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**MACHINABILITY OF HP-9-4-20
HIGH-STRENGTH STEEL**

T. O. Morris

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**OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE**

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MACHINABILITY OF HP-9-4-20 HIGH-STRENGTH STEEL

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ABSTRACT

Machinability tests have been conducted on HP-9-4-20 high-strength steel. This material has been found to be easier to machine to close tolerances than the maraging steels when heat treated to a similar yield strength and fracture-toughness level.

CONTENTS

SUMMARY	4
INTRODUCTION	5
MACHINING HP-9-4-20 STEEL	6
Experimental Work	6
Previous Experience	6
Machinability Testing	6
Material and Parameters Tested	7
Results	8
Conclusions	10
REFERENCES	13

SUMMARY

Machinability tests were conducted on HP-9-4-20 high-strength steel that was hardened to R_C 43 - 45. Carbide tool grades, machining coolants, and machining speeds were tested to determine the set of parameters that would produce the minimum tool wear over periods of time required to machine relatively large surface areas. HP-9-4-20 was found to be a relatively easy-to-machine, high-strength steel that, under favorable conditions, did not produce great amounts of tool wear. Surface areas as large as 1.75 m^2 (18.75 ft^2) were machined with acceptable tool-wear levels. This degree of proficiency would be very difficult to achieve with maraging steels having similar strengths and fracture-toughness levels.

INTRODUCTION

There are many applications for high-yield-strength steels that have good fracture toughness. However, in the past, steels that satisfied these requirements also had other material properties that, in many instances, were not desirable. One such property is high hardness and its associated high levels of tool wear during machining. Some examples of such steels are maraging 250 and 300 grades, D6AC and 4340, when hardened to R_C 50 - 52. Fabrication problems and production costs with these steels, when at this high level of hardness, are so extensive that normal single-point tooling is not adequate for many production operations. But several grades of high-strength, low-alloy steels have recently become available which attain the levels of strength and fracture toughness of the two maraging steels just mentioned with a lower level of material hardness ($\sim R_C$ 44 - 45). This property makes these steels much easier to machine to the shapes desired and results in a much more economical process for fabrication of the required parts. Two examples of these high-strength, low-alloy steels are HP-9-4-20 and HY-180, both of which have received some recognition after being used in aircraft and naval applications.

There have been several reports on the machinability of HP-9-4-20 steel and of HY-180 steel published by the steel manufacturing companies, by the Air Force Machinability Data Center, and by Metcut Research Associates.^(1 - 4) However, in all of these tests the primary objective was maximum metal removal. Depths of cut [from 1.52 to 2.54 mm (60 to 100 mils)] were taken, and cutting tests were conducted for no longer than 30 minutes. No attempt was made to machine large surface areas using finish-machining parameters.

In view of the desirable material properties of these steels and the potential use of these alloys in the Oak Ridge Y-12 Plant,^(a) a series of machinability tests oriented toward machining large surface areas were begun on the HP-9-4-20 steel.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Energy Research and Development Administration.

MACHINING HP-9-4-20 STEEL

EXPERIMENTAL WORK

Previous Experience

Machining tests on hardened steels indicate that once the hardness reaches a level of about R_C 50, the length of time that a single-point tool can be used without excessive tool wear [defined at Y-12 as > 0.254 mm (10 mils) of flank wear] is less than one hour. In fact, in most instances, tool life on these materials is only about 30 minutes. Previous reports on the machinability of maraging steel lend support to this statement. Any single-point machined part that has a large surface area, coupled with a reasonably tight dimensional tolerance, will be difficult to fabricate from such a material since contour error resulting from tool wear alone could exceed the tolerance limits. This deficiency would, of course, result in an inefficient machining operation, poor part quality, and high production costs. A material with a lower hardness level should be easier to machine, but the possibilities of poor quality and high cost would still exist.

One method of improving part quality and reducing machining costs is through the utilization of so-called "optimum machining parameters". Those parameters over which the shop has control include: machining speed, feedrate, depth of cut, type of tool material, tool geometry, and type of machining coolant. Selection of the proper set of these parameters can provide maximum part quality and minimum part costs. The proper set of parameters can be determined from machinability testing.

Machinability Testing

In any machinability testing of a material, some criteria must be chosen for evaluation of the machining parameters. In the Y-12 Plant these criteria are normally: tool flank wear; surface finish produced on the part; and, sometimes, stock-removal rates attainable on the material.

The machinability testing is done on a lathe, such as the one seen in Figure 1. A log of the test material [usually about 200 mm (8 in) in diameter and 400 mm (16 in) long] is single-point machined, and data are collected and recorded at predetermined time intervals. Tool flank wear and machined surface finish are the studies for which the data are collected. Figure 1 also shows: (1) the clock used to time the machining cuts, (2) the surface-finish measuring equipment, and (3) the microscope used to measure flank wear. The normal procedure for data collection is to machine the cylindrical surface of the test part for some predetermined time interval, then remove the tool from the machine and measure the surface finish on the part and flank wear on the tool. The tool is then placed back in the tool holder and the test part is machined for the next time period. These timed machining operations and periodic data collections are continued for some total time period, or until either the tool wear or surface finish exceed some predetermined value [usually a 0.254 to 0.381-mm (10 to 15-mil) flank wear or a 2.54- μ m (100- μ in) surface finish].

Figure 1. MACHINABILITY TESTING EQUIPMENT.

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Surface-finish measurements are made on the test log in the axial direction with a standard Brush Surfindicator set for a 0.762-mm (30-mil) cutoff and arithmetic average (AA) reading. Tool-flank-wear measurements are made on the tool-flank surface with a microscope. The microscope crosshairs and micrometer-positioned table are used to measure the flank-wear length. Figure 2 reports the correlation between flank wear and nose-radius wear for various clearance angles.

Once the data are collected for each parameter set tested, the flank wear is plotted as a function of the machining time to show the progression of wear.

Surface finish is indicated on some wear plots to show either the average finish obtained over a period of time or the final surface finish obtained before the tool was discarded.

Material and Parameters Tested

The logs used in these machinability tests were machined out of rectangular blocks cut from a forged billet. The logs were machined from the blocks while the material was in an annealed condition. After initial machining, the logs were heat treated to a hardness of R_C 43 - 45 in preparation for the machinability tests.

A(2)	X(1)		
	($\theta = 5^\circ$)	($\theta = 7^\circ$)	($\theta = 15^\circ$)
12.7	1.111	1.559	3.403
(0.5)	(0.044)	(0.061)	(0.134)
25.4	2.222	3.119	6.806
(1)	(0.087)	(0.123)	(0.268)
50.8	4.444	6.237	13.612
(2)	(0.175)	(0.246)	(0.536)
76.2	6.667	9.356	20.418
(3)	(0.262)	(0.368)	(0.804)
101.6	8.889	12.475	27.224
(4)	0.350	0.492	1.072
152.4	13.33	18.712	40.836
(6)	(0.525)	(0.736)	(1.608)
254	22.222	31.187	68.059
(10)	(0.875)	(1.228)	(2.679)

(1) $X = A \tan \theta$

Where: θ represents the tool clearance angle,
A the tool flank wear (measured), and
X the tool edge loss (radial).

(2) All values in μm (mils).

Figure 2. FLANK WEAR—MEASUREMENT/RADIAL-TOOL-WEAR CORRELATION.

Valenite VC-83) perform very well even after two hours of machining time. The flank-wear land is only about $51 \mu\text{m}$ (2 mils) after two hours. This rate corresponds to about a $5\text{-}\mu\text{m}$ (0.2-mil) radial wear on the nose radius of the tool. Two hours is a sufficient time period to machine about 1.16 m^2 (12.5 ft^2) of surface area with this set of machining parameters.

The finishing-grade tungsten/tantalum/titanium carbide tools (Kennametal K-7H) also perform adequately with this set of parameters. Graphs of those carbide grades that do not perform as well are also presented in Figure 3.

The same parameter set was run with a different machining coolant (Dascool 1000). This coolant is a biodegradable, heavy-duty, synthetic-solution-type coolant that is sometimes used in the Y-12 Plant. The graph of Figure 4 indicates the performances of several carbide tool grades with this coolant. As can be seen, there is very little difference due to coolant alone in this speed range. The performances of the different carbide grades are about the same as with Dasco 950.

Since the surface area machined in two hours is only 1.16 m^2 (12.5 ft^2) at a 76.2-smpm (250-sfpm) machining speed; and, ideally, machining time should be held to two hours or less, tests were conducted at a higher speed. Figures 5 and 6 report the various carbide-grade performances at a 114.3-smpm (375-sfpm) machining speed with each of the coolants

High tool wear due to hard work material is only a problem with finish-machining passes since rough machining will normally be done before heat treating to full hardness. In addition, tool wear is usually of less concern until the final surface is to be machined on the part, assuming that it does not become so excessive as to result in complete breakdown of the cutting edge. Therefore, the machining tests were concentrated on the finish-machining parameters (light depths of cut and light feed rates). Machining parameters (other than feedrate and depth of cut) investigated in the machinability tests to date included: machining speed, type of coolant, and carbide tool grade. The levels of each parameter tested were those normally used at Y-12 to finish-machine similar materials.

Results

Figure 3 shows a tool-flank-wear comparison of various carbide tool grades tested at a 76.2-smpm (250 sfpm) machining speed with a sulfurized, fatty-soluble oil coolant (Dasco 950). As can be seen, the titanium carbide tool grades (Kennametal K-165 and

tested. Again, as can be seen, there is very little difference in performance as a function of the coolant. The titanium carbide tools again excel with only about $63\text{ }\mu\text{m}$ (2.5 mils) of flank wear after two hours of machining time.

Figure 3. FLANK WEAR AS A FUNCTION OF TIME FOR VARIOUS TOOL GRADES. (Machining of HP-9-4-20 at 250 sfpm with Dasco 950; Depth of Cut, 5 mils; Feed Rate, 5 mils/rev)

Figure 5 also reports on the wear that was obtained on the K-165 tool at 114.3 smrpm (375 sfpm) with no coolant used. Note that wear is only slightly greater here than when a coolant is used. The titanium carbide tool-grade performance is not affected to any great extent by heat in this speed range. Also notice, in Figures 5 and 6, that the wear obtained on the other tool grade is proportionally greater at this speed than is the titanium carbides. Wear on the K-7H tool is about four to five times greater than that of the K-165 tool at 114.3 smrpm (375 sfpm), whereas it was only about two times as great at 76.2 smrpm (250 sfpm).

Figure 4. FLANK WEAR AS A FUNCTION OF TIME FOR VARIOUS TOOL GRADES. (Machining of HP-9-4-20 at 250 sfpm with Dascool 1000; Depth of Cut, 5 mils; Feed Rate, 5 mils/rev)

This 114.3-smpm (375-sfpm) speed will allow about 1.75 m^2 (18.75 ft^2) of surface area to be machined in two hours; therefore, larger parts can be machined without tool changes when using this higher speed. Normally, steels of a similar hardness are machined at lower machining speeds to avoid high tool wear; but, apparently, this steel may be machined at this speed without serious problems. Even higher speeds were tested to determine the limit at which this steel may be finish machined. Figure 7 summarizes the results of tests conducted at 137.2 smpm (450 sfpm). As can be seen, no tool grade performs adequately at this speed. Tool life is normally less than 30 minutes at this speed.

CONCLUSIONS

The following conclusions can be stated concerning HP-9-4-20 high-strength steel:

1. HP-9-4-20 steel in the hardness range of R_c 43-45 can be finish machined with single-point tools.
2. Surface areas as large as 1.75 m^2 (18.75 ft^2) can be machined on this material with as little as $7\text{-}\mu\text{m}$ (0.3-mil) radial wear on the nose of a carbide tool.
3. Coolant effects on tool wear are minimal as long as the machining speed is held to less than 114.3 smpm (375 sfpm). However, a coolant should be used.

Figure 5. FLANK WEAR AS A FUNCTION OF TIME FOR VARIOUS TOOL GRADES. (Machining of HP-9-4-20 at 375 sfpm with Dasco 950; Depth of Cut, 5 mils; Feed Rate, 5 mils/rev; Note that Tool K-165 was also Run without Coolant)

Figure 6. FLANK WEAR AS A FUNCTION OF TIME FOR VARIOUS TOOL GRADES. (Machining at HP-9-4-20 at 375 sfpm with Dascool 1000; Depth of Cut, 5 mils; Feed Rate, 5 mils/rev)

Figure 7. FLANK WEAR AS A FUNCTION OF TIME FOR VARIOUS TOOL GRADES. (Machining of HP-9-4-20 at 450 sfpm with Dascool 1000; Depth of Cut, 5 mils; Feed Rate, 5 mils/rev)

4. Titanium carbide tools and triple carbide tools with large percentages of titanium carbide perform well on this material.
5. Machining speeds as high as 137.2 smpm (450 sfpm) are detrimental to tool life in single-point machining.

From a machinability point of view, this material in the hardness range of R_C 43 - 45 would be recommended for use in large parts requiring high strength, high fracture toughness, and tight dimensional tolerances.

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