A PHENOMENON LEADING TO AN ERROR IN MEASURING THE CUTTING TEMPERATURE BY TOOL-WORK THERMOCOUPLE METHOD

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(Received November 29, 1962)

Presented by Prof. Dr. F. LETTNER

Introduction

The temperature at tool-chip interface in metal cutting is of basic interest, especially in the different methods of evaluating the machinability of metals. It is well known that for determining the cutting temperature the most commonly used methods are as follows:

1. Temperature measurement by tool-work thermocouple.
2. Temperature measurement by the so-called "thermoduo".
3. Temperature measurement by thermocouple embedded in the tool tip.

All methods mentioned above have their own advantages for special cases. This paper deals with the first one. The method was first used by SHORE [1] but has also been successfully used by many other investigators [2]. SHAW assumes that this is the only available method by which the actual temperature at the tool point may be estimated [3].

Cutting temperature measurement with tool-work thermocouple one may use a carbid tool tip, or high speed steel tool. In the case, when the machinability test relates to the evaluation of the temperature as a function of the given cutting conditions for carbon steel as the material being cut and high speed steel as tool material, it is advantageous to use high speed tool as one element of the tool-work thermocouple. The main question referring to this method is — as is known — the right calibrarion of the thermovoltages measured in millivolts for the temperature.

Some authors assume that the thermovoltage that occurred with high speed steel — carbon steel metal contact is a straight line as: a function of the temperature plotted on a log-log diagram. For example, in Fig. 1 some calibration curves given by PANKIN [4] are shown. It is interesting that the curves go only until 600 C°.

The purpose of measuring cutting temperature is usually to determine the function:

$$T = C_T \cdot v^s \cdot f^r \cdot e^p \tag{1}$$

where

T = cutting temperature C°

v = cutting speed, m/min
f = depth of cut, mm
e = feed, mm/min
p, r, s = exponents which depend on the tool and workpiece
C_T = constant, whose physical interpretation is the temperature require for unit variables v, f, e.

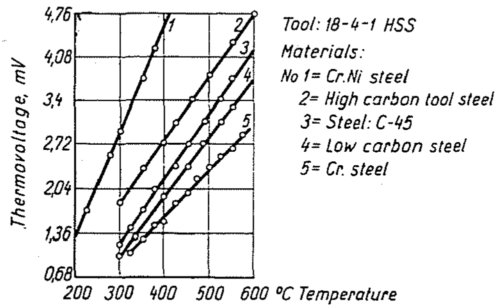

Fig. 1. Calibration curves of tool-work thermocouples using various steels as the materia l being cut and 18-4-1 high speed steel tool. Data are given by PANKIN [4]

If, what the above mentioned research workers are stating, were true, then we should have the opportunity of comparing experiments to determine only the function

$$\Theta = C_\Theta v^{s'} f^{r'} e^{p'} \tag{2}$$

where Θ = thermovoltage (mVolt).

In a special case, when turning aluminium alloy (*e.g.* at low cutting temperatures) this method gave good results [5]. In this way one source of error in converting thermovoltage into temperature would be eliminated.

Our experiments were to investigate this assumption for general use.

As will be shown in the following the experiments based on this assumption gave bad results.

1. Data obtained by measuring thermovoltages as a function of cutting variables

The cutting conditions were as follows:

The workpiece material was a Hungarian Standard carbon steel: C 55. The diameter of the testbar was 200 mm. The tool material was standard 18-4-1 high-speed steel. During the tests the tool used as one element of the thermocouple was, after every measured point, resharpened.

Tool geometry: $\gamma = 15°$, $a = 8°$, $\varkappa = 45°$, $\tau = 30°$, $r = 1$ mm.

With a given chip cross-section area (which was constant during one test) the cutting speed was increased and the value of the millivoltmeter was checked.

The tool-work thermocouple was calibrated to a temperature range of 400—600 C°, interpolated to the needed values. (As it was recommended by PANKIN.)

Fig. 2 shows the thermovoltage-cutting speed curves won by various $f \cdot e$ relations from an extensive series of tests. It is evident from the curves that either the assumption is wrong, or there is some error in the measurement. It is interesting that every line has a point between 4.2—4.4 mVolt, where the slope of the line alters very sharply.

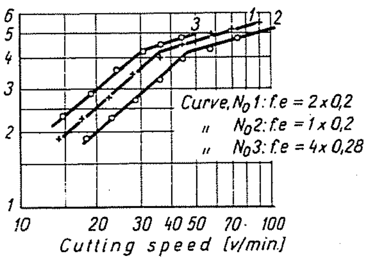

Fig. 2. Effect of cutting speed on thermovoltages by various chip cross-sectional area

First this phenomenon was assumed to be an error caused by altering the electrical conductivity of the measuring systems through the increases in the cutting temperature. Experiments made by Weathstone bridges testified that neither the varied cutting speed nor the altering of other variables had any effect on the electrical conductivity of the thermocouple system.

2. A combined method for calibration

It was taken into consideration that error might be in the calibration technique. To investigate the phenomenon resulting in error it was decided to calibrate the tool-work thermocouple in two steeps: in an oil-bath between 100—200 C° and in an aluminium alloy bath between 500—750 C°.

The results of the calibrations in the low and the high temperature range is shown in Fig. 3. (The given data of the calibration curves are calculated from 4—6 tests.) As can be seen, we got the same point of the slope-change coming from the cutting experiments, too.

The real value of this point was checked graphically and also by the Gauss method. The slope-change begins at about the value of 4.3 mVolt. Due to calibration this value means a temperature of 550 C°, which is the well-known temperature of the carbid dislocation in 18-4-1 high speed steel.

With the help of the new calibration all curves given in Fig. 2 were inverted to the function $T° = f\ (v, f, e)$ and also plotted in a log-log diagram. As it is seen in Fig. 4 the curves are straight lines due to equation (1), if $f \cdot e$ is constant.

There was no need to repeat this test by varying the elements of the tool-work thermocouple. A long time ago GOTTWEIN made many tests to investigate the function of cutting temperature versus chip cross section area [6]. But these experiments were all at a temperature range below 550—600 C°.

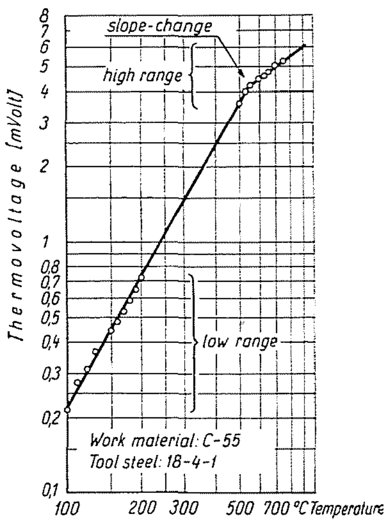

Fig. 3. Result of calibration using the combined method at low and high temperature range. Slope-change at about 550 C°

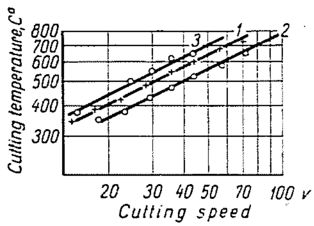

Fig. 4. Temperature versus cutting speeds, plotted from the data of the curves given in Fig. 2, inverting the millivolt values to temperature according to the real calibration diagram

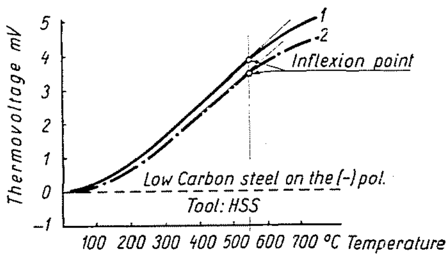

Fig. 5. Calibration curves of GOTTWEIN [6] given by various tungsten contents of high speed steel. (Curve, No. 1: 16-4-1 HSS; curve No. 2: 18-4-1 HSS.) Work material: low-carbon steel

During these tests he studied the difference between the thermovoltage generating abilities of various high speed steels applied as elements of the temperature measurement. A significant result of his calibration is shown in Fig. 5. The curves of high speed steel with 18% tungsten and 16% tungsten having the same character: each curve has an inflexion point between 500 and 600 C°.

3. Conclusions and practical considerations

It seems evident from the test described in this paper that a physical phenomenon reduces the thermovoltage generating ability of high speed steel — carbon steel thermocouple at a temperature range above 550 C°.

For this reason the curve of calibration has a definite point in a log-log diagram, above which the slope of the line changes. In the calibration curve given in Fig. 3 of this paper the function of temperature in C° versus millivoltage is as follows:

— until 550 C° : $T = 240 \quad \Theta^{0.58}$

— above 550 C° : $T = 66.3 \ \Theta^{1.45}$

That is, every method has an error when applying calibration only within the temperature range of 400 and 600 C°, either with interpolation or with extrapolation to other values.

For the same reason it is not possible to use the method of evaluating the function $\Theta = f(v, f, e)$ for purposes of comparison, in general, as it was assumed in the introduction (equation 2). A later Russian investigator is correct when stating that the temperature measurement by the so called "thermoduo" cannot give real values [7]. That is, inasmuch as the temperature arrives at the given value, the constant difference in the low temperature range between the thermovoltage of the carbid tip tool-work material and that of the high speed tool-work material begins to change and might reach high values, increasing the temperature of the cutting. (Above 700 C° the error may be 100 degrees.)

That is, according to SHAW as mentioned above, the only available method for estimating the actual temperature, at the tool point is the temperature measurement by tool-work thermocouple. If the tool applied in this thermocouple is a high speed steel, then the combined calibration technique given in this paper must be considered. For estimating the function of temperature versus cutting variables according to equation (1) of this paper, only the known method to invert the measured mVolt values to temperature can be recommended.

It may be assumed that a correlation exists between the carbid dislocation in high speed steel and the thermovoltage generating ability of the high speed steel — carbon steel thermocouple. Therefore, it would be necessary for the metallurgists and physical research workers to follow up on the investigation of this phenomenon more deeply.

Acknowledgements

The writer wishes to thank Professor Dr. L. GILLEMOT of the Metal Processing Department, University of Budapest, for his permission to calibrate the thermocouple at his institute. Special thank are due Dr. Á. KARDOS, as a constant inspirator for the experiment described in this paper.

Summary

The paper deals with an error experienced in measuring the cutting temperature by the tool-work termocouple method. The problems when using high speed steel tool and carbon steel for metal cutting are described. A combined calibration technique is given to eliminate the error of the thermocouple. Considering the results of the experiments it may be assumed that for the error making phenomenon the thermovoltage generating ability of the given thermocouple in the temperature range of carbid dislocation of the high speed steel is responsible.

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