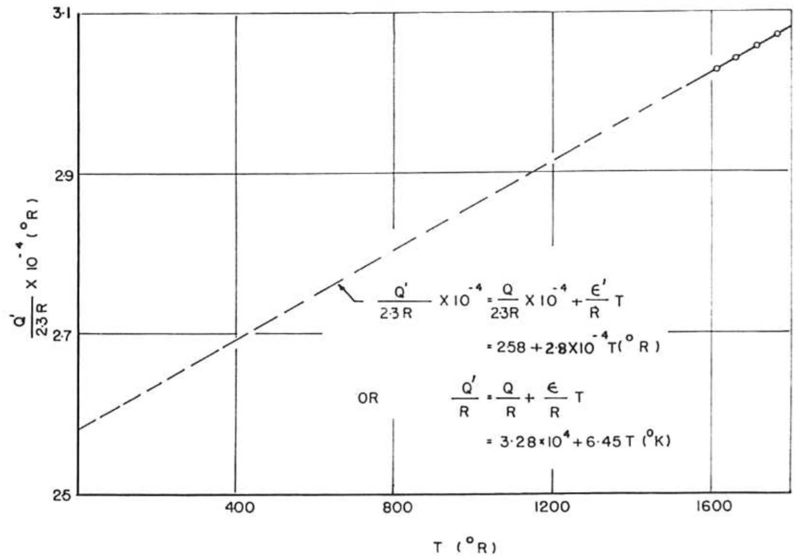

Fig. 7 Slope Constant Versus Cutting Temperature

From Fig. 7 ϵ/R is found to be 6.45.

Putting in these values, Equation [10] becomes

$$L = 1.19 \times 10^{-14} e^{3.28 \times 10^4/T} \text{ min} \quad \text{[11]}$$

As a consequence of the estimate, the following constants for Equation [10] are obtained: $C = 1.19 \times 10^{-14}$ min and $D = 3.28 \times 10^4$.

TABLE 2 VALUES OF C AND D

Equ. [2]	Empirical fit to data	$L = Ce^{D/T}$ min	$C = 3.9 \times 10^{-14}$ min	$D = 3.14 \times 10^{4}$ ° K	T in ° K
Equ. [10]	Theoretical	$L = Ce^{D/T}$ min	$C = 1.19 \times 10^{-14}$ min	$D = 3.28 \times 10^{4}$ ° K	T in ° K

Table 2 shows the estimated values for C and D, respectively, based on theoretical considerations in comparison with those found empirically. It is interesting to note that by means of a rough calculation with available data a tool-life and cutting temperature relationship based on rate-process theory is arrived at and the results have the correct order of magnitude.

Conclusion

Cutting-tool failure has been viewed as a process of rupture due to shear at or near the tool face; and the reaction-rate theory of rupture has been applied to the present problem. While no exact quantitative calculations were possible, it has been shown there are good indications that the proposed approach offers a more fundamental explanation of tool failure than exists at present. Fig. 3 shows that within limits the proposed Equation [3] fits experimental data equally well and possibly better than the empirical Equation [1]. Equation [6] shows that, in general, cutting temperature is not a desirable criterion for determining tool life inasmuch as tool life depends on all of the independent variables. Nevertheless, for a particular physical setup, tool life and cutting temperature are well correlated as shown by Equation [10]. Two constants are involved: C which is seen to be a function of the so-called apparent entropy of activation of the metal, and the parameter ϵ/R which is a function of tool and workpiece material as well as other given dimensions; D is seen to be a function of the so-called apparent activation energy of the material and a parameter f_0/R, which depends on the tool and workpiece material as well as other given dimensions.

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Discussion

B. T. Chao[4] and K. J. Trigger.[5] The authors have prepared an interesting paper suggesting a new and fundamental approach to the all-important problem of tool life in metal machining. However, there are a few pertinent facts which the writers wish to discuss in connection with the paper.

Schallbroch, Schaumann, and Wallich's cutting-temperature data were based on the "two-tool" method (zweimeissel verfah-

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ren), the reliability of which has been seriously questioned since its introduction by Gottwein and Reichel. Inasmuch as the frictional behavior between the chip and the tool face for the two different tool-work combinations may not be identical, the cutting geometry and hence the interface temperatures are likewise different. It is for this reason that the two-tool thermocouple method has virtually been abandoned by recent investigators.

The manner in which a cutting tool wears and fails to function depends to a large extent upon the cutting conditions. The top face wear or "cratering" is usually of great significance at relatively high cutting speeds for a given tool-work combination. Recent investigations on the subject have shown that tool failure due to such cause is decisively temperature dependent.[6] On the other hand, flank wear of carbide tools is often excessive at low cutting speeds where the temperature is low and is of secondary importance. The mechanism of these two common types of tool wear is obviously different, and it appears that an attempt to treat tool failure solely as a process of rupture by shear is an over-simplification.

The authors' analysis deals with parameters which also govern the more likely phenomenon of "cratering" wear, namely, the influence of local temperature on tool-chip interfacial diffusion. Trent[7] has demonstrated that diffusion between steel and free tungsten carbide in the cutting-tool material and the subsequent carrying away of the alloy so formed constitutes the major cause of cratering. Solid-state diffusion may be treated as a reaction-rate process.

Temperature values obtained with the tool-work thermocouple technique represent some sort of average temperature along the length of tool-chip contact. As a tool is put into use, such temperature varies only slightly with cutting time. On the other hand, temperature at the tool-work interface (flank) increases as wear land develops.[8] It is, therefore, difficult to see how tool-life data based on a prescribed wear land could be theoretically correlated to the temperature at the tool-chip interface rather than at tool-work interface.

The writers offer the foregoing comments with the hope of enhancing the value of the paper. When a cutting tool fails by cratering due to excessive temperature, the theory of rate process is applicable in view of the fact that rapid interfacial diffusion takes place. To derive a more universal relationship for tool life, one has to look into the mechanism of tool wear under diversified conditions.

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A. O. Schmidt,[9] B. F. Turkovich,[10] and J. R. Roubik.[11] The authors have brought to our attention a means of relating tool life to tool-tip temperature based on rate-process theory. As mentioned in the paper, life and temperature for a particular set of conditions can be well correlated through empirical determinations. Tool temperature manifests a general influence on tool life, particularly in the machining of ferrous materials. In the machining of light alloys, rapid tool wear can be encountered at relatively low tool-tip temperatures because of abrasive particles embedded in the workpiece material. In the machining of titanium a kind of cold-welding action between chip and tool occurs followed by the tearing out of relatively large particles of tool material. A general relationship of tool life to tool temperature covering the extreme characters of tool-failure mechanisms as mentioned is most welcome and all the more so if the constants in the relating equation are determinable on a fundamental basis.

Authors' Closure

The authors wish to thank Professors Chao and Trigger for their stimulating remarks. Their comment on the obsolescence of the twin-tool thermocouple method is not pertinent to the paper in that refinements which have since been made still show relationships between tool life and temperature of the same character as that of reference (1). It is the object of the paper, not to analyze the data of reference (1), but to use the existence of a relationship of this character between tool life and temperature as a starting point in the analysis of the general problem. Furthermore, as is stated, this is not a detailed theory of the mechanisms of wear processes, whatever their type or location. They may be adhesive or abrasive, they may occur at the crater or the flank, and naturally different mechanisms are involved in these different types of wear, thus different activation energies will be involved. It is felt that by expressing the wear problem in terms of activation energies, among other parameters, the magnitudes of the activation energies involved may furnish clues to the mechanisms which operate. There is no doubt in the authors' minds that they have oversimplified the problem, but prior to this approach (the paper was first submitted in February, 1954) the existing empirical relationships did little to focus attention on the variables which needed control during experimentation and it is thought that the work may provide additional motivation to future experimental work. Nevertheless, the authors are in hearty agreement with the last statement of Professors Chao and Trigger that they must look into the mechanisms of tool wear for the final "solution."

The authors also wish to thank Messrs. Schmidt, Turkovich, and Roubik for their remarks. It is thought that the reaction-rate-theory approach can be used in at least a semiquantitative way in predicting the life of the tool in that, if one knows the type of failure which is going to occur, he can use appropriate values of the necessary constants found from simpler tests. Conversely, it is thought that improvements can be made in tool life by treating the tool material in such a way as to affect advantageously the values of these constants.