RI 9112

Bureau of Mines Report of Investigations/1987

Bit Wear-Flat Temperature as a Function of Depth of Cut and Speed

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Library of Congress Cataloging in Publication Data:

Wingquist, Carl F.
Bit wear-flat temperature as a function of depth of cut and speed.

(Report of investigations/United States Department of the Interior, Bureau of Mines; 9112)

Bibliography: p. 12.

Supt. of Docs. no.: I 28.23: 9112.

1. Rock drills—Testing. 2. Boring. 3. Sandstone. I. Hanson, Bruce D. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9112.

TN23.U43 [TN279] 622 s [622'.24] 86-607955

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	g	gram
cal	calorie	in	inch
(cal/g)°C	calorie per gram times degree Celsius	in/s	inch per second
cal/s	calorie per second	lb	pound
°C/cal	degree Celsius per calorie	min	minute
cm	centimeter	mm/km	millimeter per kilometer
cm^3	cubic centimeter	ms	millisecond
°C/ms	degree Celsius per millisecond	pct	percent
ft	foot	psi	pound (force) per square inch
ft/s	foot per second	s	second

BIT WEAR-FLAT TEMPERATURE AS A FUNCTION OF DEPTH OF CUT AND SPEED

By C. F. Wingquist[1] and B. D. Hanson[2]

ABSTRACT

As part of an ongoing study to determine how the wear of mining tools affects dust generation, the Bureau of Mines has measured bit temperature rise during cutting of abrasive rock. Radial bit wear-flat temperatures generated by linear cutting in Berea Sandstone were measured as a function of cutting depth and speed. Depths of cut (DOC) were 1/8, 1/4, and 1/2 in, and cutting speeds were 10, 40, and 80 in/s, respectively. Temperature sensing was accomplished by emplacement of a miniature thermocouple into the center of the wear flat. Temperatures observed ranged from 200° to 500° C. Correlation between depth and temperature was weak. Temperature increased linearly with speed at 1/2-in DOC, but data taken at 1/8- and 1/4-in DOC produced inconclusive results. The results indicated that at least for deeper cuts (1/2 in), bit temperature, and therefore wear, can be reduced by lowering the cutting speed.

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INTRODUCTION

Since the mechanical, chemical, and metallurgical properties of materials are often temperature dependent, it is reasonable to expect that the wear resistance of tools is also a function of temperature. Some properties relevant to various wear mechanisms are hardness, yield strength, and oxidation resistance. Rabinowicz (1)[3] has derived a simple quantitative expression for abrasive wear in which wear rate is inversely proportional to the hardness of the surface being worn. A plot showing ranges of hardness (Rockwell C) as a function of temperature for various tungsten carbide (WC) formulations is shown in figure 1 (2). Note that hardness falls slowly with increasing temperature, up to approximately 500° C, but then drops off rather quickly as temperature is further increased. At approximately 600° C, the hardness of some grades of WC drops below 650° C, the room temperature hardness of quartz.

The foregoing suggests that the wear rate of WC tools is expected to increase dramatically when the tool wear-flat temperature exceeds 600° C. This is illustrated (fig. 2) by the wear-rate-versus-temperature data of Krapivin (3). The data represent steady-state (temperature) cutting and are plotted to show wear rate in millimeters per kilometer (change in bit length per unit length of cut) as a function of temperature. Wear rate is relatively insensitive to temperatures of up to 600° C, then increases by a factor of 5 from 600° to 1,000° C. The WC alloy composition for the tool used in these tests was 94 pct WC and 6 pct Co. Numerous investigators have recognized that a cutting tool's resistance to wear decreases with increasing wear-flat temperature. Cook (4) refers to temperature as "one of the most important tool-wear parameters," and states that "one cannot have an understanding of the cutting-tool wear mechanisms without first having a good picture of the temperatures involved in the cutting process and how they are affected by the basic machining variables." Hurt and MacAndrew (5) have conducted tool-life tests in "hard" limestone and have concluded that "the main agent of destruction of picks in hard rock is thermal stress." Tool wear in coal mining occurs predominately when hard inclusive material is encountered, such as pyrite, or during intermittent contact with abrasive roof or floor material, such as sandstone. When this occurs, the tool's wear-flat temperature is rapidly elevated, which results in high rates of wear and, under certain conditions, creates enough thermal energy to ignite methane-air mixtures.

Although temperature rise in metal cutting tools has been extensively investigated, the literature pertaining to temperature elevation of rock cutting tools is scarce. Shepherd (6) measured the temperature increase in two types of coal-cutting picks for longwall cutting of coal by using pellets of thermometric powder installed in holes at various points within the tool. Whitbread (7) studied temperature increase in rotary drill tools as a function of thrust and speed in sandstone. Using a thermocouple placed "as near to the bit tip as possible," temperature was recorded after steady-state conditions had been achieved (approximately 5 min of drilling).

More recently, Ortega and Glowka (8) have reported measured wear-flat temperatures taken under steady-state conditions with "miniature" thermocouples. These measurements were performed on a vertical tunnel lathe at various speeds in the presence of a water-oil coolant jet for relatively shallow (0.002- to 0.006-in) cuts in Tennessee marble.

Limited access to Soviet literature has made reviewing the work of investigations in Russia difficult; however, the Bureau did obtain a translation of Krapivin's (3) on mining tools. One topic this work addresses is bit wear-flat temperature and its relation to wear rate. Although some details regarding experimental

[3] Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

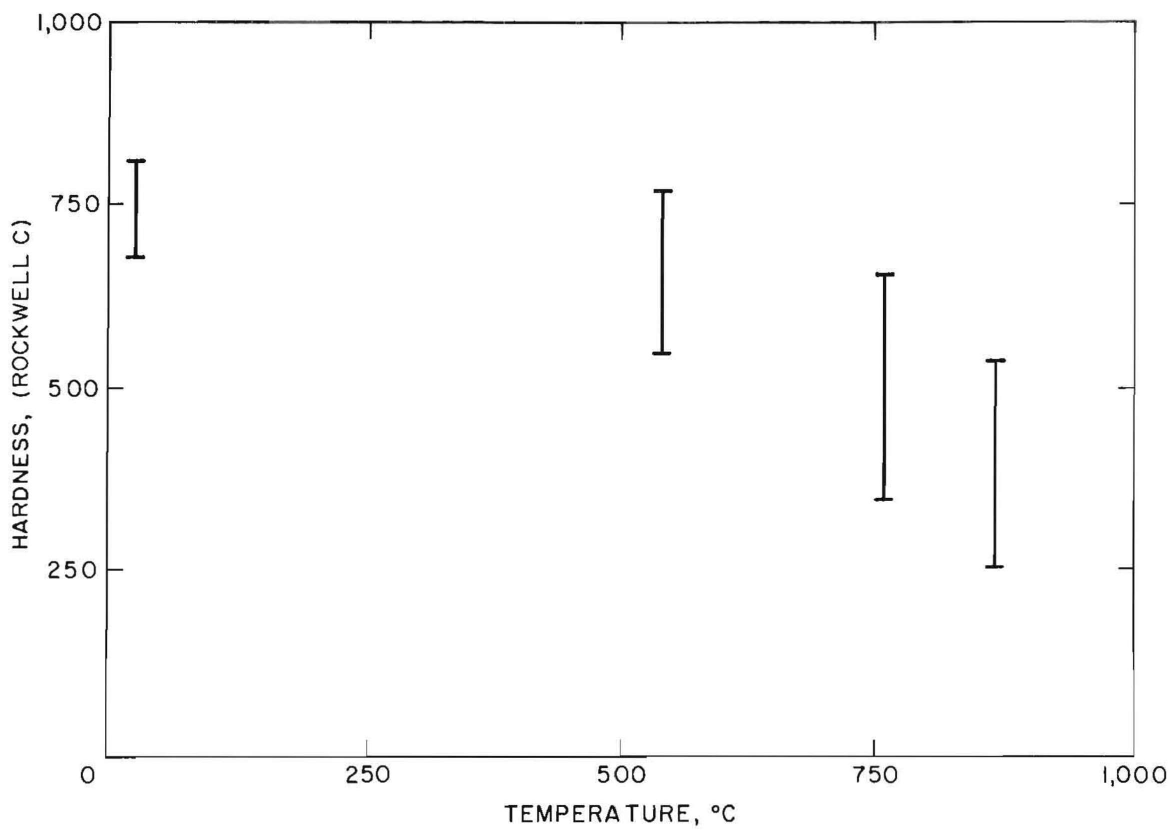

FIGURE 1.—Hardness range of various cemented carbides versus temperature.

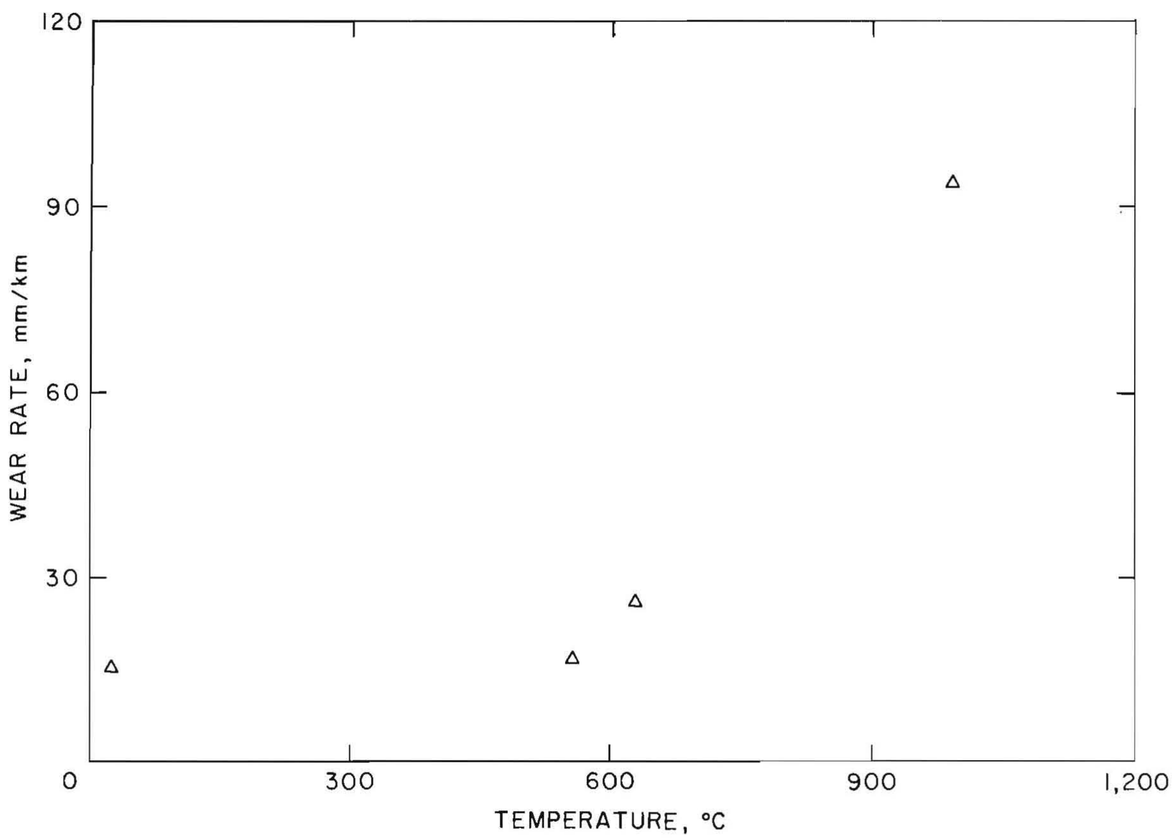

FIGURE 2.—Wear rate versus temperature, after Krapivin (3).

procedure are omitted or unclear, it is a particularly important contribution to the literature on the subject. Krapivin presents data relating bit temperature and wear rates to cutting parameters for several types of sandstones. Also potentially useful is an extensive list of references.

The authors initially attempted to measure wear-flat temperature using a radiometer. Since it was not possible to actually view the wear-flat directly with the radiometer, an indirect approach was used. This involved focusing the radiometer on a point of the rock surface directly in the bit's path and then monitoring the temperature (cooling curve) of the rock after passage of the bit. Extrapolation of the cooling curve to that point when the bit was over the radiometer target should provide an indirect measurement of the interface or wear-flat temperature. This assumes that the wear-flat surface and the rock surface in contact with it are at the same temperature. The temperatures determined by these initial measurements seemed too low (100° to 300° C), so a series of tests was conducted to directly measure wear-flat temperatures by using cutter bits instrumented with thermocouples. These data could be compared with the radiometer test data to determine the validity of the cooling curve extrapolation technique and could also provide an initial look at effects of selected cutting parameters on wear-flat temperature.

This study attempted to measure wear-flat temperature rise in abrasive rock as a function of depth of cut and cutter speed. This ruled out "steady-state" temperature measurements because too much sample would be consumed in each test, and in addition, wear-flat area would probably be appreciably increased during the test. A linear cutting machine, capable of making 48-in-long cuts at speeds of up to 80 in/s and cutting forces of 4,000 lb, was chosen for the cutting experiments, each test consisting of a single linear constant-depth cut. This mode of testing can be regarded as an approximation to the transient heating-wear event that a coal-cutting tool experiences when passing through hard abrasive material at the seam, roof, or floor.

The term "wear-flat temperature" needs qualification. For the purposes of this study, the wear flat is a 0.5- by 0.125-in rectangular surface and is that part of the bit through which most of the normal force on the bit is fed to the rock. The temperature distribution over the wear-flat area at any point in time is presumed to be nonuniform. The center of the wear flat was chosen as the point of measurement, mainly because it was the most convenient place to install a thermocouple and also because the temperature at this point is probably a reasonable approximation to the average temperature over the wear flat. The location of the hot junction is actually the point where the wires exit the bead, putting it, in this case, about 0.020 in below the surface of the wear flat. This is the actual point of temperature measurement reported in this paper. No attempt was made to estimate the magnitude of the thermal gradient within the bead itself. Such installation errors are a consequence of the finite size of the bead and are unavoidable.

Clearly, the temperature measurement previously described is a macroscopic or bulk temperature measurement, and temperatures at points of asperity interaction can reach the melting temperature of the sliding pair with the lowest melting point, in this case steel (about 1,450° C).

CUTTING TOOL

The cutting tool used for these tests was a radial-bit forging (AISI 8630 steel) modified to suit the test requirements and instrumented with a thermocouple. The forgings were obtained unfinished without WC inserts and then milled to the approximate configuration of a finished tool (rake angle = 5°, clearance angle = 10°). A 1/8-in wear flat was ground on each tool to approximate a "moderately" worn tool. The purpose of omitting the WC inserts for these tests was to expedite thermocouple emplacement, which involves drilling an access hole through the body of the tool to the center of the wear flat. The degree to which the substitution of steel for WC as the wear surface affects the heat transfer properties of the tool is likely to be fairly small, since the quantity of WC in the tool is relatively small. Because the thermal conductivity of mining tool grades of WC is about twice that of steel, it is expected that all steel tools would exhibit a somewhat higher wear-flat temperature than WC and steel tools.

TEMPERATURE MEASUREMENT

Thermoelectric measurements are subject to several sources of error (other than calibration error), including--

1. Poor thermal contact between the thermocouple junction and tool.
2. Heat-flow perturbation due to presence of the thermocouple and access hole.
3. Error due to time-response limitation of sensor (appendix A).
4. Heat loss along leads from the thermocouple junction to ambient temperature surroundings.

While such errors can, to some extent, be quantified by rigorous mathematical analysis, the usual approach is to simply design the installation to minimize the errors as much as possible. In essence, this meant using the smallest practical diameter thermocouple wires and providing a low thermal-resistance coupling of the hot junction to the point of measurement at the center of the wear-flat. Initially, 0.003-in thermocouple wire was tried, but this installation lacked ruggedness and was difficult to prepare. Wire of 0.010 in diam proved rugged and easy to handle.

Intimate thermal contact between the tool and the thermocouple junction is necessary for measurement accuracy. Thermal contact is adequate when the thermal resistance between the tool and the thermocouple junction is much smaller than the thermal resistance between the thermocouple junction and the ambient surroundings. This condition was met here by brazing the thermocouple junction to the tool.

The actual thermocouple installation was made by drilling a 0.0625-in access hole clear through the tool, exiting at the center of the wear flat. The approximately 0.020-in-diam thermocouple bead was then attached to the tool by induction brazing with an 85-pct-Ag, 15-pct-Mn alloy, just below the wear-flat surface. The brazing alloy provided good thermal coupling between the bit and thermocouple bead and also, to some extent, mitigated the disruption of the pattern of heat flow created by the presence of the hole. According to Baker (9), the thermal resistance of such an installation can be assumed negligible. The thermocouple wires were insulated

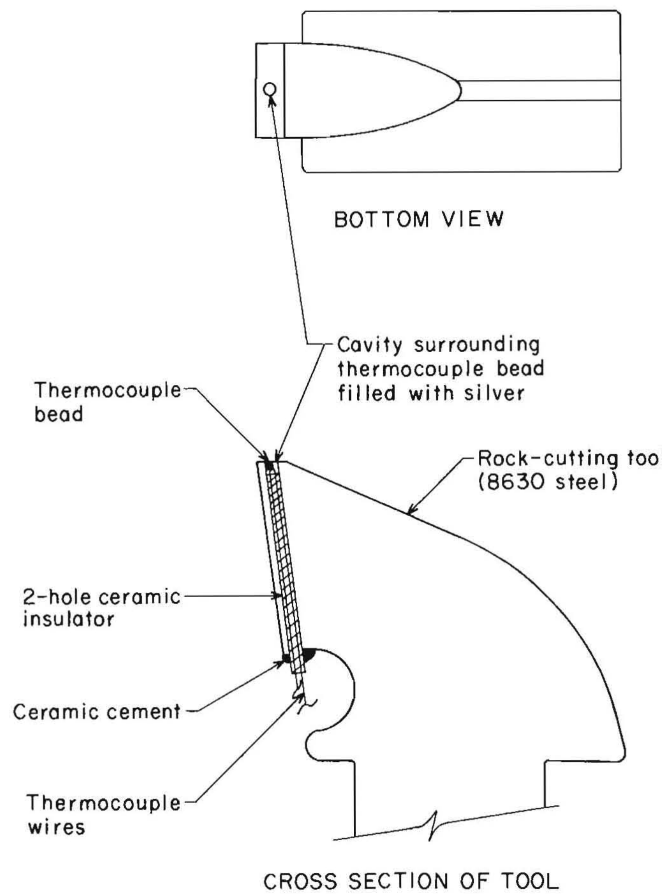

FIGURE 3.—Thermocouple installation.

from the bead to the point of exit from the tool with two-hole ceramic tubing. A cutaway drawing of the thermocouple installation is shown in figure 3.

CUTTING MACHINE

All cutting tests were conducted using a high-speed linear rock cutting device (RCD) (fig. 4) especially designed and fabricated by the Bureau for hard-rock cutting experiments. The cutting speed is continuously variable from 10 to 80 in/s and is capable of exerting cutting and normal forces of 4,000 and 30,000 lb, respectively. Maximum cut length is 60 in. In use, the rock sample (in this case a 4- by 4- by 1-ft block) is clamped to the work table, which moves laterally to control cut location and spacing and vertically to control cut depth.

Figure 5 shows a closeup of the instrumented tool installed in the machine. Bit forces are fed to this machine through piezoelectric load cells that provide a measurement of the normal bit force.

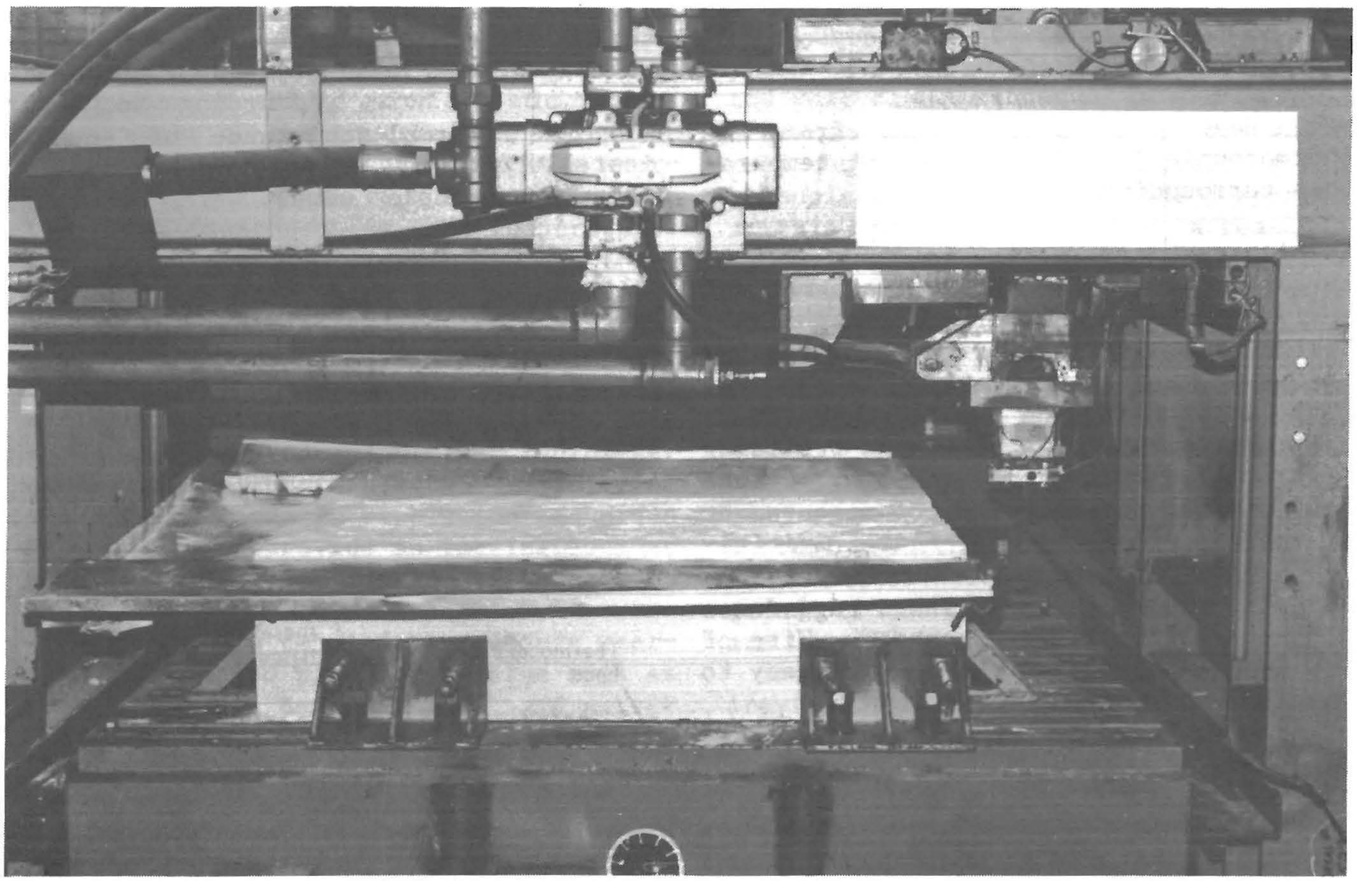

FIGURE 4.—Linear rock cutting machine.

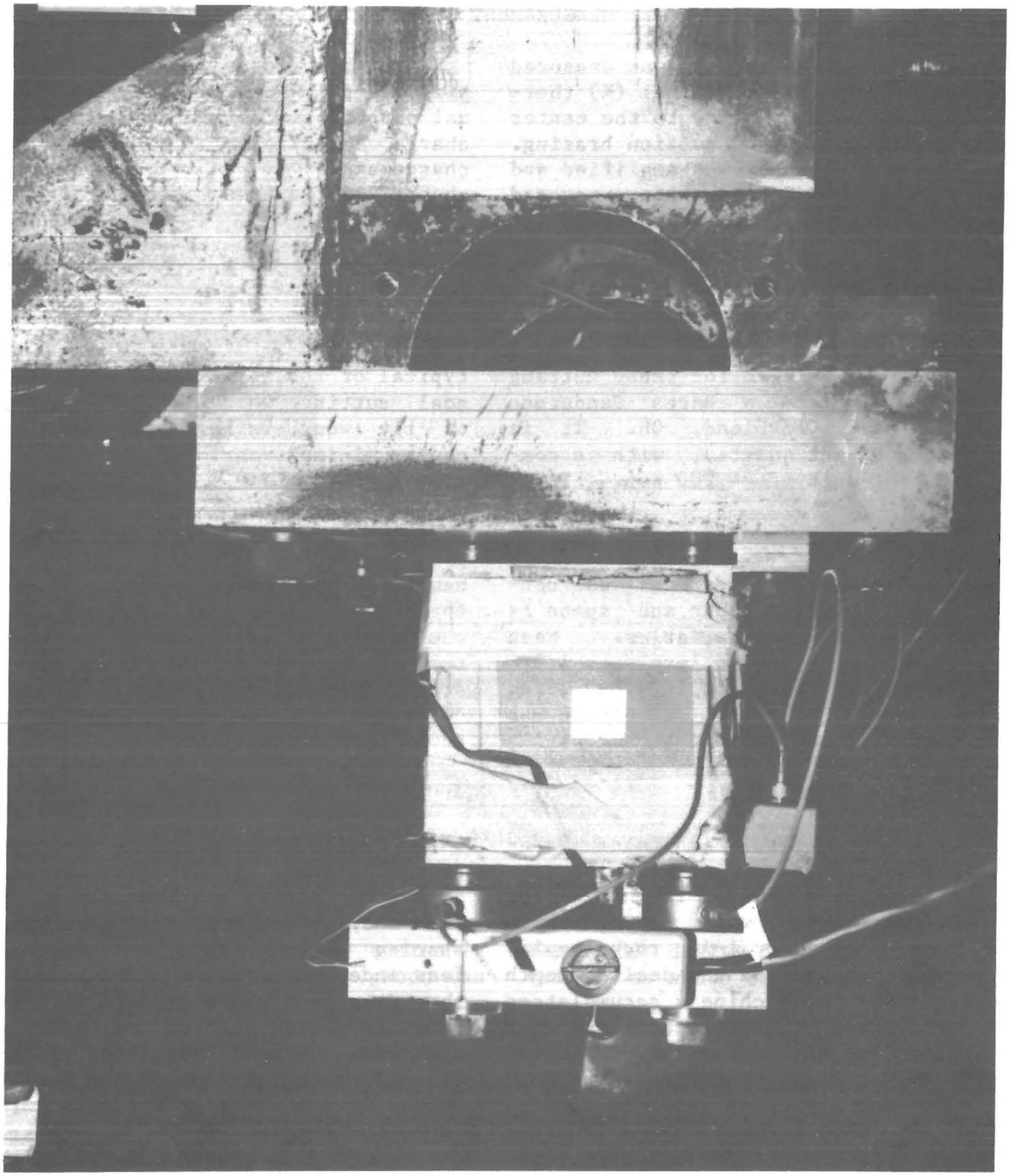

FIGURE 5.—Thermocouple instrumented bit in cutting machine.

MEASUREMENT SYSTEM

Bit wear-flat temperature was measured with a miniature chromel-alumel (K) thermocouple, thermally coupled to the center of the wear flat by induction brazing. The thermocouple signal was amplified and compensated to 0° C by battery-powered electronics mounted near the cutting bit and then recorded on an FM magnetic tape recorder.

Normal bit force was sensed by four piezoelectric load washers whose individual outputs are summed at the input to a charge amplifier. The output of the charge amplifier was recorded on another channel of the tape recorder.

SAMPLE MATERIAL

The rock sample used for these cutting tests was cut from a Berea Sandstone formation near Cleveland, OH. It is abrasive (78 pct quartz), with a compressive strength of 4,200 psi. It is typical of inclusive rock encountered in coal cutting, which is the primary agent of bit wear rather than coal, which causes minimal wear.

EXPERIMENTAL DESIGN

A full factorial experiment was conducted using cutting depth and speed as the two independent variables. Each variable was run at three levels: 1/8-, 1/4-, and 1/2-in depth and 10-, 40-, and 80-in/s speed. Each test condition was repeated a minimum of three times, and a new tool was used for each cut so that the size of the wear flat was initially the same. For each test, the wear-flat temperature and normal force were measured. Regression analysis was used to determine the significance of the two independent variables.

TEST PROCEDURE

Prior to each test, each instrumented bit was immersed in boiling water to verify thermocouple output. The height of the cutting machine work table, which held the 4- by 4- by 1-ft rock sample, was adjusted to provide the desired depth of cut. After the machine's accumulators were pressurized, the data tape recorder was started and the cut was made. It was part of the original test plan to randomize the order in which the tests were performed to "average out" the effects of rock-sample inhomogeneity, but this turned out to be impractical. Setting the cutting depth to the desired value was more difficult than anticipated, requiring several trial and error cuts to obtain the correct depth. This was very time consuming and wasted fresh cutting surface on the sample. Therefore, all the tests at 1/8 in were performed sequentially, followed by all 1/4-in tests, and finally, all 1/2-in tests. This procedure made it easier to predict the degree of lateral breakage along the cut line and, therefore, minimize intercut spacing while still maintaining more or less independent cuts. After each test, the data tape was played into a storage scope to verify that no malfunctions had occurred. Visual inspection of the wear flat of the bit followed each test. Generally, very little evidence of wear could be seen. Figure 6 compares the wear flat of an unused tool with that of a tool used for one 48-in cut.

Figure 6 shows that some of the softer silver-manganese filler around the thermocouple bead was eroded away; this was observed for most of the tests. Some of the high-speed (80-in/s) tests caused a plastic deformation of the leading edge of the wear flat, particularly at the corners.

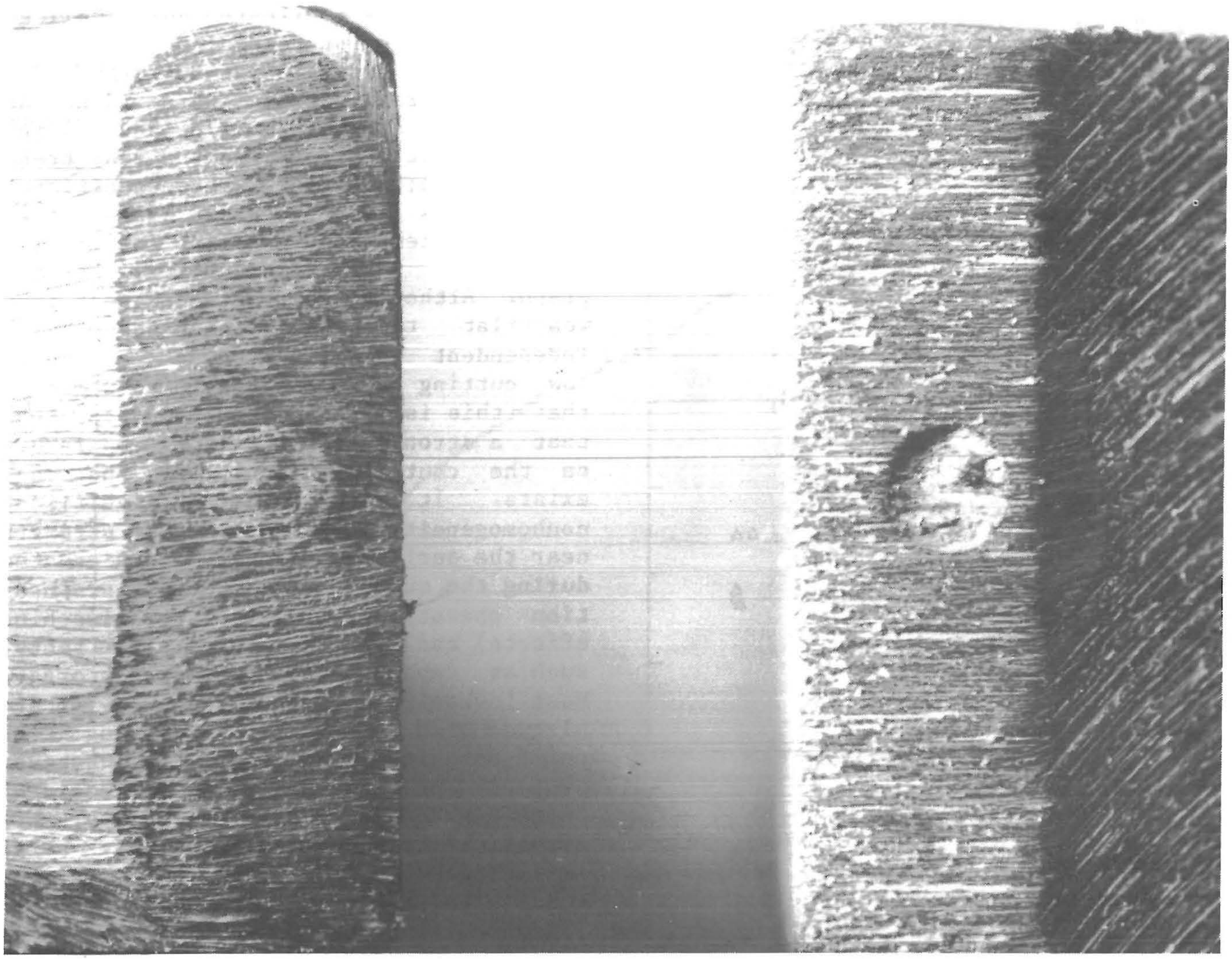

FIGURE 6.—Wear-flat area of new bit (left) and used bit (right) (X 7).

Although cutting speeds were nominally 10, 40, and 80 ft/s, actual speeds (as measured) deviated somewhat from these values, as shown in appendix B.

TEST RESULTS

Figure 7 shows the tool wear-flat temperature plotted as a function of cutting speed for 1/8-, 1/4-, and 1/2-in depths of cut (DOC). The temperature values reported are the maximum values recorded during the test, which generally occurred at the end of the cut. It was originally expected that temperature would increase with speed and also, perhaps, with depth insofar as depth affected normal force. An examination of figure 7 discloses that only for tests conducted at 1/2 in (cut depth) is the expected correlation with cutting speed evident. These data show that temperature increased with speed in a linear manner from 250° C at 10 in/s to 500° C at 83 in/s. These temperatures agree fairly well with those given by Krapivin for a low-strength, fine-grained sandstone, which varied from about 150° to 650° C over the same speed range. Krapivin's temperature measurements were recorded during steady-state heat-flow conditions using a similar, but not identical, rock type. In the present study, the steady-state condition was reached for certain only when cutting speed was slow, as evidenced by a flattening of the

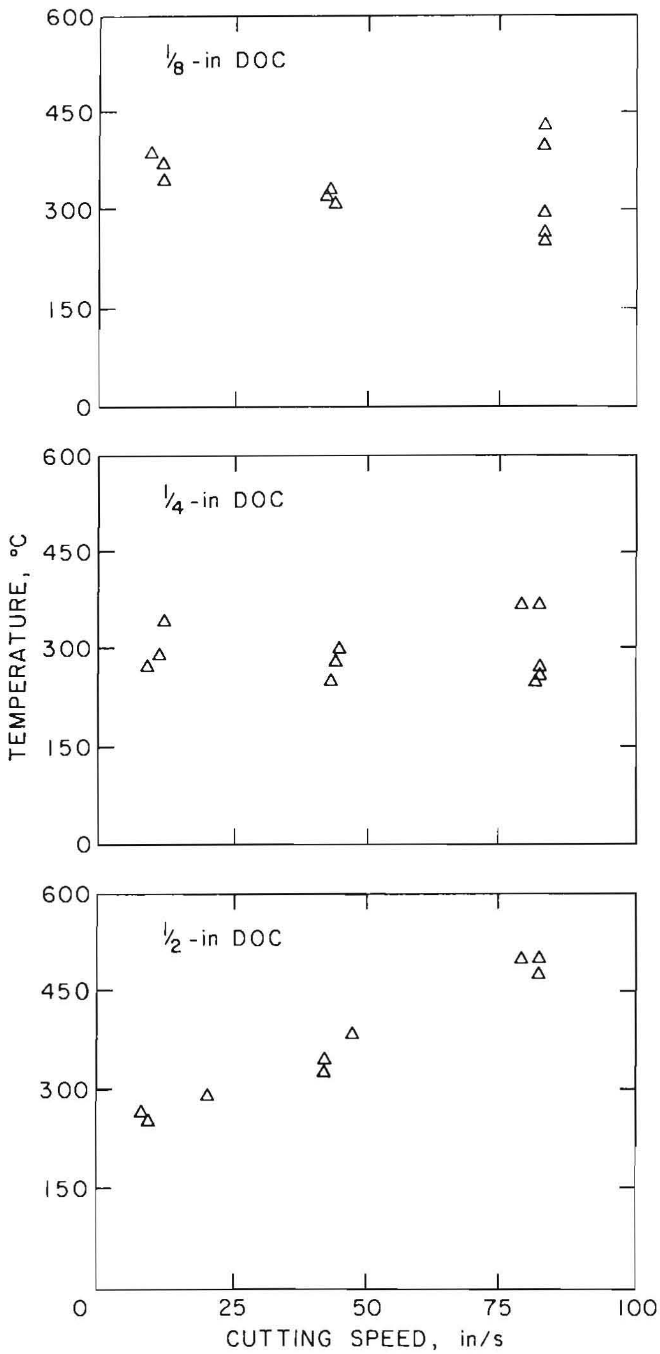

FIGURE 7.—Temperature versus cutting speed at three cut depths.

temperature-versus-time curves for the tests carried out at 10 in/s. A typical example of a temperature-versus-time curve is shown in figure 8. The cutting speed and the depth of the cut for this test was 80 in/s and 1/2 in, respectively.

The data for 1/8- and 1/4-in depths of cut (fig. 7) did not show the expected trend of increasing temperature with speed. The data replicated quite well at 10 and 40 in/s for both 1/8- and 1/4-in DOC, but were dispersed at 80 in/s. Two additional replications were done at 80 in/s for each depth (1/8 and 1/4 in) in an attempt to determine the real trend of the data; however, these additional replications in both cases cluster near the lower temperature point (originally regarded as a probable outlier) on each graph. Although these data suggest that wear-flat temperature is essentially independent of bit speed at shallow cutting depths, it seems unlikely that this is so. Krapivin's data show that a strong dependence of temperature on the contact strength of the rock exists. It is possible that significant nonhomogeneities in the rocks strength near the surface could have been created during the quarrying and sample preparation operations (i.e., water leaching effects) and by environmental effects, such as exposure to air during storage. Most investigations of rock behavior are plagued with difficulties arising from point-to-point variations in whatever property of the rock is the dominant factor in the phenomena under study; this situation is made worse when only a few replications are possible.

While the temperatures reported for the 1/8- and 1/4-in tests are believed to be accurate, the data do not represent a realistic speed-temperature relationship and are, therefore, inconclusive in that respect. No correlation between depth and temperature is obvious, and this is consistent with Krapivin's findings. The data taken at 1/2 in suggest that bit wear (temperature) can be reduced by cutting more slowly, but deeper (to maintain production rate). No temperature capable of igniting methane-air mixtures was observed during these tests. It is not unusual when cutting sandstone (especially with worn radial tools) to see a transient incandescent streak on the rock following passage of the bit, which implies much higher temperatures than those observed in this study. These higher temperatures (at least 1,200° C by color temperature) are probably the result of not just frictional heating, but also the exothermic oxidation or burning

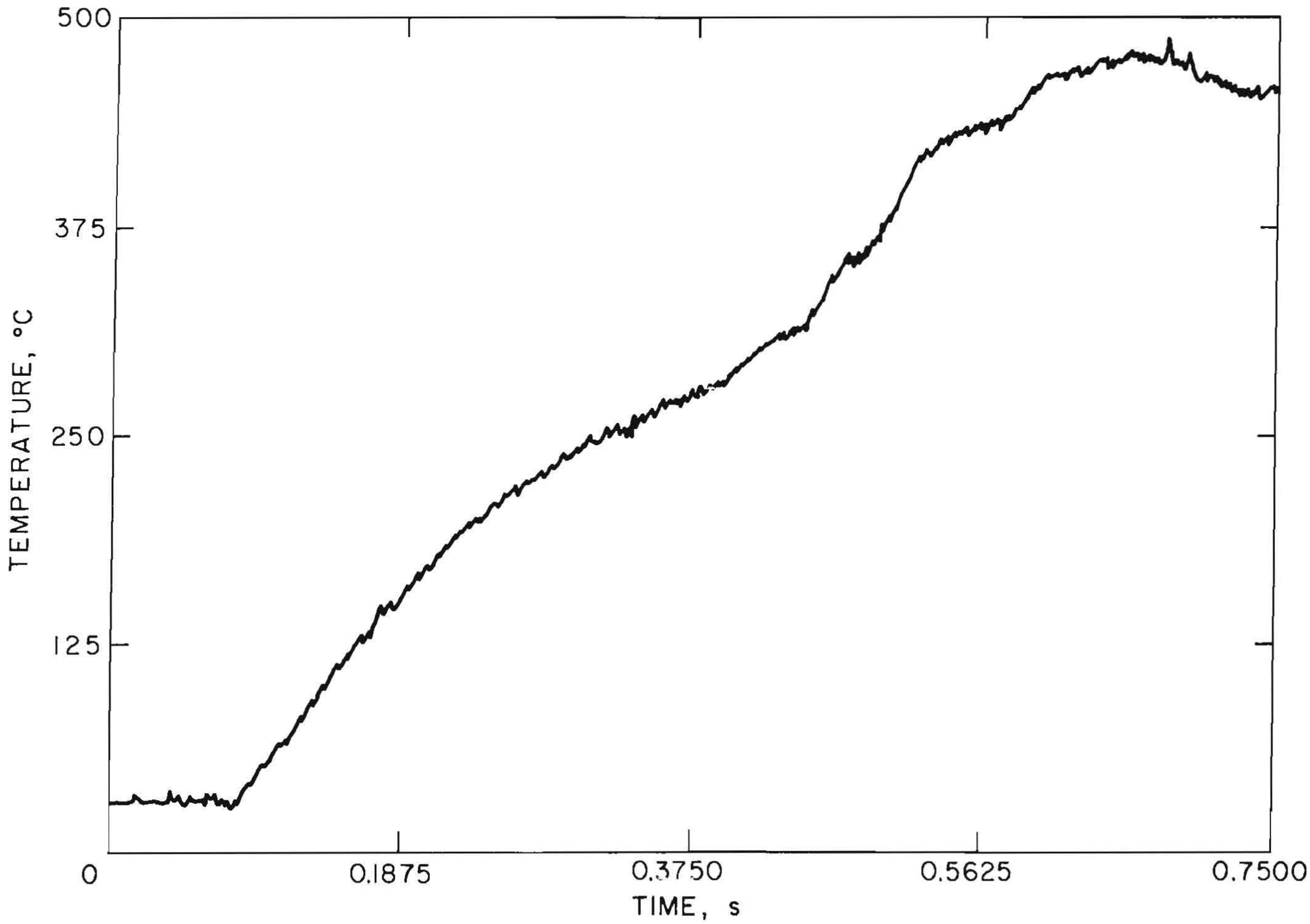

FIGURE 8.—Temperature versus time.

of a steel or cobalt smear left on the rock. Since the RCD offers no safe vantage point from which to view the rock surface, the occurrence of incandescent streaks during these cutting tests could not be verified; however, some metal transfer to the rock did occur.

Unfortunately, the measurements of normal force are not reliable. To minimize noise in the thermocouple signal, fiber-insulating washers were placed between the load cells and the bit holder. These sufficiently deformed during the test to alter the preload on the force washers and thus shift the zero on the charge amplifier output. An attempt to recover the normal force information by offsetting the recorded signal did not yield plausible results.

A tabulation of the data and statistical analysis of the temperature data are presented in appendix B.

SUMMARY

Data for tests conducted at 1/2-in DOC show wear-flat temperature increasing in a nearly linear manner with speed. The maximum temperature recorded at 500° C (at least 1/2-in DOC and 83 in/s) approaches the range at which some WC-Co alloys begin to soften. The data taken at the shallower cut depths (1/8- and 1/4-in DOC) yield an implausible temperature-speed relationship (possibly due to gross fluctuations in sample strength in the shallow layers), also precluding a definite determination of the temperature-depth relationship.

The temperatures measured with thermocouples are consistantly higher than those obtained by earlier radiometer measurements, indicating that the polynomial form used for extrapolation of the radiometer data is incorrect.

No test produced a measured temperature high enough to ignite methane. Traces of bit metal were left behind on the bottoms of some of the high-speed cuts; however, incandescence or burning of the metal smears could not be verified.

The study determined that within certain limitations, thermocouple measurement of the wear-flat temperature is feasible. Using an unground hot junction, a clean, noise-free signal was obtained; and no problems relating to the ruggedness or survivability of the installation during cutting were observed. Practical limits are imposed by response time (size of bead) and the service temperature of the braze. One disadvantage is that the point of temperature measurement is located slightly below, rather than at, the surface.

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APPENDIX A.--THERMOCOUPLE TIME-RESPONSE ERROR

A source of error sometimes ignored in temperature measurement occurs when the body temperature is changing rapidly with time. A finite time is required for heat to flow from the environment or body (in this case, the bit steel) into the sensitive element (thermocouple bead).

This is quantified by the time constant τ (in seconds) of the sensor, which is defined as the time required for the sensor temperature, T (°C) to reach 63 pct (1/e) of the final temperature in response to a step function increase in body temperature, T' (°C). The concept of sensor lag or response time has been analyzed by Baker (10) for step and ramp change of body temperature, the latter and first-order response being assumed applicable to the present case. The heat flow, Q (cal/s) into the thermocouple bead is related to the rate of temperature rise dT/dt in the thermocouple bead by the equation

$$Q = Vc\ dT/dt = (T'-T)/R, \qquad \text{(A-1)}$$

where c = specific heat of thermocouple material, cal/(g·°C),

V = volume of thermocouple bead, cm^3,

t = time, s,

and R = thermal resistance, (s·°C)/cal.

Solving for T'-T yields

$$T' - T = VcR\ dT/dt. \qquad \text{(A-2)}$$

For the case of a step change in body temperature, the solution is given by

$$(T-T_0)/(T'-T_0) = 1-e^{-t/\tau}, \qquad \text{(A-3)}$$

where T_0 = initial thermocouple temperature, °C,

and $\tau = VcR$ (s).

A ramp change in the bit steel temperature can be represented by

$$T' = T_0' + mt, \qquad \text{(A-4)}$$

where T_0' = initial bit temperature,

and m = constant (ramp slope).

In this case, the solution is

$$T'-T = m\tau + (T_0'-T_0-m\tau)e^{-t/\tau}, \qquad \text{(A-5)}$$

or for $t \gg \tau$,

$$T'-T = m\tau.$$

Thus, if τ for the installed sensor is known and the temperature increase of the bit is a true ramp function, m can be determined from the experimental data and the temperature discrepancy T'-T calculated. Measurement of τ can be readily accomplished for fluid temperature measurement by a plunge test wherein the sensor is suddenly immersed in a fluid bath at a known temperature and the output of the sensor is monitored as a function of time. Unfortunately, this method is not applicable in the present case. Kerlin (11) has developed a method of measuring sensor time response in situ by heating the thermocouple with a current pulse and analyzing the thermocouple output transient. Although this appears to be a very promising technique, it could not be employed in the present study due to budgetary restrictions, and no direct determination of the thermocouple time constant could be made. Green and Hunt (12) conducted a study on the accuracy and response of thermocouples for nuclear energy applications, part of which measured the time response of the thermocouples being used to monitor the surface temperature of a steel tube. The technique described involves heating the steel tube electrically and then comparing the thermocouple output versus time with the actual temperature of the tube as calculated from the electrical power input. The thermocouple installation tested was similar to that used in the present study, employing AWG 30 chromel-alumel thermocouple wire resistance welded to the surface. The sensor-time constant reported for this installation was approximately 10 ms, and it seems reasonable to assume that due to the similarities in the installations, this value would be a good first approximation to the time constant for the thermocouple used in this work.

Since the temperatures measured in this study were time varying, the question of thermocouple time lag was pertinent, especially for those tests conducted at 80 in/s. Figure 8 shows the temperature output plotted as a function of time for a typical 80-in/s test. A ramp function temperature increase of the bit steel was assumed, and the slope of the ramp was determined from a straight-line approximation to the time-temperature curve, in this case 0.78° C/ms. The maximum value of T for this test was 470° C, so

$$T' = T + m\tau = 470 + 0.78 \times 10 = 470 + 7.8 \text{ or } T' \simeq 478° \text{ C.} \quad \text{(A-6)}$$

In this case, the actual temperature was 8° higher (≃2 pct) than the measured temperature. This error would, of course, be less for the 10- and 40-in/s tests and was considered negligible for the purposes of this study.

APPENDIX B.--STATISTICAL ANALYSIS

A summary of the test results is shown in table B-1.

Regression analysis was used to determine if any correlation existed between temperature (T) and the two independent variables, speed (S) and depth (D). The data was first applied to a linear model incorporating all three variables. The model had the form of

$$T = A_0 + A_1S + A_2D, \qquad (B\text{-}1)$$

where A_0, A_1, and A_2 are the regression coefficients.

Using the model in equation B-1 resulted in a correlation coefficient of 0.15, which indicated little or no correlation between temperature and the speed and depth parameters. The model was reduced to

$$T = A_0 + A_1S, \qquad (B\text{-}2)$$

and

$$T = A_0 + A_2D. \qquad (B\text{-}3)$$

Applying the model to equations B-2 and B-3 resulted in the correlation coefficients of 0.09 and 0.08, respectively. These results indicated no existing significant correlation between temperature and speed or between temperature and depth. When equation B-2 was applied to the data for each depth, the 1/2-in-cut data showed a correlation coefficient of 0.96, which indicated (for at least the 1/2-in-deep cuts) a very strong correlation between temperature and speed.

TABLE B-1. - Summary of test results

Test	Depth, in	Speed, in/s	Temp, °C	Test	Depth, in	Speed, in/s	Temp, °C
1.....	1/2	47	385	18....	1/4	12	290
2.....	1/4	80	370	19....	1/4	44	300
3.....	1/2	80	500	20....	1/4	09	270
4.....	1/2	20	290	21....	1/4	83	270
5.....	1/8	42	330	22....	1/4	44	280
6.....	1/2	08	260	23....	1/2	42	340
7.....	1/4	83	370	24[1]...	1/2	83	200
8.....	1/8	42	320	25....	1/2	09	250
9.....	1/8	83	260	26....	1/2	42	320
10....	1/8	83	430	27[1]...	1/2	83	220
11....	1/8	09	380	28....	1/2	83	470
12....	1/8	11	340	29....	1/2	83	500
13....	1/8	11	370	30....	1/8	83	300
14....	1/8	43	310	30R...	1/8	83	270
15....	1/8	83	400	31....	1/4	83	260
16....	1/4	43	250	31R...	1/4	83	250
17....	1/4	12	340				

[1]Test discarded due to malfunction.

U.S. GOVERNMENT PRINTING OFFICE: 1987 - 605-017/60082

INT.-BU.OF MINES,PGH.,PA. 28534