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MACHINING TESTS AND ANALYSIS ON
1018 AND 4330 STEELS

Metcut Research Associates Inc.
Cincinnati, Ohio 45209

Contact No. DAAA22-75-M-0419

Prepared For



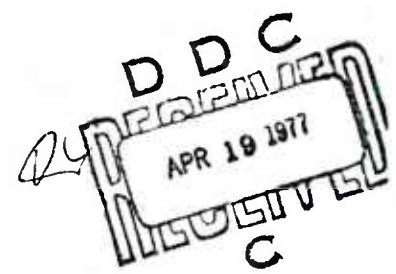
BENET WEAPONS LABORATORY
WATERVLIET ARSENAL
WATERVLIET, N.Y. 12189

January 1977

TECHNICAL REPORT

AMCMS No. 3297.16.7119

Pron No. M1-2-23084-01-M7-M7



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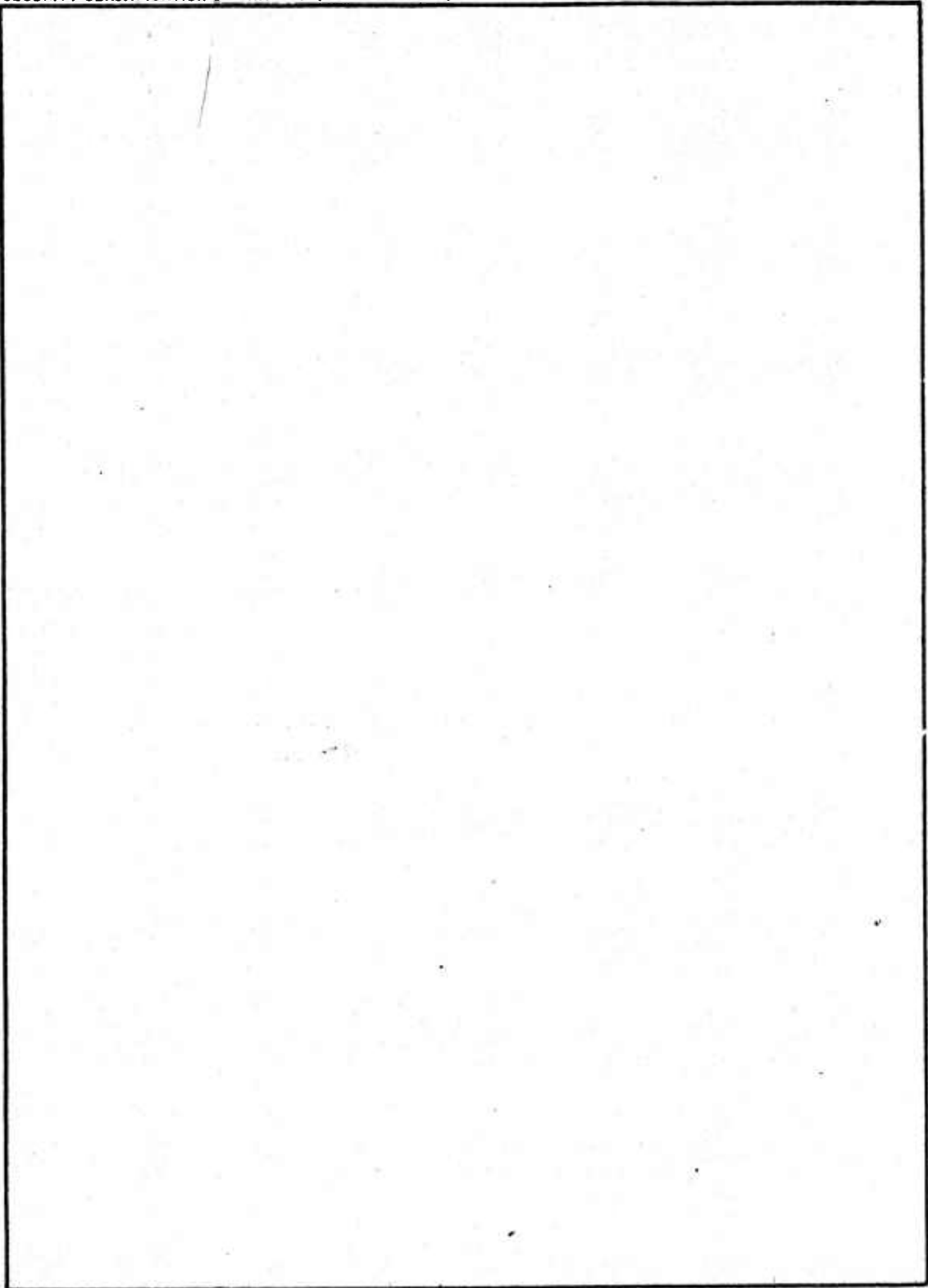
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (12) WVT-CR-77003	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) MACHINING TESTS AND ANALYSIS ON 1018 AND 4330 STEELS.		5. TYPE OF REPORT & PERIOD COVERED Thesis
7. AUTHOR(s)		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Metcut Research Associates Inc. Cincinnati, Ohio 45209		8. CONTRACT OR GRANT NUMBER(s) DAAA22-75-M-0419
11. CONTROLLING OFFICE NAME AND ADDRESS Benet Weapons Laboratory Watervliet Arsenal, Watervliet, N.Y. 12189 SARWV-RT-TP		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No. 3297.16.7119 Pron No. M1-2-23084-01-M7-M7
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 28p.		12. REPORT DATE (11) January 1977
		13. NUMBER OF PAGES 28
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. (10) 512-22568-1		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Carbide High Speed Steel Optimum Tool Geometry Application		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An examination of the report "An Investigation to Determine the Single Point Cutting Tool Angles Which Yield Maximum Tool Life by Response Surface Methodology and Evolutionary Operation of Processes," Lloyd Louis Lehn (thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Mechanical Engineering in the Graduate College of the University of Illinois, 1967) necessitated determining the optimum tool geometry which could be used to grind back and side rake tool angles for high speed steel tools. Machining tests and analysis were done on 1018 and 4330 steels.		

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MACHINING TESTS AND ANALYSIS
ON 1018 AND 4330 STEELS

Metcut Report 512-22568-1

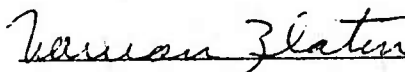
for
Watervliet Arsenal
Watervliet, NY

Contract No. DAAA22-75-M-0419

Date: November 10, 1975

METCUT RESEARCH ASSOCIATES INC.


John D. Christopher, Supervisor
Machinability Laboratory


Norman Zlatin, Director
Machinability Research

Abstract Summary

Review and Evaluation of Subject Report⁽¹⁾ to Determine Optimum Tool Geometry

An examination of the subject report clearly indicated that a review and evaluation of the report necessitated determining the optimum tool geometry which could be used to grind back and side rake tool angles for high speed steel tools. These optimum angles were not directly or specifically defined in the thesis in either the text or any of the tool life tables. It was evident that the author had a number of problems with his computer programs, but he very clearly spelled out these difficulties and identified how he finally determined the optimum back and side rake angles.

Metcut decided that the best way of testing the author's approach was to actually perform independent experimental tests using the alternative geometry suggested by the author. It should be noted that the region of the optimum tool geometry was located in the subject report in terms of the functional angles. Since the variable back rake and side rake angles were never given in the report, it was necessary to develop a computer program to calculate the angles in order to test the optimum tool geometry. The iterative procedure described in Appendix B of the report was used. The values used for the functional angles (inclination angle = -34° and velocity rake angle = 15°) were read from Figure 41 on page 112 of the report. The calculated values for the back and side rake angles (as well as the other angles which were held constant) comprise the optimum tool geometry as follows:

-
- (1) "An Investigation to Determine the Single Point Cutting Tool Angles Which Yield Maximum Tool Life by Response Surface Methodology and Evolutionary Operation of Processes," Lloyd Louis Lehn (thesis submitted in partial fulfillment for the degree of Doctor of Philosophy in Mechanical Engineering in the Graduate College of the University of Illinois), 1967.

Back rake	=	-21° (rounded off from -20.8°)
Side rake	=	32° (rounded off from 31.7°)
End relief	=	8° (rounded off from 7.9°)
Side relief	=	11° (rounded off from 11.3°)
End cutting edge	=	8° (rounded off from 8.3°)
Ground side cutting edge	=	30°
Nose radius	=	0.010 in.

The above optimum tool geometry was used for the turning tests on 1018 cold drawn steel (146 BHN) using T1 high speed steel--namely, the material and tools used by the author of the subject report.

Figures 1 and 2 of Metcut's report show the superiority of the optimum tool geometry when cutting dry and also with a soluble oil cutting fluid.

Figures 3 and 4 are plotted to indicate that tool life turning dry is improved over turning with soluble oil. These results substantiate the improvement in tool life anticipated by Dr. Lehn. The degree of improvement is surprising. Further, it is interesting to note that Dr. Lehn turned without a cutting fluid. Our first reaction was to question why he chose to cut dry. Perhaps he attempted to avoid introducing an additional variable into the testing of his unusual tool geometry. However, as it developed, he not only simplified his testing but also obtained longer tool life.

It should be noted that Dr. Lehn's choice of material and type of cutting tool is not applicable to the Arsenal's turning requirements -- and from all we can determine, there was no attempt on his part to so relate. However, we can anticipate some applications for the unusual optimum geometry using high speed steel.

With regard to additional tests which were set up to help the Arsenal improve its turning of gun tubes, several interesting conclusions were reached.

F. J. McGee and G. S. Shay (see page 3 for reference) developed an

optimized geometry for carbide tools rather than for high speed steel tools as Lehn had done. Figure 6 indicates that nothing is to be gained by using the McGee-Shay geometry for turning 4330 steel at 388 BHN. Similarly, for the various alternate carbide and ceramic tool materials investigated, there is no advantage gained over using the current SNG-432 indexable inserts, grade VC-7. (See Figure 8.)

In conclusion, the optimum tool geometry derived from Dr. Lehn's thesis provided an unanticipated advantage over widely used high speed steel tool geometry, thus confirming his work. Actually, no advantage of this unusual geometry can be taken by the Arsenal because its requirements dictate the use of carbide. With respect to the use of carbide at the Arsenal, in turning 4330 (388 BHN) it appears logical to continue using grades C-7 or C-6 until better tool materials become available. Metcut regularly tests new tools, and if an improved type is developed the Arsenal will be notified.

1. INTRODUCTION

At the request of Mr. A. Lorenzo, Metcut Research submitted Proposal No. 475-111-1 in response to RFQ No. DAAA22-75-Q-0385 for machining tests and analysis. In response to the proposal, Purchase Order No. DAAA22-75-M-0419 was issued as a contract to perform the following machining tests.

2. SCOPE OF WORK

2.1 The report "An Investigation to Determine the Single Point Tool Angles Which Yield Maximum Tool Life by Response Surface Methodology and Evolutionary Operation of Processes" (Attachment No. 1) was reviewed and evaluated. Machining tests with tool life as the dependent variable for turning cold drawn C1018 steel at approximately 146 BHN were conducted for evaluation purposes to determine if the report results were reproducible and whether other variables (i. e., coolant and feed rate) might yield more significant increases in tool life. Turning tests were conducted as follows:

- (a) A comparison of the optimized geometry from Attachment No. 1 was made with a standard geometry for three cutting speeds (including the 375 ft./min. used in Attachment No. 1). The other test conditions duplicate the original work (i. e., .010 in./rev. feed, .050 in. depth of cut, .010 in. nose radius, no coolant, and T1 high speed steel tools). The results are shown as tool life versus cutting speed curves for both geometries.
- (b) Both tool geometries were tested with the use of a water base coolant using the same conditions given in the preceding paragraph. The results are presented similarly.
- (c) Tool life versus feed rate tests were run for both geometries using the most reasonable cutting speed determined from the preceding tests. The results are shown as tool life versus feed rate curves.

2. SCOPE OF WORK (continued)

- 2.2 Machining tests for turning 4330 gun steel at 325-375 BHN to compare current practices with an optimized tool geometry developed for a similar material (4340 steel at 52 R_c) were conducted. It should be noted that the optimized geometry developed by F. J. McGee and G. S. Shay ("A New Look at Tool Angles," American Machinist Oct. 2, 1961, pp. 95-110) was selected because: (1) it was for carbide tools and for a material of similar composition to 4330, both of which are of specific interest to Watervliet Arsenal, and (2) it is not feasible from a cost standpoint to conduct tests by the method described in Attachment No. 1. This fact was in effect recognized by the author of that report on page 117 by his conclusion: "This investigation has raised more questions than it has answered. Years of work could be done to find the answers."

The machining tests were run for both geometries at a minimum of three cutting speeds compatible with production rates described in "Engineered Performance Standard (SWEWV 902)." VC-7 carbide was used at a .023 in./rev. feed, with a .188 in. depth of cut and without coolant for the work material with any scale removed. The results are shown as tool life versus cutting speed curves.

- 2.3 Using the optimum cutting speed, both standard tool geometries were tested to determine the effect of the feed rate on tool life. Feed rates of .015, .023, and .027 in./rev. were used with a .188 in. depth of cut.

2. SCOPE OF WORK (continued)

- 2.4 In addition, alternate tool materials were tested to determine if a change in tool material might yield more significant improvements, commensurate with current manufacturing procedures, than the optimized tool geometry. Only the standard tool geometry was used to determine the effect of cutting speed on tool life for C-7 carbide, TiC coated carbide, solid TiC tools, and a ceramic tool.

The following report summarizes the test results, conclusions and test procedures used in the fulfillment of the above scope of work. The test results are presented as tool life curves showing the effect on tool life of such machining parameters as cutting speed, feed rate, cutting fluid, and tool geometry.

3. TEST RESULTS AND CONCLUSIONS

- 3.1 Figure 1 shows the results of comparing the optimized geometry with a standard geometry on 1018 cold drawn steel using the following conditions: .010 in./rev. feed, .010 in. depth of cut, .010 in. nose radius, no coolant, and T1 high speed steel tools. The tool life curves in Figure 1 show that for a tool life of 60 minutes, the optimized geometry provides an increase in cutting speed (which is equivalent to an increase in productivity) of approximately 18%. Comparing the two geometries on the basis of tool life at the same speed shows that at 350 ft./min., the standard geometry produced a tool life of about 14 minutes compared to 86 minutes for the optimized geometry.
- 3.2 The optimized geometry and the standard geometry are compared in Figure 2 using a water base cutting fluid and the same machining conditions used in Figure 1. On the basis of a 50 minute tool life in turning, the optimized geometry provided an increase in cutting speed over the standard geometry of about 97% when using a water base cutting fluid.
- 3.3 An interesting situation is illustrated in Figures 3 and 4. Figure 3 compares the optimized geometry machining both with and without the water base cutting fluid while Figure 4 compares the standard geometry under the same conditions. In Figure 3, the optimized geometry is shown to perform approximately 39% better for a 60 minute tool life without a cutting fluid than with the water soluble oil. This result is reinforced in Figure 4 where the standard geometry also is shown

3. TEST RESULTS AND CONCLUSIONS (continued)

3.3 (continued)

to perform much better without the cutting fluid than with the water soluble oil. In this case for a 50 minute tool life, the standard geometry performs about 106% faster dry than with the cutting fluid.

3.4 The effect of feed rate on tool life comparing the two tool geometries is shown in Figure 5. Again the optimized geometry proved to be superior to the standard geometry in terms of increased productivity or metal removal rate. For a tool life of 60 minutes, the optimized geometry provides an increase in feed rate of approximately 21% over the standard geometry. At the same feed rate of .0085 in., the standard geometry produced a tool life of 17 minutes compared to 61 minutes with the optimized geometry.

3.5 Figures 6 through 8 show the test results obtained in turning the 4330 gun steel, 388 BHN in comparing a standard tool geometry used in current practice with an optimized tool geometry developed by F.J. McGee and G.S. Shay described in the article noted in the introductory scope of work. The experimental optimized geometry is described in detail in the test procedures given later in this report.

Figure 6 shows a comparison between the optimized geometry and the standard geometry commonly used in current practice. The standard geometry lends itself to the widely used indexable or "throwaway" carbide insert. The position of the two tool life curves in Figure 6 show that there is little significant difference in the performance of the two types of tool geometry. At the cutting speed of 150 ft./min., there is a difference in the tool life values obtained. For instance, the

3. TEST RESULTS AND CONCLUSIONS (continued)

3.5 (continued)

standard double negative rake geometry produced a tool life of about 45 minutes compared to a tool life of 61 minutes with the optimized tool geometry. However, the close placement of the two curves suggests that very slight productivity increase would be gained using either geometry over the other one.

The optimized geometry and the standard geometry are compared on the basis of feed rate and tool life in Figure 7. The test results obtained in Figure 7 again reinforce those obtained in Figure 6 for the placement of two tool life curves is very close and shows little, if any, significant difference between the two tool geometries. As a matter of fact, the two tool life curves intersect one another which indicates one to be slightly better at higher feeds, while the other may be slightly better at lighter feeds. But again, the differences are not large enough to be considered significant. At a feed of .015 in./rev., the optimized geometry produced a tool life values of approximately 5 minutes longer than the standard geometry. This increase would almost be within the limits of experimental error.

Several types of cutting tools and their effect on machining the 4330 gun steel are shown in Figure 8. The alternate tool materials are compared to the standard VC-7 which was used in the tests comparing the optimized and standard geometry in Figures 6 and 7. Two other steel cutting grades of carbide, Kennametal K45 and Kennametal K21, were tested. A solid titanium carbide tool grade Titan 80 was also evaluated along with a titanium carbide coated tool, Kennametal KC-75. A

3. TEST RESULTS AND CONCLUSIONS (continued)

3.5 (continued)

ceramic composite tool grade NPC-A2 was also tested for its performance on this material. At the outset of these tests, one thing became evident very quickly. The machining conditions used in these tests which were the same used in Figure 6 dictated by the terms of the contract, namely .023 in./rev. feed, and .188 in. depth of cut, were too heavy for some of the tools. For instance, the composite ceramic tool actually broke under these machining conditions, that is to say, the 1/2 in. square insert actually cracked and catastrophically broke into several pieces under the forces generated in machining at these conditions. Another grade of ceramic tool produced by Babcock and Wilcox Company was also tested and also performed the same; i.e., broke into several pieces. The solid titanium carbide tool, Titan 80, chipped rather severely under these heavy conditions and also was not completely satisfactory. The K21 carbide insert developed very heavy tool wear extremely fast and was unsatisfactory. The K45 carbide performed somewhat satisfactorily up to a point. Throughout these tests, one major difficulty was present; that is the need to break the chip. Under the heavy feed and depth of cut required in these tests, the chips came off in a continuous, unbroken, very strong tangle. Handling these chips during the cut is extremely difficult and hazardous. Even the use of a standard mechanical chip breaker on the indexable inserts was not totally satisfactory. One of the additional investigations on these tests was to attempt to break the chip more satisfactorily as well as obtain reasonable tool life. The K45 insert with the Kentrol[®] design broke chips satisfactorily up to a point

3. TEST RESULTS AND CONCLUSIONS (continued)

3.5 (continued)

where it had begun to wear severely. At this point, the chips again came out continuous and were difficult to handle. The titanium carbide coated tool, Grade KC75 with the Kentrol design, proved to be the most satisfactory tool. The titanium carbide coating apparently reduces both the tool wear and the effect of cratering the top of the insert to the point where the special design continues to break the chip until the tool has acquired sufficient flank wear to be considered a dull tool. The ability to break the chip and eliminate the continuous tangle of chips is an important consideration in a production machining situation. For this reason, the KC 75 tool is given a slight favor over the VC-7 standard insert. At the higher speeds, the VC-7 tool produced longer tool life values than the KC 75. However, at the speed of 150 ft./min., where tool life values in the range of 40-50 minutes were obtained, the KC 75 was slightly superior producing approximately 4 minutes longer tool life. Considering both aspects of tool life compared with productivity and chip control, the titanium carbide coated tool with the chip breaking design seems to be the best compromise from all aspects.

TURNING 1018 COLD DRAWN STEEL, 146 BHN
EFFECT OF CUTTING SPEED AND TOOL GEOMETRY

TOOL MATERIAL: T1 HSS BITS

BR: 21° NEG. ECEA: 8°

BR: 0°

ECEA: 5°

SR: 32° POS. SIDE REL: 11°

SR: 10° POS.

RELIEF: 5°

SCEA: 30° END REL: 8°
 NR: .010"

SCEA: 15°

NR: .010"

FEED: .010 IN./REV.

DEPTH OF CUT: .050"

CUTTING FLUID: DRY

TOOL LIFE END POINT: .060" WEAR

TOOL LIFE - MINUTES

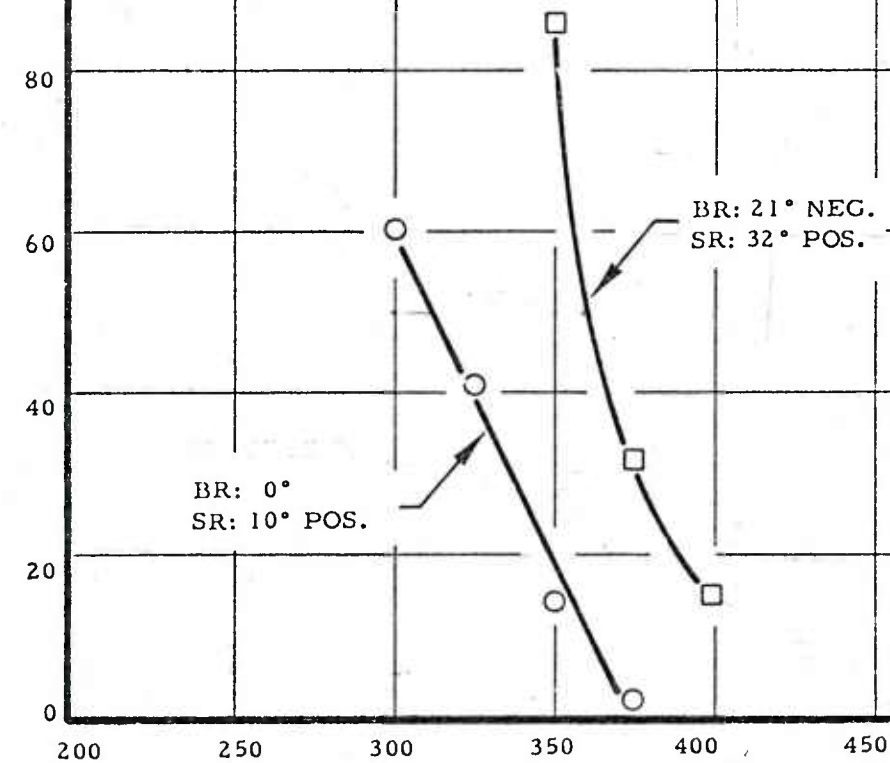
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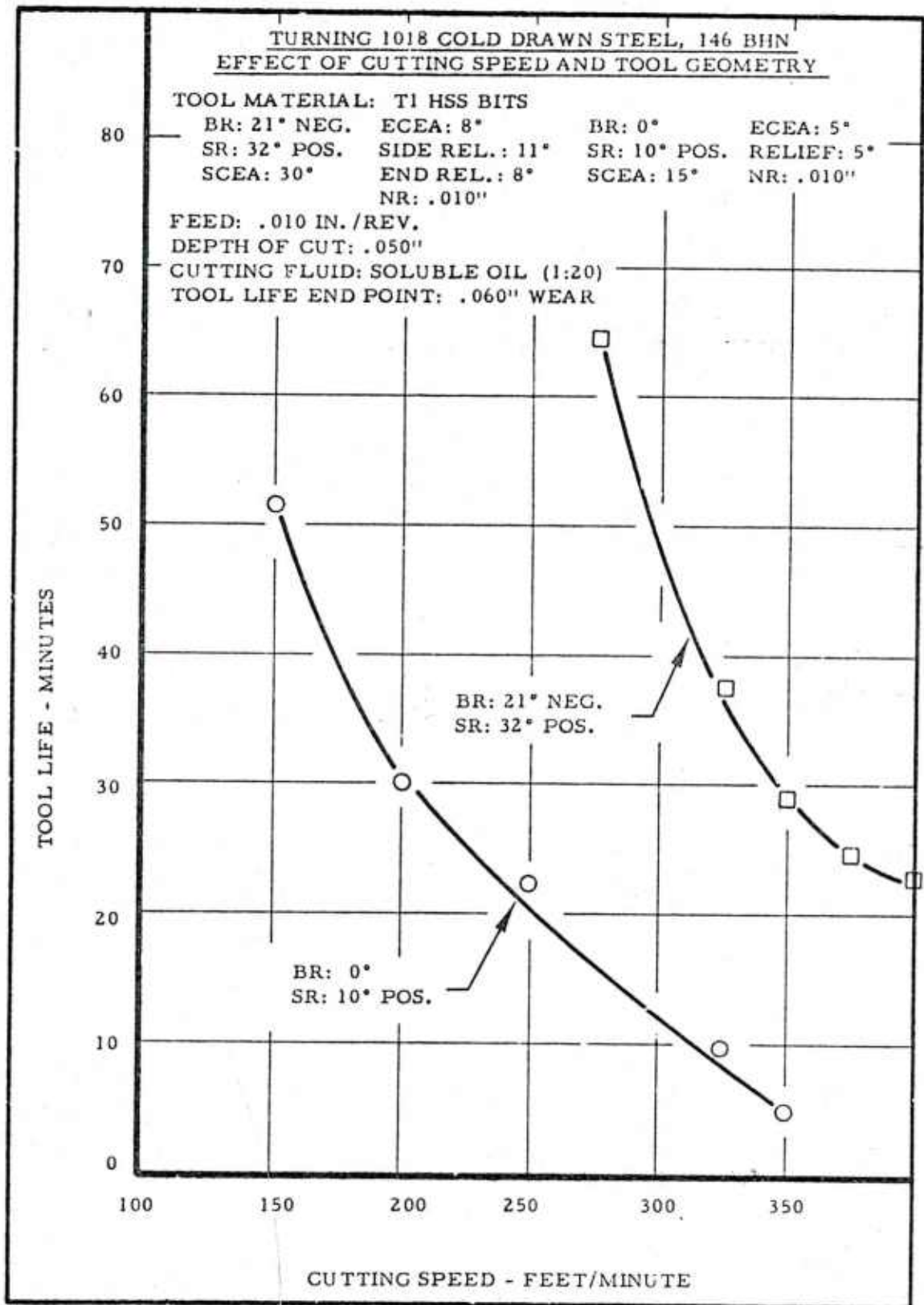
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CUTTING SPEED - FEET/MINUTE

BR: 0°
 SR: 10° POS.

BR: 21° NEG.
 SR: 32° POS.





TURNING 1018 COLD DRAWN STEEL, 146 BHN
EFFECT OF CUTTING SPEED AND CUTTING FLUID

TOOL MATERIAL: T1 HSS BIT

BR: 21° NEG.

SR: 32° POS.

SCEA: 30°

ECEA: 8°

SIDE RELIEF: 11°

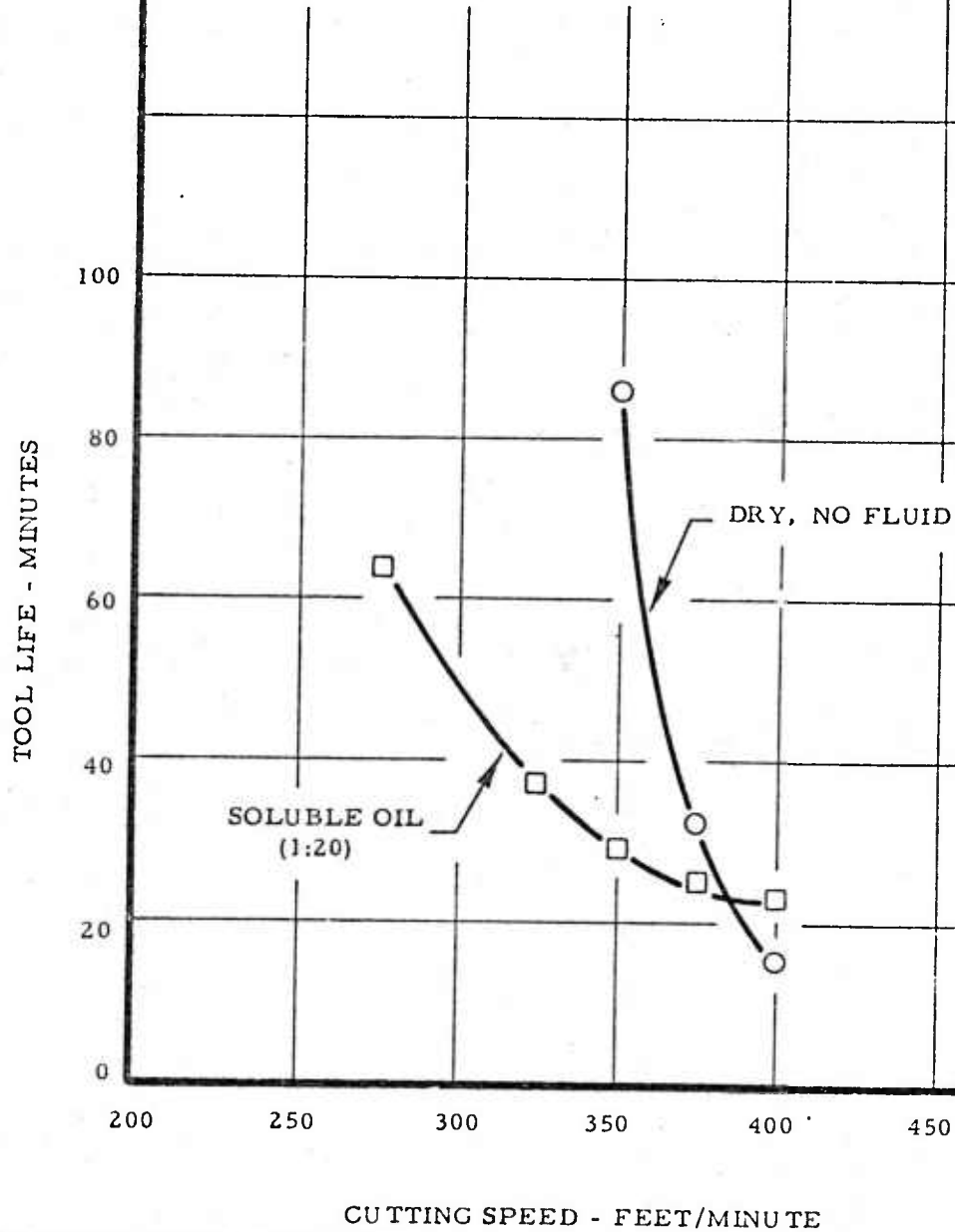
END RELIEF: 8°

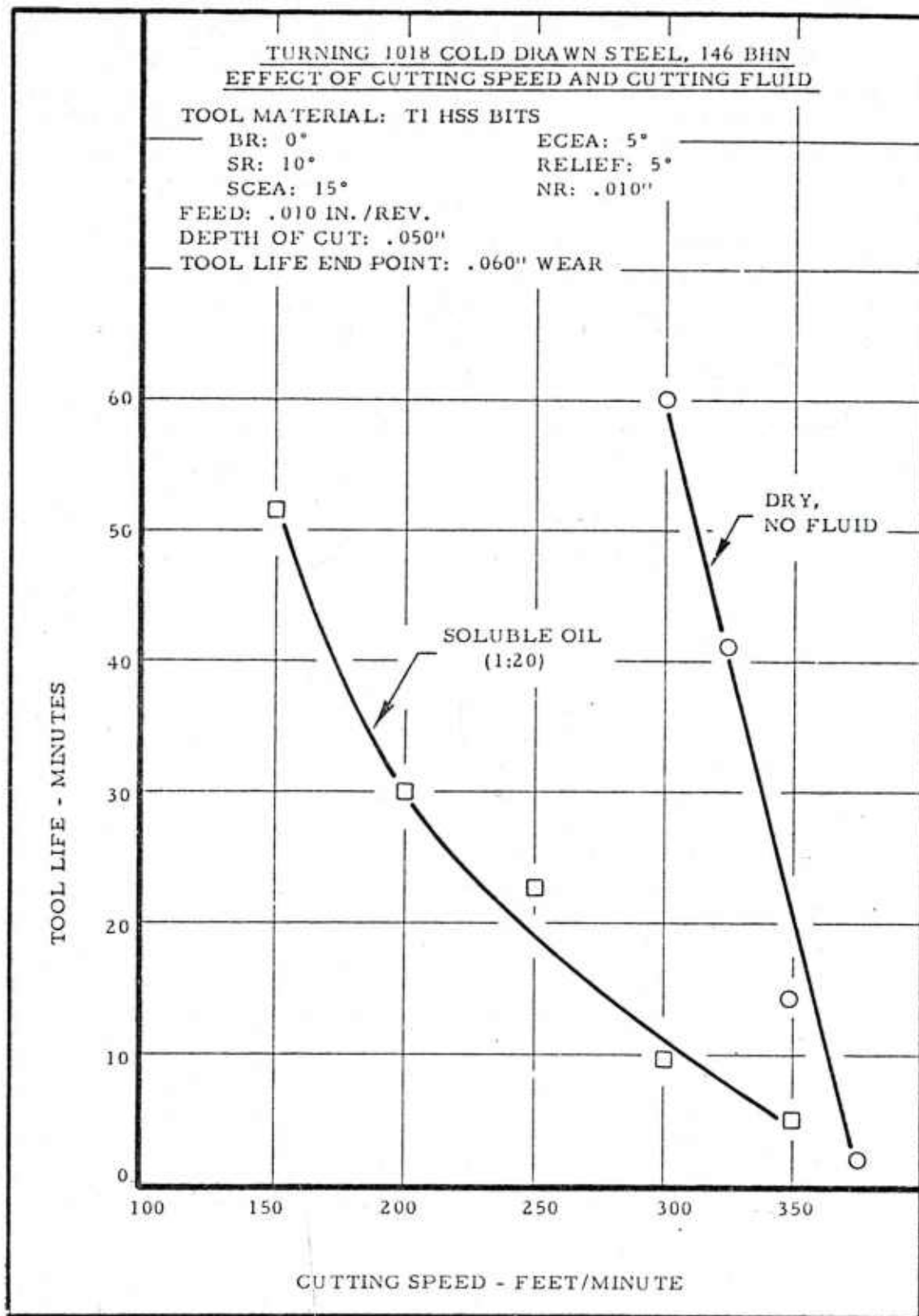
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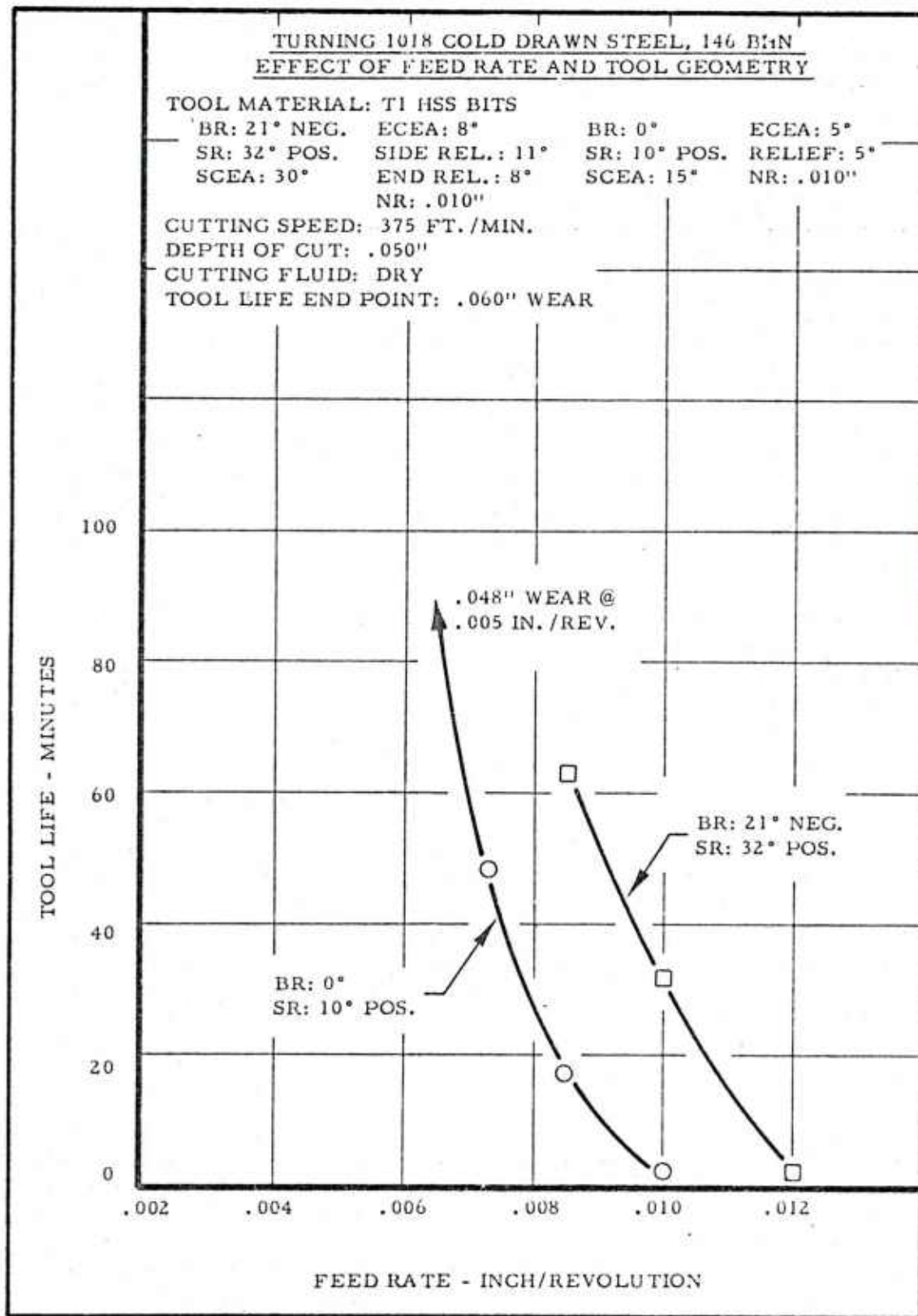
FEED: .010 IN./REV.

DEPTH OF CUT: .050"

TOOL LIFE END POINT: .060" WEAR







TURNING 4330 STEEL, 388 BHN
EFFECT OF CUTTING SPEED AND TOOL GEOMETRY

TOOL MATERIAL: VC-7 CARBIDE

BR-10 BRAZED TOOL

SNG-432 INSERT

BR: 2.5° NEG. ECEA: 15°

BR: 5° NEG. ECEA: 15°

SR: 10, 5° POS. RELIEF: 6°

SR: 5° NEG. RELIEF: 5°

SCEA: 15° NR: .030"

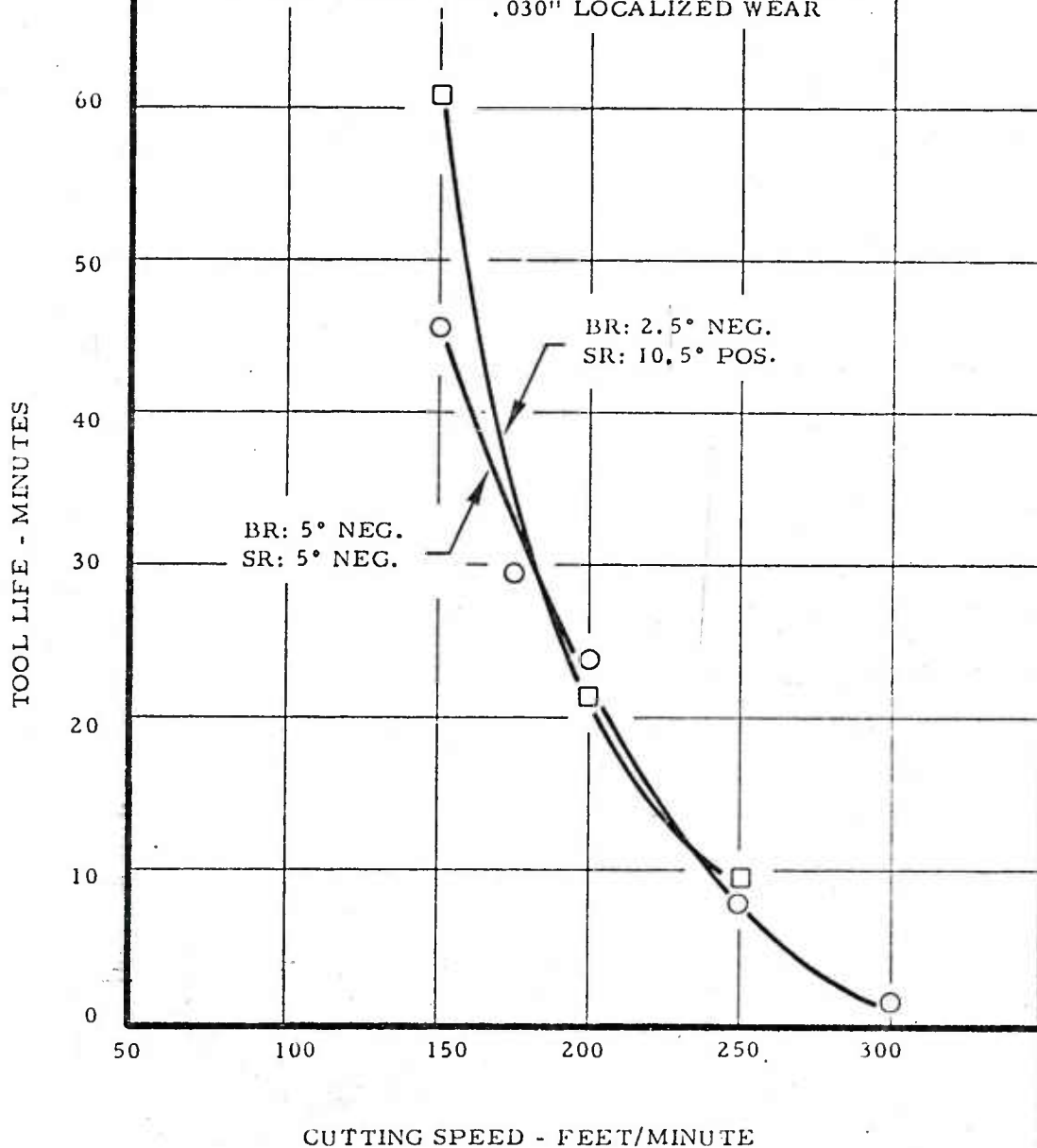
SCEA: 15° NR: .030"

FEED: .023 IN./REV.

DEPTH OF CUT: .188"

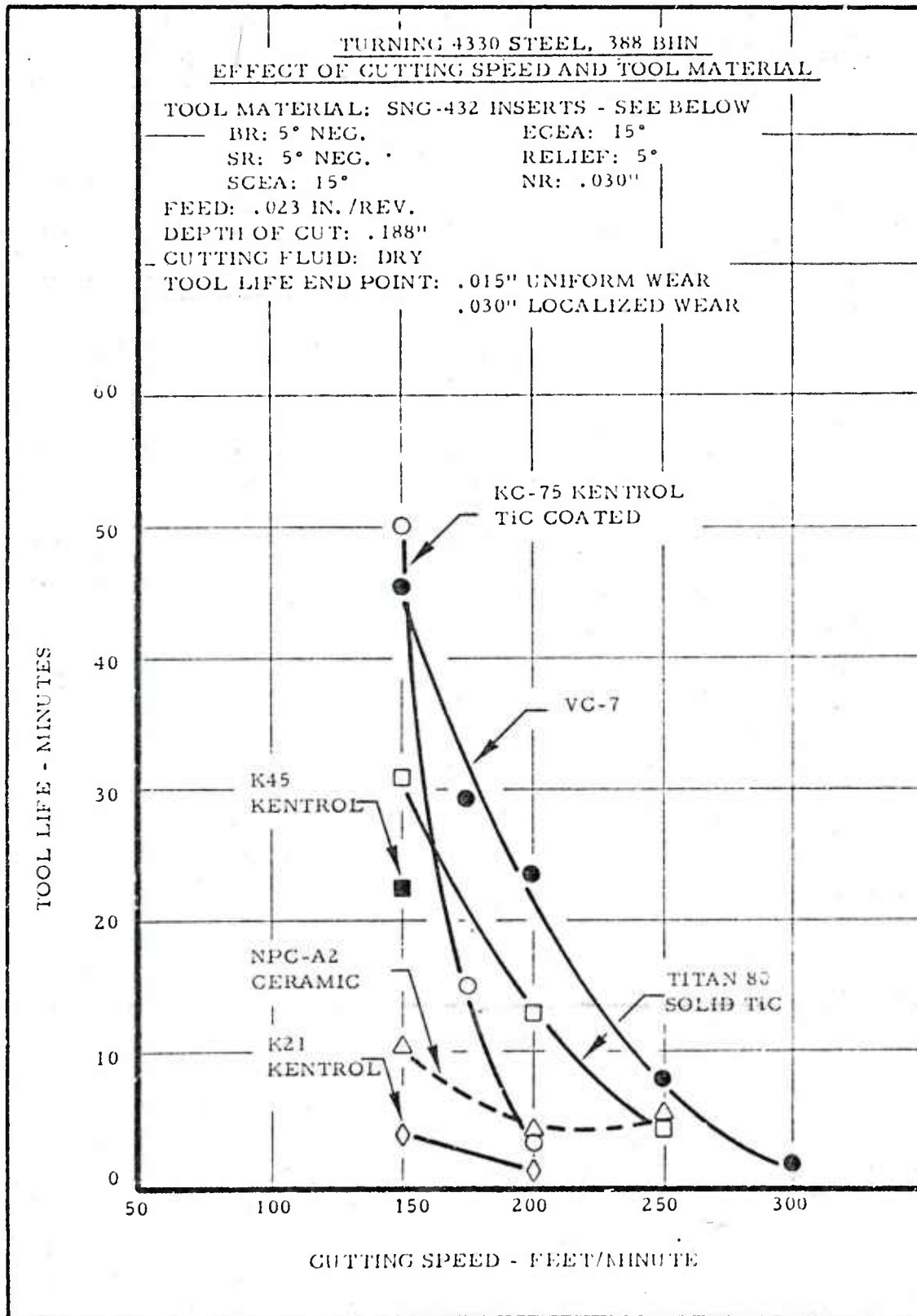
CUTTING FLUID: DRY

TOOL LIFE END POINT: .015" UNIFORM WEAR
 .030" LOCALIZED WEAR



TOOL MATERIAL: VC-7			
BR-10 BRAZED TOOL		SNG-432 INSERT	
BR: 2.5° NEG.	ECEA: 15°	BR: 5° NEG	ECEA: 15°
SR: 10.5° POS.	REL.: 6°	SR: 5° NEG.	REL: 5°
SCEA: 15°	NR: .030"	SCEA: 15°	NR: .030"
CUTTING SPEED: 200 FT./MIN.			
DEPTH OF CUT: .188"			
CUTTING FLUID: DRY			
TOOL LIFE END POINT: .015" UNIFORM WEAR			
.030" LOCALIZED WEAR			





4. TEST PROCEDURE

Machine Tool

All of the turning tests were performed on a LeBlond heavy duty 16 in. x 54 in. lathe equipped with a 30 HP variable speed drive for exact cutting speed control.

Work Material

The work material used in the first phase of this program was 1018 cold drawn steel at a hardness of 146 BHN. The test bars were 4 in. diameter cut into 18 in. long sections. The bars were turned down to approximately 1-1/2 in. diameter during the course of the tests. The work material used in the second phase of the testing program was 4330 gun steel at 388 BHN. The test bars were gun tube sections approximately 9 in. O.D. x approximately 4-1/2 in. I.D. x 18 in. long. This material was provided by the contractor and was machined in the as-received condition. No additional heat treatment of any sort was given to the work material. Any scale which might have been present was removed by a "skin cut" before testing.

Tool Materials

The tool materials used in the first phase of this program were T1 high speed steel tool bits 5/8 in. square x 4 in. long. The tools were sharpened on a Cincinnati No. 2 Tool and Cutter Grinder to the two different geometries used in these tests. The experimental optimized geometry determined from the report by L.L. Lehn was as follows:

Back Rake: 21° neg.

Side Relief: 11°

Side Rake: 32° pos.

End Relief: 8°

Side Cutting Edge Angle: 30°

Nose Radius: .010"

End Cutting Edge Angle: 8°

4. TEST PROCEDURES (continued)

Tool Materials (continued)

The tool geometry which is commonly used on turning tests with high speed steel tools at Metcut Research was used for the standard of comparison in these tests:

Back Rake: 0°	Side Relief: 5°
Side Relief: 10° pos.	End Relief: 5°
Side Cutting Edge Angle: 15°	Nose Radius: .010"
End Cutting Edge Angle: 5°	

Both types of tools were tested until .060 in. wearland developed on the cutting edge or until nose breakdown occurred from cratering. The tool materials used in the second phase of the testing program were VC-7 brazed tools, size BR-10. The optimized geometry developed by McGee and Shay was ground on these tools using a diamond cup wheel on the tool and cutter grinder. The following geometry was used:

Back Rake: 2.5° neg,	Side Relief: 6°
Side Rake: 10.5° pos.	End Relief: 6°
Side Cutting Edge Angle: 15°	Nose Radius: .030"
End Cutting Edge Angle: 15°	

The tools used as the standard of comparison of current machining practice were SNG-432 indexable inserts grade VC-7. These inserts were clamped in a standard tool holder which provided the following geometry:

Back Rake: 5° neg.	Side Relief: 5°
Side Rake: 5° neg.	End Relief: 5°
Side Cutting Edge Angle: 15°	Nose Radius: 2/64 in.
End Cutting Edge Angle: 15°	

4. TEST PROCEDURES (continued)

Tool Materials (continued)

The tools used in the third phase of the program were all basically the same size; i. e., SN- -432. The inserts with the chip control design (Kentrol) were designated as SNMM 432.

All of the carbide tools were operated until the uniform wear on the cutting edge reached .015 in. or localized peaks of wear reached .030 in. This failure criterion applied to both the brazed tools with the optimized geometry and the indexable inserts as well.

Cutting Fluid

The cutting fluid used in Phase I of the program with the high speed steel tools was a commercially available water soluble oil diluted 1:20. The actual product is Sohio Staysol 77.

Machining Conditions

The cutting speed in Phase I of the program was varied from 150 to 400 ft./min. The feed rate was varied from .005 to .012 in./rev. The depth of cut was constant in all tests at .050 in. The cutting speed in the tests using carbide tools was varied from 150 to 300 ft./min. The feed rate was varied from .015 to .027 in./rev. The depth of cut was constant at .188 in.

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