CoA Memo. No. 130

July, 1967

THE COLLEGE OF AERONAUTICS

DEPARTMENT OF PRODUCTION AND INDUSTRIAL ADMINISTRATION

A new approach to the prediction of tool wear

- by -

J. Cherry, M.Sc.

SUMMARY

Cutting tests were conducted on EN8b and EN9 materials which have led to the following hypothesis 'For a given tool and workpiece combination the wear on the rake face of the tool is proportional to the work done in friction'.

Further tests are being undertaken to determine the limits of application of this hypothesis.

1.0 Introduction

Tool life is of major concern for economical production in the metal cutting industries and a simple method of predicting the tool wearability of materials would be of considerable value in enabling optimum cutting conditions to be determined.

It has been shown[1] that tool life for minimum cost per piece = $(\frac{1}{n} - 1)K$ where 'n' is the exponent in the speed/life relationship $VT^n = C$.

Since 'n' is substantially constant for a given tool material and chip thickness, and K is constant for given operating conditions then the life of the tool (T) has an unique value under these circumstances. Also since tool life (T) will be determined by a specific magnitude of tool wear, a simple method by which the time to arrive at this criterion could be predicted would be very useful. In the experimental work to be described it has been possible from simple cutting tests to predict tool wear over a limited range of conditions. Much more extensive research is required to establish the range of the technique.

In metal cutting processes where tool wear is the criterion of tool life, wear may be caused by various factors e.g.

(a) ploughing by hardened metal or inclusions[2]

(b) shearing of the welds between chip and tool[2]

(c) diffusion of tool material into the chip[3,4].

Ploughing by hardened metal occurs predominantly at slow speeds when a built up edge is formed, and wear by diffusion occurs predominantly at high speeds where temperatures are high. Between these extremes is the normal cutting speed zone where wear is mainly caused by shearing:

It is to this practical zone that the present technique is confined.

In the course of an investigation into oblique machining[2] a series of experiments was conducted on test material EN8b using a tungsten titanium carbide tool to examine the relationship between the work done on friction on the rake face of the tool and the actual wear of the tool. High correlation was established and led to the hypothesis 'For a given tool and workpiece combination the wear on the rake face of the tool is proportional to the work done in friction'.

Tests were extended to a second material EN9 and high correlation was found between EN8b and EN9 materials. Further tests are being undertaken to determine the limits of application of this hypothesis.

2.0 Experimental procedure for cutting force measurement

2.1 Dynamometer

As previously mentioned the original test programme was to investigate oblique machining (as illustrated in Fig. 1), with particular reference to cutting forces and tool wear. Since the validity of any conclusions would depend on the accuracy of the test results, considerable attention was paid to the design, manufacture and calibration of a three-dimensional dynamometer for use on a lathe. The instrument in position on the machine is shown in Fig. 2 and a diagram of the principle of operation is shown in Fig. 3.

In the calibration of the dynamometer the conventional method of independent loading in each of the three principal directions was not considered sufficient, as this gives no guarantee of accurate resolution of the single cutting force during the machining operation, hence an additional technique was employed as shown in Fig. 4 in which an oblique force was applied to simulate the actual force experienced during the cutting operation.

Oblique forces were applied to cover the range in which the actual cutting forces were expected to occur as illustrated in Fig. 5 and deflections recorded in the vertical, F_c, side F_t and radial F_1, directions. From the known oblique forces, the corresponding forces in the vertical side and radial directions were calculated and a calibration chart drawn as shown in Fig. 6. As will be observed the variations in values over the wide range of loading is quite small, the mean deviations being as follows:-

Vertical force	F_c	= 2.5%
Side force	F_t	= 1.5%
Radial force	F_1	= 2%

These results were considered very satisfactory and average curves computed by the least squares method were drawn as shown in Fig. 7 and used for conversion purposes.

2.2 Cutting forces

The range of tools used during the test is shown in Fig. 8 and the experimental set-up is shown in Fig. 2. Diagrammatic representation of the position of the tools relative to the workpiece is shown in Fig. 9.

All tools had 30° primary rake (normal to the cutting edge) and 5° true clearance. Surface finish in all cases was less than 5 C.L.A.

Tests were conducted for each tool at .0025″ and .005″ feed per rev employing a cutting speed of 70 f.p.m. The magnitude and direction of the resultant force (cutting force) was calculated as shown in Fig. 10 and results are given in Figs. 11 and 12.

Examination of these results will reveal that the angle 'O' (the angle the cutting force R_2 makes with R_1) is approximately half the angle of obliquity 'γ' e.g.

Obliquity	.0025" Feed/rev angle 'O'	.005" Feed/rev angle 'O'
30°	15°29	15°20
45	24°14	25°19
60°	29°30	30°7

2.3 Energy relationships

As shown by E. Merchant[2] the total work done in cutting W_c is composed of the sum of the work done in shear W_s and the work done in friction W_f.

Work done in shear W_s per unit volume

$$W_s = S_s \epsilon$$

where S_s = shear stress
ϵ = shear strain

In oblique machining

$$S_s = \frac{\operatorname{Sin}\phi \operatorname{Cos}\gamma (F_c \operatorname{Sin}\gamma - F_1 \operatorname{Cos}\gamma)}{A_o \operatorname{Sin}\delta}$$

where δ = angle of shear stress

also

$$\operatorname{Tan}\phi = \frac{r_t \cos\alpha}{1 - r_t \operatorname{Sin}\alpha}$$

r_t = cutting ratio $= \frac{t_1}{t_2}$

and

$$\operatorname{Tan}\delta = \frac{\operatorname{Tan}\gamma \operatorname{Cos}(\phi - \alpha) - \operatorname{Tan}\beta \operatorname{Sin}\phi}{\operatorname{Cos}\alpha}$$

γ = angle of obliquity
β = angle of chip flow

therefore in order to obtain reliable values of shear stress it was necessary to be able to measure r_t and β with a high degree of accuracy. To enable this to be done a new technique was devised in which the test piece was prepared as shown in Fig. 13 and mounted on a vertical broaching machine as shown in Fig. 14. The test piece is machined with a number of slots to make each cutting length equal at 1". Typical chips produced by this technique are shown in Fig. 15.

By rubbing a chip on an ink pad and rolling it subsequently on paper the developed shape of the chip can be ovtained as shown in Fig. 16.

Measurement can then be made of the width of the chip after cutting W_2, and the length of the chip after cutting L_2. Examination of Fig. 16 will also reveal that the ends of the chip are not square with the sides but form an angle approximating to half the angle of obliquity. This feature is used as a check on the accuracy of measurement of W_2 and L_2 since the distance across the corners of the chip C_1 (Fig. 16) can be measured as shown in Fig. 17 and used to calculate the angle 'e' of the end of the chip. agreement between calculated 'e' and measured 'e' would indicate correct values. Having verified such measurement and knowing the original volume of the chip then the chip thickness ratio r_t can be obtained as shown in Fig. 18. The angle of chip flow is found as follows:-

$$\cos \beta = \frac{W_2}{W_1} \cos \gamma$$

A summary of the results of these calculations is shown in Fig. 19. Examination of these results show close agreement with the angle of chip flow ' ' as obtained by G. Stabler [3,4,5].

<u>Work done in Friction W_f per unit volume</u>

$$W_f = \frac{Fr_t}{Ao}$$

<u>For orthogonal machining</u>

$$F = F_t \cos \alpha + F_c \sin \alpha$$

<u>For oblique machining</u>

$$F = \frac{F_c \sin \gamma - F_1 \cos \gamma}{\sin \beta}$$

A summary of the results obtained is given in Fig. 20. A graph of Force/ Energy V_s Angle of obliquity is given in Fig. 21. It will be observed that the work done in friction is a minimum at 30° obliquity.

3.0 Wear Tests

Cutting tests were conducted to investigate the effect of the angle of obliquity on the wear of both flank face and rake face of the tool as illustrated in Fig. 22.

The measurement criteria adopted were as follows:-

<u>Flank - True wear</u>

Preliminary tests showed that rapid wear and final breakdown for each of the four angles of obliquity occurred when true wearland, as measured in