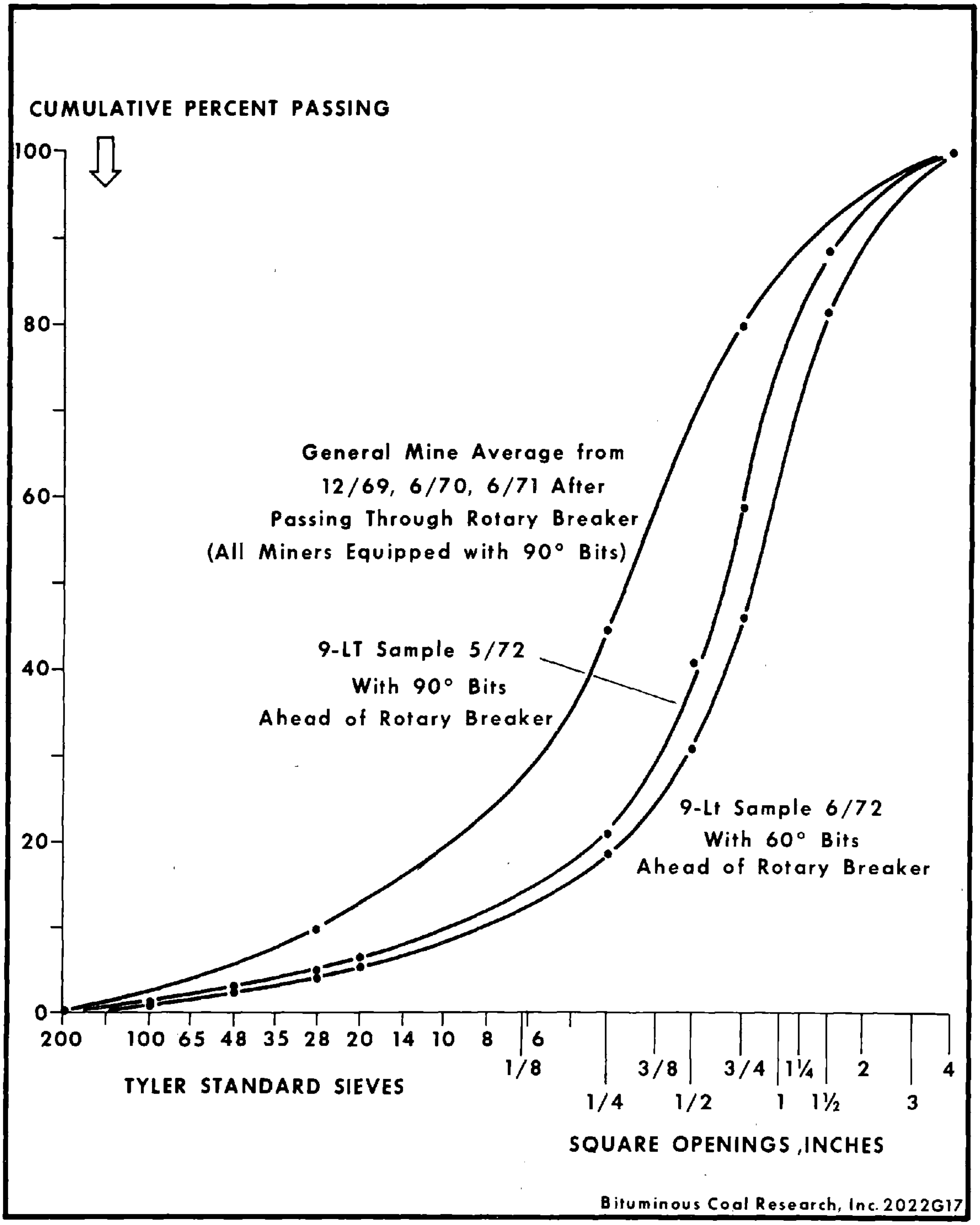

Figure 5. Screen Analysis Comparing Size Consist of Coal Samples from Company M Tests of 90° vs. 60° Point Attack Bits

curve, all continuous miners were equipped with 90 degree, Style 5 bits. The samples from the 9-LT section, used for the bit comparison study, were approximately 3-pound grab samples taken from every tenth shuttle car.

(b) From the standpoint of economics, the tests indicated that the 60 degree bits resulted in a lower cost per ton and reduced replacement requirements. (See Table 8.)

Based on these results it would appear that the 60 degree bit is superior for both dust control and operating economy.

(3) Correlation of Bit Type to Dust Concentration: Tests were conducted by Company R using two different bits, shown in Figure 6, to determine what effect bit design has on dust production. In this instance, the tests were run in adjacent headings and an attempt was made to control parameters such as ventilation, water sprays, and sampler location. Because of these controls, the results of this test are probably more reliable than those compiled from the Company Q data. However, many uncontrolled factors existed which could cause error and prevent definite conclusions from the data.

The results of this test, shown in Table 9, indicate that the smaller Style 2 bits produced less dust than the larger Style 7 bit. In addition, the Style 2 bit had the lower cost per ton, making it the better bit both from the standpoint of dust production and economics.

This test corroborates the results of the data submitted by Company Q, where the same Style 2 bit was compared to several different bits.

(4) Tests of Dust Conditions: A series of three tests was made by the Pennsylvania Department of Mines and Mineral Industries at a Pennsylvania mine to determine dust conditions in the mine relative to the Pennsylvania Bituminous Coal Mining Laws of September 1, 1961. The first two tests involved taking dust samples in the vicinity of the continuous miner, the jack setter on the intake side of the face, the jack setter on the exhaust side of the face, and the timber setter at the face area. Dust concentration was not correlated to bits but rather to ventilation and spray water volumes. The main differences between Test No. 1 and No. 2 were the increases in water pressure from 90 to 120 psi and in ventilation air from 10,000-12,000 cfm to 12,000-18,000 cfm.

The third test was made to determine changes in dust concentration due to use of a new type of cutting bit. The available reports do not specify the bit, but personnel from one of the mining machine companies involved in the tests indicated that the bits were changed from a Style 6 to a Style 2. As indicated in Table 10, the results of these tests are inconclusive. Dust concentrations with the new bit showed no trend. The jack setter, intake side, showed less dust; the jack setter, exhaust side, showed a slight increase; and the continuous miner showed a significant increase. The report on the third test made no statement on bits but recommended that more sprays be put on the miner, water pressure be increased, and ventilation be changed so the air would travel over the men to the return air course. Apparently, test observers felt the bits had no significant effect on the dust concentration.

From the text of the report it is apparent that no attempt was made to control test conditions; and, during the third test, data such as tonnage, water and air flow, and mining times were not recorded. Therefore, the results have no value for this bit survey.

TABLE 8. BIT BREAKAGE AND COST DATA FOR
60 DEGREE AND 90 DEGREE PLUMB BOB BIT TESTS
CONDUCTED BY COMPANY M

	90 Degree Bits	60 Degree Bits
No. of Bits Used	165	131
Tons Mined	3510	3267
Tons/Bit	21.3	24.9
Bit Cost/Ton, Dollars	0.067	0.055
Replacement Improvement, Percent		16.9
Cost Improvement, Percent		18.9

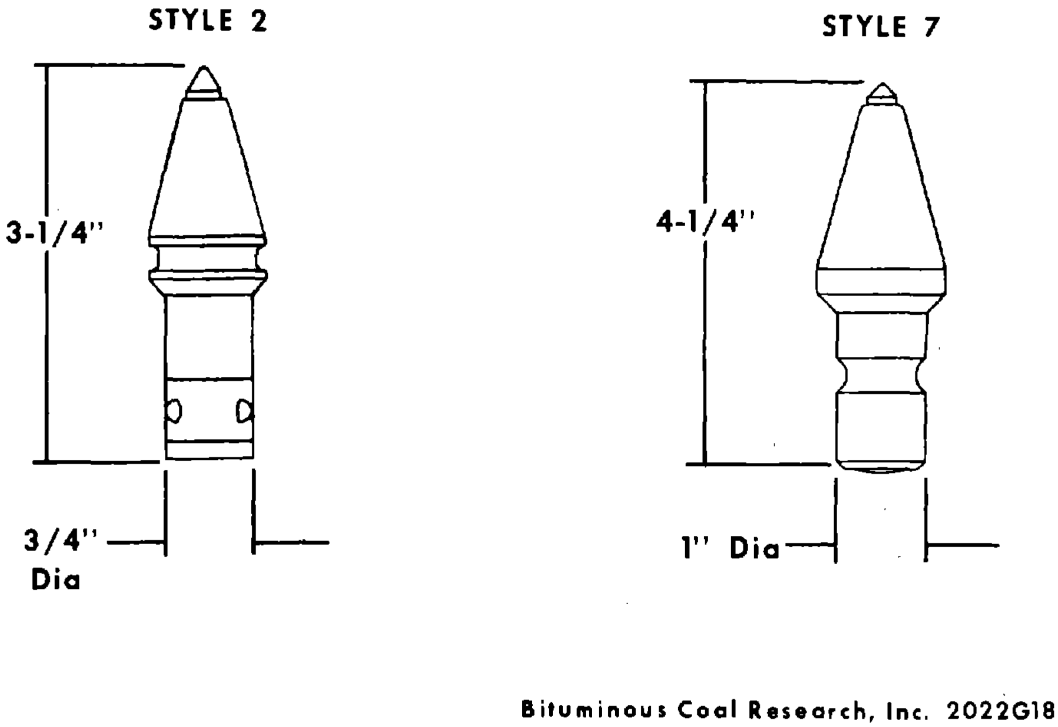

Figure 6. Point Attack Bits Used in Company R Dust Survey

TABLE 9. SUMMARY OF COMPANY R BIT COMPARISON TEST

	Style 7	Style 2
Bits Used from 10/1-12/15, No.	6500	4600
Clean Coal Mined, Tons	189,279	164,244
Percent of Total Clean Coal Mined	53.5	46.5
Percent of Total Bits Used	58.6	41.4
Unit Price of Bits, Dollars	1.08	0.93
Cost/Clean Ton, Dollars	0.037	0.026
Summary of Dust Survey		
Respirable Dust (mg-10μ)	20.69	7.21
Coal Mined, Tons	981	998.4
Mining Time, Min.	383.79	218
Respirable Dust, mg/Ton	0.0211	0.0072
Reduction of mg/Ton, Percent*		66
Respirable Dust, mg/Min.	0.054	0.033
Reduction of mg/Min., Percent		38.9
Float Dust (+10μ), mg	479.36	289.0
Coal Mined, Tons	981	1441.1
Mining Time, Min.	383.79	298.74
Float Dust, mg/Ton	0.5	0.2
Reduction of mg/Ton, Percent		60
Float Dust, mg/Min.	1.25	0.97
Reduction of mg/Min., Percent		22.4
Test Conditions		
Mining Machine	L.N. 26H	L.N. 26H
No. of Bits	104	108
Head Diameter	30"	30"
Head Speed	90 RPM	90 RPM
No. of Sprays	30	30
Sampler Types	AEC Cyclones & Unico Pumps	AEC Cyclones & Unico Pumps
Sampler Locations	Miner Intake & Return	Miner Intake & Return
Size Analysis Method	Impinger	Impinger

* Calculated as $\frac{(\text{mg/ton Style 7}) - (\text{mg/ton Style 2})}{(\text{mg/ton Style 7})}$

TABLE 10. COMPARISON OF DUST CONCENTRATIONS FOR VARIOUS JOB DESCRIPTIONS

Survey	No. 1	No. 2	No. 3
Miner Operator	44.04	15.12	29.89
Jack Setter - Intake Side	51.93	32.97	19.21
Jack Setter - Exhaust Side	84.79	25.80	33.96

Data given in million parts per cubic foot

(5) Bit Cost Surveys: The mining engineer at Mine No. 11 of Company E made several surveys designed primarily to study changes in bit costs resulting from changes in bit patterns and bit styles. The results, as reported by the mining engineer, did show some significant cost reductions; but, because of varying mining conditions during and between surveys, these cost reductions could not be specifically related to the changes in lacing patterns or bits. Therefore, the results can only be used to indicate possible trends as a result of the indicated changes.

Following are summaries of the cost surveys. The bits referred to are shown in Figure 7.

(a) Use of Style 14 Bits: This survey simply compared bit usage in a particualr mine section when using Style 14 from two different bit manufacturers. Results, as indicated in the summary below, show a much lower bit usage for the bit from Manufacturer B, but no analysis was made to determine the reason.

Bit Style	No. Used (Test Period)	No. of Shifts	Bits/Shift
Style 14, Mfg. A	3477 (Jan, 72)	51	68
Style 14, Mfg. B	1182 (May, 71)	66	18
	1033 (Dec, 71)	73	14

(b) Comparison of Style 1 and Style 3 Bits: For this survey a Lee Norse continuous miner was equipped with 34 Style 1 bits and 70 Style 3 bits at predetermined locations. The miner was put into operation to cut a boomhole in the roof, 18 ft wide by 32 ft long by 36 in. deep. Strata at this location was a sandy shale mixture interlaced with solid sandstone. After this operation, neither style of bit showed any degree of wear. The machine was then put into an area that required taking three to six in. of bottom to make sufficient height for efficient haulage. After a week's operation, the bit usage of the test machine was compared to the usage of two other Lee Norse miners being used in other sections. The results of this comparison are shown below.

Miner	Bit Consumption
Lee Norse Test Machine	540
Lee Norse Miner No. 1	190
Lee Norse Miner No. 2	169

Because the three miners were operated under different conditions and by different machine operators, it is impossible to make any valid comparison of the results. Based on observations made during the test, it was concluded that the Style 1 bits dull rapidly in coal and are not suitable for use on higher speed rotary head miners like the machine used in this test.

(c) Effect of Bit Lacing Pattern: Because of high bit costs, a survey was made to determine the effect of increasing the number of Style 2 bits on the head from 108 to 140. Based on 9-days' operation with 108 bits and 12-days' operation with 140 bits, the bit costs of the two lacing patterns were as follows:

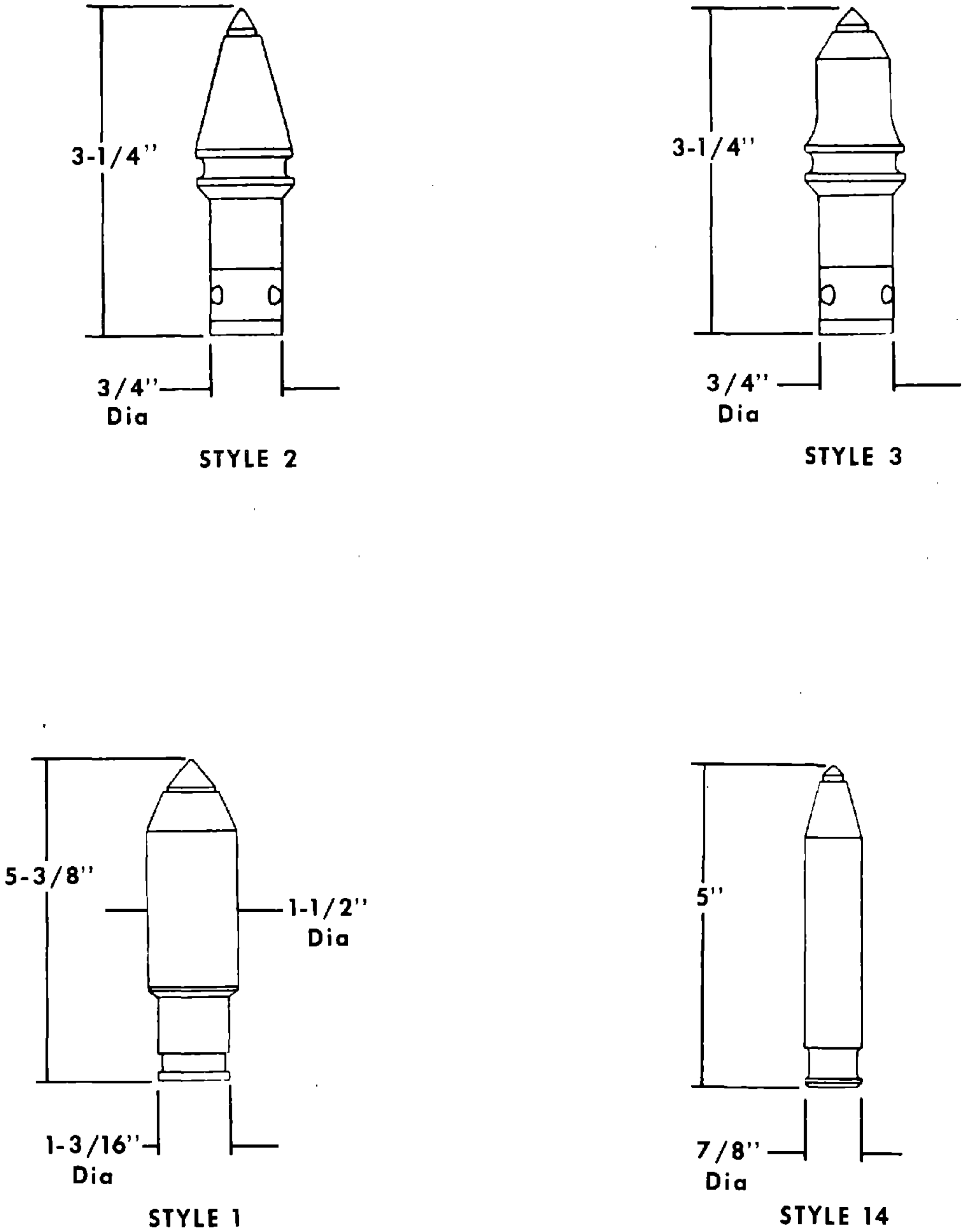

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Figure 7. Point Attack Bits Used in Company E Bit Studies

$$\text{Old lacing (108 bits) - } \frac{1115 \text{ bits x \$1.10/bit}}{1446 \text{ tons}} = \$.86/\text{ton}$$

$$\text{New lacing (140 bits) - } \frac{799 \text{ bits x \$1.10/bit}}{2232} = \$.39/\text{ton}$$

Although the bit cost was lower, the new pattern did not alleviate shank breakage or bits coming out of their assemblies.

Since the use of more bits decreases the load per bit during cutting, the bit wear would be reduced. Less frequent replacement is required; therefore, a lower bit cost per ton is achieved as in this test. However, the overall effect, as reported by other companies, is an increase in power requirements, smaller overall size consist, and more dust. As a result, the general trend in the industry is to use fewer bits.

(6) Comparison of All Steel and Carbide Tipped Bit Performance: A series of underground tests was conducted to compare the performance of boron coated all steel bits and carbide tipped bits. No data were collected except to note the number of bits used and general comments on bit performance. This information is summarized in Table 11.

The results indicate the boron coated all steel bits performed nearly as well as the carbide bits. The lack of data such as pictures of bits, progressive analysis of bit wear, description of cutting conditions, and comments on operator technique makes these results inconclusive.

A thorough evaluation of the all steel bit would require longer tests in several seams with better documentation of the results.

b. Tests Not Directly Related to Bit Design

(1) Effect of Miner Head Speed: Coal Company K conducted some tests to determine the effect of head speed on coal size. The results, presented in Table 12, indicate that a lower speed produces a larger size consist. This is in agreement with results presented in various sources in the literature. Although the dust concentration was not measured, personnel observing the test indicated that there appeared to be less visible dust and, therefore, probably less respirable dust.

(2) Effect of Lacing Pattern: Tests were conducted by Company CC to evaluate the effect of different lacing patterns on the operation of a Lee Norse CM32-2E miner. Two patterns, shown in Figure 8, consisted of:

(a) The regular discs with three rows of seven bits per row on each disc for a total of 21 bits on each disc and 84 bits on the head.

(b) A special "4-line zig-zag" pattern with four rows of seven bits per row on each disc with a secondary rig fitted with a single row of ten blocks welded to the outer edge of the primary discs, for a total of 132 bits.

TABLE 11. RESULTS OF PERFORMANCE TESTS BETWEEN CARBIDE TIPPED AND ALL STEEL BITS

Test	Carbide Tipped		All Steel		
No.	No. Used	No. Lost	No. Used	No. Lost	General Remarks
2	--	1 - tip ruptured	--	1 - broke	This test was continued for four shifts with boron coated steel tools showing considerably more wear than the carbide tools, possibly due to faster wear of the extreme point on the new bit. Tons mined during test - 416 in first shift.
1	49	0	35	0	This test continued for four shifts and showed: (a) Six steel bits were carburized and did not wear well, (b) The boron coated bits did perform well except for four bits which had poor wear patterns possibly due to ineffective sprays. (c) All the carbide tipped bits showed good wear patterns and performed well. Tons mined during test - not recorded.
3	27	1 - Broke one half inch from tip	15	0	This test was continued for four shifts and showed: (a) The boron coated all steel bits performed well and showed slightly more wear than the carbide bits. (b) The carbide tipped bits all performed well. Tons mined during test - 1250
4	48	9 - Broken carbide	21	0	This test was continued for five days and showed: (a) With the exception of the 9 broken bits all the carbide tipped bits performed well and exhibited good wear patterns. (b) All of the boron coated steel bits performed well and had good wear patterns with only slightly more wear than the carbide bits. Tons mined during test - 3000

TABLE 12. SIZE CONSIST VS HEAD SPEED

ROM Coal Sample Bypassing Silo
Taken July 11 and 12, 1972

Screen Size	Percent Weight	Cumulative Weight
+ 4	3.6	3.6
4 x 3	1.4	5.0
3 x 2	5.2	10.2
2 x 1	16.6	26.8
1 x 1/2	19.2	46.0
1/2 x 1/4	19.0	65.0
1/4 x 8m	13.8	78.8
8m x 16m	9.6	88.4
16m x 28m	6.0	94.4
- 28m	5.6	100.0

West Mogul Jig 1971 Performance Test
Raw Coal Screen Analysis

Screen Size	Percent Weight	Cumulative Weight
+ 1	20.8	20.8
1 x 1/4	42.3	63.1
1/4 x 28m	28.6	91.7
- 28m	8.3	100.0

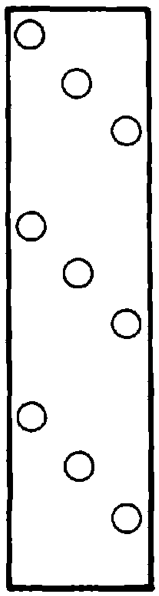
ROM Sampling Unit No. 6

ROM Sample No. 1, Head Speed 80 RPM
February 25, 1972

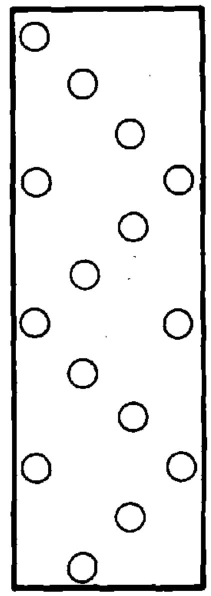
Screen Size	Percent Weight	Cumulative Weight
+ 4	1.8	1.8
4 x 3	1.9	3.7
3 x 2	5.5	9.2
2 x 1	21.3	30.5
1 x 1/2	18.8	49.3
1/2 x 1/4	18.3	67.6
1/4 x 8m	11.8	79.4
8m x 16m	7.3	86.7
16m x 28m	5.6	92.3
- 28m	7.7	100.0

ROM Sample No. 2, Head Speed 60 RPM
February 29, 1972

Screen Size	Percent Weight	Cumulative Weight
+ 4	6.7	6.7
4 x 3	2.4	9.1
3 x 2	5.6	14.7
2 x 1	20.5	35.2
1 x 1/2	19.2	54.4
1/2 x 1/4	17.4	71.8
1/4 x 8m	12.4	84.2
8m x 16m	5.1	89.3
16m x 28m	3.9	93.2
- 28m	6.8	100.0



Standard Lacing Pattern



4-Line Zig Zag Lacing Pattern

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Figure 8. Types of Lacing Patterns Used in Company CC Tests

The results of these tests, presented in Table 13, indicated no significant difference in bit performance. However, the tests were of short duration and cutting conditions were rated "severe" for one pattern and "average" for the other, which limits the reliability or usefulness of the results.

(3) Effect of Wetting Agents: Tests were conducted by Company K to determine the effect of anionic and nonionic wetting agents in spray water. Anionic wetting agents impart a negative charge to the spray water droplets, and cause the droplets to attract the respirable dust, as well as to produce better wetting of the coal particle surface. The nonionic agents do not impart any charge to the water but act strictly as wetting agents. Results of these tests, presented in Figure 9, indicate that anionic agents produce the better reduction of dust concentration.

4. Coal Industry Recommendations for Future Bit Development: The coal operators had no specific recommendations for new bit developments. They felt that coal companies are in the business of mining coal, and that bit design is the responsibility of the bit manufacturers. Some operators said they had not taken time to give any thought to bit design, while others felt they were not qualified in this area. Most of the operators agreed, however, that many bit modifications originate at the face and represent an effort to solve a particular problem.

Many of the companies using the point attack bit felt it is close to the ultimate tool and that any further changes in the basic design would produce only marginal improvements in dust reduction, which would not warrant the expense involved. Other users felt there is room for improvement but had no suggestions on what they should be.

Based on the opinions expressed by the operators, it appears the coal industry feels little obligation or desire to financially support bit development work. However, some of the operators expressed a willingness to cooperate with bit and mining machine manufacturers to develop new tools by conducting bit performance tests in their mines. If there is any hope of improved dust control through bit design, it will only be achieved through this type of cooperation. Although the bit can be "engineered" by the manufacturer, extensive underground testing is required to prove the value of a bit. A valuable contribution to bit development could be made by the coal operators by providing the required underground test facilities.

5. Recommendations for Dust Control Methods: Because of their conviction that bit design is not significant in dust control, operators have directed much effort, as indicated by the tests outlined in Section III, to the development and use of auxiliary equipment to control dust. The methods generally considered important include:

a. Use of increased ventilation air properly directed over the working area.

b. Use of auxiliary fans and duct to exhaust air from the working face.

c. Use of machine-mounted scrubbers.

TABLE 13. RESULTS OF TESTS ON LACING PATTERNS CONDUCTED BY COMPANY CC

Part I: Summary of Cutter Bit Data

Item	Phase I (Regular Discs)	Phase II (Special Discs)
Diameter of Cutter Disc	32"	32"
Number of Cutter Discs	4	4
No. Bits/Inner Disc	21	28
No. Bits/Outer Disc	21	38
Total Number Bits/Set	84	132
Type Bit Used (100% New)	Style No. 12	Style No. 12
Number Bits Dulled/Shift	134	128
Number Tips Broken/Shift	36	11
Number Shanks Broken/Shift	0	0
Number Bits Lost/Shift	0	0
Total Bits Replaced/Shift	170	139
Bits Dulled/100 Net Tons	62.04	43.84
Bits Destroyed/100 Net Tons	16.67	3.77
Cutting Condition	Severe	Average

Part II: Summary of Mining Rates

Maximum Cutter Head Width, Feet	8 - 10/12	9 - 1/6
Frontal Area/Sump, Sq. Ft.	23.56	24.44
Average Rip Height, Inches	14	14
Average Sump Rate, Mins/Inch	.0299	.0307
Average Rip Rate, Mins/Inch	.0236	.0235

Part III: Results of Screen Analyses

Partical Size Range	Phase I Percent Weight	Phase I Percent Ash	Phase I Cum. Percent Weight	Phase I Cum. Percent Ash	Phase II Percent Weight	Phase II Percent Ash	Phase II Cum. Percent Weight	Phase II Cum. Percent Ash
Plus 1/4 Inch	64.15	7.68	64.15	7.68	65.75	8.40	65.75	8.40
1/4 Inch x 28M	29.34	6.96	93.49	7.45	26.89	7.35	92.64	8.10
28M x 48M	2.25	7.66	95.74	7.46	2.79	7.26	95.43	8.07
48M x 100M	1.29	7.93	97.03	7.47	1.65	7.37	97.08	8.06
100M x 200M	0.83	11.54	97.86	7.50	0.88	8.66	97.96	8.06
200M x 325M	0.44	13.15	98.30	7.52	0.47	11.18	98.43	8.08
Minus 325M	1.70	28.75	100.00	7.89	1.57	24.78	100.00	8.43

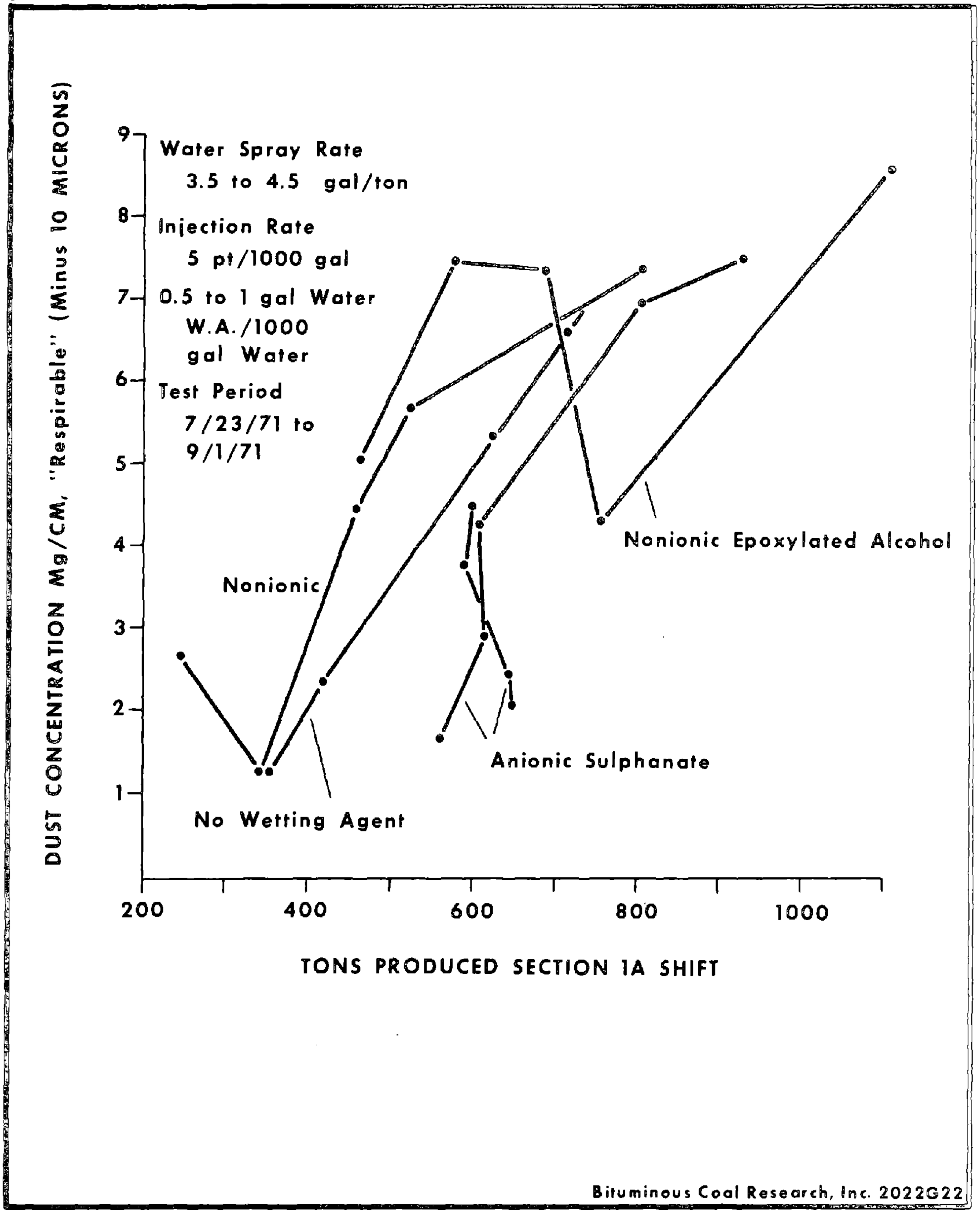

Figure 9. Relationship of Dust Concentration to Tons Produced Using Various Wetting Agents

d. Use of wetting or foaming agents in the water sprays.

e. Development of improved spray patterns.

f. Determination of appropriate lacing patterns and head speeds for mining conditions.

g. Use of water infusion, particularly in long wall mining applications.

However, as the dust limits become tighter, use of an optimum bit design in conjunction with other control methods will be necessary to stay in compliance and maintain production. It is, therefore, imperative that research and development in bit technology be continued to determine an optimum design.

6. Analysis of Data Obtained: Data were obtained both in the form of test results and from general operating statistics. Since the test results are presented as part of the test summaries, this section will deal only with the analysis of the statistical data.

a. Bit Usage as a Function of the Grindability Index: None of the operators interviewed indicated that, when selecting bits, they gave any consideration to measured physical properties of the coal. However, an analysis of the bit usage data, presented in Tables 2 and 3, indicates a possible correlation between bit design and grindability or hardness. This analysis, presented in Figure 10, shows that the smaller plumb bob bits, Styles 2 and 3, are used in softer coals having a higher grindability index while the heavier bits, Styles 4 through 8, are used in the harder coals having a lower grindability index. The data presented were apparently developed as the result of trial and error usage of different bits to determine the most economical design for a particular mine's conditions. To determine the validity of this correlation, a larger amount of data would have to be analyzed.

The significance of this relationship, if valid, is that:

(1) The grindability index could be a limiting factor in the application of certain bit designs, particularly in mines with a low index. Therefore, a design that produces less dust might be limited in application because of the grindability factor.

(2) The grindability index could control the minimization of bit costs per ton. For instance, hard coals with a very low grindability index would require a more massive, more expensive bit.

(3) The varying grindability index of various mines could indicate a need for the development of special application bits such as the all steel, spiral ribbed, and coated bits.

b. Bit Selection as a Function of Bit Cost Pér Ton: Bit cost per ton was correlated with bit style and grindability, as shown in Figure 11. No consistant correlation exists, which probably reflects the lack of adequate cost control systems to isolate bit costs as well as the great variation in mining conditions.

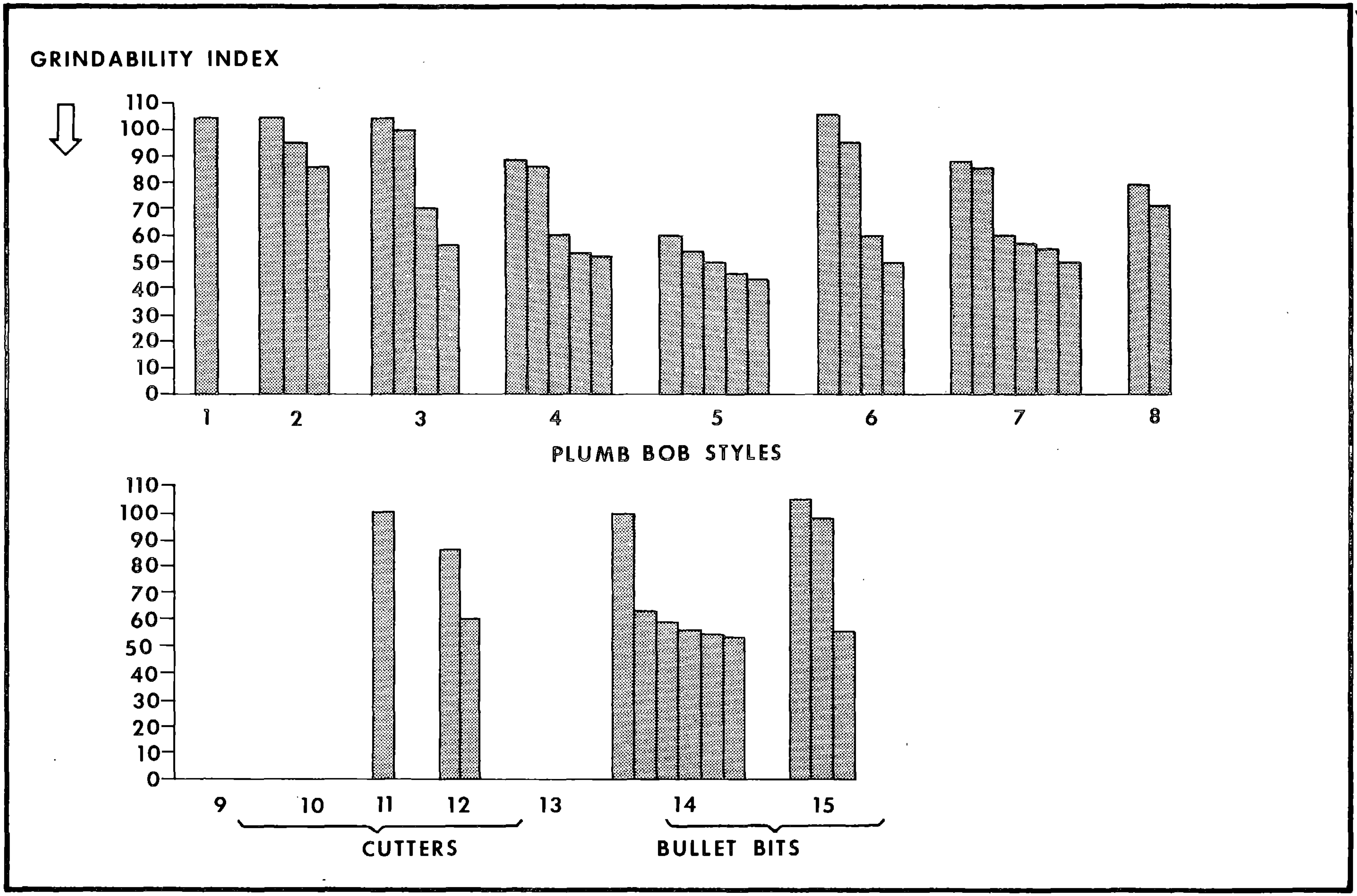

Figure 10. Bit Usage as a Function of Grindability Index

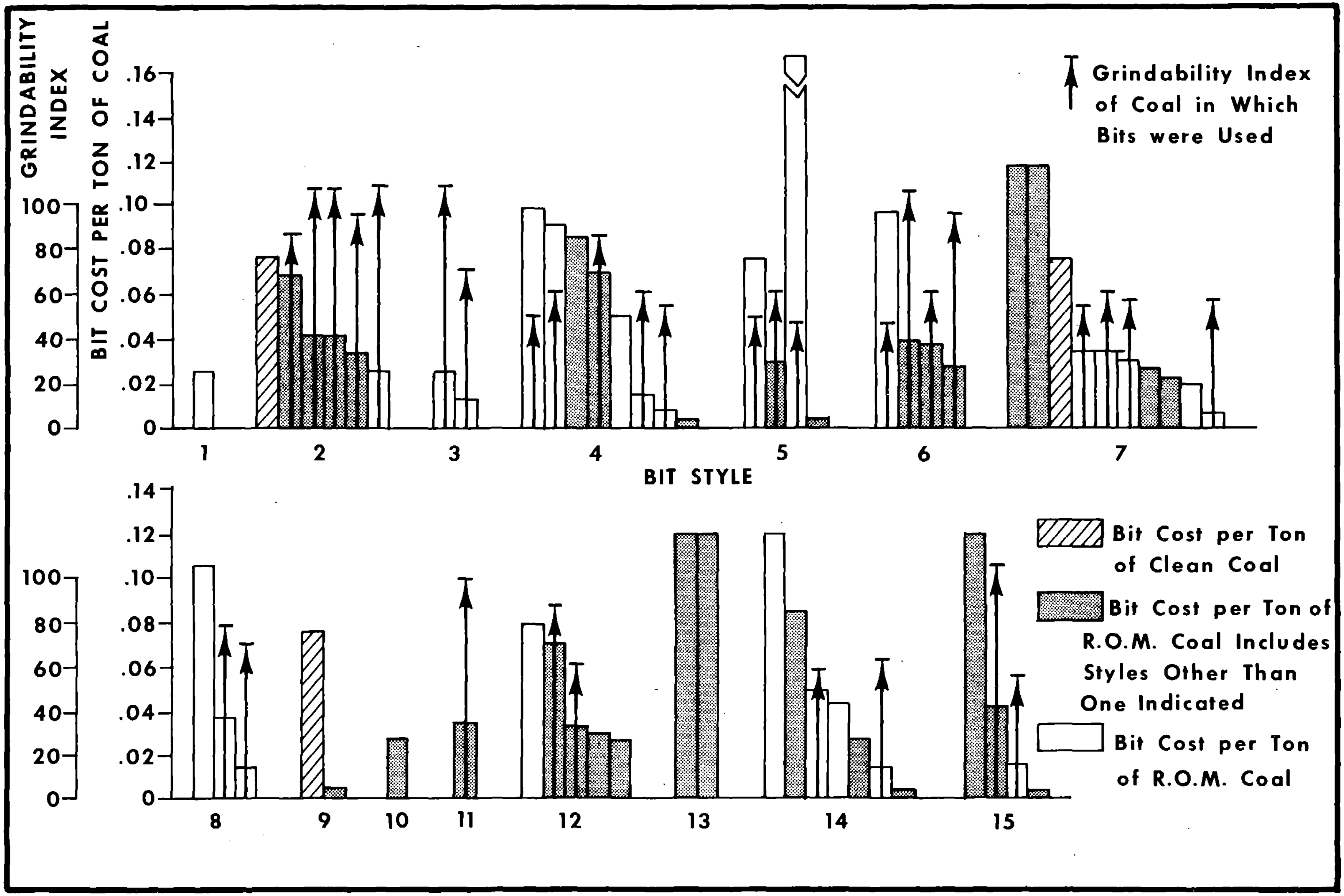

Figure 11. Bit Usage as a Function of Bit Cost per Ton and Grindability

c. Bit Usage as a Function of Initial Bit Cost: Since most operators indicated that initial bit cost was a factor in selecting bits, the analyses shown in Figure 12 was made to determine the importance of the unit price factor. The number of each style of bit used on the continuous miners was compared with the average unit price paid by the mining companies. The results indicate that the most popular bit, Style 4, is not the cheapest and other factors such as cost per ton, therefore, are more important. This shows that the operators generally realize that bit economics is a function of overall cost and performance rather than initial cost alone. It is significant since it indicates their willingness to pay more for a bit if it does a good job.

B. Bit Manufacturers

As in any industry, acknowledged "leaders" among the bit manufacturers carry out the development of new designs and/or materials. The other manufacturers utilize these developments and serve as "suppliers" to the coal industry, basing their existence primarily on being able to sell bits at or below their competitors' prices. As a result, there is practically no difference in the bit designs available from the different manufacturers. The status of each company depends, to a great extent, on such factors as development of an aggressive sales program, refinement of manufacturing processes to give maximum quality at minimum cost, and continued development of new bits. A discussion of these factors is presented in this section.

1. Comparison of Bit Manufacturers' Sales Programs and Coal Operators Buyers' Specifications: To determine the factors that bit manufacturers and coal companies considered important in bit selection, inquiries were made concerning the relationship between sales programs of the manufacturers and the purchasing specifications of the buyers.

a. Sales Program: Following is a summary of the factors, listed in order of importance, stressed by the bit manufacturers in their sales programs.

(1) Performance - Includes service life of bit, bit cost per ton, and maintenance costs directly associated with bits.

(2) Service - This includes prompt delivery plus availability of manufacturer's staff to solve a mine's particular problems.

(3) Initial cost - The unit cost of bits.

In no case was dust abatement listed as a factor used in any sales program; however, manufacturers will attempt, through trial and error with different bits, to reduce dust levels.

b. Buyers' Specifications: Following is a list of the factors, in the order of their importance, which the mine operators consider in the selection of bits. The factors are defined as in item a, Sales Program, unless noted otherwise.

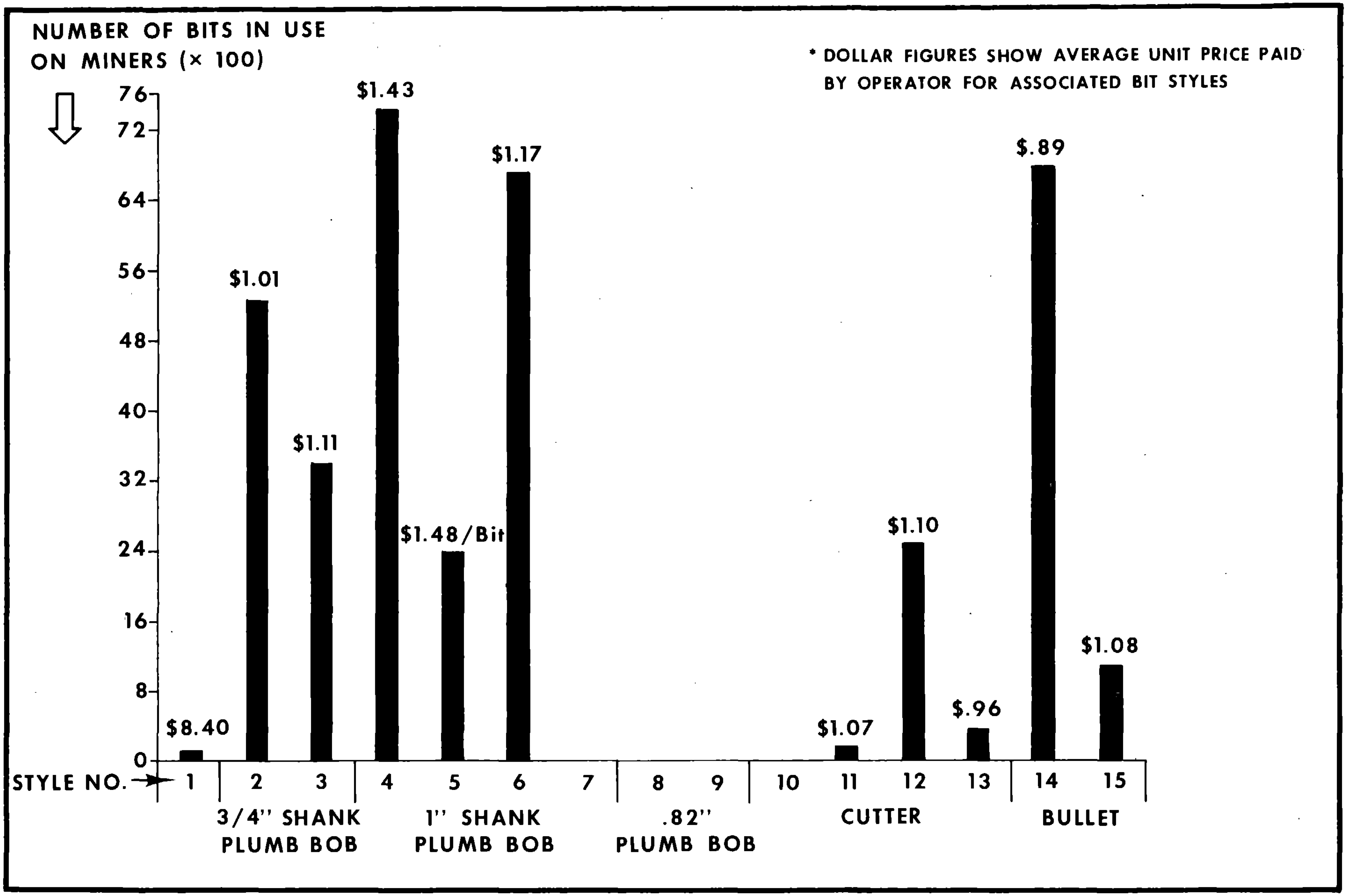

Figure 12. Bit Usage as a Function of Unit Price for Bits

(1) Initial cost.

(2) Performance.

(3) Dust - Only in recent years has dust abatement become a factor in buyers' specifications.

(4) Service.

2. <u>Manufacturing Processes</u>: All of the bit manufacturers interviewed use the same basic manufacturing processes. Many would not divulge the heat treatment used or the resulting hardness profiles of the bits. Generally, the manufacturing process consists of:

a. The rectangular shank cutter bit is always forged; the bullet-type bit is made from bar stock on an automatic screw machine; and the plumb bob type is either forged or made on an automatic screw machine, depending on the size and the manufacturer.

b. Some type of temper, quench, and draw heat-treating cycle is used by all manufacturers, the major variation being the procedure for the insertion of the carbide tip. The three heat-treating cycles commonly used in the industry are:

(1) Shank and carbide tip brazed and heat-treated as a unit.

(2) Shank is heat-treated without the tip. The tip is then brazed to shank. The brazing acts as a draw or tempering cycle resulting in a soft steel area at the tip.

(3) Same as (2), except the tip is then quenched. This hardens the area at the tip, but results in a soft line or area at the depth of heat penetration.

c. Further details, such as hardness profiles, must be modified to suit application and, therefore, no general statements can be made covering all bits.

None of the companies indicated that they had any major manufacturing problems but rather problems resulting from bit application. For example, fracturing or loss of the carbide tip results from the application of a standard bit to mining conditions for which it was not designed. This is corrected by revising the grade of carbide or use of a different style bit.

A problem present in any manufacturing process is maintaining quality control during production. Replacement of defective bits will correct the problem for the mining companies but may require modifications to control procedures used in the plant. This happens infrequently; and, although a nuisance, is not considered a major problem.

3. <u>Development of New Bit Designs</u>: Three basic types of bits are presently being manufactured, including diamond or duplex, rectangular shank

cutter*, and point attack bits. The point attack group is made up of conical shaped plumb bob and straight shank bullet bits.

The diamond bit is used only in cutting machines, and, for practical purposes, is obsolete. Manufactured by only two of the companies interviewed, it is an all steel throw away bit with diamond shaped cross section (Appendix F, Figure F-14, bits 1-11, 1-29, 1-2, and 1-6).

The rectangular shank cutter bit is being phased out for use in cutting heads of continuous miners, and use is generally limited to conventional mining cutter machines, borers, and trim chains on continuous miners. These bits are manufactured by all except one of the companies interviewed. That company indicated they do not plan to manufacture this type bit.

The point attack bit is the most popular type and the trend is to increase usage, particularly of the conical plumb bob bits. One company did not manufacture the bullet type; all others interviewed manufacture both types of point attack bits.

Illustrations of the types of bits produced by each manufacturer, along with unit prices, are shown in Appendixes E and F.

The basic reason for development of new or modified bit designs is to maintain or improve the bit manufacturer's economic position in the industry. The direction and extent of these development programs is dictated by one or more of the following:

a. Requirements of a customer to solve a specific problem.

b. Efforts to develop new bits in anticipation of industry needs.

c. Efforts to improve the economics of the mining process by increasing the productive life of the bit.

d. A desire to improve the economics of producing bits.

e. The necessity of staying abreast of competitors' developments.

A major consideration in development of new bits, or modification of existing bits, is that the tool must be produced to sell at a competitive price with a reasonable profit. In addition, the design must answer an industry need without requiring major changes to existing equipment. For example, shank modifications are kept to a minimum to insure the interchangeability of the old and new bits in the same block.

None of the manufacturers indicated that abatement of respirable dust is a factor in the development of a new bit, but is considered a side effect which is determined in field testing.

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* The term rectangular shank cutter bit refers to the "Rap-Lok" type cutter bit. The interviews indicated that the cutter bit which is held by a set screw is presently obsolete.

The consensus of the manufacturers is that determination of the mechanical properties of a bit is basically a process of trial and error involving numerous field tests to determine what modifications are necessary for the bit to successfully perform under everyday mining conditions. Among the larger manufacturers, there is a trend to employ fairly sophisticated techniques such as photoelasticity, strain gages, and stress analysis in designing new bits.

Generally, all manufacturers agreed that their initial selection of materials and metallurgical treatment is based on an engineering analysis which is modified, as required, after underground testing.

The highly competitive nature of the bit industry has undoubtedly held prices down and resulted in a favorable economic situation for the coal industry. In the overall picture, however, this market condition has probably hurt both the coal and bit industries because:

a. The bit manufacturers have not been able to support much research into fundamental cutting technology and the development of new bit designs.

b. The mining companies are reluctant to pay higher unit prices for new bit designs when relatively low cost bits will do the job. Therefore, it is economically unfeasible to develop new bit designs for which there will be little or no market.

c. The bit companies have been forced to concentrate their development efforts on the immediate "wants" of the mines and not on the long range "needs" such as a bit which produces less dust.

In view of the developments that have taken place in most engineering disciplines, it is difficult to believe that in this "space age," with its new materials and technologies, mining methods have changed so little in the past 20 years. The new mine health and safety standards and an increased demand for coal due to the energy crisis should hopefully provide the impetus for increased research in mining technology. However, until the manufacturing and mining industries agreee to conduct a joint effort of research and development, it appears this stagnation will continue.

4. Bit Manufacturers' Evaluation of Bits and Bit Performance: The assessment of bit performance from the manufacturers' point of view is shown in Table 14. The items in this table include all opinions expressed by those interviewed and indicate that in the bit industry, as in the coal industry, disagreement exists concerning the relative merits of the different types of bits.

Bit manufacturers disagree as to how various factors affect bit performance. The majority believe most of the bits do rotate during their productive life. Some of the causes given for rotation are: the bit striking the solid coal face, the broken coal falling past the bit, and the vibrations of the machine. Water sprays are felt to aid rotation by washing dirt out of the block and/or by the lubricating effect of the fine coal slurry.

Bit manufacturers feel that operator techniques can make a bit look good or bad and how the operator uses the bit is often a function of his attitude

TABLE 14. COMPARISON OF BIT TYPES BASED ON BIT MANUFACTURERS' COMMENTS

I. Diamond Bit Compared to Rectangular Shank Cutter Bit

Advantages	Disadvantages
1. Ideal from standpoint of dust and cutting ability due to the large clearance angles that reduce rubbing.	1. Short life, cannot be resharpened.
2. Each bit has two cutting points.	2. Both types of bits have high handling costs but the diamond requires more labor and down time to change bits.
3. Less expensive to produce.	3. Difficult to set and maintain proper gauge height.
4. Uses less power.	
5. Produces very little visible dust.	

II. Rectangular Shank Cutter Bit Compared to Point Attack Bits

Advantages	Disadvantages
1. Produces more uniform coal size and cleaner cutting.	1. It is not self sharpening and requires more rehandling.
2. Produces less drag in some applications such as cutter chains.	2. Will not tolerate any misalignment exceeding the clearances.
3. May produce less dust. (1)	3. Produces more dust.
4. Can be resharpened without losing metallurgical qualities of steel.	4. Gives lower production.
5. Because of more frequent replacement and resharpening procedures, bits are generally sharper.	5. Requires more labor to replace.
6. Costs less to produce. (1)	6. Requires closer inspection, more maintenance and more frequent replacement to attain optimum bit cost and production.

(1) Given as advantage of both types by different people.

TABLE 14. COMPARISON OF BIT TYPES BASED ON BIT MANUFACTURERS' COMMENTS (Continued)

Advantages	Disadvantages
	7. Higher cost, both initial and overall cost per ton.
	8. Sharpening shortens bit and results in uneven gauge lengths on head.
	9. Carbide tip is subject to some bending stress rather than pure compressive stress as in point attack.
	10. The undercuts and stress risers resulting from the bit design and the non-axial loading reduce the stress which can be applied.
III. Conical Plumb Bob Bits Compared to Bullet Bits	
1. Less susceptable to bending without breaking and mushrooming of end which make removal difficult.	1. More expensive to produce.
2. Heat treating is less critical.	2. Is less free to rotate due to holes in the shank which can retain dirt.

(1) Given as advantage of both types by different people.

toward a particular color of bit, that is, the manufacturer's color code, rather than the design.

In general, bit manufacturers feel that present bit designs are adequate and there are no major problems with these designs. Most of the problems can be attributed to:

a. A lack of maintenance, particularly the prompt replacement of broken, worn, or dull bits.

b. Misapplication of a given design on a mining machine.

c. Metallurgical or mechanical problems arising from certain mining conditions peculiar to a particular mine or seam.

Some of the manufacturers indicated that bit lacing patterns and head speed are important factors in determining bit performance. However, there is disagreement as to who is responsible for the actual development of patterns--the machine manufacturer, the mining companies, or a combination of these.

The statement that present bit designs are "adequate" would indicate complacency on the part of the bit manufacturers toward developing new bits. However, this attitude actually reflects the competitive nature of the bit industry and a lack of pressure from the coal industry to develop new bits.

5. Tests Conducted by Bit Manufacturers: Only limited test data were collected from bit manufacturers because they have not been conducting any formal testing programs. Their information on bit performance is obtained through feedback from the coal companies and observations by the manufacturers' field personnel. The available information included data on an extensive research program conducted jointly by a coal company and a bit manufacturer, and some comments on the performance of an all steel boron coated bit and a plumb bob with spiral ribs. Unfortunately the tests on the two bits were not substantiated by data.

Most of the performance tests conducted by the bit companies are part of their sales promotion effort. The test procedure consists of supplying a small quantity of bits to the mining company to be compared on a cost-per-ton basis to the bits then in use. All the bit companies interviewed in this survey have cooperated in this type of test with mines but, with a few exceptions, they did not have any data or reports available for use in this survey.

Generally they felt that collection of performance data is a function of the mining companies, and indicated that such data would be released by bit companies in a form suitable only for sales promotion use.

This lack of test data reflects several factors:

a. The companies' attitude that the present bits are adequate and require a minimum of testing to match seam conditions to a particular bit.

b. Because of the low profit margin, they cannot afford extensive testing and research programs.

c. There is a lack of any new developments which would require extensive testing.

Once again this is an indication of the lack of pressure or incentive for the bit manufacturers to engage in research and development of new bit designs.

A brief summary of the test information received follows.

a. Laboratory Investigation of Mining Tools: This test program was initiated to investigate the effect of changes in the tip configuration of cutter tools illustrated in Figure 13.

It was a cooperative project between Coal Company A and Bit Manufacturing Company C. The coal company supplied impurities and coal specimens, and the bit manufacturing company provided test tools, laboratory equipment, and manpower.

It was concluded, based on data derived from the laboratory testing program, that a design incorporating front relief angle [1] of approximately 10 degrees combined with a top rake angle [2] positioned in a negative manner at approximately 10 degrees should provide a more efficient cutting tool.

It was further concluded that higher speeds, approximately 600 to 700 surface feet per minute, are desirable for machining coal but that speed should be reduced to approximately 200 to 300 surface feet per minute when impurities are encountered. However, the feed rate or tool advance per revolution should be maintained as high as cutting conditions will permit.

The data and results of this test were not considered final but were to be used to point the direction for further study and investigation to effect the most desirable designs.

The cutting characteristics of the various tool geometries selected were investigated by the measurement of forces created while machining coal and coal impurities in a lathe.

The tangential force, or vertical force, is the result of the rotating work material being impacted upon the top surface or rake angle of the tools. The horizontal forces were the result of pressures created by the feed.

These forces and cutting action were constantly observed and measured during operation. The condition of tools after each test was also noted.

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[1] Relief angle is the angle between the edge of the tip and a line perpendicular to the center line of the tool. See Figure 13.

[2] Rake angle is the acute angle between the face of the tip and a line parallel to the center line of the tool. The angle is positive if the face slopes downward from the point toward the shank; the angle is negative if the face slopes upward from the point toward the shank. See Figure 13.

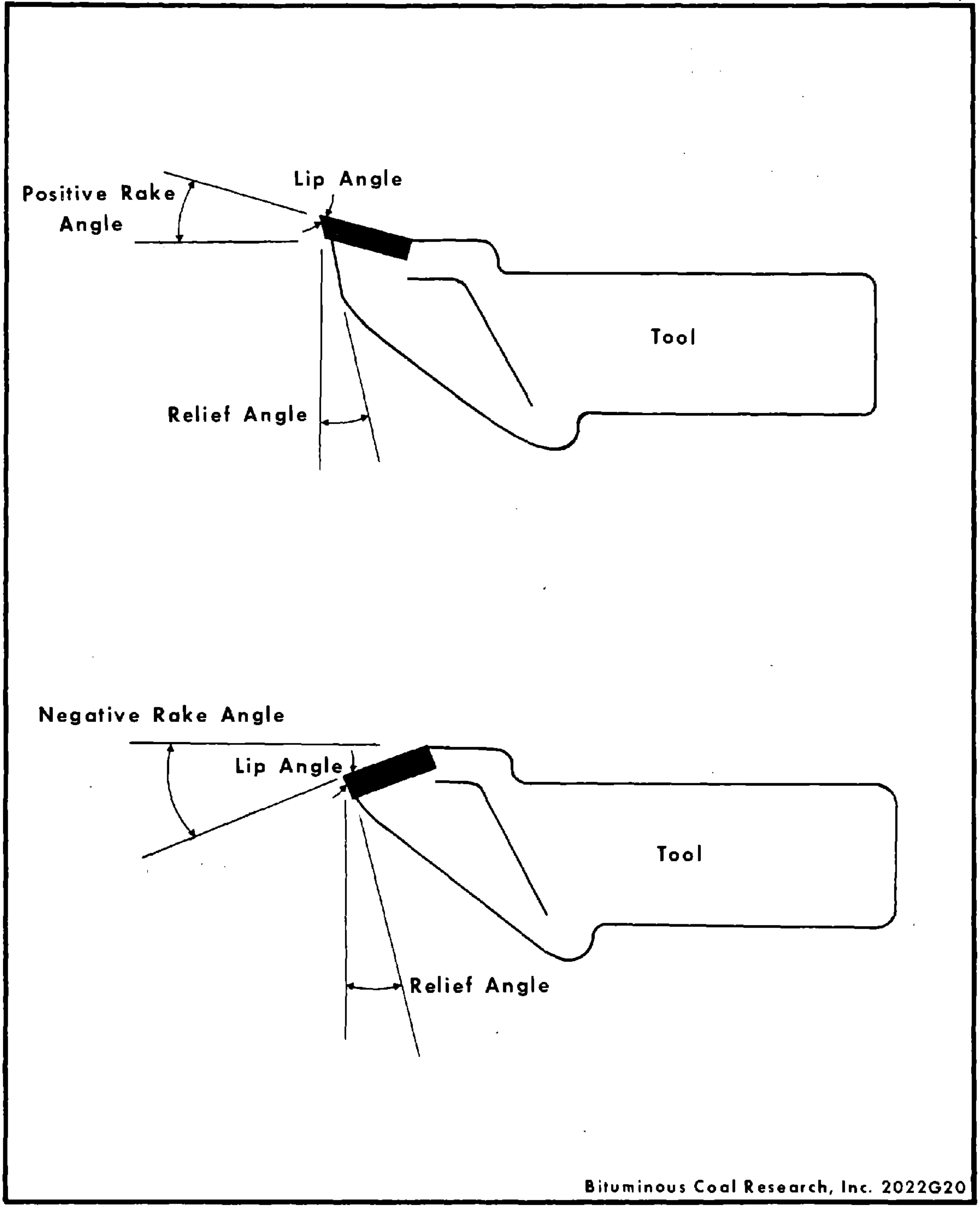

Figure 13. Types of Tools and Tip Configuration Parameters Investigated in Tool Improvement Studies

Cutting characteristics were recorded by high-speed cameras at 1000 frames per second, which is approximately 40 times normal speed, for more intensive study.

b. A Field Investigation of Mining Tools: Coal Company A and Bit Manufacturing Company C embarked on a joint development program in early 1956 to improve the design and application of coal cutting tools and mining equipment to reduce cutting costs and increase production.

This program, divided into two phases, was initiated by first procuring fundamental information regarding cutting characteristics of various cutter bit designs. The bit manufacturing company was furnished coal and iron pyrite impurity samples by the coal company. A tool dynamometer was used to measure forces involved while machining these samples. The tests were extensive, covering a wide range of relief angles, rake angles, cutting feeds[1], and cutting speeds. The results of the laboratory portion of the program indicated the following:

(1) A more efficient coal cutting tool would incorporate a 10 degree relief angle and a negative rake angle.

(2) Cutting speeds should be maintained as high as possible when machining coal but reduced upon encountering impurities.

(3) Cutting feeds should be maintained as high as cutting conditions permit.

This laboratory work supplied basic knowledge of the forces involved in cutting coal and coal impurities. Utilizing the data, successful field tests were completed. Field tests involved the design, fabrication, and testing of over 2,300 tools similar to those illustrated in Figure 13. Tools were tested on a universal cutting machine and a ripper head continuous miner under daily operating conditions. Each group of tools was continually observed while in production.

This project resulted in data confirming a new basic concept for cutter bit tip design, and theoretically would reduce cutting costs and increase production throughout the coal industry. Such a tool incorporated

(1) A rake angle between +5 degrees and -10 degrees.

(2) A relief angle of 10 degrees.

The advantages of the suggested design are derived from a strong cutting edge provided by an increased lip angle[2]. This stronger carbide sec-

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[1] Feed is the rate of bit penetration into the material being cut.

[2] Lip angle is the included cutting edge angle between the rake and relief angles.

tion will reduce tip wear, chipping, and tip breakage, resulting in increased production and decreased cutting costs.

Increased production is the result of:

(1) Increasing overall production time by shorter cutting or mining cycle[1] time.

(2) Reducing the number of necessary tool changes.

Decreased cutting costs are effected by:

(1) Reduction of machine down-time.

(2) Minimizing bit breakage.

(3) Moderation of dust production, which will alleviate employee discomfort and increase working efficiency.

(4) Reducing percentage of fine mesh coal sizes, which are expensive to clean.

c. Test of New Spiral Bit: Coal Company L tested the new point attack bit with spiral ribs, Figure 14, to determine the effect of the ribs. Although no data were available, representatives from Coal Company L reported that the condition of used bits indicated that 100 percent of the ribbed bits rotated during the test compared to 50 to 60 percent of the standard bits. This is substantiated by Figure 15 which compares a typical used bit from the test with an unused bit and shows an excellent wear pattern, which indicates the bit was rotating. Unfortunately, information on the length of service or tons mined with this bit is not available.

Personnel of a major bit manufacturing company present during these tests had the following comments:

(1) The bit had positive rotation, maintained its point, and showed excellent wear patterns.

(2) It did not significantly increase production.

(3) Due to the number and positioning of the spirals, the bit, as used in this test, cannot be forged, which results in high fabrication costs.

(4) In applications where approximately 80 percent or more of the standard plumb bob bits rotate during their life, the added cost of the spiral ribbed bit would not be justified.

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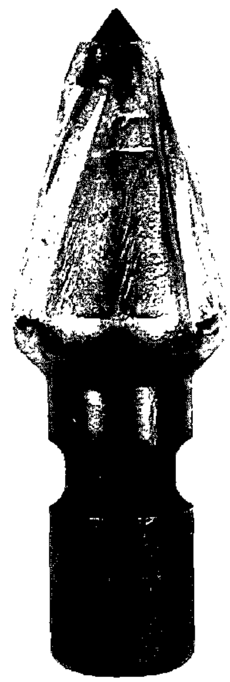
[1] A cycle of a continuous miner includes sumping into the coal face and then shearing down.



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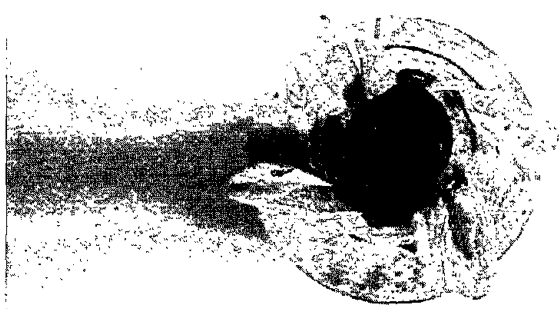

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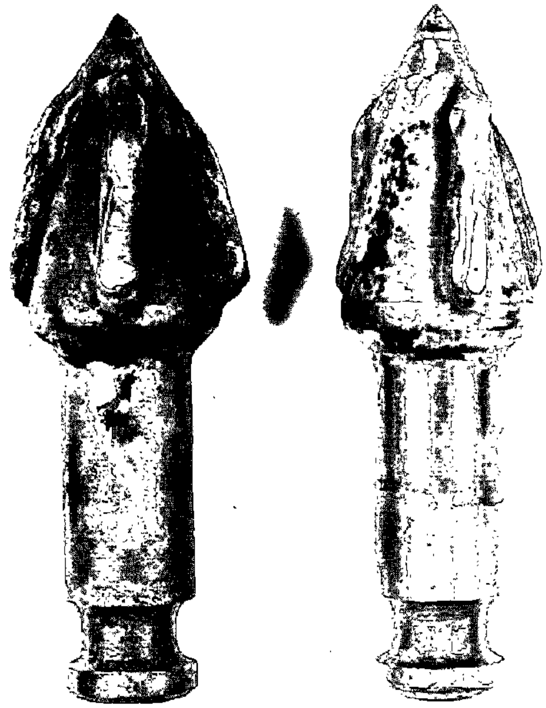
Figure 14. A Proposed Commercial Version of the Spiral Rib Bit



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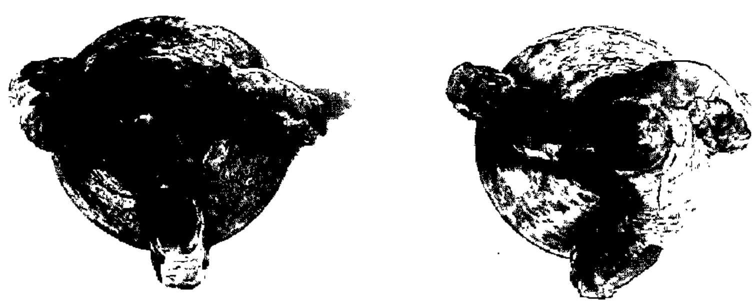

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Figure 15. Comparison of a Used and an Unused Bit with Spiral Ridges

There were no data available to indicate the effect on dust production. However, if maintaining a sharp point is critical to reducing dust, this bit may show promise.

d. Boron Coated All Steel Bit: A new all steel boron coated bit has been introduced by one of the bit manufacturers and has been tested on a very limited basis in several mines.* The results of these tests have not been documented so no specific data are available. However, during the interview the manufacturer claimed the following advantages for the all steel boron coated bit over the regular carbide-tipped point attack bit:

(1) Since there is no carbide tip, the problem of metal eroding away from around the carbide and exposing it to breakage or loss is eliminated.

(2) Less chance of operating with a blunt tip since there is no carbide tip to break off.

(3) Greater penetration.

(4) Produces larger size coal.

(5) Less visible dust produced.

(6) Increased production.

(7) Longer life.

(8) Lower initial cost.

The single disadvantage mentioned is that the new bit is very pointed and poses a safety problem, primarily in handling during installation.

The results of the limited testing to date generally showed:

(1) The boron coated bits showed more wear than the carbide-tipped bits.

(2) The wear patterns were good.

(3) Breakage of the bit was minimal and apparently no greater than that of the carbide bits.

Because of short test duration and relatively easy cutting conditions, no meaningful evaluation of this bit can be made until further testing can be done under controlled conditions.

In order to better evaluate this bit, BCR had metallurgical tests made on several bits with results as shown in Appendix G. In general the report is not

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* The proposed commercial version of this all steel bit is shown in Figure 16, and other designs of the all steel bit are shown in Appendix F, Figure F-15.

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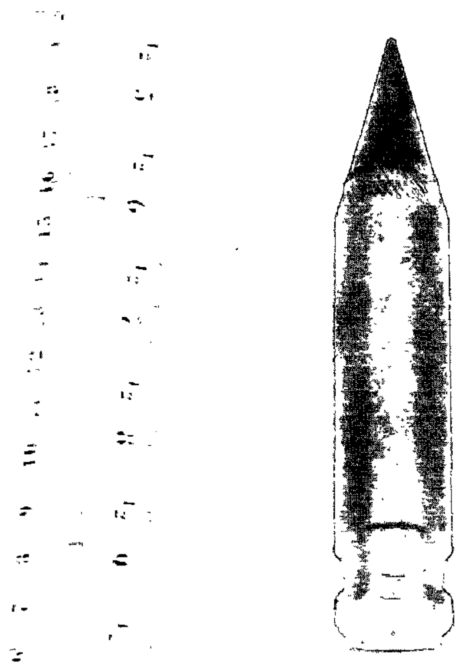

Figure 16. All Steel Bullet Bit with Knurled Surface to Improve Rotation

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optimistic about the bit, but indicates final evaluation cannot be made until controlled underground tests are conducted.

6. Future Bit Development by Bit Manufacturers: Four of the companies interviewed said they have new bits under development but information was considered proprietary and could not be released. However, indications were that one bit concerned new approaches to reducing dust production and the others involved methods to improve bit rotation.

The bit companies' main effort for future development was indicated as being in the area of improving production rather than new bits.

The inactivity in research and development of new bits reflects both the lack of funds available and the absence of economic incentive usually associated with new developments. As one manufacturer stated, his company will not develop any new bit which cannot be patented. Otherwise, it will soon be copied by other manufacturers, which kills any incentive to expend money and effort on development programs. Similarly, another company stated that they do not do any development work, they just copy like everyone else.

With the economic restrictions that exist and the attitudes expressed above, it is doubtful that any concerted effort can or will be made by the bit manufacturers to expand their research programs.

7. Recommendations for Dust Control Methods: The bit manufacturing companies feel that if bits are properly maintained, i.e., replaced when dull or broken, they can reduce dust production. However, dust production is not a design factor and bit companies do not design bits on the basis of their being a dust control method. The manufacturers are aware of the various methods of dust control; but, did not have any recommendations or opinions on their relative merits.

C. Mining Machine Manufacturers

None of the machine manufacturers are currently involved in the production of mining bits. Even though they are not involved in bit design or development, the machine manufacturers are in agreement concerning most of the aspects of bit application and design.

All the companies agreed that head speed, lacing pattern, and number of bits are more important than bit design, particularly with regard to dust production. This is shown by the fact that recent trends in machine design include:

1. Although the results of the tests outlined in the "Field Investigation of Mining Tools" (Page 66) indicates cutting speeds in coal should be kept as high as possible, machine manufacturers have reduced head speeds from 800 to 900 ft/min to 500 to 600 ft/min. This is based on field experience, and the advantages claimed include less energy expended, larger volume of coal cut per revolution, less entrainment of existing dust, and probably less dust produced. Neither information nor data were obtained to explain this difference in opinion on head speeds. The machine manufacturers indicated that the primary effect of reducing head speed is to increase bit penetration, which results in an increase in the size consist of the coal mined.

2. Generally, the number of bits being used has decreased. The resultant wider spacing of the bits theoretically gives larger size consist, less dust, and minimizes regrinding of the coal. However, the maximum spacing is limited by the coring problem, a condition which occurs when the lateral spacing between bits exceeds approximately 2-1/2 in. It results in a ridge of coal being left between adjacent cuts made by individual bits. Field experience indicates that (1) conical bits can have wider spacing than cutter bits, and (2) too many bits result in too little force per bit, which reduces cutting efficiency.

Bit gauge, distance from the drum to the tip of the bit, is not significant so long as it does not vary more than 1/4 to 1/2 inch.

Clearance, rake, and attack angles, illustrated in Figure 17, are considered important to bit performance. Clearance and rake angles vary widely on cutter bits. The guidelines for setting these angles were given as follows:

1. Clearance angle - this is associated with the cutter bit and should be a minimum of 10 degrees. Anything less will result in rubbing--with increased power requirements, shorter bit life, and more dust. One company normally specifies 30 degrees.

2. Rake angle - this also is associated with the cutter bit and is normally positive and larger than 10 degrees, with one company specifying 30 degrees. This angle can be negative and will put the carbide in compression, which should result in lower bit costs. However, the negative rake angle increases both drag and power requirements.

3. Attack angle - this is associated with the point attack bit and is normally held at 45 degrees, which tends to minimize bending stress imparted to the shank of the tool. This is particularly important with the bullet bit, which is susceptible to bending because of its larger length to diameter ratio. However, a company found that at 45 degrees the vertical component on bullet bits was causing excessive bending; they had to use a 53-1/2 degree attack angle to eliminate the problem.

Rotation of the point attack bits is important in maintaining a sharp cutting point which increases bit life, reduces dust, and maintains cutting efficiency. All companies agreed that most bits generally rotate for the life of the bit but require water to maximize rotation. The cause of this rotation was given as random movement of the bit due to machine vibration during the non-cutting portion of the cycle.

All the companies agreed that regardless of the bit used operator technique is an important factor in bit performance. The sumping and shear rates are primary factors and consideration should be given to setting a shear rate for a given condition. In addition, closer control of changing dull bits would improve production, reduce maintenance, and minimize dust production.

1. Basis for Equipping Mining Machines with Particular Bit Design: The selection of bit design on a new machine is usually made by the mining company,

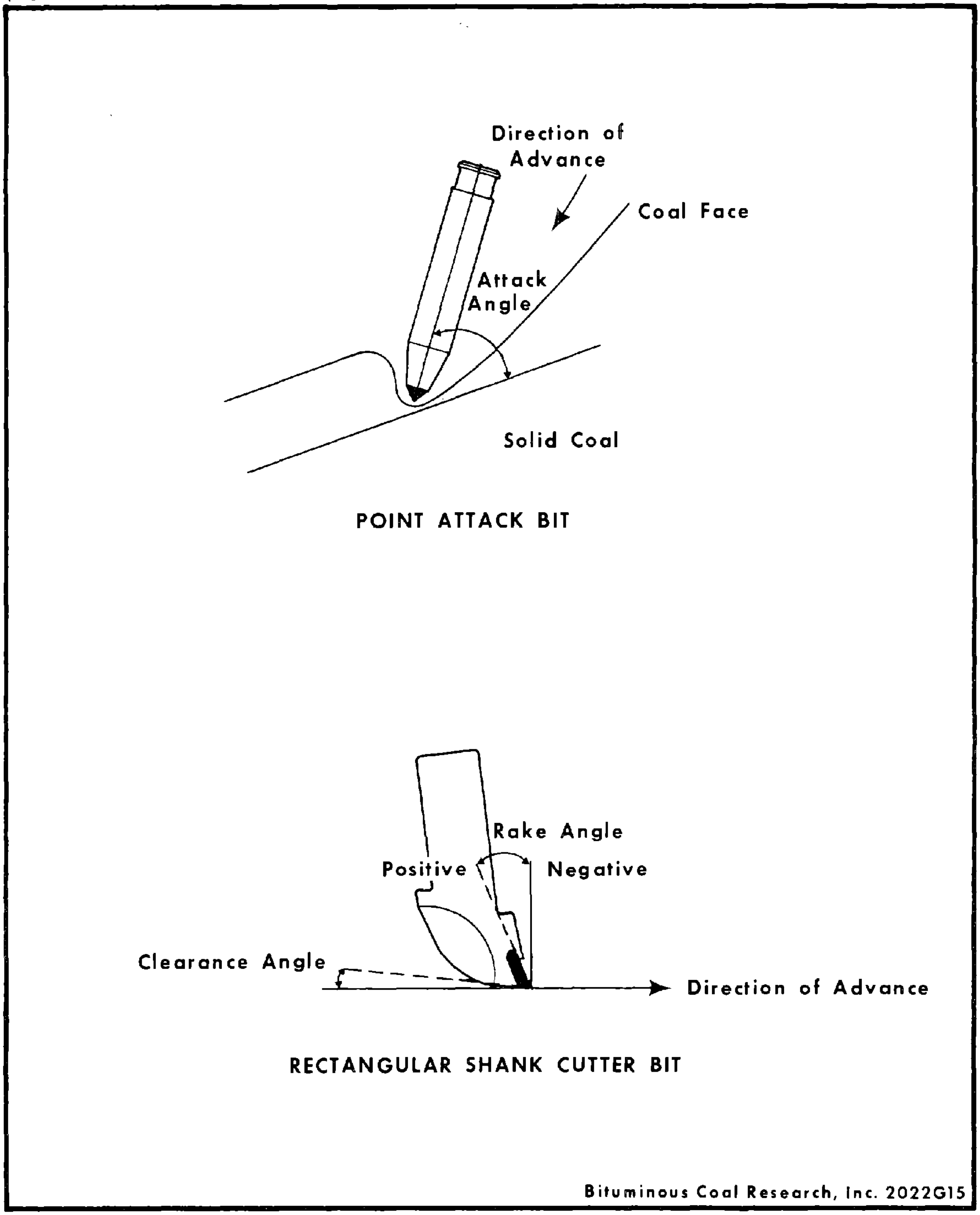

Figure 17. Illustration of Attack, Clearance and Rake Angles of Continuous Miner Bits

and is normally based on experience with bits in use in their mines. Bits may also be selected simply to standardize bit usage at a mine.

Lacing patterns are usually dictated by the machine manufacturer and then modified as required at the mine. There is no engineering method of choosing a lacing pattern, and it is basically a matter of past experience in a certain mine or seam. Dust production is not a consideration in the initial selection of a bit or lacing pattern.

Most new mining machines ordered by U.S. mining companies are equipped with point attack bits, primarily because mining companies have found them to give the best performance at best cost.

One manufacturer indicated that all of their machines sold in Australia are equipped with flat cutter bits. They did not know the specific reason but felt that either the type of coal dictated the use of cutter bits or there was lack of experience with point attack bits in Australia.

2. Machine Manufacturers' Appraisal of Bit Designs: Opinions ranged from the conical point attack being the best all around bit to the statement that its only advantage over the flat cutter bit is cheaper initial cost and possibly some convenience in changing. Specifically, the appraisal of bits by machine manufacturers was:

a. Advantages of the plumb bob (conical point attack bit)

(1) Deeper penetration.

(2) Lower cost per ton based on customer claims.

(3) Can be used to destruction.

(4) Are more convenient to change.

(5) The forces are applied along the axis, resulting in increased life of the carbide tip.

(6) On a particular type of machine, with all other things being equal, the point attack gives more breakage of the coal and less dust.

(7) Lower initial cost.

b. Advantages of the cutter bit

(1) Had higher cutting efficiency (HP-hr/ton), based on tests cutting salt.

c. Disadvantages of the cutter bit

(1) The proper clearance and rake angles cannot be maintained when regrinding. This often results in the bit rubbing or breaking off when put back in operation, which offsets the economics of regrinding.

In spite of the apparent advantages of the plumb bob bit, the machine manufacturers felt there is no "best type" bit for the industry. There are advantages and disadvantages to any type of bit, and dust will be produced during the mining process regardless of the bit used. The amount of dust produced is also a function of the seam being mined. However, one manufacturer did indicate that he felt there was a best bit and lacing pattern for any given mine.

3. Tests Conducted by Mining Machine Manufacturers: None of the companies interviewed are presently doing any research or development work in the field of bit technology. However, one of the companies did sponsor a "Bit Development Program" at Mellon Institute during the years 1965-1967. A brief summary of this project is presented below.

a. Bit Development Program: A mining bit was mounted in the tool holder of a planer and planing or cutting operations were performed on Indiana limestone, potash, and regular salt using no confining pressures. These tests were made at various cutting speeds and depths, and with different geometries of bits. Force measurements of vertical, horizontal, and lateral components were taken by means of SR-4 type strain gages and Wheatstone bridge circuits and displayed on an oscillograph recorder. Cutting energy calculations were made possible through the electrical integration of the horizontal force curves.

In general it was found that (1) forces increase proportionately with an increase in cutting depth; (2) cutting speed has little or no effect on the cutting forces; (3) the deeper the cuts, the more efficient the ploughing operation becomes; (4) cutting forces increase with an increase in dullness of the bit cutting edge, especially the vertical forces which increase at a much faster rate than does the horizontal force; and (5) the new vertical wedge type of bit is more efficient than the other styles tested.

Although the tests were not conducted in coal, the results are in agreement with the results of tests conducted by bit manufacturers and with those described in the literature.

The lack of test data on bit performance from the machine manufacturers obviously is due to the fact that their business is designing a system that will efficiently power the bits; therefore, bit design is of secondary interest. However, due to the inter-relationship between the operation of the machine and the cutting of the bits, it would seem appropriate for bit companies and machine manufacturers to conduct joint research in the area of cutting technology.

4. Recommendations for Future Bit Development: Although the mining machine manufacturers had no recommendations on new bit designs, they did make the following comments on presently used bits.

a. Bit designs should favor the profile of Style 8 rather than Style 9 bits (Figure 1). This would minimize the frontal area impacting the coal face and reduce the rubbing necessary to wear away this shoulder area.

b. Due to 50 percent volume displacement of the coal upon fracturing, a 5- to 6-inch vertical distance from the tip of the bit to the drum should be maintained for each 1 inch of penetration. This is necessary to allow the coal to be conveyed away with a minimum of secondary breakage.

c. Spiral ribs on a bit appear to be dust generators because of their roughness and additional bit surface area.

These comments are based on personal opinions and not on operating or test data. The points seem to have some validity and may significantly affect mining machine performance. Therefore, it would be appropriate that a test program be undertaken jointly by operators, bit manufacturers and machine manufacturers to investigate the effect of these items.

5. Recommendations for Dust Control Methods: The primary method of dust control proposed by the mining machine companies was ventilation, which includes both mine and section ventilation plans. One company indicated 95 percent of the dust can be removed with proper ventilation. Other methods suggested included:

a. Machine mounted scrubber units.

b. Water sprays, particularly in elimination of float dust.

c. Slower bit speeds and deeper penetration.

d. Water flushed bits.

All of the companies agreed that new techniques such as high pressure water jets would not be economically feasible in the near future. One company did indicate that high pressure jets or sonic devices may be practical if used in conjunction with a mining machine to prefracture the coal.

As with the operators, the machine manufacturers did not include bit design as a significant method of dust control. This opinion appears to be based on observation of the present bit and their conviction that dust will be produced regardless of bit design.

D. Research Organizations

Four domestic research organizations contacted were not doing, and had not done, any work that would be of value to this survey. These organizations did not anticipate doing any research in this area, which is an indication that bit design is apparently not considered significant in trying to control dust.

During the period September 23 to October 22, 1972, two BCR engineers visited research facilities in England, France, Germany, and Belgium to discuss respirable dust and related mining research. The limited amount of information obtained from the European research organizations generally refers to longwall miners, since these are predominately used in Europe. From the information obtained from the Mining Research and Development Establishment, Stanhope Bretby, England, there is a trend to use fewer bits and lower rotational speeds on longwall shearers. Previously, 60 to 70 bits rotated at 60 to 70 rpm; now, in coal with little or no rock, shearers may have eight bits, two inches wide at the cutting surface, rotating at 30 to 40 rpm.

Other factors considered to be very important are that the width and depth of the cut should be the same, and that the bit spacing should be between three and four times the width (or depth) of the cut.

Several comments on bit design were made by the personnel at CERCHAR, Paris, France. They felt that the plumb bob style bits do not have any advantages over the rectangular shank cutter bits, except that in the plumb bob bits, the carbide is positioned in such a way that it is in compression. They feel this is the best possible position, since the carbide is less likely to break off and will last longer. On some rectangular shank cutter bits, a plate of carbide is placed on the front surface. They felt this was an extremely poor and obsolete design since it makes very poor use of the properties of carbide. The carbide is resting on a piece of steel which flexes at a pressure greater than the carbide, so the carbide will break and chip off. Their preferred design is a plug of carbide, such as that used on the plumb bob bits, or with a rounded insert having a curved back surface to give full support to the carbide and prevent any flexing.

In terms of cutting coal, they feel the rectangular shank cutter bit is probably more efficient.

Research has also been done at CERCHAR in flushing water through the bit. This helped reduce the dust, but the concept has not yet been accepted by the French coal mining industry.

VI. ABSTRACTS OF ARTICLES FROM BIBLIOGRAPHY

Examination of the articles in the bibliography reveals several facts.

1. Much of the published research in the field of coal cutting (bit design, physical properties of coal, factors affecting the cutting of coal) has been carried out by the English.

2. Most of the research, both in England and America, has been with either wedge type or rectangular shank cutter bits. In addition, many of these bits are all steel rather than carbide tipped.

3. There is general agreement that the following parameters have a definite effect on bit performance:

   a. Bit linear speed.
   b. Depth of cut.
   c. Sharpness of the tool.
   d. Coal properties.

Little has been done in the area of bit design as a means of reducing respirable dust concentration. The researchers indicate that dust in inevitable and most work with dust is in the area of dust suppression using sprays, ventilation, and scrubbers.

Some of the articles do not deal specifically with continuous miner bit design; but, as indicated in the abstracts, contain research techniques and instrumentation methods that may be applicable to work on all types of tools.

Based on these articles, it would appear that there is much to do in the area of bit research, particularly with the point attack style.

Abstracts of the articles most applicable to bit design follow. They are numbered to correspond with the complete bibliography given in Appendix C.

2. A Laboratory Investigation of Rock Cutting Using Large Picks 314.000/64-7

An account is given of an investigation of the efficiency of large slow-moving picks taking deep cuts in rock. A rig, designed specially for full-scale work on rock cutting, is described. Two types of pick, one pointed, one chisel-shaped, were used, and measurements made of the forces imposed in cutting, of the quantity and size range of debris produced, and of the cutting efficiency, defined by the weight of rock removed per unit of work done. It is found that cutting efficiency increases with increase in depth of cut, reaching a constant value. It also increases with increased spacing between adjacent cuts until an optimum spacing to depth ratio is reached beyond which it falls. Efficient cutting may mean high pick forces because of the deep cuts involved. As the depth of cut and spacing between cuts are increased the quantity and coarseness of the debris increase. The chisel-type pick is found to be more efficient than the pointed pick when cutting at optimum spacing to depth ratios.

A summary of the conclusions from this project is as follows:

1. The efficiency of the cutting process increases to a maximum as the depth of cut is increased. For the picks used in the investigations, the efficiency of cutting reached a sensibly constant maximum at a depth of 1-1/2 - 2 in.

2. For a given depth of cut, cutting efficiency increases as the spacing between adjacent cuts is increased to an optimum value. Further increase in spacing results in a reduction in efficiency.

3. The spacing to depth ratio giving the highest cutting efficiency decreases as the depth of cut is increased. In the investigations described, this ratio decreases from 4:1 at a depth of 1/2 in. to 1·5:1 at a depth of 2 in. with the chisel-type pick, and from 3:1 at a depth of 1/2 in. to 1·5:1 at a depth of 2 in. with the pointed pick.

4. Increasing the depth of cut or the spacing between adjacent cuts results in an increase in the amount of rock removed per unit length of cut and in the coarseness of the debris produced. At the same time, mean and peak cutting, normal, and radial forces are increased. Each of these quantities tends to a constant value as the spacing is increased beyond the point where relief is no longer afforded by the preceding cut.

5. At pick spacings, measured by pick centres, less than the width of its cutting edge, the chisel-type pick leaves no annulus or core of coal to be removed between adjacent cuts. At these spacings the pointed pick, which leaves an annulus to be removed at all spacings, shows a higher cutting efficiency and produces coarser debris. At spacings greater than this, the chisel-type pick, leaving a narrower annulus, cuts more efficiently; the benefit obtained from the narrower annulus decreases with increase in depth of cut.

6. The specific energy requirements of the chisel-type pick were lower than those of the pointed pick when cutting at optimum spacing to depth ratios.

7. Peak forces ranging from 4·7 to 8·8 times the mean forces occurred during cutting. Peak to mean force ratios were lower with the pointed pick due to the nature of the cutting action provided by the wedge-shaped attacking face.

8. Despite occasional peak cutting forces of nearly 13 ton, no chipping of tungsten carbide tips occurred during the investigations, and the rate of abrasive wear observed was low.

9. The investigations have proved the chisel-type pick to be superior in performance to the pointed pick. The possibility exists, however, that the efficiency of chisel-type picks may be improved by examination of individual design factors, and further investigation is required.

There was no specific reference to dust production, but data on the size consist produced is presented, indicating that the chisel type bit, particularly for wider spacing, produced larger size consist. It would, therefore, be logical to assume that the chisel bit would also produce less dust.

3. The M.R.E. Large-pick Shearer Drum 314.000/66-1

In this paper the application of the basic principles of coal cutting to the design of a drum for use on an Anderton shearer loader is discussed. The results of underground trials with the prototype drums are also reported. The following aims were adopted as the essential requirements for a successful shearer drum:

(i) The quantity of coal extracted for a given power utilization should be high.

(ii) The product should contain a minimum of fines and a maximum of large and graded-size coal.

(iii) The formation and dispersion of airborne dust should be low.

Laboratory work on coal cutting has shown that:

a. For efficient cutting, tools should have as large a rake angle as possible and a back clearance of about 6 degrees.

b. Simple flat-faced chisel-shaped tools are at least as efficient as other shapes of cutting tool and generally show a marked superiority over more complex designs.

c. Shallow pick penetrations are essentially less efficient than deep penetrations.

d. A succession of shallow pick penetrations leads to the formation of ridges or cores of coal between adjacent pick lines with a further substantial decrease in cutting efficiency.

e. To avoid coring, pick penetrations should exceed one-third of the line spacing, and for maximum relief the pick penetration should be roughly half the line spacing.

f. With the above condition (e) observed, cutting efficiency improves as the line spacing is increased.

g. In general, the higher the cutting efficiency the larger is the proportion of large coal that is produced and the smaller is the proportion of fines and of airborne dust.

h. Over the normal practical range cutting efficiency is independent of pick speed (3), so that pick speeds should be kept as low as possible to reduce the dispersion of dust into the air stream.

i. The loads on each pick fluctuate continuously during cutting, rising to a maximum immediately before a fragment of coal or rock breaks away and the load on the tool falls. This process repeats successively throughout the cut, the magnitude of the rise and fall in the values of the cutting force reflecting the size of the fragment of material broken away.

j. The cutting edges on picks should be kept sharp, since the force required to cut coal increases in proportion to r 1/2 where r is the radius of the tip edge.

These results show that efficient cutting results from deep cuts with large picks widely spaced. If a machine can be designed or modified to accept the high forces on individual picks and the force fluctuations that are inherent in rock and coal cutting, there will be substantial benefits in the increased size of product and in the reduction in the make of fines and the amount of dust produced. The rate of extraction should also be higher for a given expenditure of energy than that achieved with a machine using a larger number of picks which cut the material into comparatively small pieces.

The trials that have taken place have shown that it is possible to design shearer drums with a very small number of large picks and that these drums can cut both efficiently and smoothly. The size of the product is substantially greater than that obtained with orthodox shearer drums and the formation of dust is reduced. However the benefits that can accrue from these large-pick drums will only be realized if the haulage rate of the machine and hence the pick penetration at mid-seam height are correct for the selected drum speed. While the trials with small diameter drums proved that it is possible for these drums to cut the coal, the machines failed to be successful because the broken material could not be discharged on to the face conveyor quickly enough and hence the haulage rates were restricted.

This difficulty is not present on the ranging drum shearer, or when large diameter drums are used. Until the drum loading characteristics of small diameter drums are improved it is necessary to restrict the use of the large-pick drum to diameters above 40 in. Work is continuing on the small diameters and it is expected that the size restriction will not be permanent.

4. Study of the Picks of Mining Machines — 311.000/64-2

This paper deals with flat cutter bits and is divided into two phases:

1. A single bit on a test rig, and
2. The work of the pick set in a cutting head.

The object of the investigation is to develop general laws governing:

1. The action of a new pick.
2. The wear on a pick.
3. The work of the pick set in a cutting head.
4. The work of groups of picks.

In addition, work was also done on (1) determination of the detrimental effects of rocks on picks, (2) hardness of the coal, and (3) abrasiveness tests.

Some of the important results of the work include:

1. Bit speed has no noticeable effect on the forces required to cut the rock.

2. The forces required to cut the rock increase as the rake angle decreases from +10 degrees to -35 degrees.

3. The clearance angle has little effect on the forces as long as the angle exceeds 5-6 degrees.

4. The temperature at the cutting surface can reach 1500 C which is an important factor in bit wear. This temperature varies with depth of cut, speed of the pick, and the nature of the material being cut.

No specific work was done on dust generation, but a water injection pick was developed which cooled the tip and apparently had a fairly spectacular effect on the suppression of dust in the underground tests of this bit.

The laws relating to the phenomenon of cutting by sets of picks that were determined in these experiments, and the special studies on the cutting heads which followed, show that the cutting heads used on present machines can be very considerably improved, although experience has shown that it is sometimes very difficult to avoid secondary phenomena of the type due to lateral clearance and abnormal friction.

It should be noted, moreover, that the study of a cutting head must take into account its role as loader, which is too often neglected. Loading, in fact, imposes a limit on the rate of advance of the machine; if we approach this limit too closely, loading absorbs a large amount of power and causes degradation of the products.

On the whole, therefore, the achievement of a cutting head requires a considerable amount of study followed by a long trial period.

7. Bit Design: Key to Coal Cutting 314.000/70-3

This article deals primarily with factors of bit design which affect operating costs and does not mention dust production. The general results of the work discussed in this article can be summarized as follows.

1. The most efficient bit design has a frontal relief or clearance angle of 8-12 degrees and rake angle ranging from +5 to -10 degrees.

2. Cutting impurities in the coal is a problem for bits, and they should be designed to efficiently cut pyrite.

3. Power requirements to cut a given coal are almost constant regardless of the sharpness or dullness of the bit. The ampereage required decreases as

the bit dulls, but the time required to cut the same volume of coal increases proportionately.

4. Bit cost is the real basis of selecting bits and should include consideration of down time to change bits, number of bits used, and initial cost.

This paper deals only with the rectangular shank cutter bit.

10. Single Pick Cutting in Dunsil Coal 314.000/58-3

This investigation was carried out using a standard carbon-steel pick of duckbill shape having pick and clearance angles of 30 degrees.

Since this study dealt with only one bit design, it is not particularly significant; but it does give some indication of the importance of bit application in terms of depth of cut and forces acting on the bit.

The investigation described in this report was designed to determine the effect of depth of cut, cutting speed, and direction of coal cleat relative to line of cut, on the mean force and mean peak force acting in the direction of motion on a single full-size coal cutter pick cutting in Dunsil coal. A study was also made of the size grading and amount of broken coal produced during the cutting operation. Cutting speeds used were 50, 200, 400 and 600 ft/min, nominal depths of cut were 0·1 in., 0·25 in., and 0·5 in., and cleat directions were 0 degrees (cleat parallel to direction of cut) and 90 degrees (cleat at right angles to direction of cut), with the cut always in the bedding plane.

It was found that mean force and mean peak force increased in an approximately linear manner with increasing depth of cut; cutting speed had no significance. Cleat direction affected only the mean peak force, which increased more rapidly when cutting with cleat direction 90 degrees than with cleat direction 0 degrees.

It was also shown that the larger percentages of fine coal obtained were associated with the shallow depths of cut.

The energy consumption required to produce a given amount of coal was found to be higher for the shallow depths of cut than for the deep cuts.

14. Coal Cutting Research

The object of this investigation was to determine the effect of natural blunting on bit performance and frictional losses in the machine. The bit used was a 1/3 size, untipped, carbon-steel type with a rake angle of 30 degrees and clearance angle of 25 degrees. The bits were mounted in a cutter chain driven by an A.C. motor to give any chain speed between 14.2 and 130 m/min.

Since only one style of bit was used, the results of these tests are limited, but they do give information on the effect of dulling and point out the desirability of changing bits before they get too dull. The conclusions from these tests can be summarized as follows:

1. For both sharp and blunt picks, the mean chain sprocket torque and the mean haulage force increased linearly with pick penetration up to 2 mm, after which there was a gradual decrease for both parameters up to a penetration of 2·5 mm. Additional tests with the sharp picks showed that with pick penetrations between 2·5 and 10 mm the linear increase was re-established at 0·8 of the initial rate for the torque and 0·3 for the haulage force. The "dip" in the curves can be explained in terms of the relief given to one another by adjacent picks in an array.

2. Over the range of experimental conditions investigated the machine, when fitted with blunt picks, required on average 13 percent more chain sprocket torque and 180 percent more haulage force than when fitted with sharp picks.

3. The energy consumed by the machine in advancing unit distance through the coal decreased as the pick penetration increased to an approximately constant level of 100 KJ per metre cut. On average 4 percent more energy was required when using blunt picks than with the sharp picks.

4. The percentage fines, defined as the percentage of the total weight of coal passing through a 0·8 mm sieve, was greatest at the shallowest pick penetrations and decreased as pick penetration increased. The blunt picks, on average, produced 21 percent more fines than the sharp picks.

5. Analysis of the forces on the jib showed that, for the sharp pick, the pick boxes were subjected to tilting causing the bridge links to "jam" across the jib race, while for the blunt picks there was no such effect. As a result an average of 46 percent of the measured values of torque were used in overcoming frictional resistance with the sharp picks compared with 52 percent for the blunt picks despite the much higher haulage force (and hence the higher expected resistance to chain motion) in the latter case.

6. When the effects of friction in the machine are eliminated it is shown that the cutting forces acting on both the sharp and blunt picks were indistinguishable and that the penetrating force, measured in the direction of jib advance was, on average, 250 percent higher for the blunt picks compared with the sharp ones. In practical terms for a coal winning machine

underground, provided there is a capacity for providing this higher penetrating force overall efficiency will not be greatly affected by allowing a certain amount of tool wear.

15. Initiation of Cracks in Coal Specimens by Blunted Wedges 314.000/64-6

This article describes laboratory tests performed to determine the effect of blunting on the force required to initiate a crack in coal. The tool used was an all steel asymmetric bit .375 in. broad and with rake and clearance angles of 30 degrees. It was initially used sharp and after several cuts was blunted by grinding a flat land on the cutting edge perpendicular to the leading face.

Only one type of tool was used and no data were taken on changes in size consist with the different degrees of bluntness. Therefore, the value of this test to the survey is limited.

From the results of this test it was concluded that the force necessary to propagate a crack in coal by using a blunted wedge is directly proportional to the width or radius of the cutting edge raised to the power of half.

It is suggested that an explanation of this half-power relationship can be found by an application of Inglis solution for the stresses around an eliptical hole in a stressed plate.

16. Investigations into the Effect of Blunting a Wedge-Shaped Tool 314.000/60-2

A. Effect of Direction of Blunting

This report is concerned with the performance of coal-cutting machines and of coal-cutting tools.

A carbon steel pick suffers from two forms of blunting: in manufacture the cutting edge is blunted by a land approximately 1/16 in. wide in a direction perpendicular to the leading face, while abrasive wear results in the tip acquiring a wear land parallel to the coal surface.

Laboratory experiments are described in which a simple wedge-shaped tool was used to cut grooves in coal. The tool was blunted in each of the two ways described above and the effect on two of the components of force investigated. These two components were: the cutting force acting on the tool parallel to the direction of cut and the normal force acting perpendicular to the coal surface. A 1/8 in. land parallel to the coal surface produced no significant change in either component when compared with forces acting on a sharp wedge. However, a 1/16 in. land perpendicular to the leading face more than doubled the cutting force and altered the character of the normal force as well as producing a seven-fold increase in its magnitude.

A simple analytical treatment of the results indicates that, under all the conditions tested, the penetration of the pick in the buttock of coal is very small, so that only a small area near the tip of the tool is vitally concerned with the cutting process. For the blade blunted perpendicular to its leading face, virtually the whole of this land is subjected to the compressive strength of the coal. The relevant value of coal strength is several times greater than that derived from the crushing of 1 in. cubes.

The bits used in this test were all steel wedges blunted to give various radii at the cutting tip, and the application of the results is limited. In addition, no data were taken as to the effect on size consist of the various bits, which limits the usefulness of the results for this survey.

The conclusions from the tests are summarized as follows:

1. When the cutting tool was modified from its sharp condition by introducing a blunt land 1/8 in. wide parallel to the coal surface no significant increase could be detected in either the cutting or normal forces. A simple analytical treatment suggests that this result is likely to be valid only for small lands (~ 1/8 in.).

2. In both cases the mean cutting force (~ 36 lb wt) was much greater than the mean normal force (~ 7 lb wt).

3. For both the sharp tool and the one blunted parallel to the coal surface the characteristic form of the force-distance records are the same. For each peak cutting force there exists a corresponding negative peak value in the normal force, i.e., acting in a direction into the coal surface.

4. The effect of blunting the sharp tool with a land only 1/16 in. wide perpendicular to the leading face was to modify drastically the magnitudes of the forces acting. The cutting force was subjected to a twofold increase from 38 lb wt to 88 lb wt and the normal force a ninefold increase from 7 lb wt to 66 lb wt. The blunt land left when the 'flash' is removed from a 'standard' forged pick would therefore be expected to affect the normal and cutting forces substantially.

5. For the tool blunted perpendicular to the leading face the characteristic form of the force-distance record is changed. The normal force no longer makes any excursions in the negative direction. For each peak cutting force there is a corresponding peak normal force always in the positive direction and of approximately the same magnitude.

6. In the analytical treatment it was assumed that the full compressive strength of the coal acted over fractions m and n of the wedge faces. For the sharp tool and the tool blunted parallel to the coal surface these fractions are very small, indicating that the part of the tool which is effective in initiating the breakage of the coal is the very small area near the tip.

7. For the tool blunted perpendicular to the leading face the compressive strength of the coal acts over virtually the whole of the area of the blunt land. The front face, however, is in contact over only a very small area, indicating that again the penetration of the tip of the tool is very small.

8. The analytical treatment of the results has shown that over the small areas of the tool surface in contact, the crushed coal can exert a thrust equal to more than 3-1/2 times its uniaxial compressive strength (1 in. cubes).

17. Investigations into the Effect of Blunting a Wedge-Shaped Tool 314.000/60-3

B. Effect of Width of Blunted Edge

This report describes a theoretical and practical investigation into the effect of progressively blunting the cutting edge of wedge-shaped tools. It will be of particular interest to engineers concerned with the operation of coal-cutting machines and to the designers of cutting tools. A deduction is made that the force to be applied to a blunt wedge in order to propagate a crack in a specimen of coal is proportional to the square root of the width of the blunt land. Two experiments are described which were designed to test this prediction.

An asymmetric wedge was used to cut grooves in specimens of Cwmtillery Garw coal. It was used initially in its sharp state and then blunted in five progressive stages by grinding flats on the cutting edge perpendicular to the leading face. The fracture force, defined as the component of the peak cutting force and the peak normal force acting perpendicular to the blunt land, is shown to be proportional to the width of the land raised to the power $0{\cdot}52 \pm 0{\cdot}05$.

In the second part of the experimental investigation, four symmetrical wedges were used, one sharp and the others having different radii ground on their tips. These tools were used in straight wedge penetration tests on samples of Rossington Barnsley Hards. The load necessary to initiate a crack is shown to be proportional to the radius of the tip of the tool raised to the power $0{\cdot}48 \pm 0{\cdot}04$.

Both these experimental results agree with the theoretical prediction within the limits of experimental error.

As in Section A, the value of the results of this report are limited because of testing only one style of bit and the lack of data on the effect of the bits on size consist. The conclusions from this test are summarized as follows:

Theoretical considerations lead to the expression

$$F_p = Kr^{0 \cdot 5}$$

relating the fracture force F_p and the radius of curvature r of the tool tip. This is confirmed experimentally in both the continuous cutting and wedge penetration experiments.

For a continuous cutting process in Cwmtillery coal using blades blunted by flat lands the exponent of r was 0·52 with a standard error of 0·05, where r is the equivalent radius of curvature of the tool tip.

For wedge penetration in Barnsley Hards using wedges with 'radiused' tips the exponent of r was found to be 0·48 with a standard error of 0·04, where r is the radius of curvature of the tool tip.

Both results agree with theory within the limits of experimental error.

31 Production of Dust by Anderton Shearers 310.000/64-9

The paper deals with a study made in a number of coal faces of the production of respirable dust by Anderton shearers. The techniques of dust measurement are described and the dust concentrations produced during the operation of the machine are discussed. It was found that the mean dust concentrations arising during shearing ranged from 35 to about 15,000 particles per cubic centimetre. It appears that the dust levels fall as haulage speed is increased and increase with cutting in roof or floor. The weaker coals tend to produce less dust. Substantial reductions in dust dispersion can often be obtained by changing operating conditions and this approach to dust control should always be considered in conjunction with the application of conventional dust suppression measures.

The levels of dust concentration found, arising from both intake operations and the Anderton shearers themselves, have, in many cases, been very high. On the 25 faces visited, the average face return concentration during the shearing operation was less than 850 particles/cu cm in only seven cases. As mentioned earlier, the dust sampling techniques were not those of the "approved conditions" sampling programme, but give, nevertheless, an indication of the magnitude of the problem facing the dust suppression engineer. The trend towards concentrated mining means that a cutter loader will be operated on every shift and that, within a shift, improved techniques of roof support, roadway ripping and stable hole advancement will allow the machine to be used during a high proportion of the time. In consequence, the shift mean dust concentration will tend to approach that recorded during shearing in the present work. Similarly, the average dust level from the ancillary roadways and face operations can also be expected to rise.

The Anderton shearer causes the dispersion of relatively large quantities of fine dust because of its high rate of working of up to 5 ton/min and its relatively small depth of cut per pick which, at the most favorable angle of incidence, is rarely greater than 1 in., and the high pick speed. A further feature of the machine is that a high proportion of this fine dust is generated at the top and bottom of the drum, where the picks take small-depth tangential cuts.

The observations made in the present study indicate, that the dispersion of respirable dust from an Anderton shearer can be affected by operational, environmental, and geological factors, as follow:

(a) Operational

(i) The haulage rate of the machine along the coal face: dust production per ton rises as haulage speed is reduced. The consequent dust concentration is also increased under these conditions, notwithstanding the smaller rate of coal production.

(ii) Cutting in roof or floor: dust make is greater because of the change in material at a place where depth of cut is at a minimum. In some cases, there is an associated reduction in haulage speed.

(iii) The number of picks and drum rotation speed: dust level is greater at lower depths of pick penetration.

(b) Environmental

Face ventilation: as the volume of air flowing through the face is increased, dust is diluted to a greater extent. The limited information obtained does not give any firm evidence of when greater respirable dust pick-up at high air speeds annuls the advantages of dilution.

(c) Geological

(i) The nature of the coal appears to have considerable effect on dust make. Strength and moisture content are probably the important parameters: there is a tendency for dust production to be at a minimum with rather fragile coking coals in the 20 to 30 percent, volatile content range.

(ii) Characteristics of floor and roof are of importance in view of the high dust production from top and bottom of the drum. Unevenness of roof or floor may necessitate cutting in the shale; cutting in a hard material can cause reduction in haulage speed.

(iii) The presence and nature of dirt bands in the seam, though affecting mineralogical composition, appear to have but little effect on dust quantity, apparently because of the large depth of cut at mid-seam height.

A salient feature of the present results is the indication of common requirements for high productivity and reduction in health hazard. If a machine is operating most efficiently, being hauled along the face at the maximum rate and avoiding floor or roof cutting, conditions are likely to be most satisfactory. As a preliminary to effective operation, the choice of the best size of drum, with the minimum number of picks to maintain optimum performance, is important. Pick design and maintenance of pick sharpness is also likely to affect dust production, both directly and by allowing the greater depths of cut resulting from higher haulage rates.

Although the Anderton Shearer is a long wall machine, some of the factors noted as influencing dust production can probably affect mining in general and indicate factors that should be considered in bit testing and development work.

33. The Properties of Coal in Relation to Mechanical Coal Winning 314.000/68-2

This paper describes research done on the physical properties of coal; elasticity, compressive strength, and tensile strength; and application of the results of this research to the mining process.

The results of the research on physical properties can be summarized as follows.

1. Elasticity - In rapid compression tests, coal shows a more or less linear stress-strain relationship, with little hysteresis loss in a complete cycle of straining.

2. Uniaxial Compression - Uniaxial compression is probably the simplest test to carry out. Many tests of this nature were performed, mainly on cubical specimens of a range of size. Two important conclusions emerged from this work:

(a) The crushing strength of cubes of a particular size shows a wide variation, even when specimens are cut from a single lump of coal (see Figure 2);

(b) Mean crushing strength decreases as side of cube increases.

The physical picture of coal which emerges from these investigations is that of a material which is ramified with cracks and flaws, ranging in size from macroscopic to sub-microscopic. The action of stresses applied at the surface of specimens is to generate high tensile stresses in the vicinity of cracks, even when the applied stresses are compressive. The 'links' in the 'chain' are cracks situated in a potential line extending through the specimen. The tendency to propagate depends upon size and shape. One of these cracks, the 'weakest link,' will propagate first, and this composite crack become increasingly long, until a chain of breakage extends from one end of the sample to another.

3. Tensile Strength - The implication of the work on compressive strength, that tensile failure is an important factor in the breakage of coal, led to an investigation of tensile strength in its own right.

In terms of actual magnitude, tensile strength varies from about 100 lb/in^2 for friable coking coals (Oakdale, Meadow Seam and Cwmtillery, Garw Seam) to about 400 lb/in^2 for a hard bituminous coal (Rossington, Barnsley Hards). These values are in the region of 1/20 of the corresponding compressive strengths. The low values of this ratio reinforces the view that tensile strength is of paramount importance in breakage studies.

Both compressive strength and tensile strength exhibit a roughly U-shaped relationship with rank expressed in terms of volatile content, with coals of high and low rank tending to be stronger than those of intermediate rank. However, the relationship is not sufficiently specific to be of much practical importance.

4. Triaxial Compression - In the ground, in the undisturbed state, coal is acted upon by a vertical pressure due to the weight of the overburden which in round figures is 1 lb/in^2 per foot of depth. The lateral pressures are a matter of conjecture. Remote from a working they may approximate to the vertical pressure, but nearer a working they are clearly modified; at the coal face for example, the pressure normal to the face itself is zero.

While it may not be possible accurately to simulate the stresses acting during the processes of coal winning, a general impression of the effect of lateral pressures on strength can be obtained by submitting a specimen to triaxial compression, whereby the specimen is supported laterally by hydrostatic pressure while being compressed axially. Compressive strength increases with lateral pressure.

It is possible, using various dodges, to submit specimens to tensile tests while they are subject to lateral pressures. It is found that the tensile strength may increase under this regime, but the large disparity between compressive and tensile strengths that was noted in uniaxial tests still remains.

As has been said, coal remote from the coal face is acted upon by approximately hydrostatic pressure. As the coal face approaches, the lateral pressures fall off, particularly the component perpendicular to the face, while the vertical pressure is intensified by the necessity to support the strata over the worked-out area. Under these circumstances, coal at the face itself may become partially broken by strata stresses, a desirable occurrence, as it leads to easier winning; and miners are familiar with the splitting and rending noises that are emitted from a face that is actively 'working.' If this redistribution of stresses is not or cannot be nicely contrived, as a result of bad ground, or of poor organization of roof supports, the coal may not be broken, and a hard or 'woody' state, implicit in triaxial stress conditions, results. This is a situation equally recognized by miners.

The foregoing work on aspects of the strength of coal has been used in investigations into the mode of action of picks and blades, used singly and in concert. In order to facilitate further reference, certain characteristics of a pick are defined below. An idealized pick can be thought of as a wedge mounted on a supporting shank.

Rake angle - The angle made by the front face of the pick with respect to the normal to the direction of the cut.

Clearance angle - The angle made by the back face of the pick with respect to the direction of the cut.

Wedge angle - The complement of the sum of rake angle and clearance angle.

Depth of cut - The distance between the tip of the pick and the unbroken surface of the coal, normal to the direction of cut.

Cutting force - The force acting in the direction of cut.

Normal force - The force acting at right-angles to the direction of cut.

The investigations carried out at M.R.E. have been mainly laboratory experiments in which the cutting and normal forces have been measured for various types of pick as other parameters such as the following have been varied:

Type of coal
Direction of weaknesses in coal
Speed of cutting
Depth of cut

The frontal aspect of the picks during these experiments has usually been one of two kinds, either a standard 'duckbill' type, or a simple rectangular shape. The results do not depend very much upon which is used.

The forces were measured by mounting the picks in dynamometer holders equipped with resistance strain gages. A continuous record of forces experienced during the cut against distance cut is therefore obtained. The record is irregular, but two parameters are extracted from it:

(1) The mean force.
(2) The 'mean peak force,' this being defined arbitrarily as the mean of the ten highest peaks encountered during a cut.

All tools used in the initial experiments were sharp. The main conclusions of M.R.E. experimental work are:

1. Mode of breakage of coal - This was investigated by allowing a wedge to cut immediately alongside a sheet of plate glass through which the breakage process could be photographed by means of a high-speed camera. Breakage appears to be initiated in the coal by cracks which start at the cutting edge and propagate thence to the surface. On its way a crack may be diverted from a simple path by means of the weaknesses in the coal such as the cleats, so that the shape of the broken piece may be complex. In a coal where the weaknesses are not pronounced the breakage path takes the form of a simple curve extending from the edge to the surface.

2. Cutting speed - In experiments covering a range of cutting speed of up to 600 ft/min (3 m/s), changes in cutting speed had no effect on the mean cutting force.

The explanation of this important result may lie in the speed at which tensile cracks propagate through the coal during the process of chip formation. It is estimated from the high-speed films already referred to that the velocity of propagation of cracks in Barnsley Hards may be in excess of 500 m/s. The maximum pick speed used in these experiments is small in comparison. It seems probable that the breakage process will not be appreciably modified over the range of pick speeds used in practice, and the mean cutting force will be independent of speed.

3. Depth of cut - Mean force increases roughly in direct proportion to depth of cut.

4. Cutting efficiency - Efficiency can be measured in terms of specific energy, defined as the amount of energy required to break unit weight of coal. It is found that this parameter decreases continuously as depth of cut increases, although the rate of decrease gradually becomes less marked.

5. Coal type - From experiments in which the mean peak cutting forces were examined in relation to various aspects of coal strength, it was concluded that the force is closely related to the tensile strength of the coal.

The ratio mean peak cutting force/mean cutting force has been found to vary a little according to the coal and the attendent circumstances, but a rough representative ratio is about 2·5:1.

6. Characteristic angles of picks - The effect on cutting of varying the characteristic angles of a pick is of great importance in designing effective picks.

For a clearance angle of zero or thereabouts, both mean cutting force and mean normal force are unusually large, presumably due to frictional rubbing between the coal and the back of the pick.

At a clearance angle of 5 degrees this effect disappears and the forces for larger angles are virtually independent of clearance angle.

The rake angle cannot be made too large in practice as the pick becomes structurally weak. Moreover, by the time the rake angle has been increased to 30 degrees most of the possible benefits in reduction of cutting force have been attained. An angle of 30 degrees is therefore suggested as a target for practical attainment, associated with a clearance angle of 5 degrees. For a sharp pick of this design the normal force would be effectively zero.

7. Side play - A wedge breaks coal out sideways, as well as in the direction of motion. This 'side splay' is important, as it enables an array of isolated blades to take off a strip of coal, the breakage pattern extending over the region between the blades. It has been found that for efficient

breakage the depth of cut should be about equal to the width of the wedge, and the distance between consecutive blades should be about twice the depth of cut (Figure 15).

8. Theory of cutting and ploughing action - A theory has been suggested for the action of cutting or ploughing in terms of the concept of tensile breakage in the coal. The expression for cutting force for a sharp wedge is:

$$P = 2td \frac{\sin(\theta + \phi)}{1 - \sin(\theta + \phi)}$$

where: P - Peak cutting force per unit width of wedge (i.e., per unit distance at right-angles to the diagram in Figure 10a),

t - tensile strength of coal,

d - depth of cut,

θ - semi-angle of wedge (Figure 10a),

ϕ - angle of friction between coal and steel.

The tensile theory of breakage has been employed to deduce other important results in relation to ploughing.

(a) An estimate has been made of the energy required to break coal by an impulsive blow. For hard British coals this has turned out to be of the order of 10,000 ft lb -- much higher than had ever previously been comtemplated for this purpose and virtually prohibitively difficult to attain in practice. A small blow is likely to be ineffective by pulverizing the coal instead of breaking it by wedge action.

(b) It has been deduced that a simple wedge is probably at least as effective in breaking coal as blades of more complicated shape. This finding has been confirmed in laboratory and underground experiments. As a consequence, in recent years cutting picks and plough blades have undergone a radical simplification in design, and a considerable measure of standardization has been achieved.

38. Measurement of Cutting Tool Forces During Coal Winning 312.100/00-1

The detailed study of a type of coal-winning machine known as the rapid plough culminated in the requirement for a research machine which was to be essentially similar to a standard plough but which would incorporate such features as variable blade disposition and measurement of three force components on each blade.

Special blade holders have been designed which incorporate tri-axial strain-gage force transducers. The calibration of these transducers and the compensation of interactions between force components are described. These blade holders are attached to the plough head which may carry from eight to fourteen transducers. In addition, the lid of the plough head, which is a hollow fabrication, forms a suspended-plate transducer for the measurement of forces on an individual blade used to bring down top coal, and two uni-axial transducers, incorporating semi-conductor strain gages, measure the forces in the chains hauling the plough along the coalface.

The electrical equipment associated with the strain-gage transducers is intrinsically safe, so that it presents no hazard where methane is present, and operates from four dry batteries. Much of the electronics is housed in the plough head and had to be designed to tolerate a severe environment. Normally, twenty-one forces are measured on this plough but only nine can be recorded and selection of these is made at the plough head. The difficulties of transmitting these signals from a plough moving at some 60 ft/min along a coalface 200 yards long are discussed.

This machine has been used in two full-scale production trials totaling more than six months of underground work. The trials have shown that blade shape and blade disposition can have important effects on both the cutting efficiency and the steering of coal ploughs. Some of the results are presented in detail.

Although this article does not discuss bit design, some of the instrumentation techniques may be of interest in other test programs.

39. Coal Breakage: The Size Distribution of the Dust 314.000/52-1

This report describes a study of the size distribution of the fine (subsieve) dust formed in breaking coal. A study of the size distribution of the larger products of breakage in the sieve range is described in an earlier report from this laboratory (1). The object of the present work was to determine whether the formation of fine dust appears as an extension of the breakage patterns found with the larger sizes or if it appears to be an independent process. A further part of the work was to compare the size distributions obtained in the laboratory with those known to exist in airborne dust clouds in coal mines.

From the work described, there seems to be no doubt that the fine dust is an integral part of the normal 'breakage pattern,' and there is no evidence that any independent process of 'dust formation' is involved. This conclusion is supported by the fact that the size distribution of breakage products continues down as a 'smooth spectrum' to 1 micron, and also by study of the results of the investigation of particle shape. This remains almost constant throughout the range examined; in addition, particles smaller than this range (3000 - 6.6 microns) look the same down to sizes smaller than 1 micron where the effect of resolution limit makes accurate observation of shape impossible.

The constancy of size distribution of the breakage products has been demonstrated, and appears to be independent of breakage method, and type of coal and 'direction of breakage.' This size distribution conforms to the form $\frac{\Delta F_N}{\Delta D} = \frac{a}{D^{3.25}}$. If the removal of larger particles by settlement is taken into account, the distribution agrees extremely well with that observed by other workers in underground airborne coal dust clouds. Extrapolation of the size distribution curve to very small particle sizes indicates that the component of very small particles in some underground dust clouds, noted by Wynn and Dawes, is, in fact, part of the normal distribution.

42. Mechanical Properties of Non-Metallic Brittle Materials 314.000/58-4

Studies have been made of the mechanics of dust formation and of the size distributions of the fine dust particles arising from the breakage of coals and various coal-measure rocks. The objects of these experiments have been to find out more of the origin of dust, in particular the potentially airborne particles in the respirable size range, and to provide basic information as to the production of dust in various mining processes and the effect of changes in their operating conditions on dust formation. This paper gives an outline of the results of these laboratory experiments and indicates their correlation with theory and with observed dust conditions in coal mines.

The size distribution of the finer products of breakage is a function of the material but is largely independent of the method of breakage, being in fact part of a 'natural' distribution whose upper size limit is set by the experimental conditions. There is no evidence that the micron-sized dust is produced by any process which can be controlled independently from that giving rise to the coarser sizes.

It has been found that for particle sizes below about 76 microns (200 mesh B.S.), irrespective of breakage process, the breakage products from several coals and coal-measure rocks conform to a power law frequency distribution of form given by the expression

$$\frac{dF_N}{dD} = \frac{\alpha}{D^{\beta}}$$

For coal the value of β appears to be approximately equal to 2·25. For the three coal-measure rocks examined β has greater values, in the range 2·7 - 3·1. These experimental results are in good agreement with frequency distributions deduced from the 'weakest-link' theory of breakage. Observations of the frequency distributions of airborne dust clouds in coal mines are also compatible with the laboratory results.

The amount of fine debris produced in a given breakage process, such as rotary drilling or coal cutting, although of a constant size distribution pattern, can be altered between wide limits by modifying the operating conditions, such as penetration per revolution in drilling, and haulage speed in coal cutting.

The amount of fine dust produced when a given amount of work is carried out on coal, for example in a shatter test apparatus, is inversely proportional to coal strength. The amount of airborne dust dispersed during a breakage process, under conditions where there is little external air movement, varies only slightly between coals of different strengths, because, although weaker coals produce more dust, stronger coals break more violently, causing a greater proportion of the fines formed to be dispersed than with the weaker coals.

44. Experiments in Dust Control with the Mk.II (Joy-Sullivan) Ripping Machine 314.000/65-7

This report describes experimental work on dust control with the Mk.I (prototype and Mk.II (Joy-Sullivan) ripping machines in their development phases and with the latter machine in routine use in various collieries. Experiments are still in progress, both with this and with other ripping machines, so that this is really an interim report; it is of particular interest, however, in that it describes work with one of the few commercial mining machines in which the control of dust has been considered during the machine design stage.

It is disappointing not to be able to record a story of complete success in dealing with the dust problem of the Mk.II (Joy-Sullivan) Ripping Machine but work in this field is continuing at the Mining Research Establishment.

Conclusions which can be drawn from the work described in this report are as follows:

(a) To minimize the production of fine dust, the depth of cut by each pick must be as great as possible, achieved by sumping-in and cutting-over in the least possible time.

(b) The use of lower pick speeds is of considerable advantage because it gives less dispersion of the fine dust produced and because a larger pick penetration can be obtained without the excessive rate of make of debris associated with a very short cutting-over time. A reduction of pick speed from 280 ft/min to 180 ft/min probably gives in practice a 50 percent reduction in respirable dust dispersion.

(c) The reduction in dispersion of respirable dust provided by pick-face flushing is about 65 percent compared with dry cutting if the water fittings are in good condition.

(d) External sprays fitted to the radial arm (as designed by Central Engineering Establishment) suppress about 40 percent of the respirable dust. Although this is a lower efficiency than that obtainable from pick face flushing when working properly, it is possibly better than that given by the latter system in poor condition and

(e) The dispersion of dust from the sumping-in operation is not reduced either by the use of pick-face flushing jets directed on to the peripheral picks only or by the use of external water sprays.

The existence of machines in unsatisfactory condition after a relatively short time of use is disturbing. Rapid sumping-in and cutting over, needed to keep dust levels within reasonable limits, can obviously not be achieved when a large proportion of the picks are damaged or missing. The high dust make by the machine, even operating under favorable conditions, necessitates the use of a high efficiency suppression system and this cannot be obtained when there is poor maintenance leading to operation with picks missing and to consequential damage to water manifolds and other fittings.

In two ways at least the Mk.II (Joy-Sullivan) Ripping Machine cannot be said to be entirely pitworthy. The use of a large number of small picks does not encourage frequent inspection and replacement; fewer larger picks would not suffer from this defect and would probably last longer and give rise to less dust. In addition, the water fittings on the drums, which have to be fairly complicated because of the large number of picks, are not sufficiently robust and are placed in vulnerable positions. Clearly it would be advantageous for changes to be made in these features of the machine. At the same time water should be fed to the faces of the picks on the drum faces also in order to provide effective dust suppression during sumping-in. The use of an even slower pick speed than 180 ft/min could well give further reductions in dust dispersion.

The dust concentration downwind of a ripping machine is always high but since the machine is normally operated for only a fraction of the working shift the effect on shift mean concentration need not necessarily be excessive. As will have been apparent in the results given in this report, however, when long cutting-over times are unavoidable, possibly because of very hard rock or where water cannot be used for dust suppression purposes, other techniques of dust control must be employed. The Mining Research Establishment is carrying out both laboratory and field experiments into the use of extraction ventilation with dust removal by filtration for this purpose.

47. The Hoy Hollow Pick 314.000/67-3

This article gives a brief description of a new hollow pick with the following technical features:

1. A quick-release "large pick," simple in construction, low cost and easy to handle underground.

2. Provision of water at the pick-point at any desired angle.

3. Complete rigidity of pick and pickholder.

4. Morse taper for positive lock and massive strength.

5. Pick protects toolholder for maximum toolholder life.

6. Positive positioning of pick.

7. Location-pin eliminates accidental pick losses.

8. Water reservoir in pick.

9. Simplicity and lightness (12 oz).

Based on field trials, the bits have proved to be mechanically sound, have indicated a marked improvement in dust suppression, and substantial savings in pick cost/ton.

50. <u>An Attempt to Devise New Cutter Pick Designs and Lacing Board Patterns</u> 314.000/65-5

The cutting tools produced by Polish manufacturers for use in coal-getting machines are used for extracting coal of varying physical-mechanical and mining properties.

When used under good strata conditions for coals without hard mineral inclusions the cutter picks as at present produced are perfectly adequate for their work. However, concretions of pyrites or sphero-siderites are repeatedly found in the coal seams and on meeting these hard minerals the picks will usually suffer damage to the carbide tip or fracture of the shank. The reason for this kind of damage is the incidence of heavy dynamic loads on the blade at the moment of its contact with these hard minerals.

After having carefully studied the work of picks reinforced with sintered carbide tips of rounded and flat shape, and having then conducted extensive laboratory experimentation, we undertook the task of devising cutting tools that would be more robust in action against hard rocks.

The following conclusions can be drawn from the test program hereinover described:

1. Variation of rake angle within limits of $\pm$ 5 degrees has no appreciable effect on the magnitude of the force on the lines nor on the power consumption. Therefore, from the standpoint of blade strength it would be best to select a pick with a negative rake angle.

2. The pick lacings examined had no noticeable effect on the haulage force in the lines.

3. Use of a reduced pattern lowers the mean load on the motor.

4. For working inhomogeneous rocks, the best design from the standpoint of wear is offered by rounded-tipped picks; flat-tipped picks should however be used for more homogeneous rocks since they generate a lesser cutting resistance than do round tips.

5. The present series of tests do not permit any conclusions to be drawn regarding the effect on tool life of conferring extra flexibility on the pick-points; this aspect will need to be further investigated.

53. <u>Large-pick Drum</u> 314.000/70-5

This issue contains two articles pertaining to bits.

1. Tool Wear and Performance - discusses but does not give details on research being done on tool wear by MRDE. It briefly indicates the following results.

a. On simple wedge shape tools a flat surface develops parallel to cutting direction which increases cutting forces.

b. Design features to give efficient cutting when sharp do not necessarily give best performance when worn.

c. The width of the wear flat is a function of the distance cut and not of tool width.

2. Large-pick drum - discusses the experience of mining companies using the new large-pick drum. It has generally been successful, giving less dust and equal or lower bit cost.

54. New Bit Designs Contribute to Lower-Cost Coal Cutting 314.000/58-2

This article summarizes the results of tests on rectangular shank, flat cutter bits to determine the best tip configuration. Results indicated that the best configuration was a negative 10 degree rake angle and a 10 degree relief angle with benefits as follows:

1. Lower overall cutting cost.
2. Greatly reduce tool breakage.
3. Not require more electrical energy per ton.
4. Not increase the amount of fine coal.
5. Keep tools sharp longer.
6. Decrease cutting time.
7. Reduce downtime through fewer tool changes.
8. Permit use of harder grades of carbide.

56. Development of Impact Ripping 314.000/72-1

This article describes the development and testing of a mining machine using a single pick on an impact tool for use in areas not suitable for rotating head miners. Although not specifically concerned with bits, the basic concept may provide the basis for future developments. The conclusions from these tests are as follows:

1. Equipment is now available for ripping medium-hard rock, i.e., rock that can be cut by picked machines, even when it contains ironstone bands or nodules which would normally prevent the use of picks. This equipment could also be used for ripping well laminated and cleated hard rock. In such conditions the ripping could be advanced at rates sufficient for the majority of advancing longwall faces over the next five years.

2. For truly hard rock rips the indications are that eventually it will be possible to advance these at a suitable rate provided that a sufficiently high-energy impact unit is utilized with a heavy-duty boom and stable chassis.

3. Provided the impact units are mounted on equipment which allows the tools to be presented to the rock at various angles of attack, the roadway can be profiled with reasonable accuracy.

4. The mounting of the impact units on to machines by means of booms or arms maintains the best possible face access and is suitable for use with all known dirt disposal systems, provided the debris sizing is suitably controlled.

5. It appears likely, although this has not yet been proved, that with further development of tool shapes it will be possible to control debris sizing for all dirt disposal devices.

6. With the further development of tool shapes to improve the efficiency of the rock breakage operation the dust make from impact rippers can be restricted to a level significantly below that currently produced by pick-type machines. Dust can be further controlled by the application of water sprays around the impact tool.

7. The impact breakage of rock is most unlikely to cause incentive sparking when working in abrasive rock conditions.

8. The ability of an impact unit to work in situations similar to the half-gate ripping system, where rock or coal has to be removed from the floor, has not yet been proved. However, the advantages to be gained are such that considerable efforts will be made to ensure success.

9. The trend towards smaller and less costly ripping machines will continue.

10. The coal industry must benefit from the tremendous amount of technical and commercial activity which is now taking place on impact ripping and from which we are now confident will emerge several long-term products to provide safe and economic operations at the face-ends.

61. A Laboratory Study of the Effect of Cutting Speed on the Performance of Two Coal Cutter Picks — Part I 314.000/63-3, Part II 314.000/63-2

In recent years there has been a general tendency in longwall working to increase the speed at which machines progress along the coal face, with a consequent increase in the power demands. For machines which utilize coal cutter picks mounted in chains, on revolving drums, or on cutting heads of various designs, an increase in machine speed results in an increase in depth of penetration of individual picks into the coal. This in turn results in an increase in the force acting on an individual pick, approximately proportional to the increased depth of penetration, with a consequent greater risk of damage or breakage. In addition, there is the danger that if the depth of penetration becomes too great there will be inefficient clearance of the gummings, leading to a very rapid rise in power consumption. A simple means of overcoming these problems which is often adopted is to increase the pick speed, which has the effect of reducing the depth of cut. In this sense pick speed has a profound effect on the operation of a cutting machine, but it is not known whether the action of an individual pick in grooving coal is affected by its speed.

The work described here was carried out to determine whether an increase in pick speed was itself likely to have an important effect on pick performance, using a range of speeds and depths of cut normally attained in practice.

The apparatus used is shown in Figure 1, consisted essentially of a hydraulically-operated ram, which carries a cross-head moving between two slide bars. The ram has a stroke of 5 ft, and during operation it accelerates to a selected speed over the first foot, maintains a constant speed over the next two feet, and decelerates to rest over the remaining distance. The speed attained during the constant speed portion of the cycle can be varied between limits of 40-600 ft/min. The picks were mounted in a tool holder which was bolted to the cross-head of the ram. The coal specimen was mounted in a framework, positioned so that the pick would cut a groove of the required depth, and held in place by a hydraulic jack.

The duckbill pick, produced by machining, had a tip of similar design to that of a typical forged pick, with a rake angle of 27 degrees, and a back clearance angle of 30 degrees, but its tip was arranged to lie on the longitudinal axis of the shank to facilitate the cutting force measurement. The cutting edge was rounded to remove the very sharp edge produced by the machining processes, so as to simulate a forged pick, the cutting edge of which is severely blunted by the removal of the "flash" produced during forging. A subsidiary programme of cuts established that the experimental pick required a cutting force not significantly different from that required for a proprietary forged pick. The straight bar pick was a proprietary pick with a sintered tungsten carbide tip, having a rake angle of 8 degrees, and a back clearance angle of 9 degrees. In its manufactured condition the pick had a tongue of metal in front of the carbide tip which was partially filed away exposing the carbide to a distance of about 1/4 in. Additionally, part of the pick shank was removed, to enable the tip to lie on the longitudinal axis of the tool holder.

The important conclusion was that variations in the cutting speed, over the range 200-600 ft/min did not affect the mean cutting force, specific work, or percentage fines. It is considered probable that for the range of speeds envisaged for cutter chains, changes in speed alone are unlikely to modify the breakage process sufficiently to affect the quantities measured.

The mean cutting force was practically proportional to the depth of cut. The intrusion of the tongue of metal, covering the tungsten carbide tip of the straight bar pick, resulted in the cutting force being approximately doubled at a given depth. The duckbill pick was equally effective in both coals, in that it required approximately the same force, because its good wedging action was able to exploit the well developed cleating. The straight bar pick was at a disadvantage in Dunsil with larger forces than in Garw, because its crushing action resulted in a difference in force which was a reflection of the difference in crushing strength of the coals.

Generally speaking there was an increase in cutting efficiency as the depth of cut became greater, which is reflected in a decrease in both specific work and in the percentage fines. The intervention of the tongue of metal of the straight bar pick, however, resulted in a reduction of efficiency at deeper cuts opposing the usual improvement, with the result that in Garw there was no increase in efficiency with increasing depth, and there was even a reduction at greater depths in Dunsil. The percentage fines for the straight bar pick, however, still showed a fall with increasing depth, and this may be because much of the extra energy is utilized in crushing still finer coal which was already less than 1/16 in.

The straight bar pick showed to advantage in the friable Garw with greater cutting efficiency (lower specific work), because of its greater bursting action; in the more compact Dunsil coal, however, the duckbill pick was more efficient, because of its better wedging action. From the point of view of percentage fines there was little difference between the picks in the friable Garw, but the duckbill pick had the merit of producing a lower percentage in Dunsil.

In general, the results showed no evidence of any difference between the two cleat directions used in Dunsil coal (0 degrees and 90 degrees). The only exception was for mean cutting force, which was higher for the 90-degree direction than for the 0-degree direction for the straight bar pick only.

62. A Study of the Forces Acting on a Single Coal Cutter Pick 314.000/62-10

The work described in the report concerns laboratory investigations in which a groove was cut in specimens of Teversal Dunsil coal using a standard forged pick and a straight-bar pick with a tungsten carbide insert. The object of the work was to examine the effects of variations in cutting speed and depth of cut on pick performance. Measurements were made of the cutting force required, and the coal produced from the cut was weighed and sized.

In agreement with the earlier work with Garw coal it was found that, over the range of speeds examined (200 to 600 ft/min), the cutting speed had no significant effect on either the basic measurements of mean cutting force, total weight of coal and weight of fines or on the quantities derived from them, viz. specific energy consumption, percentage fines, and the degree of breakout from the geometric cut.

As with Garw coal the mean cutting force was found to increase in approximately direct proportion to the depth of cut, and again it was observed that with the straight-bar pick the rate of this linear increase was approximately doubled when the depth of cut increased beyond the point at which the tongue of metal in front of the tungsten carbide tip became engaged in the cut. The effect of this tongue in impairing cutting efficiency was shown in the increase in specific energy with depth of cut observed with the straight-bar pick, in place of the more usual decrease that was obtained with the standard pick.

Comparison with the earlier work on Garw coal showed that the better wedging action of the standard pick was an advantage in the compact, though cleated, Dunsil coal, whereas the more pronounced crushing action of the straight-bar pick was not detrimental in the friable Garw coal.

The conclusions from these tests are:

1. The primary objective of the work was to examine the effect of cutting speed, and the results showed clearly that, over the range 200-600 ft/min,

speed had no significant effect on the mean cutting force, the weight and sizing of the coal cut, nor on any of the quantities derived from these basic measurements.

2. Apart from a marginally significant increase in cutting force when the straight-bar pick was cutting at right angles to the main cleat over that when cutting parallel to the cleat, the cleat direction had no effect on any of the measured quantities (cutting force, weight of product and weight of fines) nor on the derived quantities, breakout factor, percentage fines and specific energy.

3. Increasing the depth of the cut taken by the pick had the following effects:

a. The mean cutting force increased.

b. The total weight of coal cut increased at an increasing rate.

c. The weight of fines (< 1/16 in.) increased linearly for the straight-bar pick but at an increasing rate (although less rapidly than the total weight of coal) for the standard pick.

d. The specific energy showed a decrease for the standard pick, but an increase for the straight-bar pick.

e. The percentage fines (< 1/16 in.) decreased.

4. Breaking out of the coal beyond the volume swept by the tip of the pick was largely independent of depth, and was of equal extent for both picks.

5. The variation of mean cutting force with depth of cut was approximately linear and proportional to depth, except where pick configuration showed a marked change with depth as for the straight-bar pick on which the tungsten carbide tip was covered by a tongue of shank metal from 0·28 in. from the end. Even in the latter case a satisfactory representation of the results was given by a combination of two straight lines, one of low slope for the shallow cuts, and one of much greater slope for the deeper cuts in which the tongue played a harmful part.

6. Comparison of the specific energies for the two picks shows that the values are comparable at the shallower cuts, but that the straight-bar pick requires a much greater energy at the deeper cuts, where the intrusion of the shank metal mars the efficient cutting of the tip.

7. The results for both picks show a good correlation between the energy required in cutting and the weight of fine coal produced, except for the deeper cuts with the straight-bar pick when the intrusion of the tongue of shank metal uses energy in secondary crushing.

8. In general the findings of the present investigation using Dunsil coal confirmed those obtained in the earlier work using Garw coal. A point of contrast, however, was that the standard pick, with its better wedging action showed to advantage in the compact, though cleated, Dunsil coal,

whereas the greater crushing action of the straight-bar pick was not detrimental in the friable Garw coal.

65. Breakage of Coal by Wedge Action 230.000/63-1

Part I - Factors Influencing Breakage by any given Shape of Tool

Most coal is broken from the seam by some form of wedge action. This is equally true of breakage by coal ploughs, by pick machines such as shearers or trepanners or by impact from a hand-held jigger pick. It follows that a knowledge of the mechanics of breakage of coal by wedge action should result in a greater mining efficiency. Such a knowledge can be obtained from "underground experience" which takes years to acquire, or from a combination of laboratory tests coupled with properly instrumented underground studies of coal winning machines. The latter is the better way to obtain this information, the many different aspects of wedge breakage being studied systematically.

The factors that affect wedge breakage fall roughly into two categories. There are those that affect breakage by any given shape or type of blade, and there are those that affect tool design. The first part of this paper is concerned with those factors that are not primarily concerned with tool shape. These include:

1. The mechanical properties of the coal.
2. The cleat orientation.
3. The depth of cut.
4. The speed of cut.
5. The size of tool.
6. The width of cut.
7. The pressure from the overbearing strata acting on the coal.
8. The effect of relief from other picks cutting in an array.
9. Breakage by impact.

These factors have been studied in laboratory experiments in which cuts have been made in rectangular blocks of coal of various types. The same basic technique has been used throughout, although a number of slightly different test rigs have been used. Moreover, as the paper is based on many different experiments, definition of large and small coal is not consistent throughout, but the conclusions are not affected in any way.

The basic experimental arrangement consisted of a rectangular block of coal, which has been machined from a larger parent lump of run of mine coal clamped on to a heavy steel table that can be driven horizontally by an electric motor. The steel table passes under a gantry which supports a cutting tool. A groove can be cut in the top surface of the coal by suitably adjusting the height of the upper coal surface relative to the tool edge.

A dynamometer, fitted with electrical resistance strain gages, is used to record the forces acting continuously on the cutting tool. In many of the experiments three orthogonal components of the grooving force were measured, in the cutting direction, normal to the surface of the coal and sideways on the pick. This was not always true, and in some of the tests only the first or the first two components were measured.

The rectangular coal blocks were always machined and mounted on the tables so that cuts were made in predetermined directions relative to the bedding and cleat planes. The majority of the cuts were made parallel to the bedding planes and perpendicular to or parallel to the main cleat. The pressure between the steel plates used to hold the specimens on the table was of the order of 50 psi unless it is otherwise stated.

The results given and discussed in this paper were obtained from a large number of individual experiments, and for convenience the factors are being considered in the following sequence.

1. Depth of cut.
2. Coal properties.
3. Tool size.
4. Other factors.
5. Impact breakage.

This paper has outlined some of the principal factors that affect breakage of coal by pick action. The second part will deal with other factors that affect tool design. These factors include the basic shape of the tools and the effects of wear on tool performance. However, before considering tool design it is worthwhile considering the implications of the findings reported so far. These may be summarized as follows:

1. Shallow cuts (low pick penetrations) are highly inefficient and produce small coal and hence an abundance of dust.

2. Cutting efficiency (reciprocal of work done per unit coal yield) increases with increase in depth of cut.

3. The most efficient orientation of the cleats during cutting is 45 degrees to the line of attack, mean cutting forces being low and coal yield high. Cleat orientation has little bearing on trepanners and shearers where much of the cutting is done perpendicular to the bedding planes.

4. Provided the size and shape of the cutting tool are such that the channel of coal actually extracted is greater than and independent of the area swept by the tool, tool size does not affect the forces needed to groove a strong coal significantly, while it has a large effect on cutting friable coals. In terms of cutting efficiency, however, the size of tool used in the friable coal is not important, while large tools and deep cuts lead to improved efficiency in cutting strong coals.

5. Pick speed does not affect cutting forces or coal yield significantly, although high pick speeds can throw additional dust into the airstream.

6. Pressure from the overbearing strata can either weaken or strengthen coal at the face, so that throwing extra weight on the face will in some cases ease coal winning while in others it will make it more difficult.

7. Picks cutting in an array help one another, provided the penetration by individual picks is 1/3 - 1/2 the line spacing. Moreover wide line spacings, and therefore deep cuts, are more efficient than the converse of shallow cuts from closely spaced picks.

8. Deepening an existing groove is highly inefficient, requires much higher forces than cutting the same depth of cut in a plane surface, and results in severe coring or ridging of the coal.

9. Breakage by impact can be as efficient as continuous cutting but if the blows are either too light or too heavy efficiency suffers. If the blows are too light, repeated impacts will not cause breakage, no matter how many blows are applied.

10. Impacts of the order of 3,000 ft-lb are needed to ensure the breakage of a 6 in. by 6 in. section from a strong coal, such as Barnsley Hards.

11. The strength characteristic that appears to control the breakage forces closely is tensile strength, but as cleat orientation and overburden pressure affect breakage forces, care must be taken in predicting breakage forces from laboratory strength measurements.

The general conclusion from these experiments, therefore, is that mining machines should be designed to take as deep a cut with each pick as is compatible with the strength of the picks and the strength and stability of the machine. The depth of cut taken by the picks defines the optimum spacing between adjacent lines of picks, which is two to three times the depth of cut.

The combination of a deep cut and a wide line spacing is ideal for the production of large sizes of coal and small quantities of dust. Many of the existing machines are unsuitable for use with large picks, since machine vibration or the high pick forces cannot be tolerated. There is, however, an optimum arrangement of picks on these machines, and the minimum number of picks should be used. An over picked machine could even have greater loads on each pick, in view of the coring that takes place, than would be observed if some of the picks were removed.

Part II - Factors Affecting Tool Design 314.000/64-3

It was shown in the first part of this paper that for efficient coal cutting, machines should be designed with widely spaced picks which bite deeply into the coal. In this way the size of the product is larger and the formation of fines is smaller than from a machine that contains a greater density of picks, and the cutting efficiency is high. No consideration was given to tool design, however, and the present paper describes work that has been undertaken at the Mining Research Establishment to find the most efficient designs of cutting tool. Cutting efficiency cannot be separated from the effects of tool wear and some aspects of wear are also considered.

The same basic types of experiment were undertaken as those described in the first part of the paper. Single grooves were cut into a plane surface of a rectangular block of coal by wedges and cutting tools of different design. The forces acting on the tools were measured and related to the quantity and sizes of coal extracted. In all of the experiments, cuts were made in specified directions relative to the bedding and cleat planes. Most of the cuts were made parallel to the bedding planes and perpendicular to the main cleat.

At this point it is worth summarizing the findings from the laboratory experiments on pick design.

1. The back clearance angle should be not less than 6 degrees, but neither should it be much greater than this to avoid weakening the tip needlessly. There should also be side clearance of at least 3 degrees.

2. The front rake angle should be as large as possible commensurate with a tolerable amount of pick wear.

3. Broad picks are better than pointed ones, but if for some reason pointed picks are used a radius of at least 1/16 in. should be ground on the tip.

4. A ridge on the front face of a pick brings no advantage and for strong coals (such as Barnsley Hards) can have a deleterious effect on cutting efficiency. This is equally true for chisel edged and for pointed tools.

5. A pencil point pick is a highly inefficient cutting tool, particularly if there is a negative clearance angle between the tip point and the back of the pick.

Were it not for considerations of tool wear it would now be possible to design an "ideal pick" based on the recommendations listed above. However, in practice some of the most highly efficient picks have a very weak tip, wear rapidly and quickly lose their superiority over other pick shapes. Some studies of the influence of pick wear on cutting performance have recently been made, but the experiments are not sufficiently advanced to enable generally applicable conclusions to be reported. The experiments completed so far are:

1. A study of the forces needed to initiate cracks in coal with symmetrical wedges, blunted by grinding known radii on the tips.

2. A study of the cutting forces on picks blunted by grinding known lengths of flat parallel to the tool path and perpendicular to the rake face.

The second series of experiments showed that blunting perpendicular to the rake face has a much larger effect on both the cutting and the normal forces than does blunting parallel to the tool path.

The experiments were extended to study the effect of variation in the widths of the wear lands either perpendicular to the rake face or parallel to the direction of cutting. Variation in the length parallel to the direction of cutting did not produce any consistent effect.

The two papers on the breakage of coal by wedge action have summarized some of the basic experiments that have been undertaken to find the best designs of picks and the best ways to use them.

It is worth remembering that, in general, efficient cutting implies not only the utilization of the minimum amount of energy, but also the formation of the minimum amount of fine coal for the particular pattern of picks and depths of cut that are being employed. It follows that good tool design should be married to the good design of the "cutting heads" on mining machines. Data are now available, both experimentally and theoretically, which permit the calculation to be made of the forces that are likely to be encountered by the cutting head. The first stage in the design of a new machine should therefore be the consideration of the cutting elements on the machine. Only when a satisfactory pattern has been evolved should the provision of power and the design of the machine structure be considered in detail. All too often the reverse procedure is adopted and the cutting elements are attached to a motor assembly and power is either wasted and the coal is needlessly degraded or the machine is under-powered and so is useless.

On the other hand, consideration of the conclusion from this work should enable existing machines to be operated with greater efficiency.

67. Mechanical Properties of Non-Metallic Brittle Materials 314.000/58-1

A logical development from the quasi-static wedge penetration experiments, in which a two-dimensional study was made of the relationships between load and depth of penetration of simple wedges into coal, is to consider the forces and energies needed to cut grooves into a plane surface of prepared rectangular blocks of coal by the action of slow-moving wedges. This may be considered as an idealized investigation of coal ploughing provided the bedding planes and cleats are suitably orientated in the laboratory experiments.

Coal in the seam is subjected to compressive stresses caused by the overbearing strata and the magnitude of these stresses likely to affect the forces needed to extract the coal from the seam. Unfortunately these stresses vary from one place to another in a single seam and even along a single face it is difficult if not impossible to undertake experiments underground in which the stresses on the coal are accurately known. Laboratory experiments are described in this report in which grooves have been channelled into blocks of coal subjected to uniaxial compressive loads, applied normally to the bedding planes, in an attempt to understand possible effects that might occur for different conditions of coal stressing by the overburden. Since the effect of a uniaxial compressive load is likely to vary with distance from the free surfaces of a rectangular block grooves of various depth have been considered.

The tools used in these experiments were all steel wedge type with a rake angle of 55 degrees, a wedge angle of 30 degrees, and a clearance angle of 5 degrees.

Three coals with distinctive mechanical properties were used as follows:

Rossington, Barnsley Hards, a strong, dull and relatively cleat-free bituminous coal.

Oakdale, Meadow Seam, an extremely friable metallurgical coking coal.

Deep Duffryn, Five Feet Seam, a friable dry steam coal.

The mean peak loads necessary to cut grooves in rectangular blocks of Barnsley Hards increase with lateral pressure over the range studied. For the two friable South Wales coals the mean peak loads decrease markedly from maxima as the lateral stresses approach the compressive strength of the coals. The maximum peak forces which occur at about 500 lb/in.^{2} for Oakdale coal and 750 lb/in.^{2} for Deep Duffryn coal are between 50 and 100 percent higher than those at zero lateral pressure. It is suggested that this may afford an explanation of why some coals are alleged to work more easily if the overburden stresses in the coal are increased, whereas the converse is true for other coals.

For all coals studied an initial decrease in the amount of energy needed to cut a specified quantity of coal with increasing depth of cut is followed by a subsequent increase in energy consumption. This is accompanied by an initial decrease and subsequent increase in the production of fine coal. This is attributed to a change in the mode of breakage from one in which cracks run freely to the surface for the most efficient cuts to one where the propagation of the cracks is inhibited and localized crushing occurs in the vicinity of the wedge. This increases the percentage fines and reduces the cutting efficiency.

68. Laboratory Investigations of Cutting Processes Applied to Coal-Winning Machines — 314.000/68-1

The excavation of naturally occurring minerals has been mechanized almost completely, both at surface level (during open-cast working) and underground, and the fracture processes have been studied in experiments designed to provide basic design data for the rock- or coal-winning machines. The ultimate objective of the investigation is the design of cutting tools and cutting-tool patterns for efficient breakage of rock or coal. This will include not only tool-shape studies, but knowledge of size effects as well.

The problem was tackled from a fundamental standpoint and the original questions posed were concerned with scaling effects that might influence the application of measurements made on models to full-scale working. As the work was directed primarily towards improving the efficient extraction of coal from the seam the basic raw material was coal or, to be more precise, types of coal selected to be representative of the principal sources of coal in the United Kingdom.

These coals were broken by simple stress systems (uniaxial compression or tension) and the effect of specimen size on the strength was measured (I).

The main conclusions to be drawn from the single-pick experiments are that cutting efficiency generally benefits from the use of large tools to take a deep bite into the solid. These tools should approximate to simple chisel with as large a front rake angle as practicable and with a back clearance angle of a little more than 5 degrees. The included angle of the tip will dominate the tip strength, so that there are limits to the magnitude of the rake angle that can be used.

Other facets of tool geometry have been studied, but the results have in no way conflicted with these broad principles of efficient cutting.

Before extending the work to practical breakage problems, it is worthwhile restating the main conclusions from the laboratory studies.

Tool Shape - Ideally, cutting tools should be chisel-shaped with a large front rake angle and a back clearance of 5-10 degrees.

Tool Size - The specific energy required to break a strong coal is lower with a large tool making a proportionately deep cut, while in a weaker coal tool scale has less effect. The use of a large tool favorably affects the product size and the formation of dust for both strong and weak coals.

Depth of Cut - Deep cuts are more efficient than shallow ones with the same size of tool.

Tool Spacing - When tools cut in an array the minimum energy required to cut a given volume of coal, for a given depth of cut, occurs when the depth of cut is equal to one-third to one-half of the space between adjacent picks in the pattern, a few deep cuts widely spaced being superior to a larger number of shallow cuts made closer together.

Experiments were undertaken to check the validity of these results in practice.

It has been shown that laboratory techniques enable the factors affecting efficient breakage of coal by pick action to be studied systematically, the scaling studies emphasizing the influence of the gross weaknesses in coal on the breakage processes. The results have been applied to operational machines and while good agreement is shown in instances where the machine power is used primarily in cutting the coal, the anticipated improvements from a better choice of pick, depth of cut, and line spacing can be masked when a considerable proportion of the available power is wasted in moving the broken coal from a confined space and in comminuting the extracted coal during the process.

72. A Comparison of Borer, Ripper, and Conventional Mining Products in Illinois No. 6 Seam Coal RI-7687

The Methane Control and the Respirable Dust Groups at the Twin Cities Mining Research Center (TCMRC) cooperated recently in obtaining production samples of approximately 1 ton each, from the loading conveyors of a ripper, a borer, and a loading machine in conventional development headings. These samples were sized, in four stages, from plus 4 in. to minus 10μm. The conventional product had the least fines of the three production methods. The borer product had more fines than did the ripper product, but it also had a greater amount of large pieces. All three products, as sampled, had essentially the same amount of minus 10-μm particles. Photomicrographs and surface-area comparisons were made. Gas-adsorption, surface-area determinations on particles under 37 μm give essentially the same value. Surface-area calculations, assuming spherical particles and no porosity, give a smaller area to the conventional product.

The conventionally mined coal sampled contained less total fines and less dust of aerofloat size than did either the borer or ripper product. Of the two machines, the borer produced more total fines and more dust of aerofloat size than did the ripper. The borer also produced a larger percentage of oversize pieces than did the ripper, probably because of the complex borer cutting mechanism. All three products as sampled contained the same percentage of minus 10-μm dust. No attempt was made to capture any aerofloat dust at the working face.

The gas-adsorption, surface-area determinations for the three products show some anomalies in two undersized ranges. When particles under 37 μm are measured, all show nearly the same value. For particles under 10 μm, the specific surface of the ripper product was twice that of the borer product, and the conventional mined coal was intermediate in value (Table 3).

If mining methods or breakage mechanisms would truly produce coal particles with different shape character (despite the "natural" fracture pattern), then, of course, particles of approximating cubic shape (ideally spherical) would have the lowest ratio of surface-area to unit weight. In microscopic analysis, however, all three types appear to be similar and curiously acicular. Further, specific surface determinations that use gas adsorption depend upon a monolayer of nitrogen gas being adsorbed, then totally desorbed. It is common in this analytical technique to express significantly different areas when they differ by more than 100 percent. It is tentatively concluded that all three coal production methods yield the same surface area within the size ranges tested; that is, a given mining method does not yield a particularly differently shaped coal particle.

The spherical-shape calculations for the total mined product (Table 4) show an even more diverse trend among the three coal production types. But they are for the total tonnage-sized sample, starting with 4-in. coal, and the trend supports the first concluding statements of this section; that is, the conventional product gives the smallest surface area.

The scanning electron micrographs appear to support the idea that coal has a natural breakage pattern, and that the three production methods yield no particular differences in shape.

As indicated before, the most important limitation of this study is that aerofloat dust was excluded from consideration in the size analyses. Therefore, it is not possible to use these data to compare respirable dust generation because dust must become airborne to become respirable. It is quite possible that the process that delivers the most dust of aerofloat or respirable size to the loading conveyor has, by nature of its cutting action, the least tendency to impel particles into the air.

Some error in the findings could also have resulted from uncontrolled variables such as bit sharpness, sump speed, variations in coal properties, and variations in roof pressures.

Data based on a sample from one machine on one shift cannot be considered statistically adequate. In this case, interference with coal production and logistical problems of handling larger samples precluded any replications.

A series of statistically designed experiments is obviously needed, one which would consider all current coal-extraction processes to determine the effect of operator and machine variables on product size. The measurement of aerofloat dust during these experiments is of paramount importance. Work is currently underway by the Bureau of Mines, both in-house and by contract to private industry, that will lead to such a series of experiments.

80. Machine and Cutting Design 314.000/70-2

This article deals specifically with the effect of bit design and mining machine design as related to respirable coal dust. It reviews the cutting theory of R. H. Goodrich who theorized that the action of a cutter bit in brittle material was a constantly repeating cycle of crushing and chip formation. This indicates that dust will be produced as long as a cutting action is used.

The factors which affect dust formation are:

1. Bit penetration (greater penetration lessens dust).
2. The kind of material mined.
3. The bit speed and penetration force available.

The general conclusions from tests made to verify cutting theory include:

1. Cutter element design is very complex and no single tool design will operate efficiently in all coal seams.

2. Some general rules can be followed in applying bits, as follows:

a. To optimize cutter efficiency, bit penetration must be maximized, therefore the number of bits should be minimized commensurate with bit strength and frequency of changing bits.

b. Keep bit velocity at as low a speed as possible, since high speeds cause greater dust entrainment.

c. Dull, broken, or missing bits dramatically increase the force necessary for cutter element penetration. Since only limited bit penetration force is available, the distance penetrated by each bit will decrease, causing more fines and lower production.

d. The relative position of the bit block, as it is welded to the cutter element, is very important. The bit must cut proper clearance so that the bit block will not rub on the face. Rubbing bit blocks will cause severe dust generation.

3. Some of the factors which affect dust exposure are:

a. Quantity of dust produced at the face.
b. Type of ventilation.
c. Quantity of ventilating air.
d. Type of coal.
e. Inherent moisture in the coal.
f. Quantity of dust in the incoming air.
g. Effectiveness of water usage or other dust suppression devices.

4. Bit design affects only one of these factors, the quantity of dust produced, and the only method to reduce the fines is to increase bit penetration.

81. Effect of Pick Shape on Cutting Forces 314.000/62-9

This paper describes the results of tests with wedge type picks to determine the effect of changes in clearance and rake angles.

In every instance in which the back clearance angle was zero the mean cutting force and the mean normal force were both large--in the range 50 lb to 300 lb per wt with Barnsley Hards, according to the rake angle and depth of cut being used. When the clearance angle was increased to 5 degrees the cutting force was reduced to approximately half, and further increase in clearance angle produced little or no further reduction. The effect of clearance angle on the normal force (thrusting the pick out of the coal) was similar though much more pronounced, the normal forces falling to near-zero and even negative values for the picks with the larger rake angles.

For picks with clearance angles of 5 degrees or more, an increase in rake angle produced a continuous decrease in both cutting and normal forces, rapid at first and then more gradual.

It was found that the decrease in cutting force was approximately 4:1 between the extremes of zero and 45 degrees, and approximately 3:1 between zero and 30 degrees. Thus most of the possible improvement over a pick with zero rake angle has been obtained by the time the rake angle has been increased to 30 degrees; further increase produces a lower return in terms of the absolute magnitude of the cutting force. However, a given increase in rake angle results in a large proportional decrease in cutting force even up to the largest rake angles used in this investigation.

The change in normal force with rake angle was on the whole smaller than that in cutting force, though it resulted in normal forces becoming negative for rake angles greater than about 20 degrees.

The amount of coal removed by a given depth of cut was virtually the same for all pick shapes, and so the energy used per unit of coal won varied with the angles in the same way as the cutting force.

These results can be explained satisfactorily by postulating the simple force system shown in Figure 3. The force Q acting at the extreme tip of the pick is small compared with P for the sharp-edged picks used in these experiments. Thus the cutting and normal forces will consist mainly of the resolved components of P and μP, where μ is the coefficient of friction between 0·2 and 0·4. It is easy to see that these calculated forces will vary with rake angle in the way found in the experiments.

Laboratory investigations have shown that the following recommendations on pick shape will lead to efficient pick action if the picks can be maintained in a sharp condition:

1. A back clearance angle of 5 degrees should be used.

2. The rake angle should be as large as possible. A value of 30 degrees should provide sufficient tip strength for most conditions and a larger angle may be practicable in easy cutting conditions. A reduction below 30 degrees should be made only when severe cutting conditions make it imperative.

3. The face of the tungsten carbide tip should be flat and should not be masked by any tongue of shank metal that might interfere with the cutting action of the tip or with the flow of broken coal away from the tip.

4. Until firm recommendations on the shape of the tip face can be given the usual duckbill shape should be retained.

VII. ABSTRACTS OF PERTINENT PATENTS FROM PATENT SEARCH

A patent search was conducted to determine the existence of any novel bit designs which claimed to reduce dust production. An analysis of the 34 patents received shows the following classification:

1. Eighteen for point attack bits.
2. Seven for rectangular shank cutter bits.
3. Two for diamond bits.
4. Two for core breakers.
5. Two for chain cutters.
6. One for a rotary cutter bit.
7. One for a carbide insert for cutting tools.
8. One for a mining machine rotary cutting bar.

A listing of all the patents reviewed is given in Appendix C-1.

None of the patents made any claim to reduce dust production. Most of the bit patents concerned the method of mounting the bits in the bit blocks and design of retaining pins or rings.

Four of the patents (copies included) did describe bits which could affect dust production, although they did not make such a claim. Abstracts of these patents are given below.

1. Patent 3,361,481, Rotating Cutter Bit - issued January 2, 1968

A cutter bit for a mining machine formed as a frustoconical head having a hard metal tip and a concentric reduced diameter shank mounted for free rotation in a cutter block socket. The conical head is provided with a plurality of spiral ribs to frictionally engage the material being mined to cause positive rotation of the cutter bit. The spiral ribs are uniform in cross-section throughout their length so that the furrows remaining between the ribs increase in width from the front to the rear of the bit.

2. Patent 3,476,438, Cutter Bit - issued November 4, 1969

The present invention provides for enhanced rotation of the cutter bit by the provision of a plurality of vanes or fins projecting radially from the peripheral surface of the head portion of the cutter bit. The fins extend from a position rearward of the hard cutting tip to a position forward of the cylindrical shank. The fins are adapted to form non-cutting frictional contact with the surface being cut. It has been found that the provision of such peripheral fins considerably enhances the free rotation of the bit in the block and thus serves to prolong the life of the bit and its cutting tip. It is believed that the enhanced rotation results from the addition of a component of force acting on the outer periphery of the tool in a direction perpendicular to the center line of the tool. In other words, the fins create a torque which enhances the rotatability of the cutter bit in the cutter block during operation.

3. Patent 3,652,130, Bit and Block Assembly - issued March 28, 1972

In the embodiment, the tapered head has a substantially conical configuration. A turning means is provided on the tapered head, the turning means providing a cross section perpendicular to the shank and head axis which is a departure from a circular cross section. This turning means engages the wall during picking action by the tapered head, the interengagement of the turning means in wall causes the head and shank to turn. In the bit species disclosed, the turning means includes ribs on and extending spirally along the length of the tapered head. Specifically, the spiral ribs extend laterally outward of the conical head. The number of spiral ribs provided on the tapered head can vary. A turning motion is imparted to the tapered head by the action of one or more such ribs striking the wall, thereby causing the tapered head to be self-sharpened.

As indicated in the abstracts, all of these three patents claim that rotation of the bit is improved, which tends to maintain a sharp point on the cutting end. During the survey, maintenance of a sharp point on a point attack bit was cited as a factor in helping to reduce dust production. If these claims are factual, bit designs described in the patents may be beneficial in controlling dust levels.

4. Patent 3,697,137, Resilient Mounting for Cutting Tools of Mining Machines and the Like - issued October 10, 1973

The present invention relates to cutting tool-lugmounting means combinations provided with resilient means such as to permit limited movement of the cutting tool in at least a direction substantially opposite the cutting direction.

In recent years, mining machines have become more powerful. The cutting tools of such heavy duty mining machines, operating continuously during the mining operation, are subjected to heavier and more continuous strains. The resilient mountings of the present invention ease the load on the cutting tips of the cutting tools. When rotatable bits are used, they will tend to rotate more freely. Simultaneously, the resilient mountings allow pressure to be built up between the cutting tools and the material being mined, so as to fracture the material being mined. Cracks in the material, formed in the cutting operation, tend to propogate faster. When the material gives way, the fracturing pressure is released imparting a "kick" to the bit. As a result of the above, the cutting tool-lugmounting means assemblies, provided with the resilient mountings taught herein, are characterized by longer service life. In addition, the assemblies of the present invention feed in the advancing direction more readily.

If, as claimed in this patent, pressure is built up between the bit and coal then a fracturing, rather than smashing, effect will exist and may increase the resultant size consist of the mined coal. Based on the theory that larger size consist results in less respirable dust, the mounting arrangement described, if valid, could reduce dust concentrations.

VIII. CONCLUSIONS

Because of the lack of data on the application and performance of bits, the conclusions from this survey must be based primarily on opinions expressed by the people interviewed and information included in publications. Often these opinions differ because mine conditions vary widely and result in operators having different experiences with the same bit. Therefore, the conclusions stated reflect a consensus and may not apply to specific operations.

The conclusions formulated as a result of this survey are as follows:

1. In the present "state-of-the-art," bit design parameters such as diameter, length, and metallurgical properties are fairly well fixed and appear to be adequate for the job. The parameters in use have evolved primarily from trial and error methods in underground usage and not from textbook analysis.

Based on test data, the smallest bits, Style 2, appear to produce the least amount of dust. This would indicate that smaller diameter, shorter bits are the best design for dust control. However, many parameters which could affect dust production were not taken into consideration during these tests, and statements on the effect of bit design are speculative. The primary reason for varying bit design parameters is to produce a bit which has the properties required for the most economical operation for a specific application.

2. "Best bit" design - There is no single "best bit" design for the coal industry, only for individual mines. This conclusion is substantiated by several facts.

a. The operators, bit manufacturers, and machine manufacturers all agree on this point.

b. The number of designs currently in use indicates the variation in conditions which make a single "best bit" design improbable.

c. In spite of the number of designs available there is still interest, although little active work, in development of a better bit.

In addition, a design which reduces dust production may not be compatible with the optimum design for mine conditions. For example, test data indicate that the mini-bob bit, Style 2, produces the least amount of dust. However, the bit usage data in Figure 8 shows that this bit is better suited to softer coal with a high grindability index, while the more massive bits, such as Styles 5 and 7, are better suited to harder coal having a low grindability index. Moreover, survey information indicates that bits wear out faster when used to mine harder coal. Therefore, even though a Style 2 bit is best for dust reduction, its use in harder coal seams would be economically unfeasible.

The bit manufacturers, also, were not able to agree on a particular bit style being the "best bit" design for the industry. As shown in Table 15, the best selling bit is not always the bit considered best by the manufacturer; and the opinion of what is "best" design varies among the manufacturers.

TABLE 15. "BEST BITS" AS VIEWED BY BIT MANUFACTURERS

Bit Manufacturer	Best Selling Bit	Best Design
A	Style 5	Style 15
B	Style 7	Style 15
C	Style 7	Style 15
D	Style 3 and Style 14	Severe cutting - Style 4 and Style 7 Easy cutting - Style 14
E	Style 14	Style 15
F	Proprietary	Customer opinion
G	Note	Diamond
H	Style 2	Depends on conditions

Note - Company "G" does not market bits for use on continuous miners.

3. The establishment of bit research and development programs has been hindered by the competitive nature of the bit industry and, according to some bit manufacturers, by the coal operators' reluctance to help defray the cost of development work by paying a higher price for new, untried bits. At the present time there are approximately 13 bit manufacturers of which three or four are considered the "leaders" of the industry. These few are responsible for the limited research and development work being done on new designs and materials. The other manufacturers utilize these developments and serve as suppliers to the coal industry, basing their existence primarily on being able to sell bits at or below their competitors' prices.

This competitiveness has resulted in a lack of initiative and incentive on the part of manufacturers to research new designs or techniques and, therefore, a lack of significant new developments in mining techniques or equipment. The situation can be summed up by the following comments of two different bit manufacturers, in reply to questions about bit development:

a. One representative said his company doesn't do any development work, they just copy like everyone else.

b. Another representative said his company will not invest in developing new bits unless they can be patented.

4. The coal industry at present generally believes that dust control will be attained through the use of auxiliary equipment and that the effect of bit design is not significant. This is evident by the fact that (1) there are very few tests being run to determine the effect of bit design; and (2) the major effort has been on scrubbers, spray systems, and auxiliary ventilation systems.

Thus, the general attitude of the industry appears to be that bits must be considered an operating expense about which little can be done. Facts and opinions which support this conclusion are:

a. Several operators felt the overall bit cost/ton is too small to justify expending manpower and money to control.

b. Mining companies had little or no data available on bit cost/ton. Obviously no effort is made by these companies to control bit costs.

c. The lack of organized formal tests to determine bit performance reflects a lack of concern for obtaining valid data on which to base selection of proper bit design.

d. Thousands of dollars are spent to provide power to the bit, but relatively little is spent to optimize the bit which actually does the work.

e. Research, underground testing, and mining experience all indicate that operating conditions, bit speed, number of bits, and operator technique have considerable effect on bit performance, particularly with respect to dust production.

Recent developments in machine design, which corroborate research results, include the reduction of linear bit speeds from 900 ft/min to approximately 600 ft/min and a trend to use of fewer bits. Results of some tests indicate these changes tend to produce larger size consist and theoretically less dust.

There is some disagreement among mine operators on the effect of operator technique. It was generally agreed that a skilled operator can make a bad bit look good and an unskilled operator can make a good bit look bad.

IX. RECOMMENDATIONS

The lack of valid test data and the diverse opinions on bits and bit performance make it impossible to recommend any particular design over the others either on the basis of operating cost or dust production. Based on usage, the point attack bit is the most popular design and Style 4 the most popular point attack bit. Popularity, however, is obviously not a sound basis for selecting the best bit.

Therefore, the recommendations being made deal primarily with determination of present bit performance and development of new bit designs and material.

1. The limited data collected during the survey indicated that bit design, particularly that of the mini-bob or Style 2, could affect dust production. To determine the validity of these results the USBM, coal operators, and manufacturers should, through a joint effort, conduct controlled and documented underground tests to correlate bit design with dust production, cost per ton, and other operating parameters.

Hopefully, these tests could determine whether a "best bit" design for the industry can be developed. Although such tests are costly, difficult to design, and to carry out, it is our opinion that this is the only way to determine bit performance accurately, and obtain information that would serve as a basis for bit design improvement.

2. Operators and manufacturers agree that the present bits perform well when cutting coal, and that the cutting of rock and other inclusions destroys the bits. Research into the cutting technology of rock, pyrites, and other materials found as inclusions should be done with the object of developing bits or materials which can cut these inclusions more efficiently. This work should be performed initially on a laboratory scale using samples of inclusions taken from the mines to determine cutting requirements, similar to the procedure outlined in Section V-B, test No. a and b. New tools or techniques developed should then be subject to underground tests for final evaluation.

3. In recent years many significant advances have been made in most engineering disciplines as a result of knowledge contributed by the space program and development of supersonic jet planes. A search of this new technology should be made for possible application to mining. For example, could the material and/or bit design used on the equipment for obtaining core samples of the moon surface be applied to mining?

4. Most bit manufacturers cannot individually support research and development programs because of low profit margins. A research program jointly supported by the bit industry could be beneficial to both the manufacturers and the operators. The programs could include new mining techniques (high pressure water, for example), new bit materials, and new bit manufacturing techniques. These programs could develop the basic technologies, with refinement, and commercial application left to the bit manufacturers on a competitive basis.

5. Interviews conducted during the survey revealed that testing is being done by some mining companies on auxiliary equipment for dust control and that, generally, operators are not aware of research being done in cutting technology, dust control methods, or dust monitoring techniques. More effort should be made to disseminate the results of this testing and research so they can be put into practice where feasible.

6. Most of the published work on research in cutting bits involves wedge type or flat cutter bits. There appears to be little information on point attack bits. The acceptance of the point attack bit is, therefore, not based on a technical appraisal of its cutting efficiency, but primarily on sales claims of the manufacturer. It is recommended that a program be established to test the various bit designs--wedge, flat, and point attack--to determine:

a. Which design is, in fact, the most efficient cutting tool in terms of power required per ton of coal mined,

b. Which design produces less dust, particularly after the bit has become worn,

c. Whether there is a need for the large number of variations available in each design,

d. The actual cause of point attack bit rotation, with work to make rotation more positive,

e. Whether the use of metallurgical techniques, such as infusion of boron into the bit surface, can have a beneficial effect on bit life.

7. The bit survey revealed two new bits, the spiral ribbed bit and the all steel boron coated bit. The developers of these bits have not been successful in obtaining industry cooperation in testing these bits. A facility should be set up, either by the USBM or jointly by the coal industry, for complete evaluation of new developments, with a procedure for dissemination of the results. The lack of an adequate test facility could result in the loss of potentially important mining developments.

X. INVENTIONS

There are no patentable results or inventions from the work performed under this contract.

APPENDIX A

ORGANIZATIONS INTERVIEWED DURING SURVEY

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APPENDIX A

ORGANIZATIONS INTERVIEWED DURING SURVEY

Bit Manufacturers	Personnel Interviewed: Name	Personnel Interviewed: Title
Austin Powder Company Minetool Division Cleveland, Ohio 44113	Bob Chorpenning	Manager
Bowdil Company Canton, Ohio	F. T. Bowman	President
Carboloy (Subsidiary of GE) Detroit, Michigan	Arnold B. Bower Dale Whitman	Carbide Product Design Engineer Specialist - Mining Sales
Carmet Co. Minetool Division Shinnston, West Virginia	Jack Steel Bill Zelenka Lloyd Hansen	Sales Manager Manager Manufacturers Manager Product Development
Cincinnati Mine Machinery Co. Cincinnati, Ohio	A. O. Bruestle C. B. Krekeler	President Vice-President, Engineering
Columbia Bits Columbus, Ohio	James Butts Dennis Alexander	President Production Manager
Kennametal, Inc. Bedford, Pennsylvania	Tom Kniff Don Leiber Seibert Oaks	Marketing Manager Product Manager Product Manager
VR/Wesson Mining Division Lexington, Kentucky	Hugh Bastian Ken Emmerich	Sales Manager Plant Draftsman
Mining Machine Manufacturers		
Jeffrey Mining & Machinery Co. P. O. Box 1879 Columbus, Ohio 43216	Jack Brantner Jack O'Neil Warren Fife	Vice-President & Chief Engineer Assistant Manager, Mining Engineering
Joy Manufacturing Co. Franklin, Pennsylvania	E. Warner R. Lehner L. Rollins	Director of Engineering Consulting Engineer Manager, Chain Plant

Mining Machine Manufacturers	Personnel Interviewed Name	Title
Lee-Norse Company Charleroi, Pennsylvania	Clyde Holvenstot	Vice-President of Engineering
Research Facilities		
U.S. Bureau of Mines Minneapolis, Minnesota	Kelly Strebig	Project Engineer
Government Agencies		
Department of Mines & Minerals Springfield, Illinois	Mr. McReaken	Director
Kentucky Department of Mines & Minerals Lexington, Kentucky	Hareld N. Kirkpatrick,	Commissioner
Ohio Division of Mines Columbus, Ohio	Arnold W. Snowden	Chief
Pennsylvania Deparment Environmental Research Harrisburg, Pennsylvania	Walter J. Vicinelly	Chief Division of Mine Safety
Virginia Division of Mines Big Stone Gap, Virginia	W. Foster Mullins	Chief Mine Inspector
West Virginia Department of Mines Charleston, West Virginia	John Ashcraft	Director
Consultants		
E & E Bit Company Christopher, Illinois	Mr. Gerald Elders	Retired
Pettito Mine Equipment Repair Company Morgantown, West Virginia	Mr. A. Pettito	President
John Y. Riedel, Steel Consultant R. D. 4, Black River Road Bethlehem, Pennsylvania 18015		
Coal Mining Companies		
Bell and Zoller Coal Co. Ziegler No. 4 Mine Johnston City, Illinois	Frank L. Dillard	Chief Engineer

Coal Mining Companies	Personnel Interviewed: Name	Title
Freeman Coal Mining Orient #3, 4, and 6 Mine West Frankfort, Illinois	Bill Dexton Frank Padavic	Industrial Engineer Project Engineer
Inland Steel Company Sesser, Illinois	D. M. Dwosh	Supervisor, Industrial Engineer
	G. W. Lockin	Manager of Technical Services
	H. B. Smith	Superintendent of Maintenance
Monterey Coal Company Carlinville, Illinois	B. Morton G. Roberts P. Pinaneschi D. Burkhalter	Op. Manager Mine Superintendent Engineer Prep. Engineer
Old Ben Coal Co. Benton, Illinois	A. J. Webster	General Manager
Peabody Coal Company No. 10 Mine Pawnee, Illinois	Joe Craggs	Vice-President of Underground Oprs.
	Ken Chambers Bob Danko	Supply Clerk Chief Elec.
Sahara Coal Company Mine #20 Harrisburg, Illinois	Tom Goldman	Mine Superintendent
Sahara Coal Company Mine #21 Harrisburg, Illinois	Charles Boyd	Mine Superintendent
Martin County Coal Corp. Warfield, Kentucky	R. A. Bradbury	General Manager
Scotia Coal Company Scotia Mine Cumberland, Kentucky	Fred Maggard	General Superintendent
Southeast Coal Company Polly Mine Whitesburg, Kentucky	Mr. Cahoon	Mine Superintendent
F & P Coal Company Buffalo #2 Mine Vindex, Garrett Co., Maryland	Franklin Polce	Superintendent
Consolidation Coal Co. (Hanna) Rose Valley No. 6 Mine Cadiz, Ohio	William McCullough	Superintendent

Coal Mining Companies	Personnel Interviewed: Name	Title
North American Coal Co. No. 5 Mine Powhatan Pt., Ohio	M. G. Pydosz John C. Bennett Mr. McCartney	Superintendent Asst. Mgr. to the Mines Supt. Maintenance
Oglebay Norton Co. Norton No. 3 Mine Powhatan Pt., Ohio	Bruny Scypta	Manager
The Youghiogheny & Ohio Coal Co. Martins Ferry, Ohio	Warren Kmetz	Asst. Superintendent
Barnes and Tucker Lancashire Mine No. 24D Barnesboro, Pennsylvania	Edward Arotin William Dasley	Manager of Mines Superintendent
Bethlehem Mining Corp. Mine No. 77 Mineral Point, Pennsylvania	Robert DuBreucq Joseph Fether	Engineer Asst. Superintendent, Mines 73 & 77
Consolidation Coal Company Library, Pennsylvania	Paul Mohr	Safety and Health Coordinator
Island Creek Coal Company Tire Hill, Pennsylvania	W. L. Schwartzenberg	Mgr. of Mines - Northern Division
Pennsylvania Power and Light Co. Greenwich Collieries Barnesboro, Pennsylvania	Joseph Kreutzberger Dallas Leamer Jack Straw Andrew Smylo William Flick	General Superintendent Maintenance Superintendent Safety Coordinator Safety Inspector Sales Engineer, Kennametal
R & P Coal Co. Jane No. 1 and No. 2 Elderton, Pennsylvania	Mr. R. Billings Mr. F. Hilliard	Vice-President of Operations Production Engineer
R & P Coal Co. No. 6 Lucerne Mine Indiana, Pennsylvania	Mr. Calhoun Mr. Eget	Manager, Quality & Environmental Control Supervisor, Environmental Control
Republic Steel Banning Mine No. 4 Van Meter, Pennsylvania	E. J. Semsoy Carl Lemley	Superintendent Purchasing Agent
Republic Steel Clyde Mine Fredericktown, Pennsylvania	William Stimmel Harry Hamer	Mine Foreman Master Mechanic

Coal Mining Companies	Personnel Interviewed: Name	Personnel Interviewed: Title
Rushton Mining Company Rushton Mine Philipsburg, Pennsylvania	Mr. Rickard	Superintendent
Clinchfield Coal Corp Dante, Virginia	James Justice	Group Vice-President, Virginia Division
Bethlehem Mines Corp. Barracksville Mine No. 43 Barracksville, West Virginia	James Gray J. McLeary	Project Engineer Superintendent
Carbon Fuel Company Carbon, West Virginia	L. N. Thomas L. Bottom Lee	Vice-President, Planning & Development Industrial Engineer
Consolidation Coal Co. (Christopher) Osage No. 3 Mine Osage, West Virginia	Wilbur Simon Gerry Spindler	Safety Director Project Engineer
Consolidation Coal Co. (Mountaineer) Williams Mine Monogah, West Virginia	G. Sholice Wayman Goodwin	General Superintendent Maintenance Foreman
Imperial Coal Company Nos. 11 and 14 Mines Eskdale, West Virginia	A. L. Clark Thomas Fernett	General Superintendent General Mine Foreman
United States Steel Gary, West Virginia	Joseph Subrick	Asst. General Superintendent
Westmoreland Coal Co. Clothier, West Virginia	Paul Meek	Supervisor Health and Safety
Westmoreland Coal Co. Eccles No. 5 Mine Tams, West Virginia	R. E. Short W. McCutcheon	General Superintendent Chief Engineer
Zapata Coal Corp. Sharples, West Virginia	Mr. Bessinger	President

APPENDIX B

SURVEY QUESTIONNAIRES

"State-of-the-Art" Bit Survey - Mining Companies

Bituminous Coal Research, Inc. - Project 2022

Company ______________________ Date ______________________

Personnel Interviewed

Name	Title

Section I - Production and Engineering Departments

1. Could you list your considerations for selection of bit design in the order of their importance? Is coal dust production a factor?

2. What type of bit are you currently using? If more than one type is in use, what is your experience with each type and your preference? What type is used with each miner?

3. What do you consider to be the advantages and disadvantages of each type?

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4. Do you have data available on bit performance such as tons mined/bit, bit cost/ton of coal mined, maintenance and replacement experience, purchase price/bit? Is this data available for use in this survey?

5. Do you have data on bit performance in regard to bit failures, wear on the block, excessive bit wear, point of wear, probable cause, and maintenance costs, including replacement frequency?

6. Please supply the following general information:

a. Coal seam being mined

b. Seam height_______Maximum_______Minimum_______Average_______

c. Seam characteristics

d. Associated rock strata

e. Type and number of mining machines in use

f. Speed of miner head

g. Number of bits on head

h. Type and number of sprays, if used

i. Normal work schedule - shifts/day

avg tons/shift/section

number of sections

7. Have you changed the type of bit in the past five years? If so, what changes were made and the reason for each change?

8. Have you experienced any major problems with the various designs? Describe these problems and how they were corrected.

9. Have you made any studies of different bit designs to determine their relative characteristics in regard to production, maintenance, dust propagation, bit life, etc.?

10. Have you made any studies relating dust production to bit design? If so, what were the results?

11. Are there any areas of bit design that you feel should be investigated to try to improve the design with regard to production, maintenance, and/or dust suppression?

12. In your opinion, do bits generally rotate? If so, what are the main forces that cause rotation? What factors increase or retard rotation?

13. What effect do operator techniques have on bit life, production, dust, etc.?

14. Is the design of bits a process involving "text book" engineering or is it primarily a trial and error process? Is the engineering primarily mechanical or metallurgical?

15. With respect to generation of dust, what appears to be the most promising method of dust abatement? What methods have you tried and what were the results?

Section II - Research and Development

1. Are there any completed R&D projects pertaining to bit design? If so, are copies of the project reports available, including results of lab and/or field studies?

2. If the reports are not available, can you give a summary of the objectives and results of these projects?

3. Were the results of these projects used in any commercial applications? If so, where and with what results?

4. Are there any current projects pertaining to bit design? If so, what are the objectives of these projects and the results to date? Are the project reports available?

5. What were the reasons for initiating these projects?

6. Are you aware of any research being done by other organizations, domestic or foreign, in the areas of bit design and/or dust suppression techniques?

7. In particular, have you done or are you doing any research in the area of dust suppression? If so, what are the objectives of this research and what are the results? Are copies of project reports and data available?

"State-of-the-Art" Bit Survey - Bit Manufacturers

Bituminous Coal Research, Inc. - Project 2022

Company ______________________ Date ______________________

Personnel Interviewed

Name	Title

Section I - Production and Engineering Departments

I. How many different basic bit designs do you manufacture? Can you supply descriptive literature and price lists for each design?

2. How would you rank the various designs with respect to sales volume and how would you account for the order of rank?

3. What needs initiated the development of these different designs?

4. What were the basic considerations and the priority given them in the development of these bits? In particular, was the suppression of respirable dust a consideration?

5. What do you consider to be the advantages and disadvantages of the various designs?

6. Do you have any data on the performance of the different designs in regard to production/bit, maintenance requirements, bit life, production of respirable dust, etc.? Is this information available for use in this survey?

7. Do you currently have any new bit designs under development? If so, what initiated the design and what were the basic considerations influencing its development?

8. Based on your contacts with customers and your own experience, are there any areas which you feel require development to improve bit performance or the manufacturing process?

9. Have the bits been used with water flushing? If so, what were the results, particularly with respect to dust abatement?

10. What factors do you stress in your sales presentations to buyers? Do you include dust suppression as a selling point for any of the designs?

11. When mining companies or mining machine manufacturers order bits, what are their specifications? Specifically, is dust suppression a factor when ordering?

12. Do you have any feedback on the reactions of mining companies and mining machine manufacturers to the various bit designs?

13. Is the same basic manufacturing process used for all bits? If not, what are the differences and what are the reasons for them? Give a brief description of your processing, including forming and metallurgical processes.

14. Have you had any specific manufacturing problems or customer complaints on excessive breakage or short life with a particular design? Give a brief description of problem and how it was resolved.

15. In your opinion, do bits generally rotate? If so, what are the main forces that cause rotation? What factors increase or retard rotation?

16. What effect do operator techniques have on bit life, production, dust, etc.?

17. Is the design of bits a process involving "text book" engineering or is it primarily a trial and error process? Is the engineering primarily mechanical or metallurgical?

Section II - Research and Development

1. Are there any completed R&D projects pertaining to bit design? If so, are copies of the project reports available, including results of lab and/or field studies?

2. If the reports are not available, can you give a summary of the objectives and results of these projects?

3. Were the results of these projects used in any commercial applications? If so, where and with what results?

4. Are there any current projects pertaining to bit design? If so, what are the objectives of these projects and the results to date? Are the project reports available?

5. What were the reasons for initiating these projects?

6. Are you aware of any research being done by other organizations, domestic or foreign, in the areas of bit design and/or dust suppression techniques?

7. In particular, have you done or are you doing any research in the area of dust suppression? If so, what are the objectives of this research and what are the results? Are copies of project reports and data available?

APPENDIX C

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APPENDIX C-1

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APPENDIX D

EXAMPLES OF WEAR PATTERNS AND FAILURES OF CONTINUOUS MINER BITS

2022P22

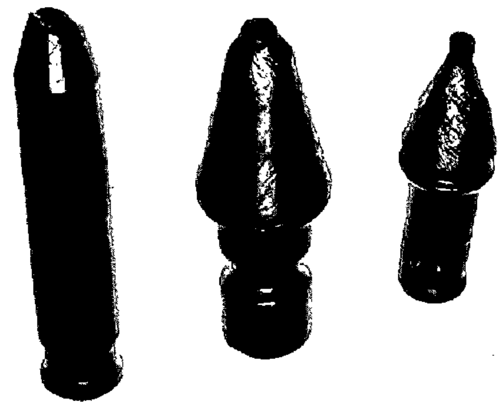

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Figure D-1. Examples of Wear Patterns of Point Attack Bits

1. Bullet Bit from Company G, Mine 14, Showing Carbide Failure.

2. Plumb Bob Bit from Company BB, Mine 46, Showing a Good Wear Pattern.

3. Plumb Bob Bit Contributed by Joy Manufacturing Co. Showing Metal Washed Away from Around Carbide Tip.

2022P23

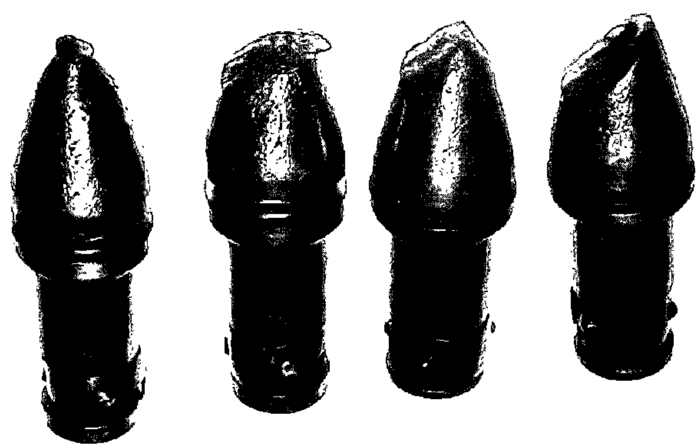

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Figure D-2. Examples of Wear Patterns of Plumb Bob Bits from Company K, Mine 18

1. Normal Wear Pattern

2, 3, 4. Wear Resulting from Non-rotation of Bits.

2022P24

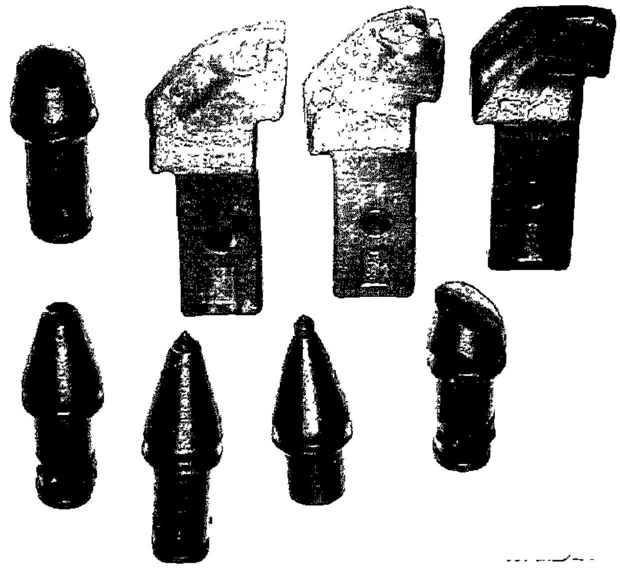

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Figure D-3. Examples of Wear Patterns of Continuous Miner Bits from Company Q, Mines 27, 28, 29, and 30

1. Plumb Bob Bit Showing Normal Wear Pattern for Long Production Cycle.

2. New Rectangular Shank Cutter Bit.

3. Rectangular Shank Cutter Bit Showing Carbide Failure.

4. Rectangular Shank Cutter Bit That Has Been Resharpened.

5. Plumb Bob Bit Showing Carbide Failure.

6. New Plumb Bob Bit.

7. Plumb Bob Bit Showing Normal Wear Pattern with Failure of Shank.

8. Plumb Bob Bit Showing Wear Due to Non-rotation.

2022P25

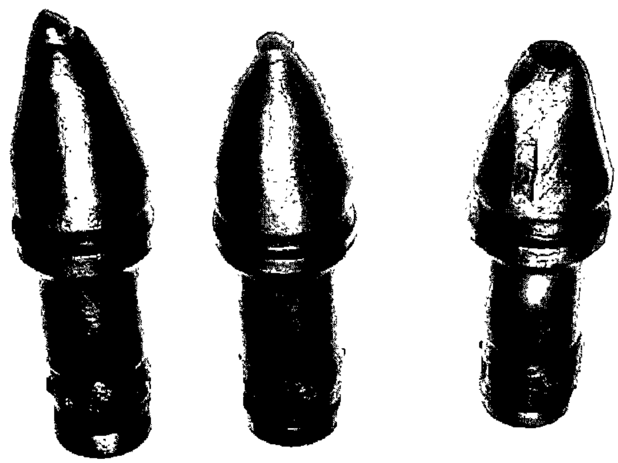

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Figure D-4. Wear Patterns of Plumb Bob Bits from Company M, Mine 22

1. Carbide Tip Forced Out of Normal Position.
2. Normal Wear Pattern.
3. Shear Failure of Carbide Tip.

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2022P26

1. 2. 3. 4. 5.

6. 7. 8.

Figure D-5. Examples of Wear Patterns of Continuous Miner Bits from Company C, Mines 5, 6, 7, and 8

1. Wear Pattern of Bullet Bit from Non-rotation.

2. Wear Pattern of Plumb Bob from Non-rotation.

3. Shear Failure of Shank of Rectangular Shank Cutter Bit.

4. Shear Failure of Carbide Tip of Rectangular Shank Cutter Bit.

5. Normal Wear Pattern of Resharpened Rectangular Shank Cutter Bit.

6. Wear Pattern of Plumb Bob from Non-rotation.

7. Normal Wear Pattern of a Plumb Bob Bit Used after Carbide Tip Had Worn Away.

8. Shear Failure of Carbide Tip of Bullet Bit.

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2022P27

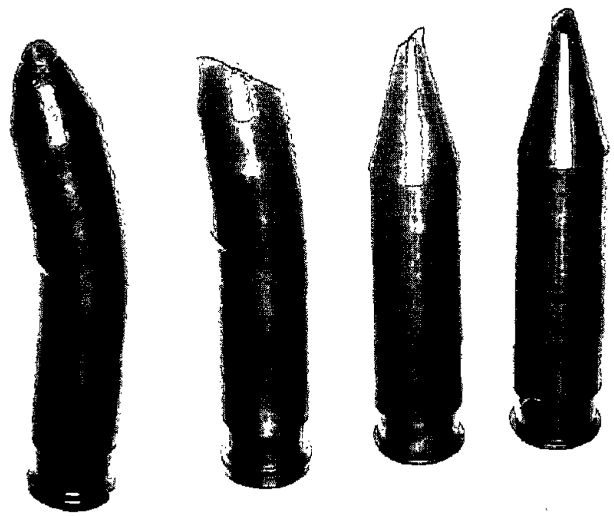

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Figure D-6. Wear Patterns of Bullet Bits

1. Normal Tip Wear Pattern with Bending Failure of Bit from Company E, Mine 11.

2. Wear Pattern Due to Non-rotation and Bending Failure of Shank from Company E, Mine 11.

3, 4. Normal Wear Patterns of All-Steel Bits, Boron Coated, Supplied by Advanced Atlantic Metals.

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2022P28

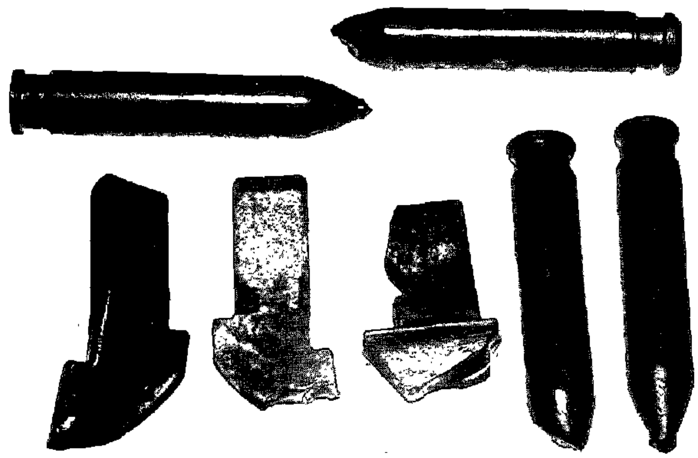

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Figure D-7. Wear Patterns of Continuous Miner Bits from Company E, Mine 10

1. Normal Wear Pattern of a Bullet Bit.

2. Wear Pattern of a Bullet Bit due to Non-rotation.

3. Shear Failure of the Bit Body of a Rectangular Shank Cutter Bit.

4. Shear Failure of the Bit Body of a Rectangular Shank Cutter Bit.

5. Normal Wear Pattern of a Rectangular Shank Cutter Bit.

6. Shear Failure of the Carbide Tip of a Bullet Bit.

7. Normal Wear Pattern of a Bullet Bit.

2022P29

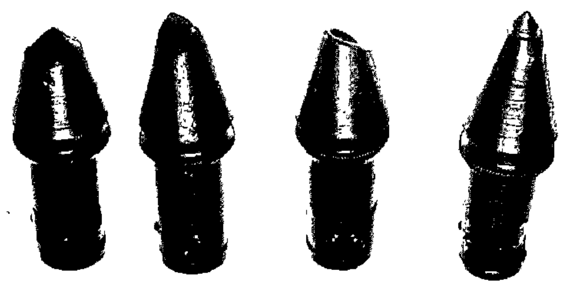

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Figure D-8. Wear Patterns of Plumb Bob Bits from Company R, Mines 31 and 32

1. Normal Wear Pattern.

2. Wear Pattern from Poor Rotation.

3. Wear Pattern from Non-rotation and Shear Failure of Carbide Tip.

4. New Bit Shown for Comparison.

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2022P30

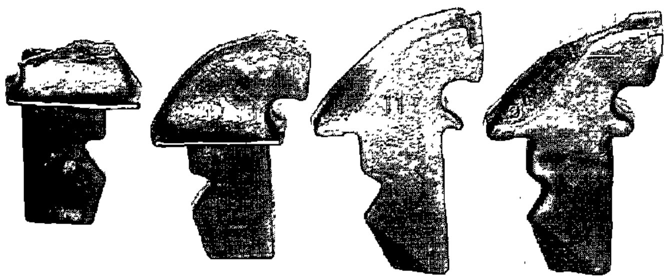

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Figure D-9. Wear Patterns of Rectangular Shank Cutter Bits

1. Shear Failure of Bit Body of Bit from Company F, Mine 13.

2. Shear Failure of Carbide Tip with Subsequent Metal Errosion of Bit from Company F, Mine 13.

3. Shear Failure of Carbide Tip of Bit from Company D, Mine 9.

4. Normal Wear Pattern.

2022P31

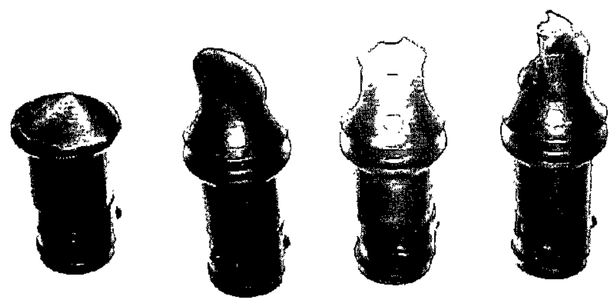

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Figure D-10. Wear Patterns of Plumb Bob Bits from Company E, Mine 11

1. Shear Failure of Bit Body.
2. Wear Pattern from Non-rotation.
3. Normal Wear Pattern but with Shear Failure of Tip.
4. Failure of Bit Body and Shear Failure of Tip.

2022P32

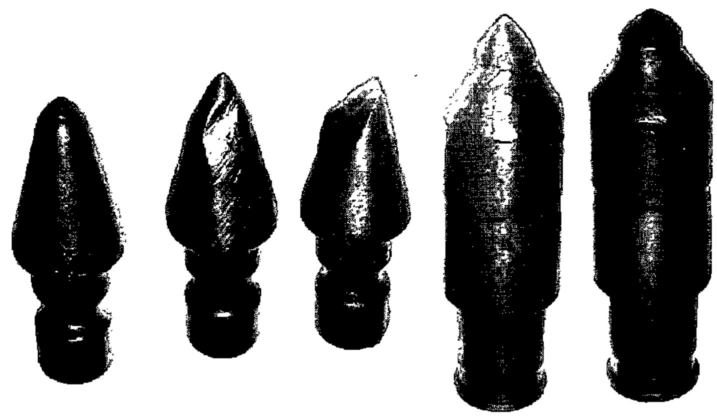

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Figure D-11. Wear Patterns of Plumb Bob Bits from Company N, Mine 24

1. New Bit Shown for Comparison.
2. Wear Pattern due to Poor Rotation.
3. Wear Pattern due to Non-rotation.
4. Used Bit after Regrinding.
5. Normal Wear Pattern before Regrinding.

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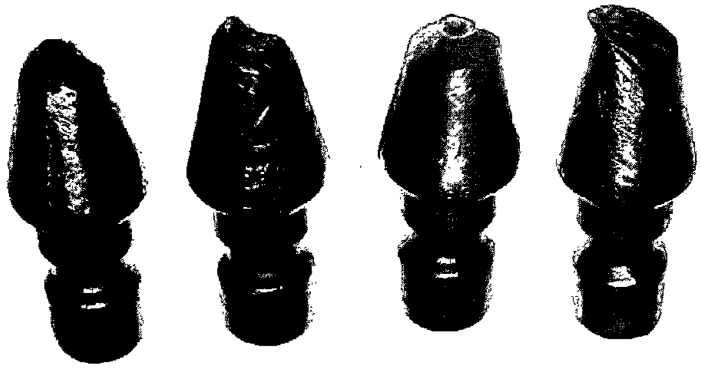

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Figure D-12. Wear Patterns of Plumb Bob Bits from Company CC

1. Shear Failure of Carbide Tip with Resultant Errosion of Metal.

2. Shear Failure of Carbide Tip.

3. Normal Wear Pattern but with Shear Failure of Carbide Tip.

4. Wear Pattern due to Non-rotation.

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2022P34

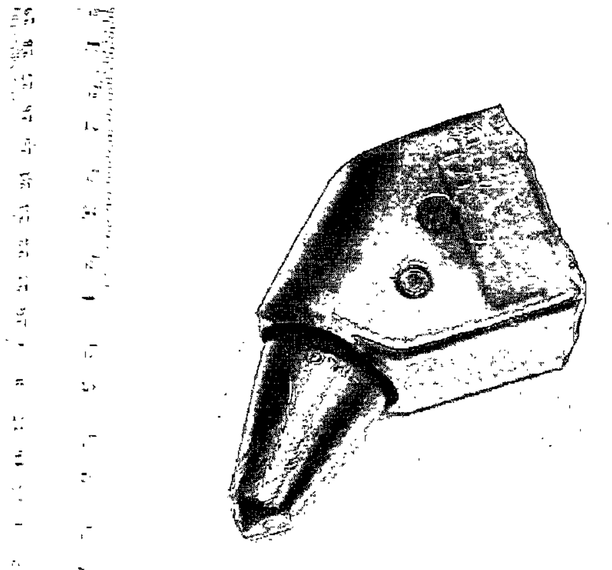

Figure D-13. Normal Wear Pattern of a Plumb Bob Bit Showing Very Loose Fit in Bit Block from Company BB, Mine 46

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APPENDIX E

UNIT PRICES OF REPRESENTATIVE BIT STYLES PRODUCED BY EACH BIT MANUFACTURER INTERVIEWED

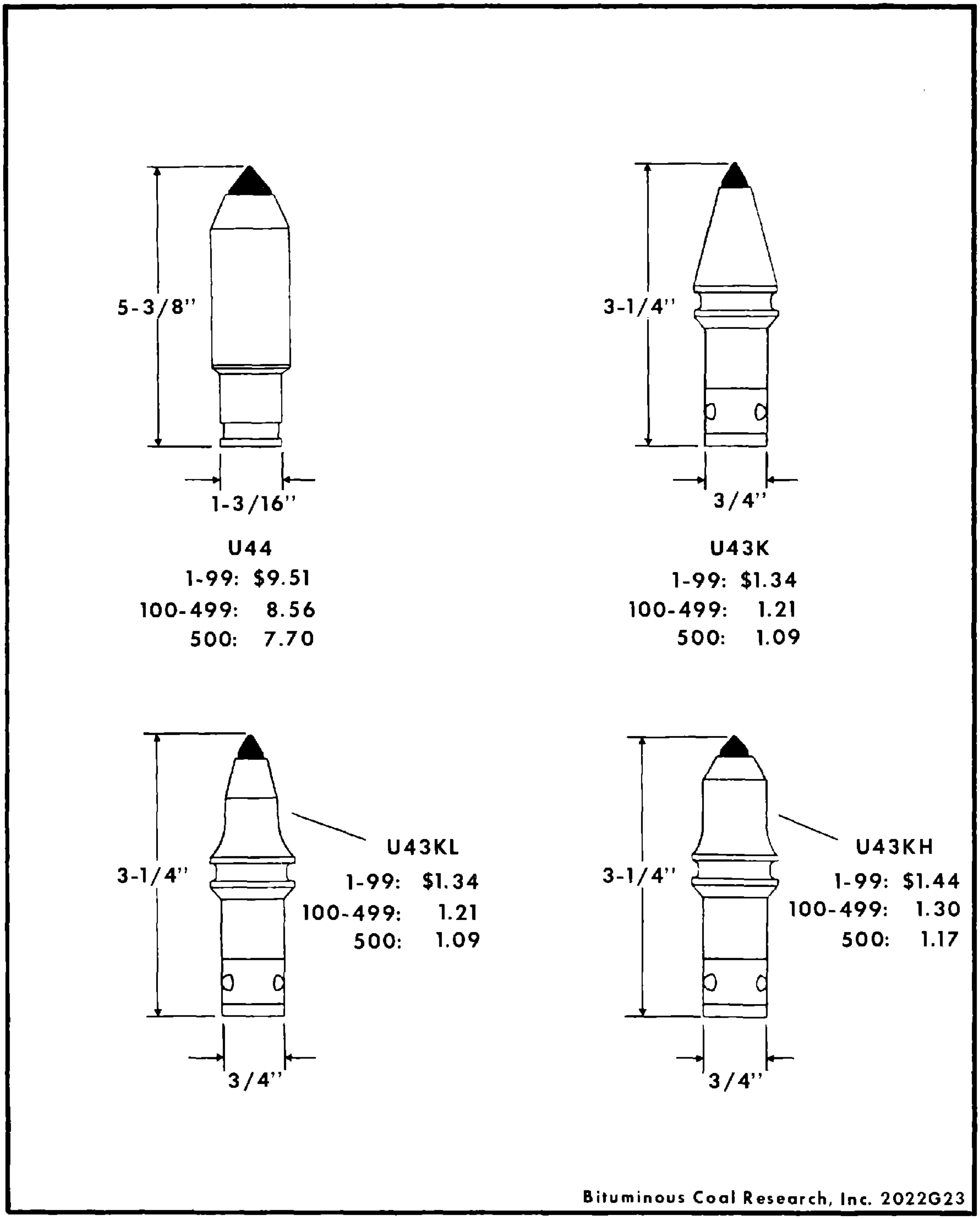

Figure E-1. Unit Prices of Representative Point Attack Bits Produced by Kennametal

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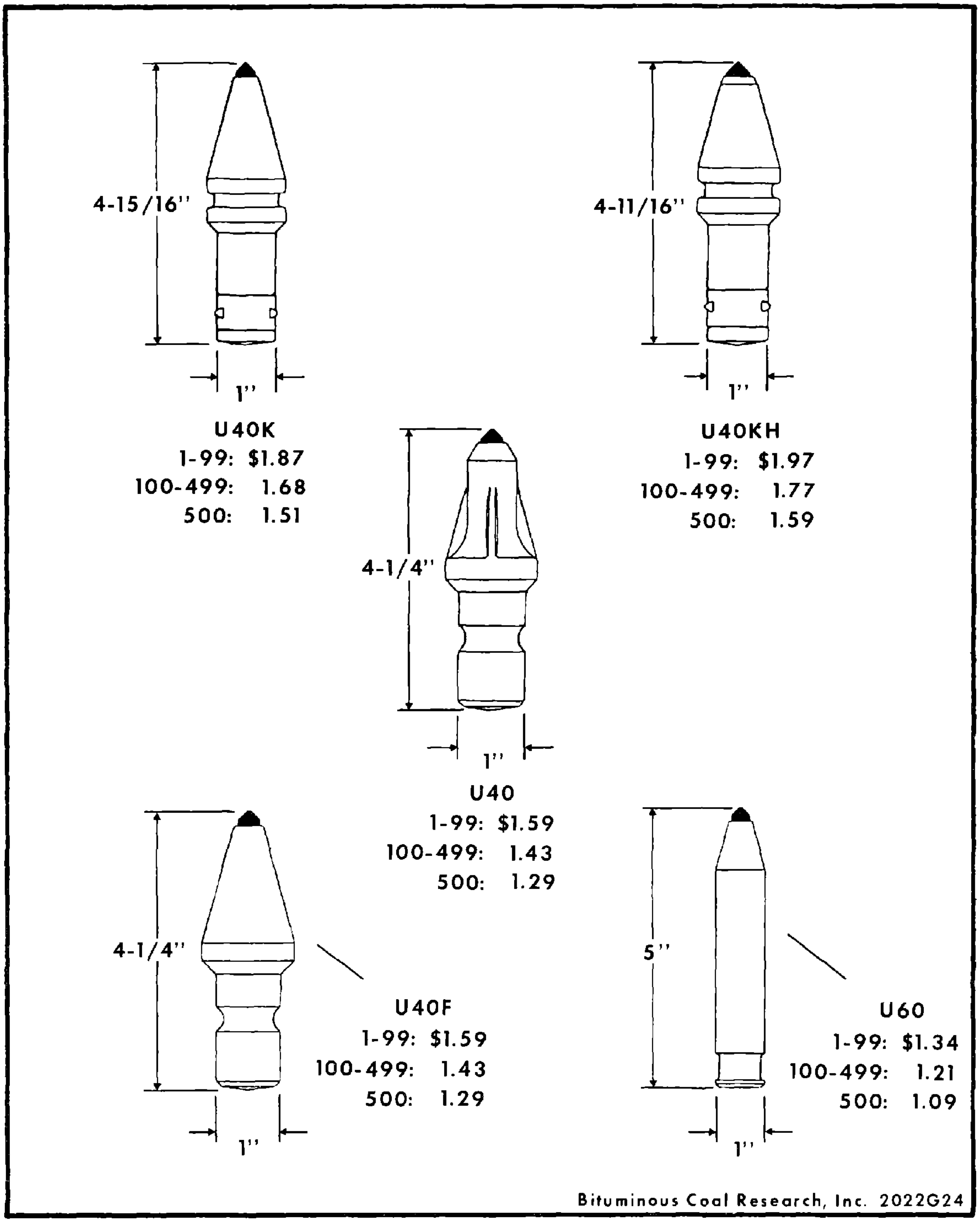
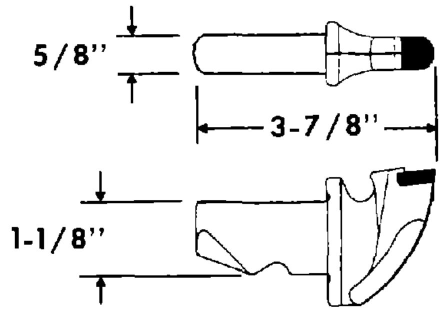
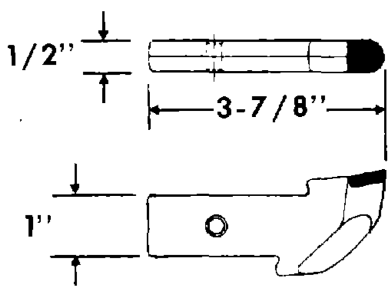


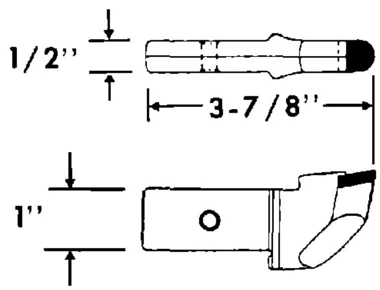
Figure E-2. Unit Prices of Representative Point Attack Bits Produced by Kennametal (Continued from Figure E-1)



U31S
1-99: $1.66
100-499: 1.49
500: 1.34



U7P
1-99: $1.43
100-499: 1.29
500: 1.16



U15PS
1-99: $1.51
100-499: 1.36
500: 1.22

Note: Price may vary slightly with style of carbide tip

Bituminous Coal Research, Inc. 2022G25

Figure E-3. Unit Prices of Representative Cutter Bits Produced by Kennametal

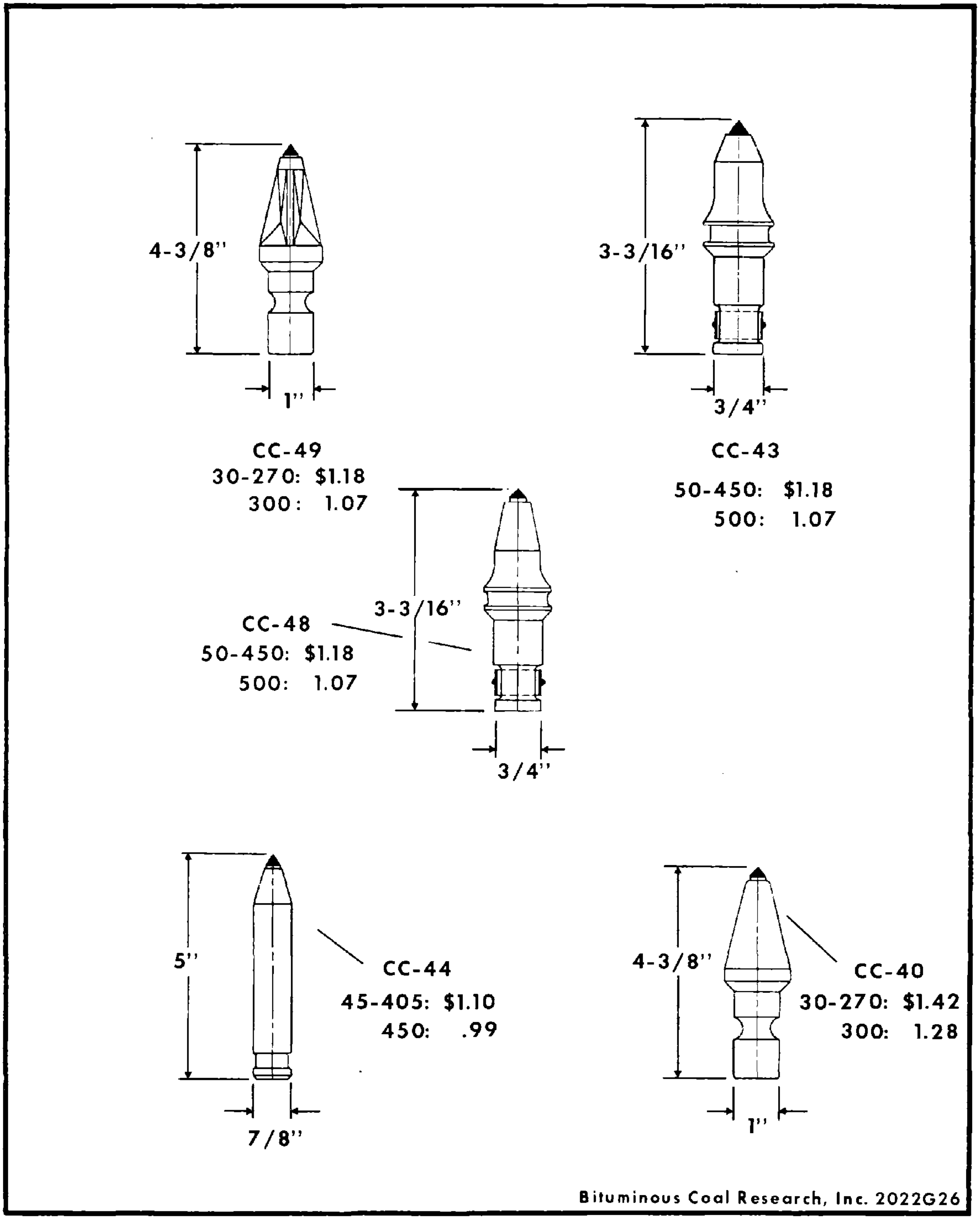


Figure E-4. Unit Prices of Representative Point Attack Bits Produced by Carboloy

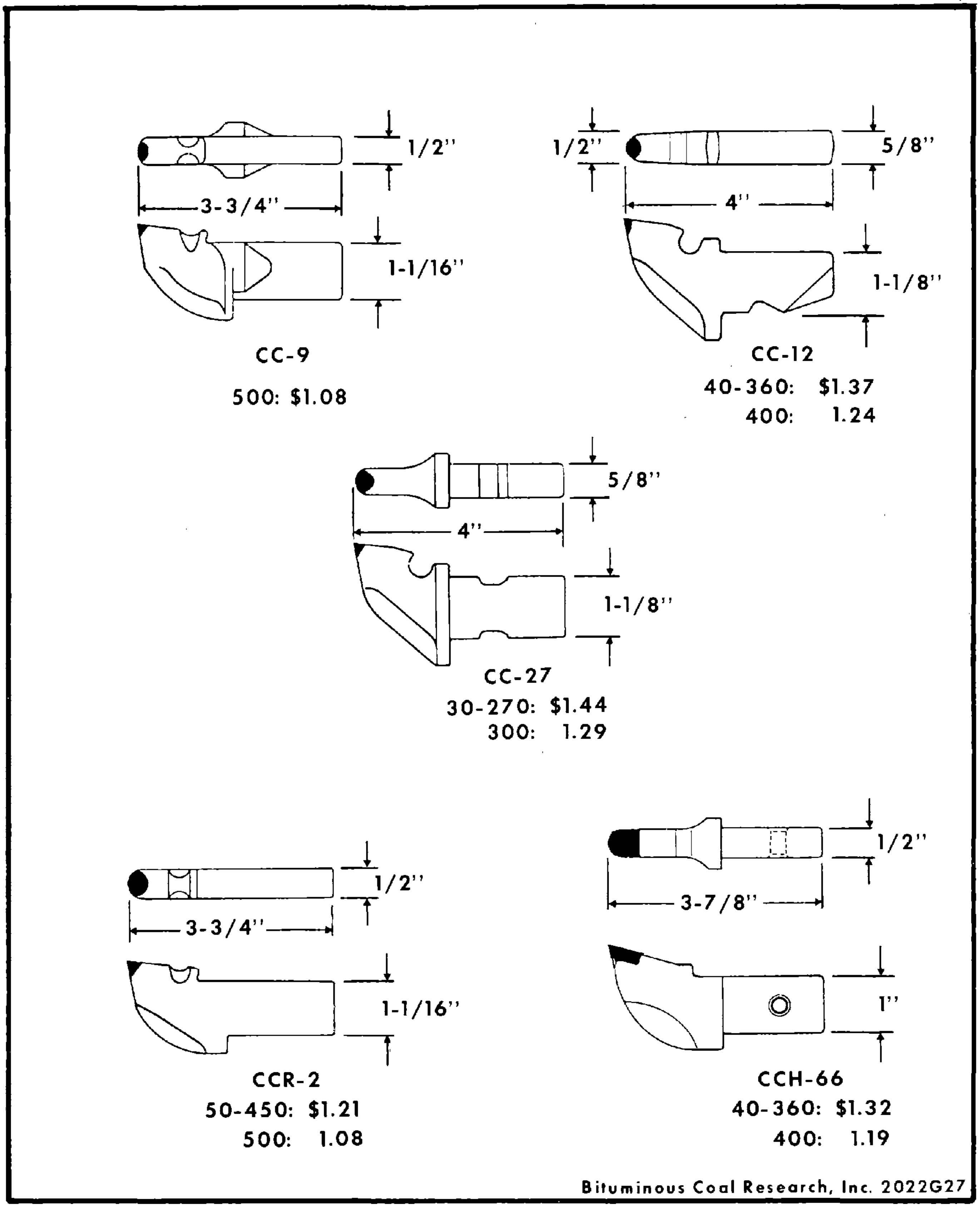


Figure E-5. Unit Prices of Representative Cutter Bits
Produced by Carboloy

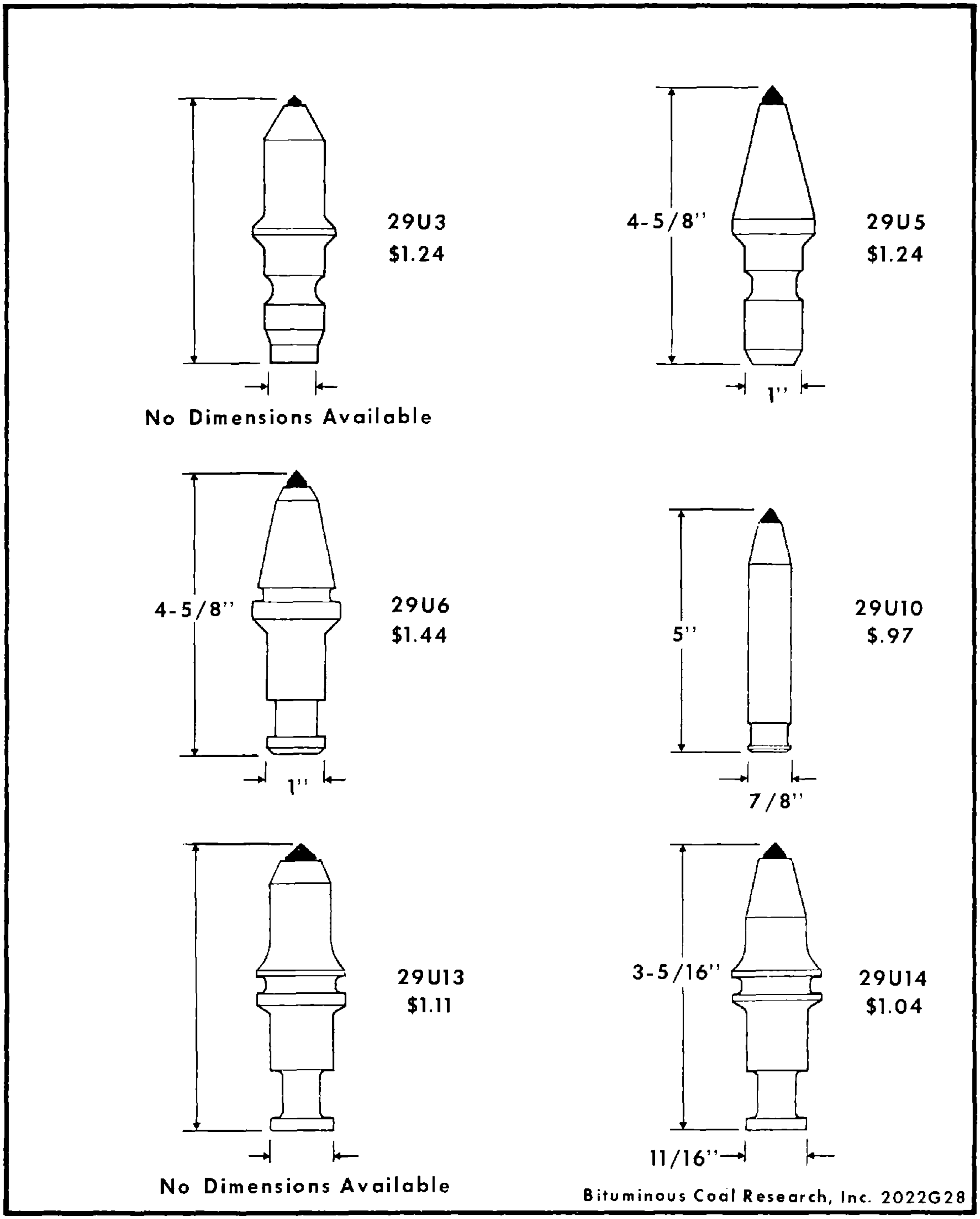


Figure E-6. Unit Prices of Representative Point Attack Bits Produced by Carmet

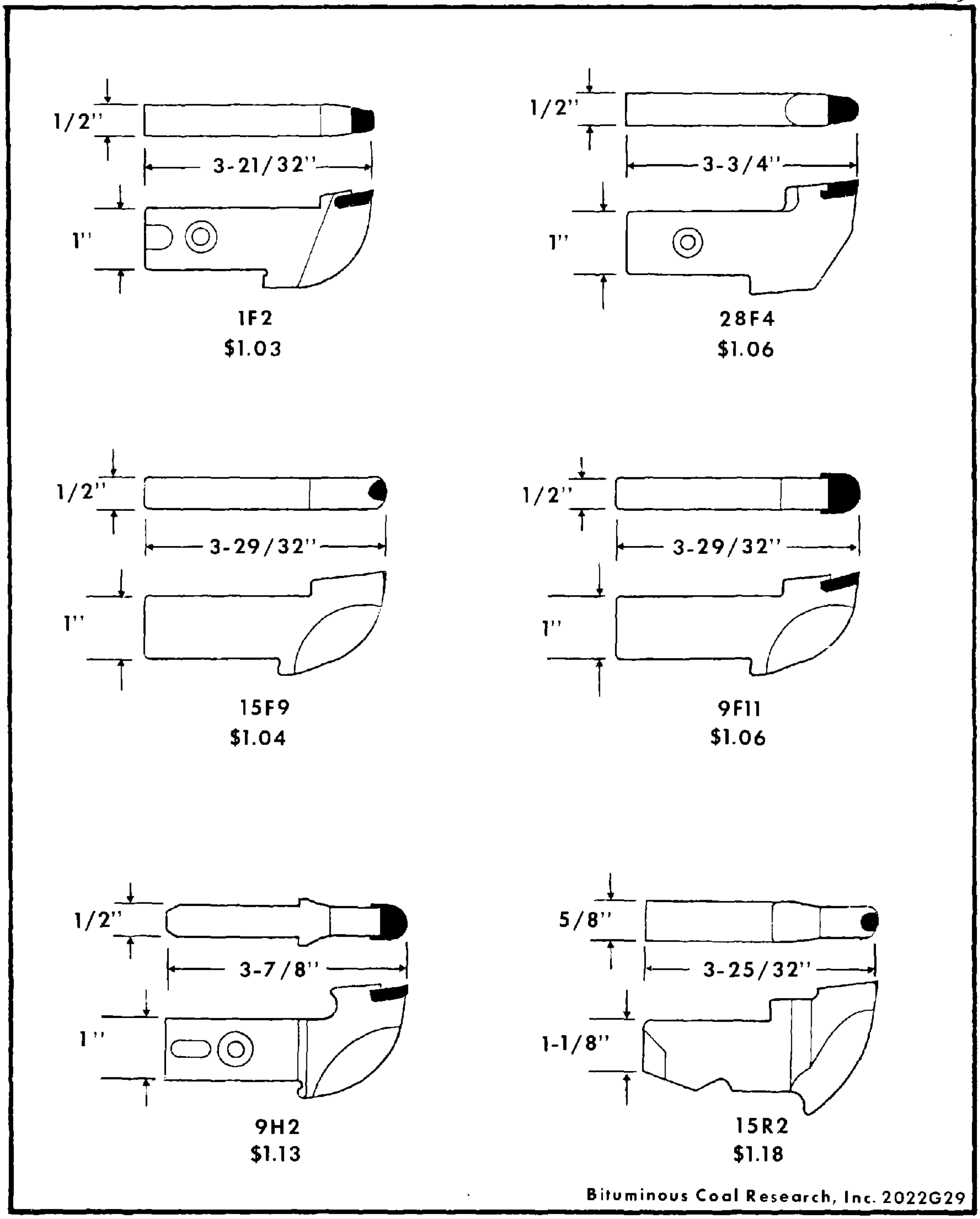


Figure E-7. Unit Prices of Representative Cutter Bits Produced by Carmet

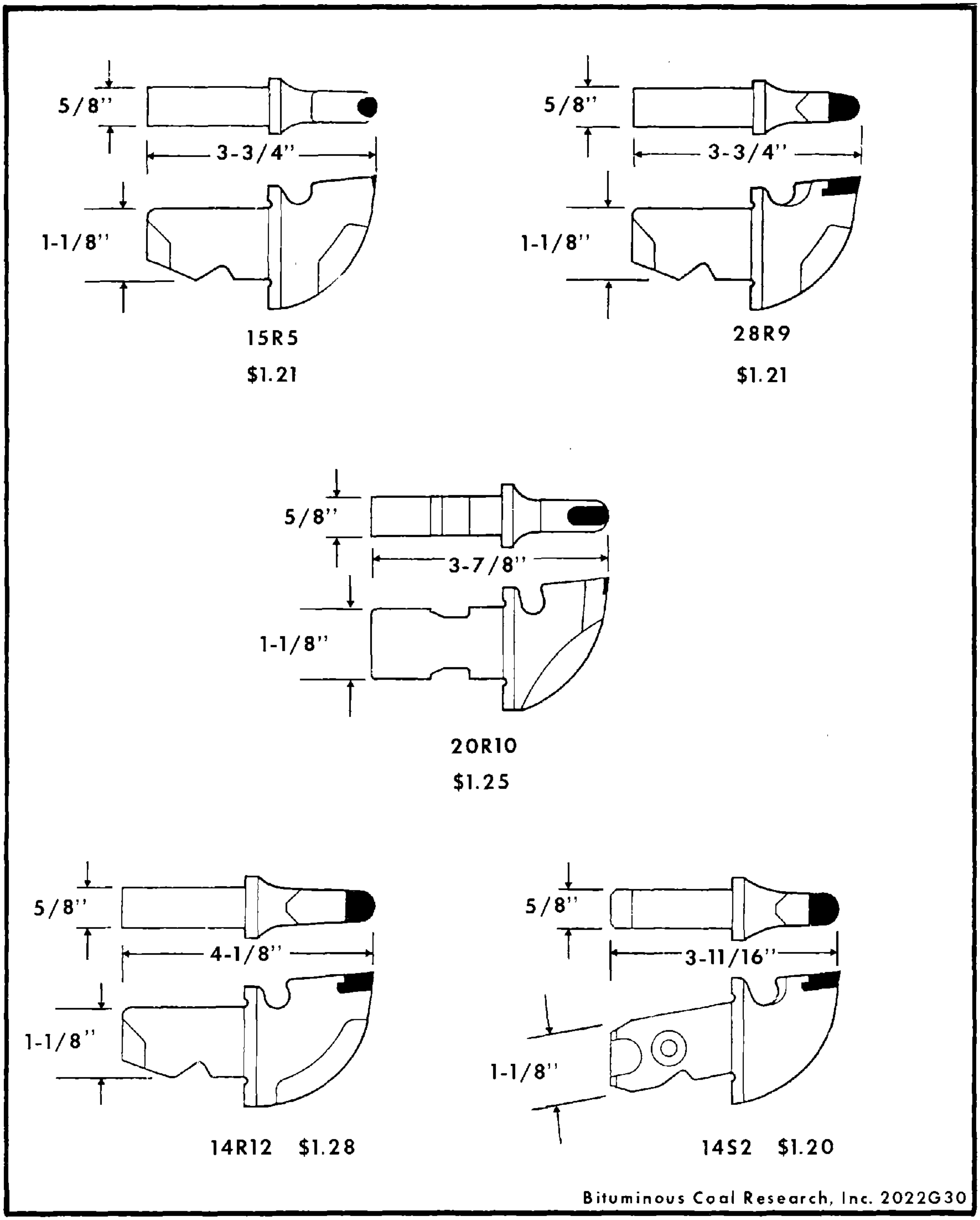
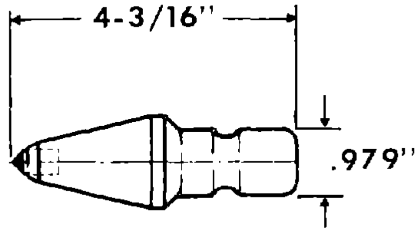
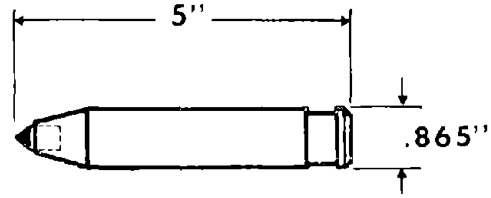


Figure E-8. Unit Prices of Representative Cutter Bits Produced by Carmet (Continued from Figure E-7)



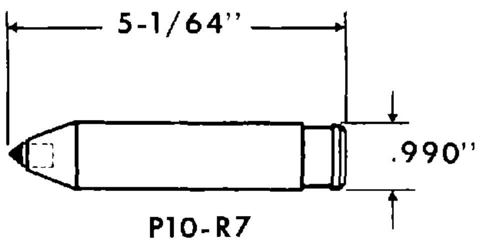
P1-R9

1-99: $1.59
100-499: 1.43
500+: 1.29



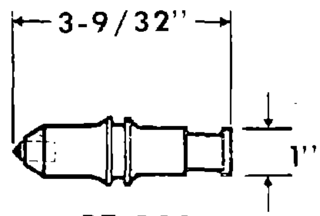
P3-R7

1-99: $1.34
100-499: 1.21
500+: 1.09



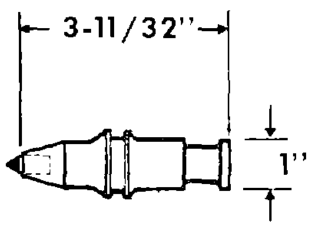
P10-R7

1-99: $1.46
100-499: 1.31
500+: 1.18



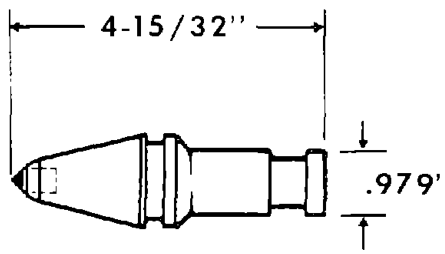
P7-R9S

1-99: $1.44
100-499: 1.30
500+: 1.17



P8-R6E

1-99: $1.34
100-499: 1.21
500+: 1.09



P11-R9

1-99: $1.97
100-499: 1.77
500+: 1.59

Bituminous Coal Research, Inc. 2022G31

Figure E-9. Unit Prices of Representative Point Attack Bits Produced by VR/Wesson

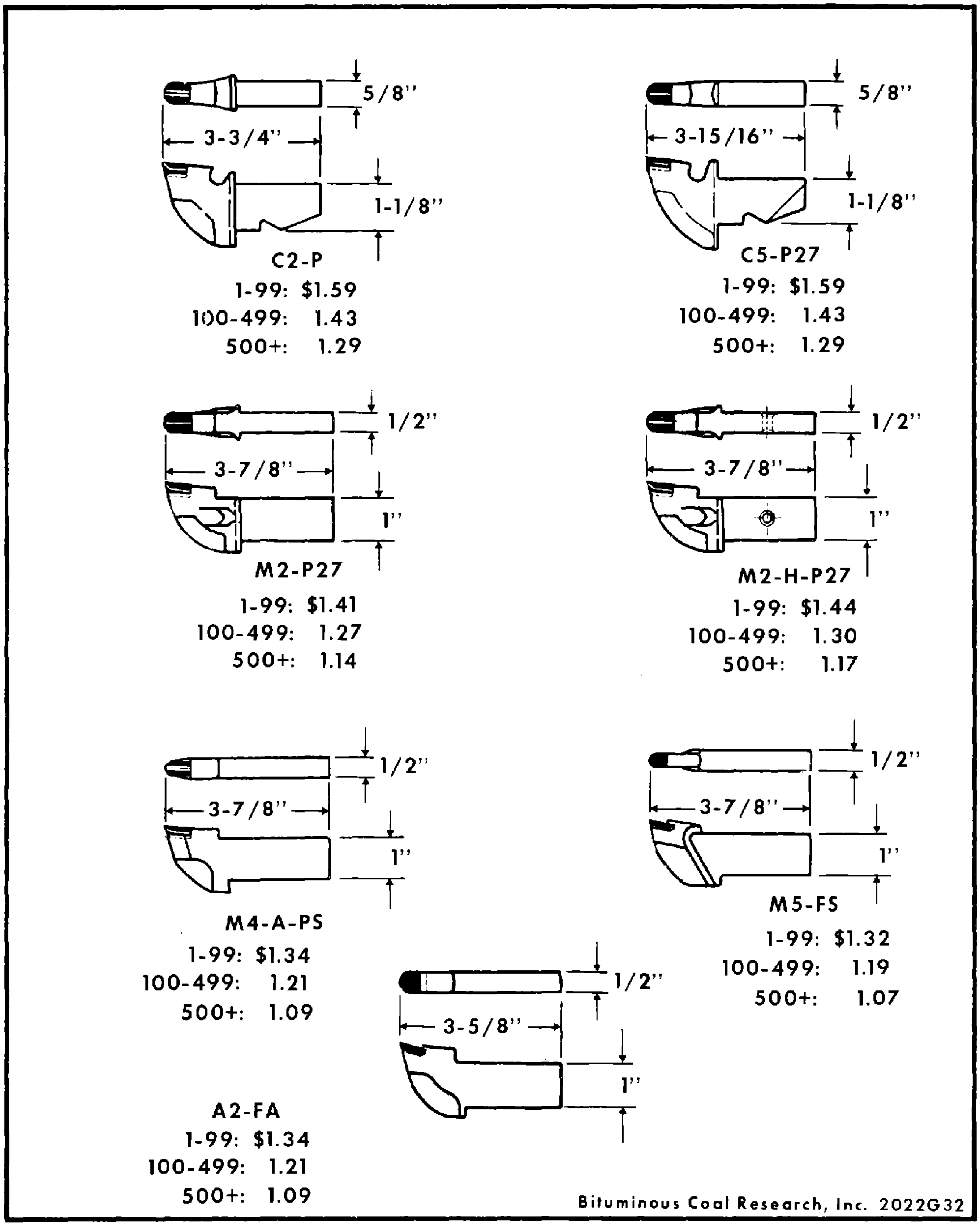


Figure E-10. Unit Prices of Representative Cutter Bits Produced by VR/Wesson

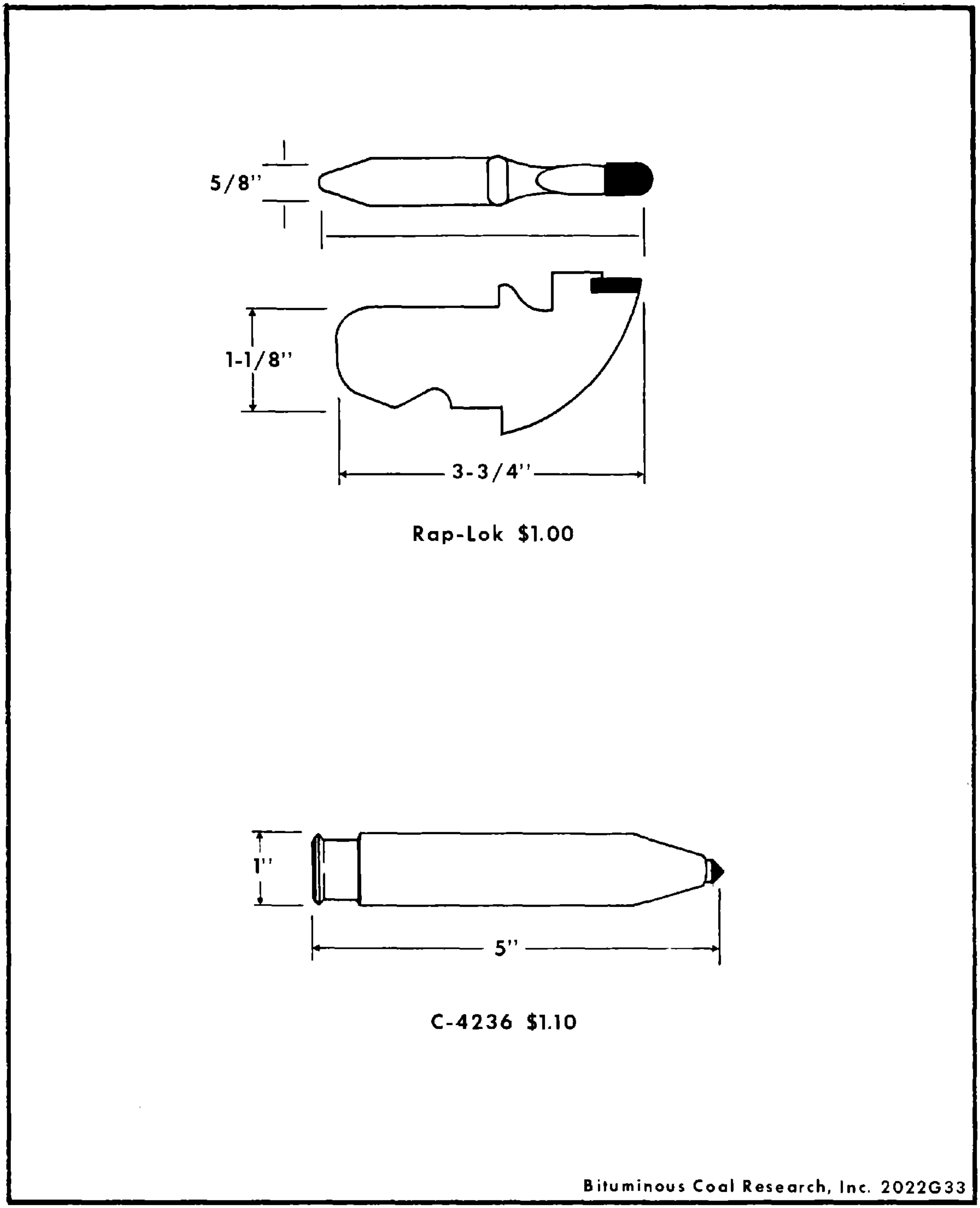
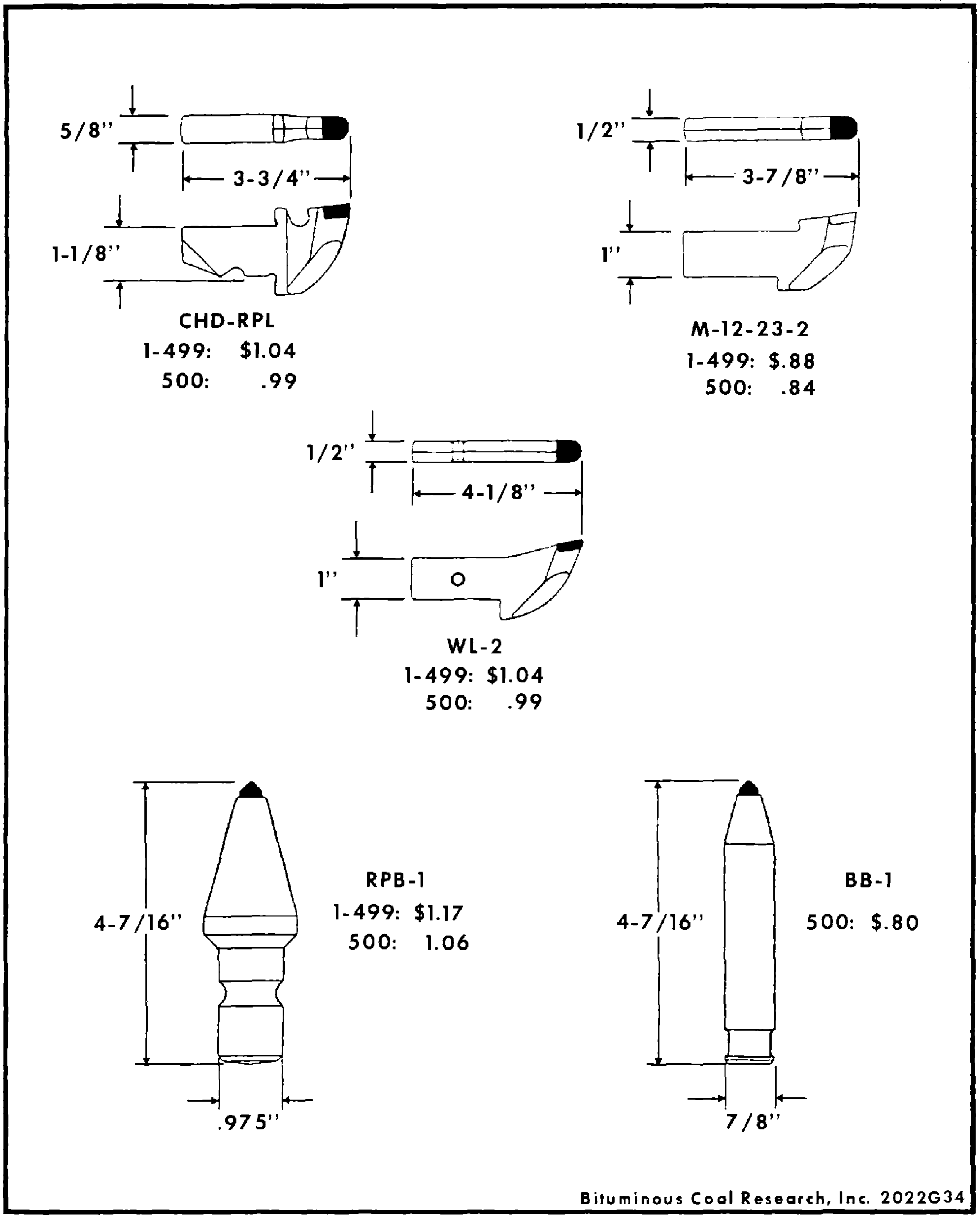


Figure E-11. Unit Prices of Representative Mining Bits Produced by Cincinnati Mine Machine



E-12. Unit Prices of Representative Mining Bits Produced by Long Airdox

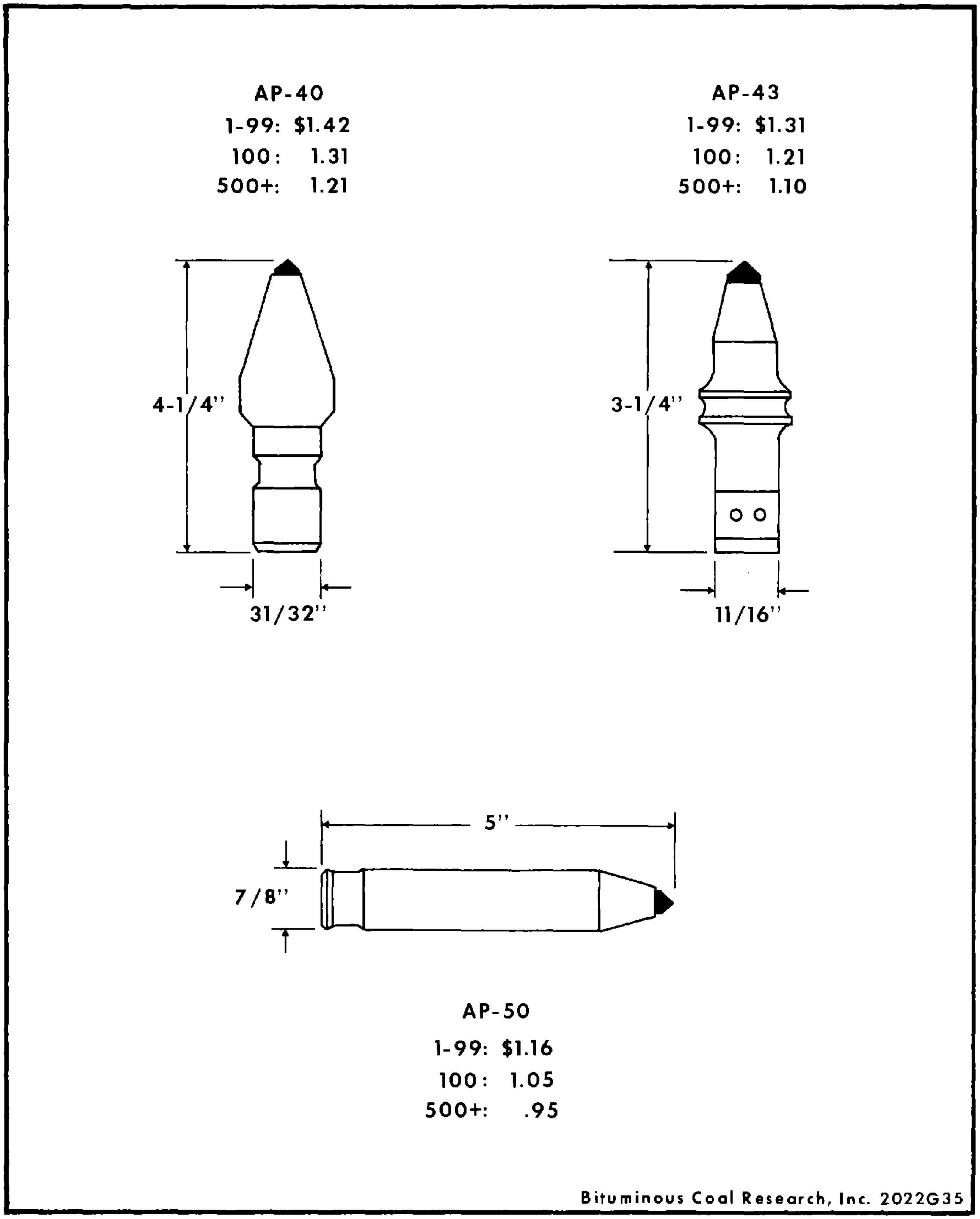


Figure E-13. Unit Prices of Representative Point Attack Bits Produced by Austin Powder

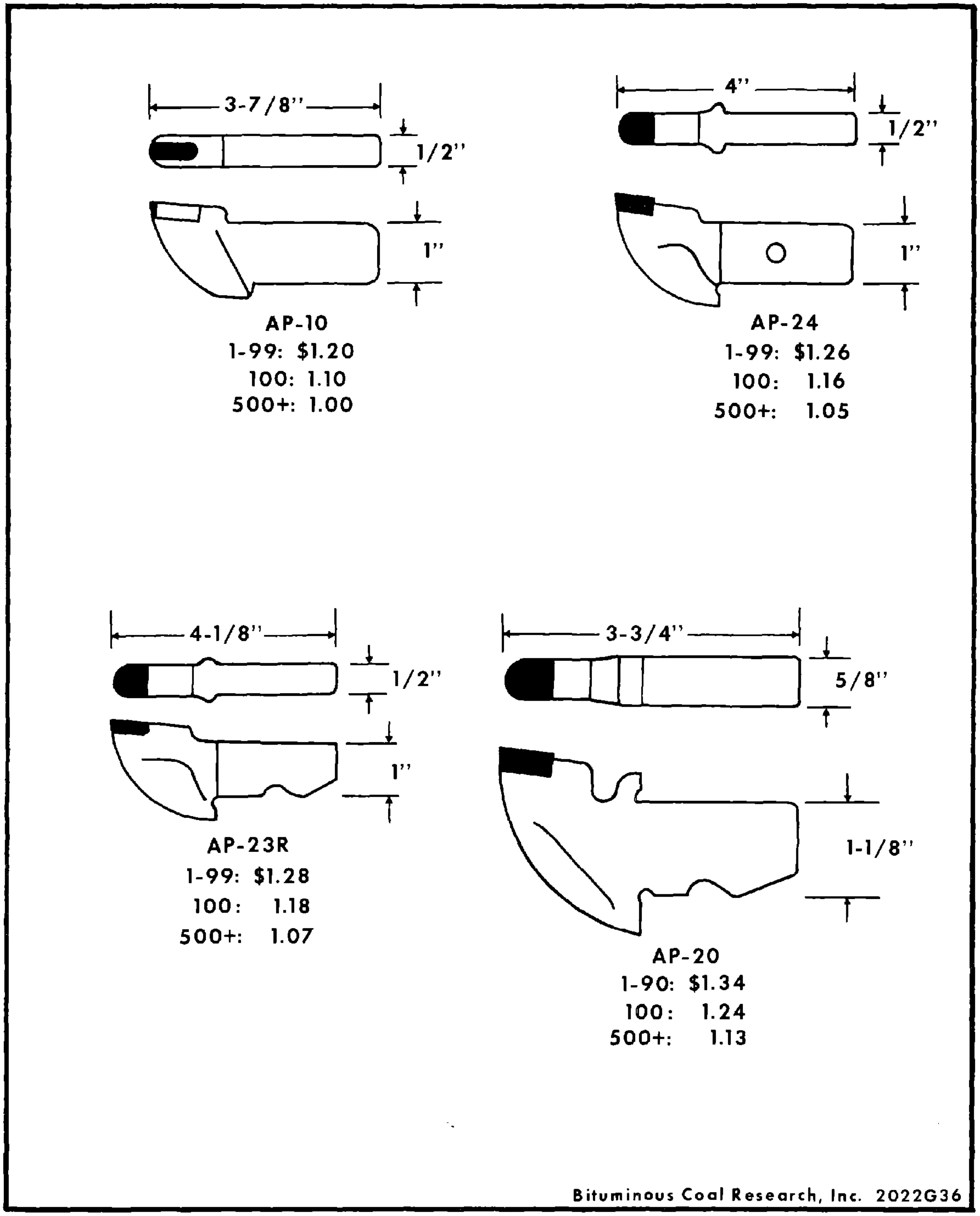


Figure E-14. Unit Prices of Representative Cutter Bits Produced by Austin Powder

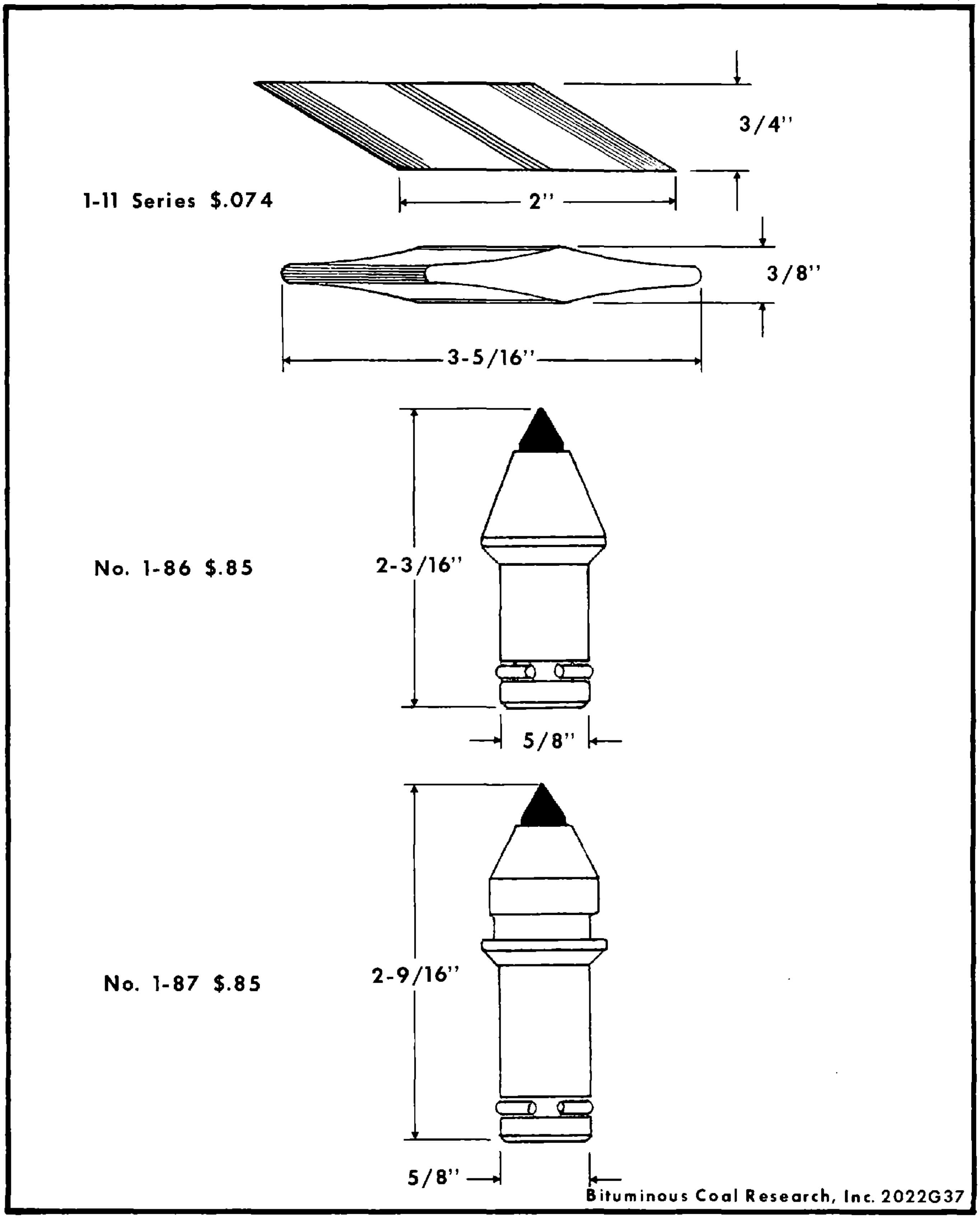


Figure E-15. Unit Prices of Representative Mining Bits Produced by Bowdil

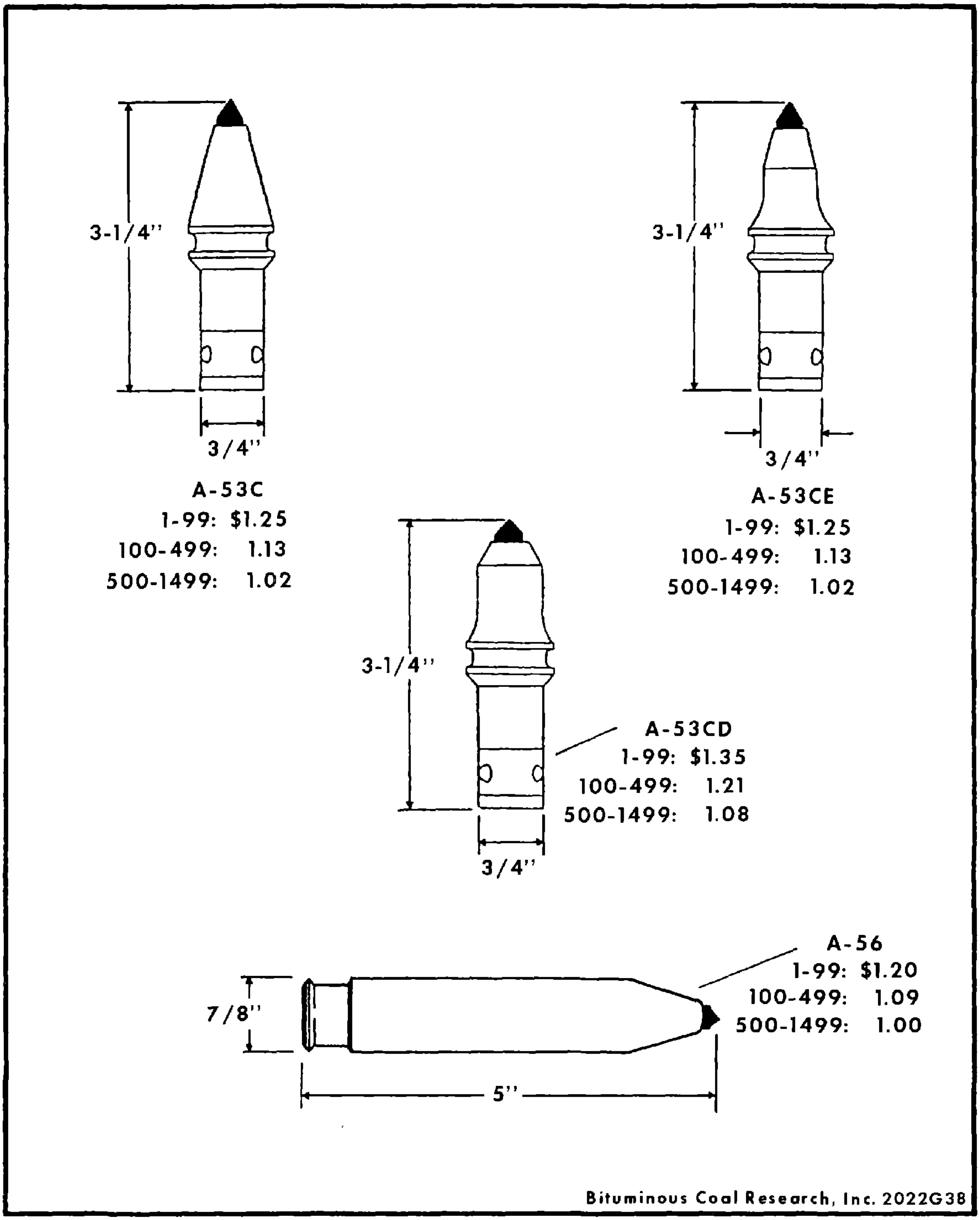


Figure E-16. Unit Prices of Representative Point Attack Bits Produced by Columbia Bit Company

APPENDIX F

PHOTOGRAPHS OF SAMPLES OBTAINED FROM THE VARIOUS BIT MANUFACTURERS

2022P11

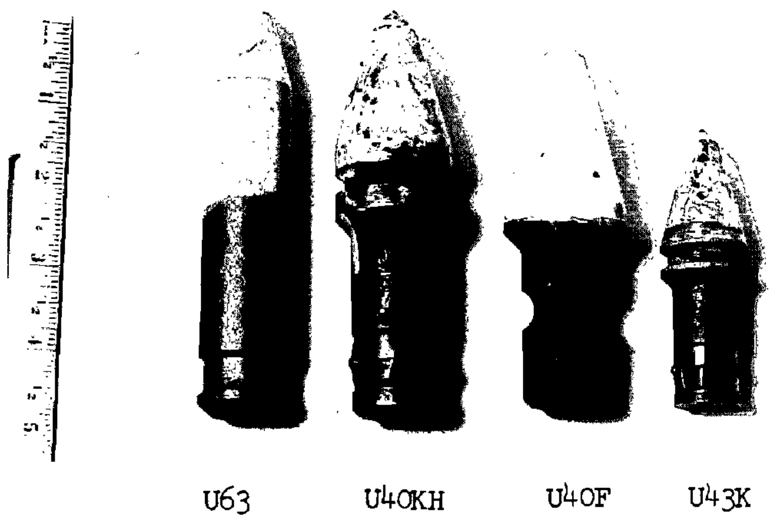


Figure F-1. Kennametal Bit Company - Carbide Tipped Point Attack Bits

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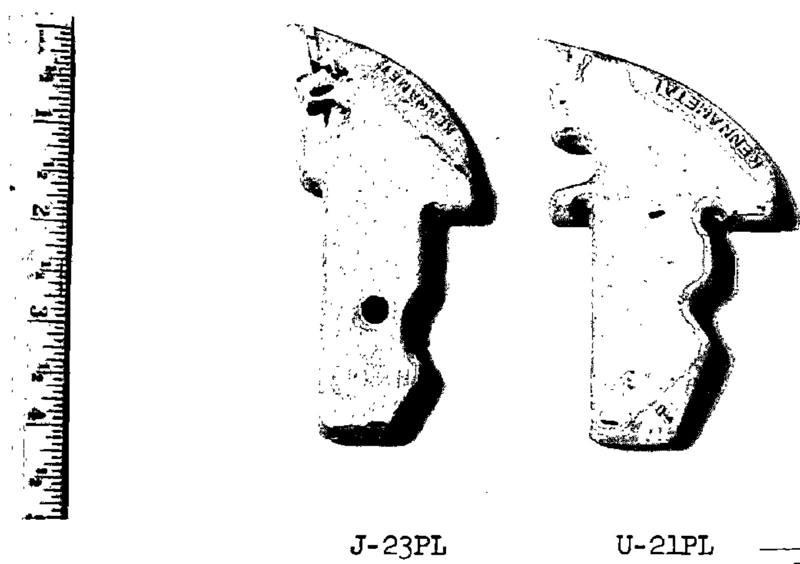

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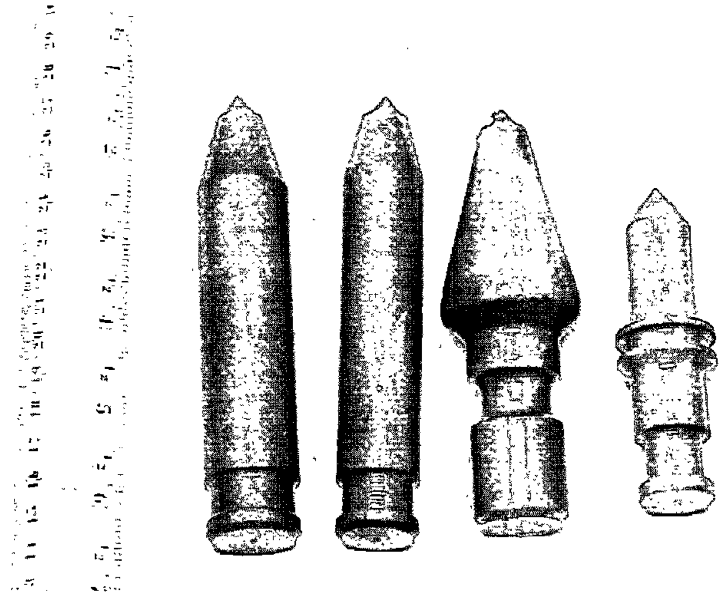
Figure F-2. Kennametal Bit Company - Carbide Tipped Rectangular Shank Cutter Bits

2022P14



CC-45 CC-44 CC-40 CC-43S

Figure F-3. Carboloy Bit Company - Carbide Tipped Point Attack Bits

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2022P13

CCS-2 SCC-12-P CC-19-H-S CCR-2 CC-3-RB

Figure F-4. Carboloy Bit Company - Carbide Tipped Rectangular Shank Cutter Bits

2022P15

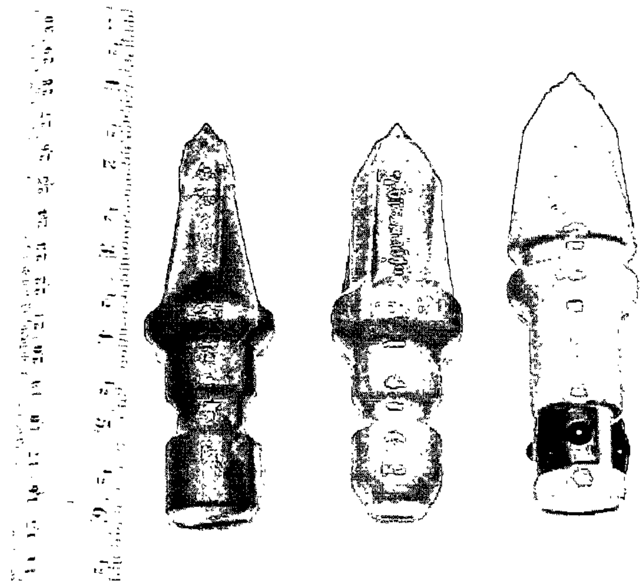

Figure F-5. Carboloy Bit Company - Carbide Tipped Ribbed Plumb Bob Bits Carboloy

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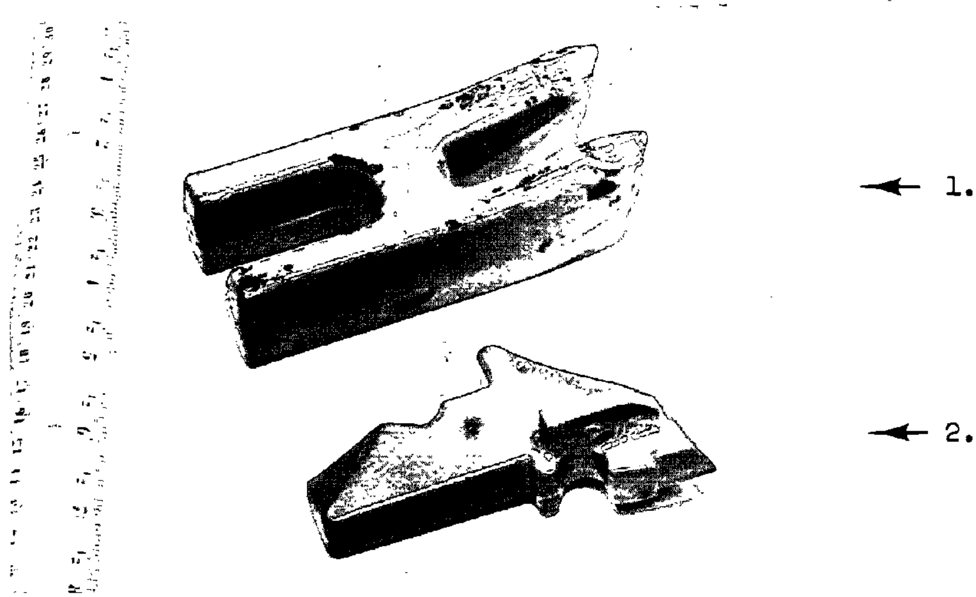
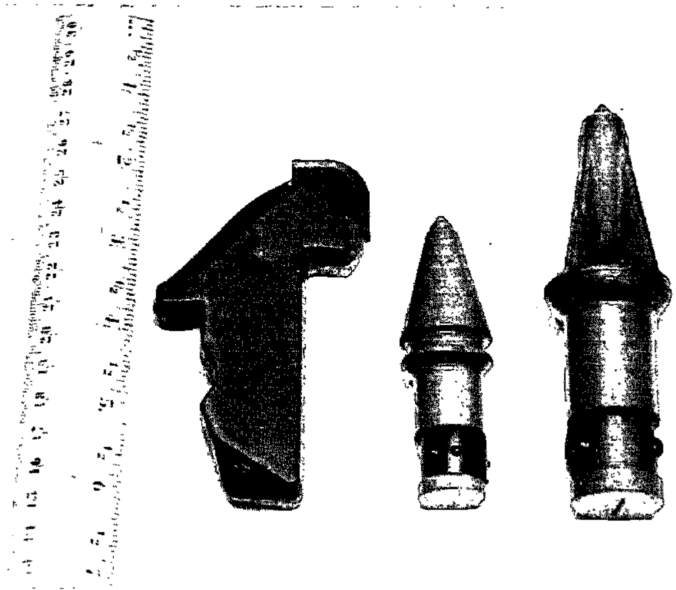


Figure F-6. Carboloy Bit Company - Experimental Bits

1. Double-headed Cutter Bit
2. Undercutter Bit with Side Wiper

2022P17



1. 2. 3.

Figure F-7. Carboloy Bit Company - Experimental Bits

1. Standard Rap-Loc Type Tool with Large Carbide Insert
2. Small, Spring Held Plumb Bob Style Point Attack Tool
3. Thin Nose, Spring-Held Point Attack Bit

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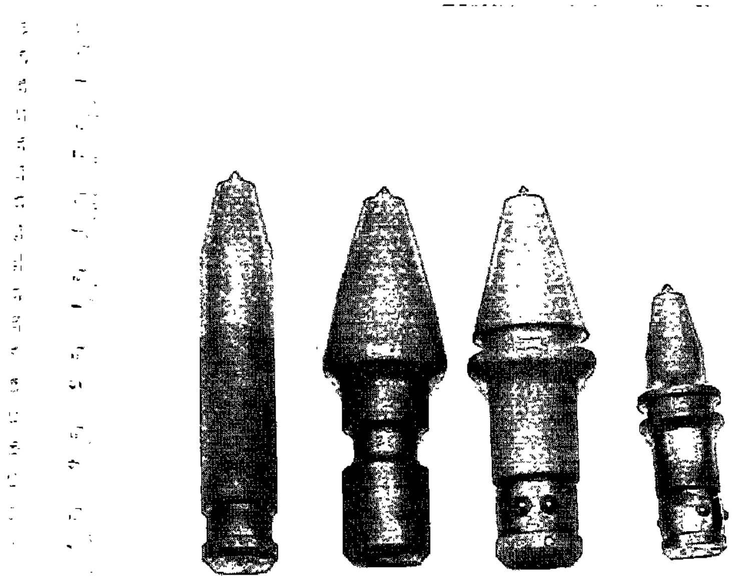

29U10 29U5 29U6 40U14

Figure F-8. Carmet Bit Company - Carbide Tipped Point Attack Bits

2022P8

F-6 R-2 F-4

Figure F-9. Carmet Bit Company - Carbide Tipped Rectangular Shank Cutter Bits

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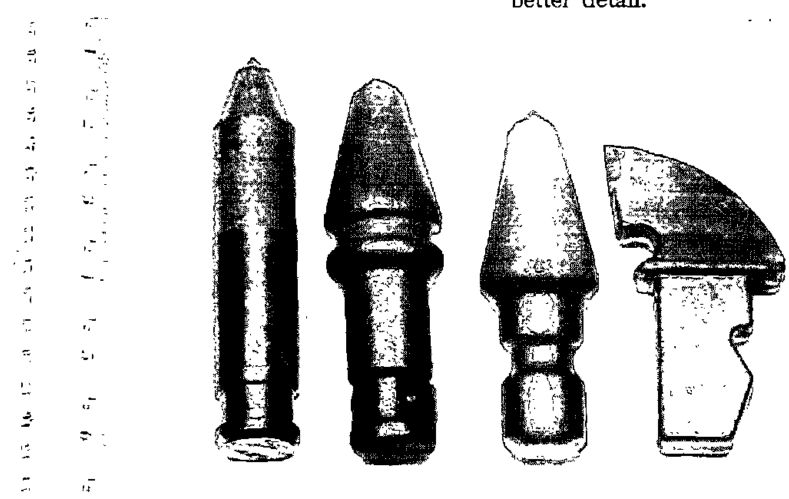
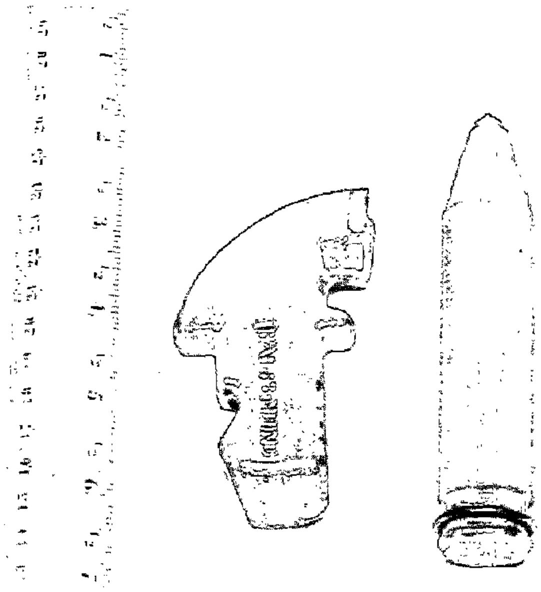


P10 P11 P1 C2

Figure F-10. VR/Wesson Bit Company - Carbide Tipped Continuous Miner Bits

F-8.

2022P18



M6 C4236

Figure F-11. Cincinnati Mining Machine Company - Carbide Tipped Continuous Mining Bits

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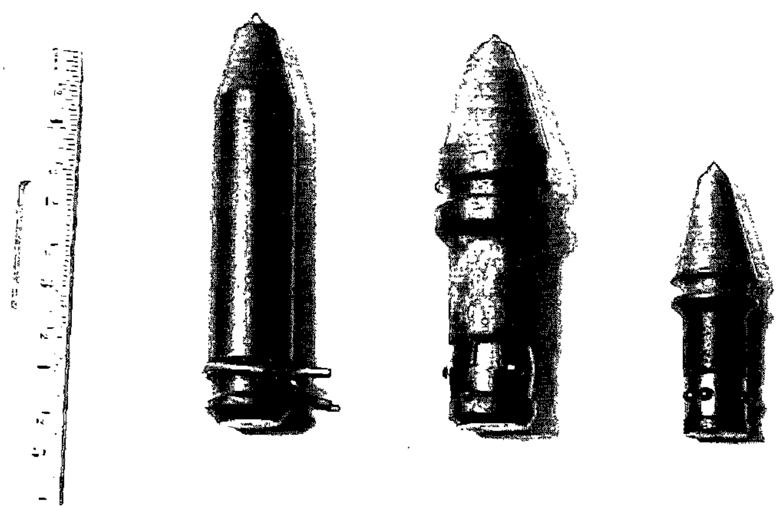

8853 8855 8860

Figure F-12. Long-Airdox Bit Company - Carbide Tipped Point Attack Bits

2022P21

M12-RPL WL2-RPL CHD-RPL

Figure F-13. Long-Airdox Bit Company - Carbide Tipped Rectangular Shank Cutter Bits

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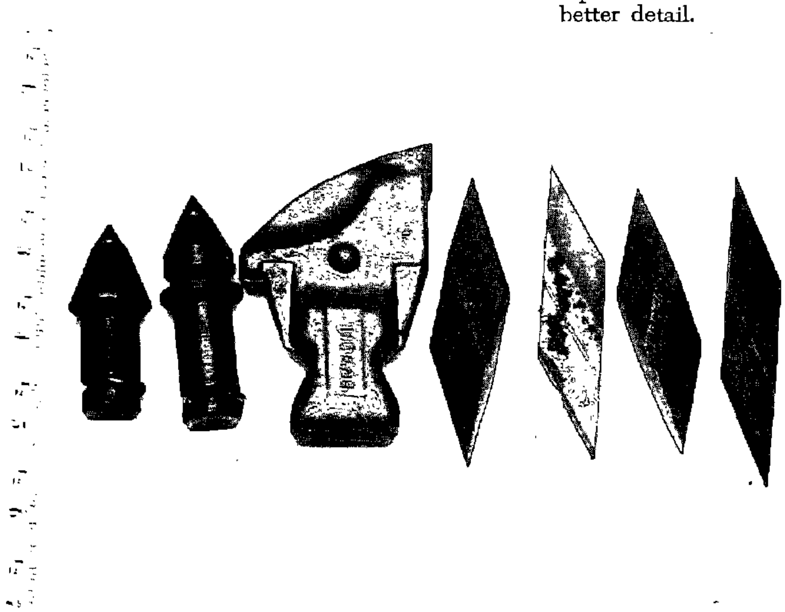

Series 1-52 1-86 1-34 1-11 1-29 1-2 1-6

Figure F-14. Bowdil Bit Company - Continuous Mining Bits

APPENDIX G

REPORT ON METALLURGICAL INVESTIGATION OF BORONIZED BITS

APPENDIX G

REPORT ON METALLURGICAL INVESTIGATION OF BORONIZED BITS

I. INVESTIGATION OF A 1 IN. DIAMETER CONICAL BIT

A. General Examination

1. The surface showed a random, spotty, black adhering slag on portions of the body and conical tip. This slag was soft - could be cut with a razor, and was not very adherent - could be removed by wire brushing. No significance was attributed to the slag except that it could be remnants of the boronizing agents.

2. The surface of the cylindrical body of the tool was the as-rolled bar stock surface, i.e., no metal had been removed by machining the body. This means that any decarburization present on the original bar stock is still present on the tool, with resulting lower hardness and wear resistance.

3. The tool was spark tested on a high speed grinding wheel to obtain a rough indication of composition. The results indicated a medium carbon alloy steel containing molybdenum.

4. The tool was file tested using a standard Nicholson test file. The results showed that the conical tip and the adjacent 1/8 in. of the body was "file hard" (above Rockwell C65) while the body showed "medium bite" (below Rockwell C60).

5. A sketch of the tool and test locations is shown in Figure G-1.

B. Chemical Analysis

The analysis was run at a point midway between the surface and the center. Results were (percent)

	C	Mn	P	S	Si	Cr	Mo	Al	Ni, V, W
Sample	.40	.83	.015	.028	.25	.87	.18	.025	all under .02
Range 4140	.38 .43	.75 1.00				.80 1.10	.15 .25		

The steel is identified as standard AISI 4140 steel and is fine-grain aluminum killed.

C. Fracture Tests

Sections were cut from the tool as indicated in the sketch; but a portion of each cut was left incomplete, so the sectioning could be completed

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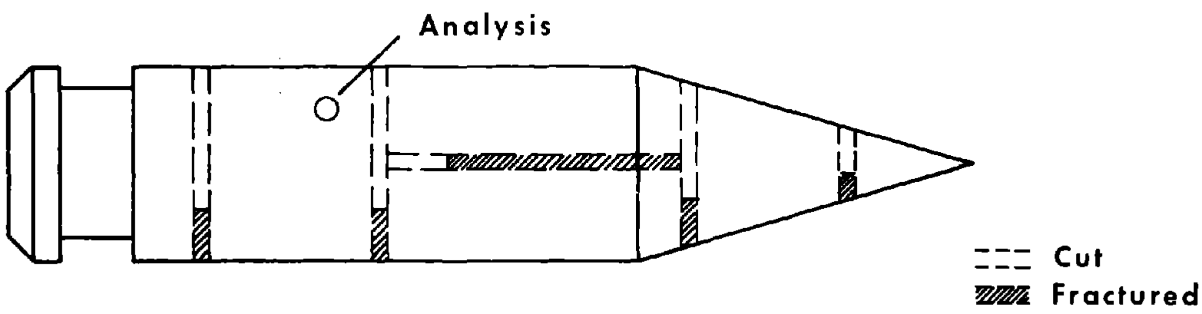

Figure G-1. One-inch Diameter Conical Bit Showing Tool and Test Locations

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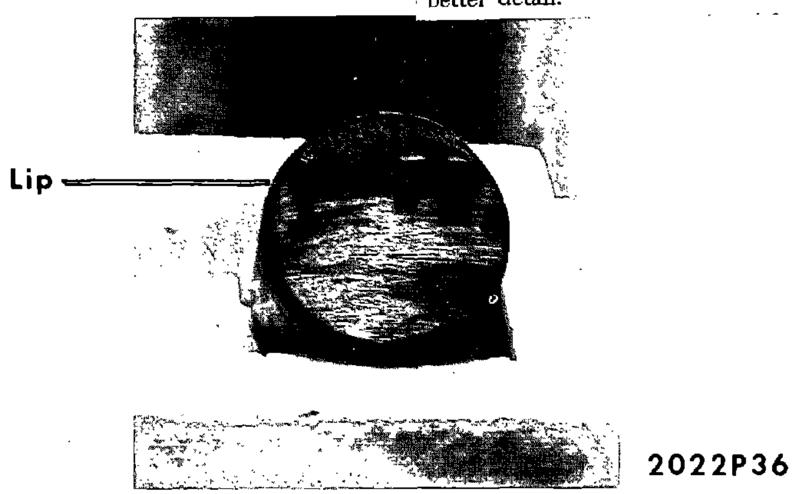

Figure G-2. One-inch Conical Bit Cross-section Showing Appearance of the Lip (1¼X) by fracturing with a hammer blow. The fractured surfaces were refined but coarser than expected for the grade and were rated Shepherd No. 7. (No. 9 is expected.)

The fracture through the conical tip showed the presence of a case and the longitudinal fracture of the body showed that the case only extended about 1/8 in. along the body from the tip.

All fractures showed prominent "lipping" at the surfaces where a case was present. This type of fracture indicates some degree of ductility in the case. Slight spalling of the case was noted in locations of bending but there was no evidence of complete case spalling that occurs on many types of cases. Figure G-2, at the 1-1/4 magnification, shows the appearance of one of the lips.

D. Hardness Tests

Rockwell C. hardness tests were taken on all sections shown in the sketch, plus the transverse end of the shank. All results were in the range of C48 to 50, except near the surface of the body where C45 to 47 was noted. Hardness was also measured on the round body surface using a V-block anvil, with erratic results varying from C37 to 44. Rockwell 15-N superficial hardness was taken in the same location and showed 79 to 81 (equivalent to C37/41).

It was not possible to measure Rockwell hardness on the case because it was too thin. (See case micro-hardness later)

E. Microscopic Examination

Samples were polished for examination at all locations of sections on the sketch. The structure at all internal locations consisted of quenched and tempered martensite that showed considerable grain coarsening. (Grain coarsening usually results from either excessively high quenching temperature or a long holding time at the quenching temperature or both).

The structure at the surface of the round body showed partial decarburization to about 0.020 in. deep as a result of carryover from the original bar stock. This finding accounts for the low hardness on the surface of the body.

The structure of the case that was on the conical tip plus 1/8 in. of the adjacent body was a typical boronized case that measured about 0.002 to 0.003 in. deep, as illustrated in Figure G-3, a photomicrograph at 100X magnification using a nital etchant. The structure beneath the case consists of tempered martensite that shows some evidence of coarse grain size.

To further identify the case a sample was examined on an electron-beam microprobe. This examination definitely identified a large concentration of boron in the case, although quantitative measurement could not be made.

As a final check on the case, microhardness was taken with a diamond pyramid at 50 gram load (Reichert). Average of three readings showed a hardness of 1190, which is equivalent to about Rockwell C75, and in the same range as sintered carbides.

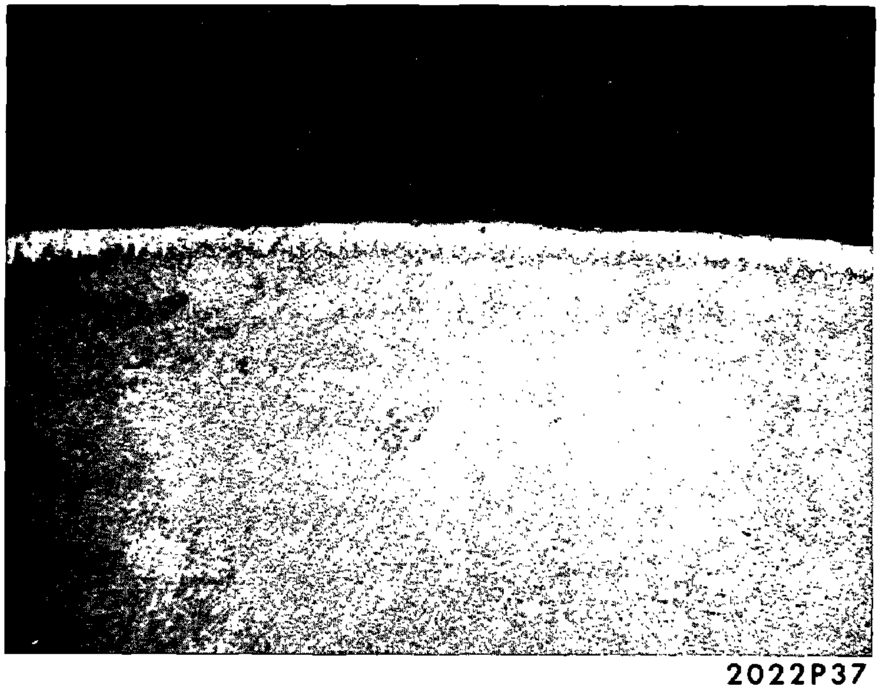

Figure G-3. Cross-section of the One-inch Diameter Bit Showing .002 to .003-inch Deep Boronized Case (100X)

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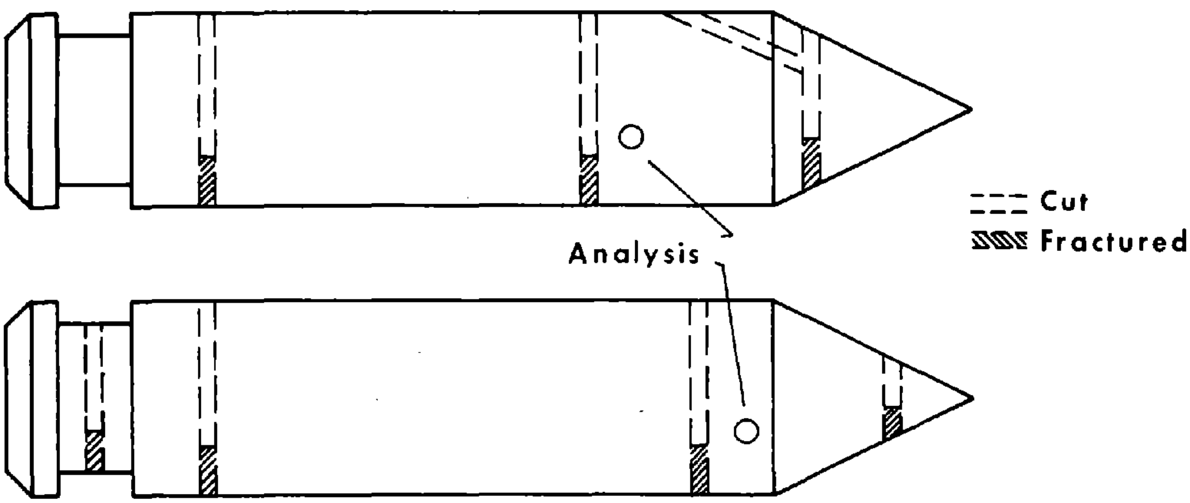

Figure G-4. 7/8-inch Diameter Conical Bits Showing Tool and Test Marks Locations

F. Summary of Results on 1 in. Conical Bit

The bit was made of AISI 4140 steel and had been heat treated all over by quenching and tempering to a hardness of Rockwell C48 to 50. The surface of the body was softer than the interior hardness due to the presence of decarburization on the surface of the original bar stock and not being removed by machining.

The conical tip of the bit plus 1/8 in. of the body showed a hard boronized case about 0.002 to 0.003 in. deep. In addition to characteristic high hardness the case also exhibited some ductility.

It is surmised that the case was put on by a treatment with fused salt during heating to the quenching temperature and that the tool was held at this temperature for a considerable period of time beyond the usual time, in order to develop a relatively deep case which was accompanied by some grain coarsening of the martensite.

Generally, it was considered that the boronizing treatment had been effectively done, as long as it was judged unnecessary to harden the cylindrical body surface.

II. INVESTIGATION OF TWO 7/8 IN. DIAMETER CONICAL BITS

A. General Examination

1. No surface slag was visible on the bits.

2. Both bits showed the as-rolled bar stock surface on the cylindrical body and appeared to have been made from the same bar.

3. Both bits were spark tested and appeared identical to each other, but showed higher carbon and less alloy than the 1 in. diameter bit.

4. Both bits were file tested in many locations and appeared quite similar to each other. Both bits showed "medium bite" (below Rockwell C60) at all locations; there was no "file hard" case on the conical tip or elsewhere on these bits.

5. Sketches of the tools and test locations are shown in Figure G-4.

B. Chemical Analysis

Samples from both pits were analyzed at midway locations with the following results: (percent)

	C	Mn	P	S	Si	Cr	Mo	Al	Ni, V, W
Sample 2	.41	.82	.016	.025	.27	.87	.17	.028	all under .02
Sample 3	.39	.81	.014	.032	.27	.85	.17	.030	all under .02

This steel is also AISI 4140 and in fact appears to be from the same heat of steel as the 1 in. bit. (The false indication of composition on the spark test was due to presence of a carburized case, as discussed later).

C. Fracture Tests

Fractures were made on both bits at locations marked in the sketch. All fractures were uniformly fine (rated Shepherd No. 9) and showed no "lipping" or other evidence that a case was present.

D. Hardness Tests

Rockwell C hardness tests were made on all sections indicated on the sketch. Hardness was uniformly C49 to 50 at all internal locations except that the hardness gradually increased to C53 just under the surface. (This increase is an indication of a case and the absence of decarburization). Hardness was also measured directly on the round body surface using a V-block anvil and was quite erratic, varying from C41 to 52 in random manner. Superficial Rockwell 15-N readings on the round surface showed 87 to 88 (equivalent to C53 to 55) and again indicate a case that is harder than the interior.

E. Microscopic Examination

Samples were polished for examination at the section locations shown in the sketch. At all internal locations the structure consisted of fine grained tempered martensite. This indicates that customary quenching temperature and holding time were used (1550° F for one hour would be typical).

Structures at the surface at all locations tested showed the presence of a carburized case about 0.014 in. deep and spotty occurrence of a boronized case that varied from 0 to 0.0004 in. deep. Figure G-5, a photomicrograph, illustrates a typical location that shows the variation of boronized case depth.

Note that the martensitic structure is fine grained. The carburized case contains spheroidal carbides to a depth of about 0.004 in., where the carbon level is estimated at about 1 percent. Thus, the original surface decarburization on the surface of the bar stock has been not only neutralized but replaced by excess carbon. The carburized case would increase the wear resistance of the bits somewhat, until worn away.

The spotty boronized case was present on the tips and body of the bits to within 1/4 in. of the retainer groove. The carburized case was present over the entire surface of the two bits.

A sample of one of the bits was examined on the electron-beam microprobe to confirm that the white appearing areas of the case were actually boronized and boron was positively identified. The boronized case was too shallow to permit taking micro-hardness.

Boronized Case

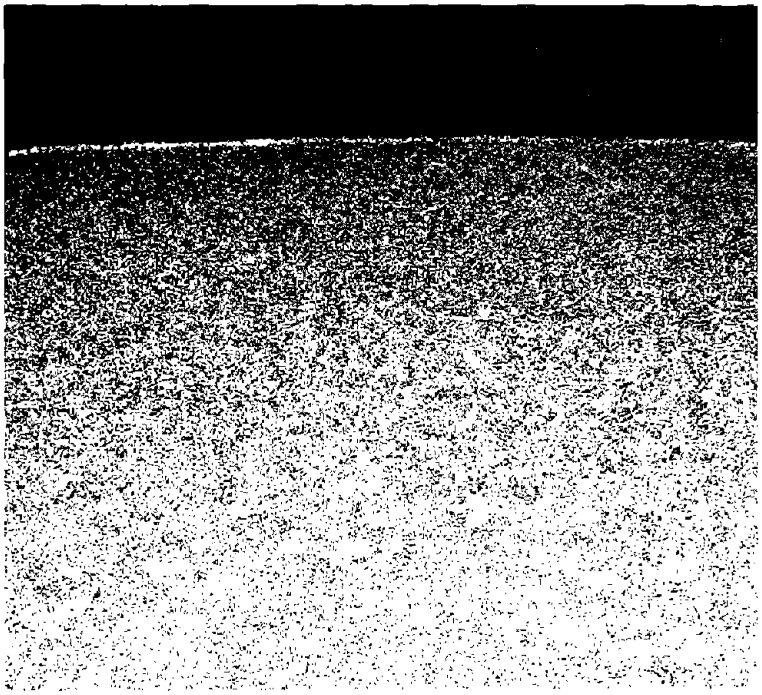

Figure G-5. Cross-section of a 7/8-inch Diameter Bit Showing Variations in Depth of Boronized Case from 0 to .0004-inches

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F. Summary of Results on Two 7/8 in. Bits

The bits were made of AISI 4140 steel and had been heat treated by quenching and tempering to a hardness of Rockwell C49 to 50. The surface of the bits contained a carburized case 0.014 in. deep, all over, plus a spotty boronized case from 0 to 0.0004 in. deep on the tip and body to within 1/4 in. of the retainer groove.

The hardness of the carburized case ranged from the internal hardness up to Rockwell C55 and its presence eliminated the disadvantage of the original decarburization present on the bar stock surface.

The boronized case was too shallow to permit hardness tests and was so shallow that nowhere were the bit surfaces "file hard."

It is surmised that the carburized case was put on by providing a carburizing atmosphere during normal heating for the quench and that the boronized case was put on by applying a salt to the bits on the tip and the body to a point just short of the retainer groove during this same heating period.

Generally, it was considered that the boronizing treatment was ineffectively done because of insufficient time at temperature. The carburized case was effective and properly done but could not be expected to provide wear resistance approaching that obtained from inserted carbide tipped tools.

III. EVALUATION OF TEST RESULTS ON BITS NO. 1, 2, AND 3

1. All three conical bits, intended for use with a hard boronized case, were made of AISI 4140 steel heat treated to a hardness of about Rockwell C50. In the absence of any reliable data regarding the failure mode of this type of bit, the grade of steel and hardness appear satisfactory.

2. The 1 in. diameter bit had an adequate boronized case on the conical tip plus 1/8 in. of the adjacent body. If it is known that wear on the cylindrical body is of no concern, then this type of boronized bit appears suitable for use in service to develop service life data. If severe wear is known to occur in the body location, then the boronized case should also be applied on the body on bits used for service life data.

3. The two 7/8 in. diameter bits had a shallow, spotty boronized case that did not show high surface hardness even in a file test. The use of bits, made in the same manner as these two, for development of service data on boronized bits does not appear warranted since an adequate boronized case was not present.

4. The two 7/8 in. bits had higher hardness on the cylindrical body surface than the 1 in. bit because of a carburized case and would be expected to show better wear resistance at this location than the 1 in. bit (which actually had a loss of surface hardness on the body due to decarburization). However, the lack of a good boronized case would make it illogical to test this type of bit against carbide tipped bits.

IV. ESTIMATE OF SERVICE POTENTIAL OF BORONIZED BITS COMPARED TO CARBIDE TIPPED BITS

The best boronized steel bit offers little hope of equalling the performance of carbide inserted tools, assuming that the latter are properly made and used.

This statement is not intended to deprecate the boronizing process but is based on the fact that the process applies a thin (0.002 to 0.003 in.) layer of a hard material that has hardness in the same order as sintered carbides. Once this thin layer is worn off, the remaining wear resistance is essentially that of steel. In comparison, a carbide inserted tip still has considerable wear potential after a few thousandths of an inch are worn from the surface, assuming the carbide bit does not break early in its service life.

V. PRELIMINARY RECOMMENDATIONS

In spite of the rather pessimistic view expressed above about boronized bits, it is recommended that a controlled service test be set up, that would provide an unbiased evaluation of their merits and possibly at the same time provide useful data about the life of carbide inserted bits. This recommendation is made because prediction of performance of tools in wear applications is notoriously inaccurate. Essentially, a controlled service test would involve the use of a number of identical bits of the two types of tools to be compared, in the same cutter; duplicate tools of each type would be removed from service after preselected intervals such as 1, 2, 4, 8, and 16 hours and examination of these tools would enable observations and measurements regarding wear and mode of failure or deterioration.

This type of data cannot usually be obtained when the tools are used to destruction in an uncontrolled test, since secondary failures obscure much of the information.

VI. INVESTIGATION OF A 7/8 IN. DIAMETER CONICAL BIT (NO. 4)

A. General Examination

1. A boron coated, all steel bit, supplied by a different source than bits 1, 2, and 3 was submitted for analysis. The bit was coded No. 4 to distinguish from bits previously investigated. A comparison bit of the same type and from the same source as bits 1, 2, and 3 was submitted to check sparking; this bit was coded as No. 5.

2. Bit No. 4 showed a uniform gray matte appearance in contrast to the black and gray mottled surface of bit No. 5. The surface finish of No. 4 may reflect its processing in contact with salt or the finish could have been put on by "liquid honing." In either case no significance is attached to the surface finish.

3. Both bits showed the cylindrical surface to be constituted of the original bar stock surface. This is not good practice since decarburization on the bar stock is carried over into the finished tool. Good practice requires machining of the body surface which, of course, requires a larger size of bar stock to be used.

4. Both bits were spark tested on a 3600 rpm 7 in. oxide grinding wheel to examine the non-sparking characteristic claimed for the boron coating treatment and to identify the steel grade. The results showed that the lightest possible touch produced brilliant sparking as soon as the bit contacted the wheel. The sparks from both bits indicated a medium carbon alloy steel containing molybdenum. Bit No. 5 showed evidence of higher carbon near the surface compared to internal locations, indicating a carburizing treatment in addition to the boronizing.

5. Both tools were file tested using a standard Nicholson test file. Neither of the bits was "file hard" at any location. Bit No. 4 was hardest on the conical tip surface and the machined retainer groove surface and showed "light bite." The body surface of both bits could be readily filed. This does not represent a good wear resisting surface.

B. Sketch of Bit and Test Locations (No. 4)

A sketch of the bit and test locations is shown in Figure G-6.

C. Chemical Analysis

Analysis was not run on these tools. The results of spark testing are adequate for this investigation, since composition is not critical in the evaluation of the boronizing treatment.

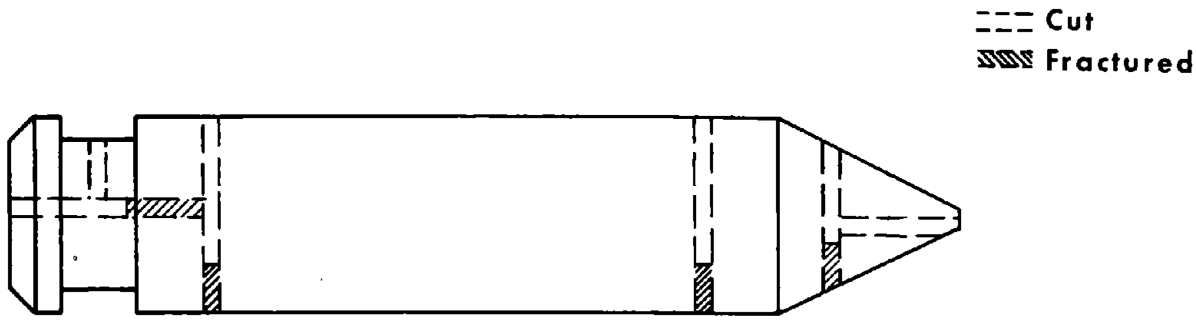

Figure G-6. 7/8-inch Diameter Conical Bits Showing Tool and Test Marks Locations

This page is reproduced at the back of the report by a different reproduction method to provide better detail.

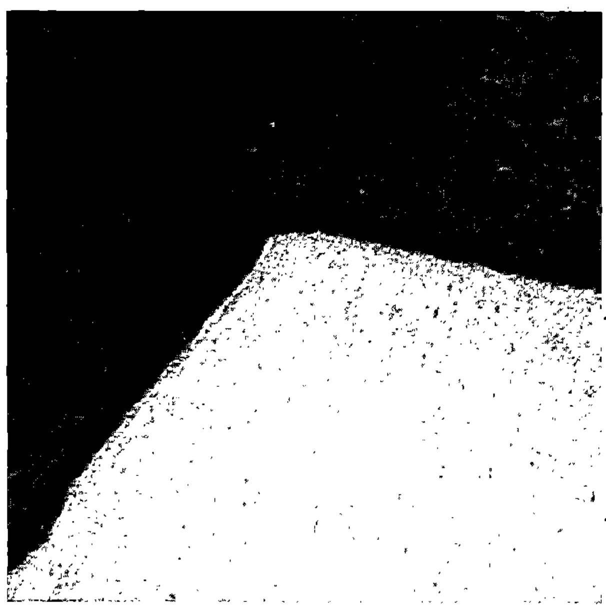

Figure G-7. Cross-section of a 7/8-inch Diameter Bit Showing Variations in Depth of Boronized Case from .0002 to .0008-inches

D. Fracture Tests

Sections were cut from Bit No. 4 where shown in the sketch with portions left uncut so that fracturing with a hammer blow would complete the sectioning. The fractures were uniformly fine and were rated Shepherd No. 9, indicating an effective quench. One fracture on the body showed a slight "lip" but otherwise there was no evidence of a case.

E. Hardness Tests

Rockwell C hardness tests were made on all sections shown in the sketch and on the cylindrical body surface. At all locations the internal hardness was uniform and within the range C51 to 53. Readings on the surface were erratic with random variations from C41 to 57 and reflect the non-uniformity of the original bar stock surface. The boronized case was too shallow for hardness testing.

F. Microscopic Examination

Specimens were polished from the section locations shown in the sketch and a longitudinal section through the tip was also prepared. At all internal locations the structure consisted of fine grained tempered martensite that indicates effective heat treatment using normal temperatures and times.

A shallow boronized case was present on all exterior surfaces of the bit. The case was most uniform on the conical tip and the machined retainer groove surfaces and typical appearance of the case is shown in the photomicrograph, Figure G-7 at 100X as it appeared on the apex of the tip. The case was accurately measured at several spots and averages .0008 in. deep. The case on the round body was erratic, varying from .0008 in. to about .0002 in. and this fact is consistent with the finding of variable hardness on the body. There was no decarburization or carburization visible at the as-rolled surfaces (but this condition is not always visible in the heat treated condition).

G. Check Testing of Bit No. 5

The comparison bit No. 5 was tested by cutting and fracturing a section 1/2 in. from the tip. The tip was cut longitudinally for polishing a microsection to compare with bit No. 4. The results were:

1. Fracture - fine grained, no "lip" or case visible.

2. Hardness - on cylindrical surface of body hardness was Rockwell C47 to 58 varying in a random manner.

3. Microstructure - fine grained, boronized case depth on tip is about .0005 in. and a carburized case about .015 in. deep was seen.

4. Summary of Results on Bit No. 5 - all tests results were identical to those reported on January 19, 1973 for Bits No. 2 and No. 3, and it appears that bit No. 5 was from the same lot.

H. Summary of Results on Bit No. 4

The No. 4 bit had been heat treated all over to a hardness of Rockwell C51 to 53 and had been given a boronizing case treatment all over. The case depth was quite shallow, averaging .0008 in., and this depth was not enough to produce a "file hard" surface. The case on the body was erratic in hardness and depth as a result of the variation of the as-rolled bar stock surface present.

The bit sparked readily when touched to a grinding wheel which indicates that, if the boronized case is actually non-sparking, the case depth was too shallow to show it.

I. Evaluation of Test Results for Bits No. 4 and No. 5

The boronized case on bit No. 4 was too shallow, in view of the fact that it was not "file hard," and the service testing of this type of bit would not adequately evaluate the potential merits of boronizing treatment. The same judgement applies to bits No. 2, No. 3, No. 4, and No. 5.

J. Recommendations

It is recommended that boronized bits conform to the following requirements:

1. Bits should have a minimum boronized case of 2 mils (.002 in.) as measured by microscope after nital etch.

2. The working surfaces of the bits must be "file hard."

3. The working surfaces must be machined all over before heat treatment to remove as-rolled bar stock surface.

K. Estimate of Service Life of Boronized vs Carbide-tip Bits

1. It is estimated that carbide-tip bits would outwear boronized bits made like No. 4 or No. 5 by 5 to 10 times; and, therefore, it is not worthwhile service testing bits of this type.

2. It is possible that carbide-tip bits would outwear boronized bits made to specification J above by several times. However, the subject of wear resistance is so complex that it would be worth service testing bits with an adequate boronized case to be sure that something good is not overlooked.

3. Even more productive would be a controlled test program on carbide tip bits, since so little factual knowledge exists in this area there is a good probability of significant improvement.