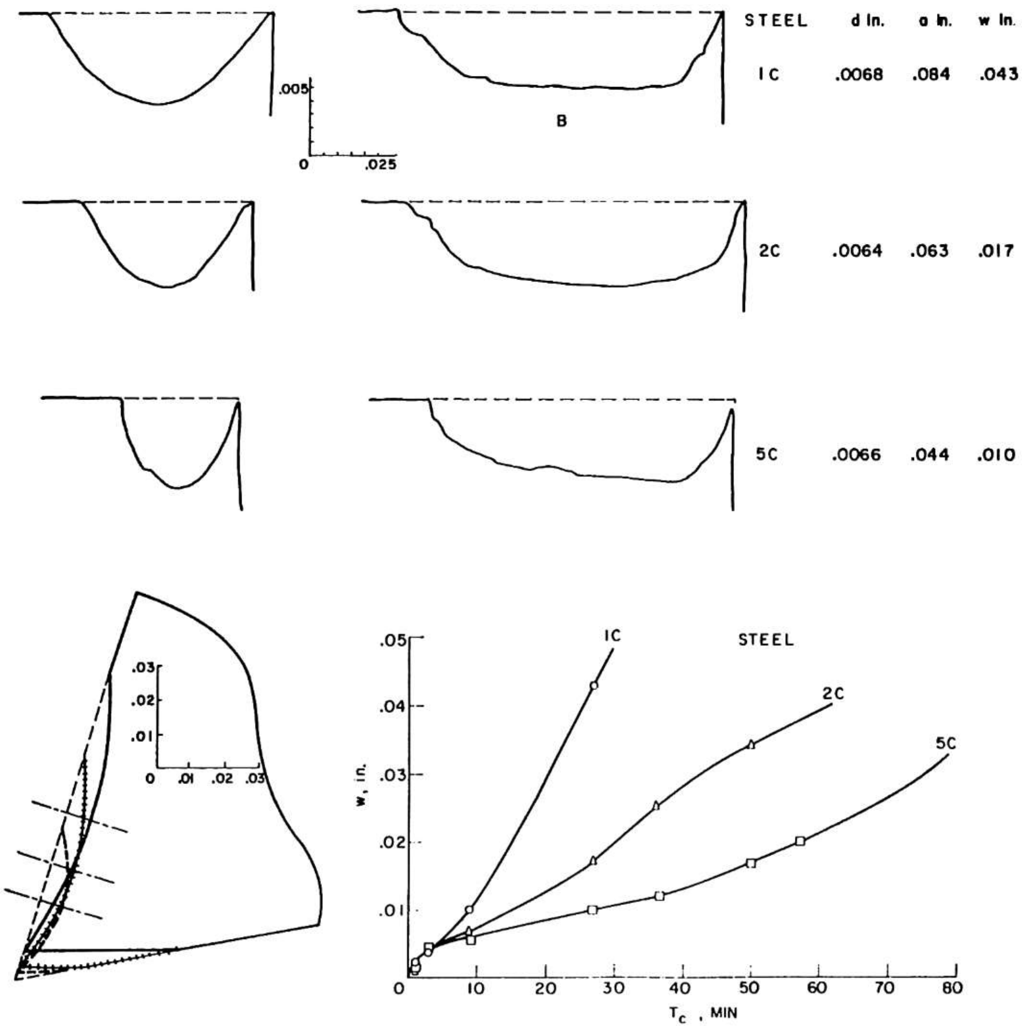

Fig. 17 Tool-face crater development for carbide tools cutting cold-rolled resulfurized steels at 600 fpm. Feed, 0.0046 ipr; depth of cut, 0.100 in.; rake angle, —7 deg; clearance angle, 7 deg; nose radius, 0.03 in.; cutting fluid, none.

practice, the tool life of carbide tools is usualy expressed in terms of a given wear land such as the 0.030-in. value specified by the American Standards Association.

Crater traces for carbide tools that have cut dry at 600 fpm for 27 min are shown in Fig. 17. The traces in the second column are taken parallel to the major cutting edge in the plane of maximum crater depth, while the traces in the first column were taken in a direction perpendicular to the major cutting edge and at the point of greatest crater depth. The corresponding wear-land curves are shown in the lower portion of Fig. 17. When T_c is 27 min the value of maximum crater depth is seen to be nearly the same in all cases. On the other hand the tool-chip contact length a is found to decrease significantly with sulfur content. The extent of wear land w after 27 min of cutting is found to vary inversely as the square of the contact length a for the steels of different sulfur content.

A scale drawing of the crater and wear-land values after 27 min of cutting at 600 fpm is shown in the lower left portion of Fig. 17. The center of the crater is seen to be very much closer to the cutting edge for the sulfurized steel.

Acknowledgment

The authors wish to acknowledge helpful discussions with Messrs. Thomas M. Garvey and John H. Gambill, Jr., of the United States Steel Applied Research Laboratory. They are also grateful to the United States Steel Corporation for the grant that supported this research. Valuable assistance in collecting data was rendered by Mr. Ralph Bowley.

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2 H. Opitz and G. Weber, "Einfluss der Wärmebehandlung von Baustahlen auf Spanentstehung Schnitkraft und Standzeitverhalten," Nr. 215 Forschungsberichte des Wirtschafts und Vekehrsministeriums Nordrhein-Westfalen, West Deutscher Verlag, Köln, Germany, 1956.

DISCUSSION

William Pentland[2]

These papers on the machinability of free machining steels are excellent and timely contributions to our knowledge on this subject. The authors are also to be complimented on devising the instrument for recording tool face crater shape.

The following comments deal only with some statements made

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in the paper concerning tool temperature, which might be clarified by discussion.

The main question in the writer's mind on reading this paper was whether or not tool temperatures were measured during the tests, for none were reported?

The first point of discussion centers on the statement made that "increase in feed causes an increase in tool temperature."

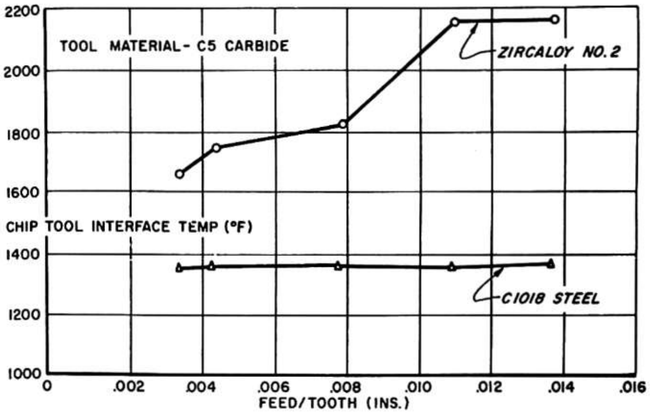

Fig. 18 Cutting temperature versus cutting feed at 343 fpm cutting speed

This is not necessarily so, as Fig. 18 shows. Increasing feed will increase the amount of heat being generated due to plastic deformation, but it also increases the shear plane area allowing greater heat conduction away from the shear zone through workpiece and chip. It would seem from these results obtained by the writer[3] that the tool temperature will significantly increase with feed when the heat conductivity of the work material is low, as is the case for this zirconium alloy, and will not increase if thermal conductivity is high, as it is for this C1018 steel.

The second point of discussion hinges on the statement made that n (the slope of the T/V plot on log/log paper) is a measure of the sensitivity of tool life to temperature. In fact, n is a function of several quantities, including abrasive properties of the work material, cutting forces, and impact (in intermittent cuts), as well as temperature. Though it may be a reasonable and acceptable approximation to say that tool temperature has the greatest influence on n for these low-strength work materials and HSS tools, with the advent of high-strength work materials and carbide tools this statement becomes inaccurate. With some of the materials presently being cut in the aircraft industry, n is more significantly affected by high abrasion and high cutting forces and pressures than by cutting temperature.

Fig. 19 shows for the same tool material in hot machining that the n value can vary considerably and differently for different situations; either different operations (turning versus milling), or different work materials being cut, or different cutting temperatures. So it is seen that the n value can remain constant over a range of workpiece or cutting temperatures, as in turning AM 350, where both abrasion and cutting forces are much reduced with increasing temperature. Also, n can either increase or decrease with cutting temperature, as shown in the other curves, which suggests that the weight of each factor involved in composing n can vary considerably.

The third point of discussion deals with the statement that "a tool that is completely temperature insensitive would have a value of $n = 1$." As indicated in Fig. 20, $n = 1$ means that $VT = C$ or that the volume of metal removed to tool end point is the same at any cutting speed. But at higher cutting speeds forces are reduced, and cutting temperatures increased which can reduce the abrasive properties of the workpiece matrix. Thus, a completely temperature insensitive tool could conceivably remove more metal to tool end point at higher cutting speeds than at lower cutting speeds, which would mean an n value greater than 1.

[3] William Pentland, "Milling Zircaloy—Recommendations From Research," American Society of Tool and Manufacturing Engineers, 1960, vol. 60, no. 250, p. 4.

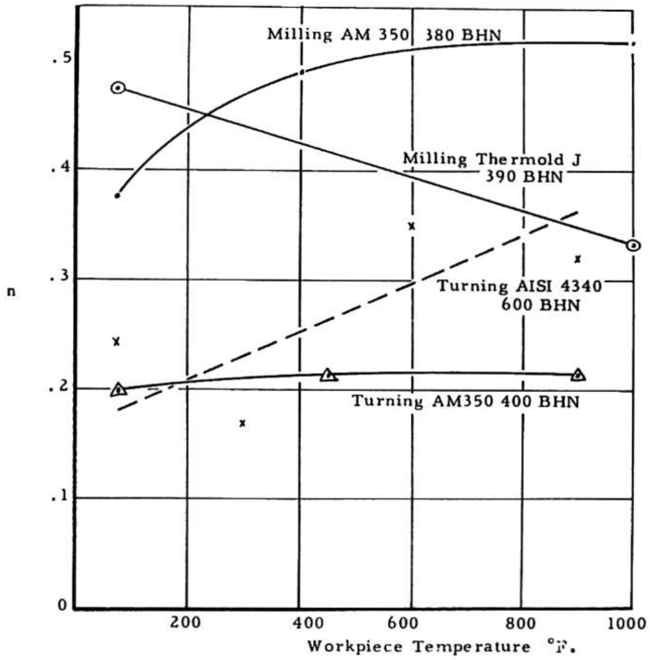

Fig. 19

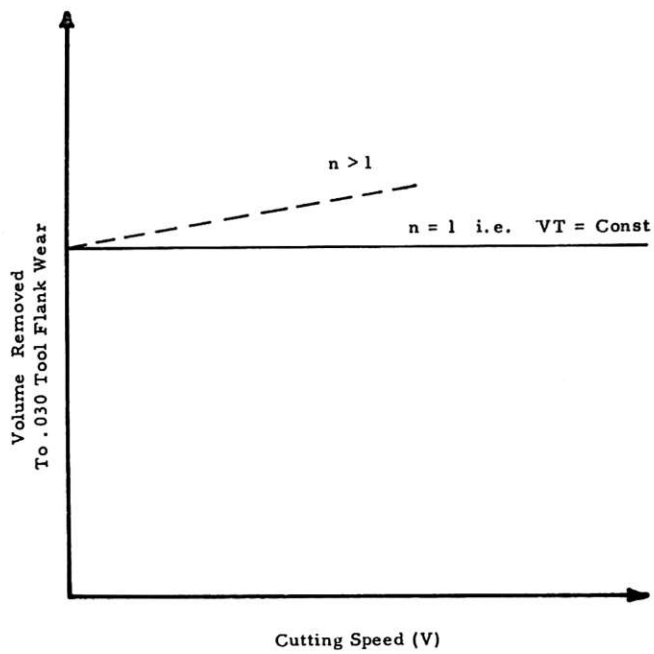

Fig. 20

Authors' Closure

The authors wish to thank Professor Pentland for his comments.

Cutting temperatures were not measured in this study since in most cases a built up edge (BUE) was present and under such conditions chip-tool thermocouple measurements are very questionable.

In reply to the comment concerning generality of the statement regarding increase in mean tool face temperature with feed, we can only state that we have never seen a case where the temperature failed to increase with feed *when a BUE was not present.* There are, of course, several theoretical treatments of tool temperature, all of which lead to an increase in temperature with feed. It is suggested that in the example cited by Professor Pentland for C1018 steel, which shows a constant temperature with increase in feed, a BUE may have been present. Presence of a BUE will provide a lower emf than expected for a given temperature. Since we should expect the relative influence due to BUE to increase with increased feed (at constant speed), this could act to compensate the increase in temperature with feed that actually may have occurred.

We concur with Professor Pentland's comment concerning the limited generality of the idea that an increase in the Taylor exponent (n) might be interpreted as an increase in thermal stability of the tool, since this corresponds to a decrease in the influence of speed on tool life. It is correct that comparisons should not be made between high temperature alloys and free machining steels on this basis, since other factors such as abrasiveness and chemical affinity enter the problem in addition to tool temperature (or cutting speed). However, it was intended that our comments concerning the influence of temperature and cutting speed be limited to the *turning* of free machining and low alloy steels. It is certainly to be expected that most of the results cited in the paper must be altered when the workpiece is shifted to a high temperature alloy or when milling is substituted for turning.