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A Review of Effects of Temperature Distribution on Tool Life in Turning Process by using Finite Element Analysis

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Abstract: ***Temperature on the chip-tool interface is important parameters in the analysis and control of machining process. Due to the high shear and friction energies dissipated during a machining operation the temperature in the primary and secondary shear zones are usually very high, hence affect the shear deformation and tool wear. This paper is a review of research work in last decade on temperature distribution in turning process. Research is going on to investigate the level of maximum temperature generated at tool rake face and to control this temperature thereby improving the tool life and quality of work piece. In this study, the temperature generated on rake face of cutting tool and experimental methods for measurement of temperature are reviewed. Out of number of interface temperature measuring methods, the special attention has been paid to the tool work thermocouple as it is easy to apply and inexpensive as compared to other techniques. The procedure for the working of tool work thermocouple and the method of calibration is described in this paper. The calibration set up establishes the relationship between emf developed and the cutting temperature. To compare and validate the experimental results, the FEA model is the best way and also it helps to locate the highly temperature affected area on the tool insert.***

Keywords: Temperature distribution, Tool-work thermocouple, FEA

1. Introduction

The importance of knowledge on the temperature gradient and its distribution within the cutting zone resulting from changes in the cutting conditions is well recognized due to severe effects on the tool and work piece materials properties and a considerable influence on the tool wear [1], 3]. In general, three regions of intensive heat generation are distinguished, namely the primary shear zone, the tool–chip interface or the secondary deformation zone and the tool–work piece interface.

Heat is removed from the primary, secondary and tertiary zones by the chip, the tool and the work piece. Fig.1 schematically shows this dissipation of heat. The temperature rise in the cutting tool is mainly due to the secondary heat source, but the primary heat source also contributes towards the temperature rise of the cutting tool and indirectly affects the temperature distribution on the tool rake face [11, 14]

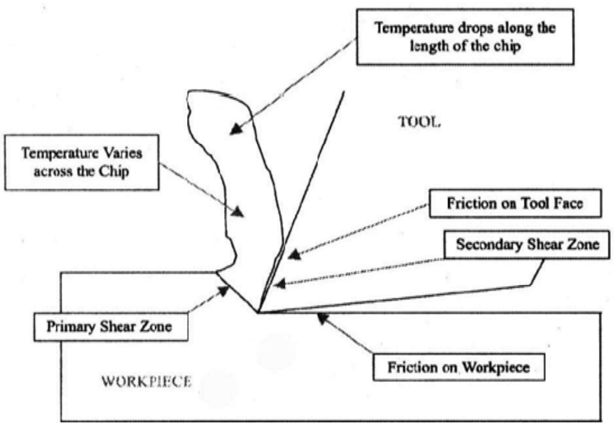

Figure 1: Dissipation of heat in machining

During the process, part of the heat generated at the shear plane flows by convection into the chip and then through the interface zone into the cutting tool. Therefore, the heat generated at the shear zone affects the temperature distributions of both the tool and the chip sides of the tool–chip interface, and the temperature rise on the tool rake face is due to the combined effect of the heat generated in the primary and secondary zones [14].

1.1. Estimation of Heat Generation in Metal Cutting

The rate of energy consumption in metal cutting is given by:

$$W_C = F_V V$$

Where, Fv is the cutting force and V (m/sec) is the cutting speed.

Assuming that all the mechanical work done in the machining process is converted into heat [5, 6], heat generation in the primary deformation zone may be calculated from the work done and the cutting force Fv, as:

$$Qr = Fv V$$

The amount of heat generated due to the work done in the secondary deformation zone along the tool rake face is calculated from the friction energy given by the following equation:

$$Q_S = F_{Fr} V/\mu$$

Where, F_{fr} is the total shear force acting on the rake face (N), V is the cutting speed (m/s) and μ is the chip thickness ratio.

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The force F_{Fr} can be calculated by using the following equation:

$$F_{fr} = F_V \sin\alpha + Fs \cos\alpha$$

Where, Fv is the cutting force, Fs is the feed force and α is the rake angle.

1.2 Tool Work Thermocouple

The tool-work thermocouple is work on the principle of seebeck effect which states that if there is a temperature difference between any two junctions then there will be a development of emf in between the two junctions [13, 14]. The principle of this method is shown in fig. 2

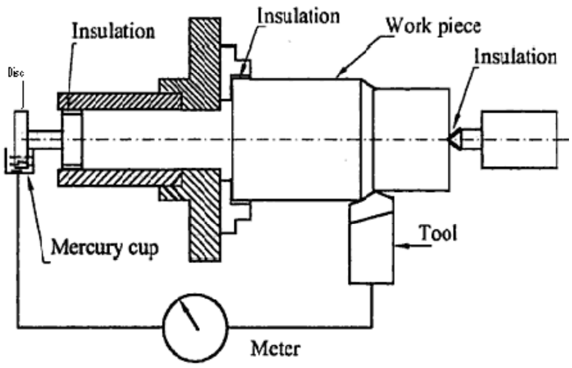

Figure 2: Setup of Tool-Work Thermocouple

In a thermocouple two dissimilar but electrically conductive metals are connected at two junctions. Whenever one of the junctions is heated, the difference in temperature at the hot and cold junctions produces a proportional current which is detected and measured by a milli-voltmeter. In machining like turning, the tool and the job constitute the two dissimilar metals and the cutting zone functions as the hot junction. Then the average cutting temperature is evaluated from the mV after thorough calibration for establishing the exact relation between mV and the cutting temperature [13, 14, and 16]. Fig. 3 typically shows a method of calibration for measuring average cutting temperature in turning steel rod by uncoated carbide tool.

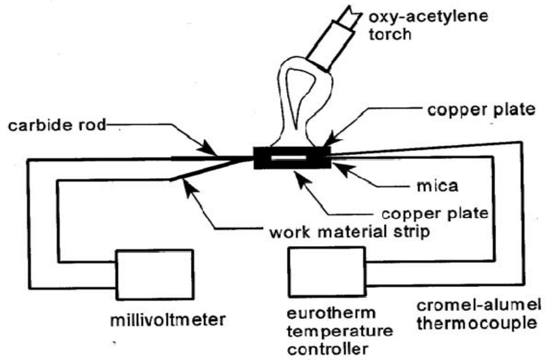

Figure 3: Calibration setup of tool-work thermocouple

In this work tool-work thermocouple junction was constructed using a long continuous chip of the work-material and a tungsten carbide inserts to be used in actual cutting and clamped to the copper plate. A standard Alumel-chromel thermocouple is mounted at the site of tool-work (junction of chip and insert) junction. The oxyacetylene torch heated the copper plate and it simulated the thermal performance phenomena in machining and raised the temperature at the chip-tool interface. Standard thermocouples directly monitored the junction temperature (Alumel-chromel thermocouple) while the emf generated by the hot junction of the chip-tool was monitored by a digital milivolt meter [14].

1.3 Finite Element Analysis

A commercial finite element analysis system ANSYS 14 is used to solve the problem of thermal distribution in the cutting tool insert. The analysis is based on the experimental values of the temperature at the tool work interface, cutting forces induced in machining, mechanical properties of material used and the cutting conditions applied [5, 6, 7, 16].

2. Literature Review

X. L. Liu *et al*. investigated the performance of PCBN tool in the finish turning of GCr15 bearing steel with different hardness between HRC30and 64. A natural thermocouple was used to measure the cutting temperature, and tool life and cutting temperature were investigated and compared [1].

W. Grzesik *et al.* obtained some results of extensive experimental investigations of the thermal interactions between the coating/substrate and the moving surface of the chip. Semi orthogonal cutting when bar turning medium carbon steel and an austenitic stainless steel was carried out. Both flat-faced and grooved inserts coated with TiC, TiC/TiN, and TiC/Al_2O_3/TiN was tested. A standard K-type thermocouple embedded in the workpiece was used to convert measured emf's to the interfacial temperatures. In addition, the chip rake contact length and the area of contact were determined by using computer processing of scanned contact images. The minimum steady-state temperature at the interface between the moving chip and the coating substrate system was explained in terms of the heat flux intensity and the thermal properties of both components of a unique closed tribo-system [3].

Josef Mayr *et al.* performed some experiments on measurement of temperatures and displacements, especially displacements at the tool centre point, computations of thermal errors of machine tools, and reduction of thermal errors. Computing the thermal errors of machine tools include both, temperature distribution and displacements. Shortly addressed is also to avoid thermal errors with temperature control, the influence of fluids and a short link to energy efficiency of machine tools [4].

Pradip Mujumdar *et al*. developed a finite element based computational model to determine the temperature distribution in a metal cutting process. The model is based on multi dimensional steady state heat diffusion equation along with heat losses by convection film coefficients at the surfaces. The models for heat generations within primary and secondary zones, and in the rake face due to friction at the tool–chip interface are discussed and incorporated in the FEM model. Results are presented for the machining of high-speed carbon steel and for a range of cutting conditions [5].

W. Grzesik *et al*. investigated the applicability of various simulation models to obtain finite element solutions of cutting forces, specific cutting energy and adequate temperatures for a range of coated tool materials and defined cutting conditions. The various thermal simulation results were compared with the measured cutting temperature [6].

Sarat Babu Singamneni introduced a new method of solving the thermal fields of metal cutting tools combining certain classical techniques suggested in the past with some relatively new methods of the continuum approach. The moving work piece and the chip are considered as one domain and the stationary cutting tool as another domain to simulate the material flow conditions. The iterative solution sufficiently takes care of the distribution of the primary and secondary heat sources and the need to assume a heat partition coefficient is eliminated. A mixed finite element and boundary element method finally enables the estimation of the cutting temperatures [8].

N. A. Abukshin *et al*. presented the results of temperature measurements on the tool rake face during orthogonal cutting at cutting speeds ranging between 200 and 1200 m/min. These measured temperatures are compared with temperature fields in the cutting tool obtained from a finite element transient thermal analysis and showed the tool–chip contact area, and hence the proportion of the secondary heat source conducting into the tool, changes significantly with cutting speed [11].

Abhijeet Amritkar *et al*. designed and developed a calibration set-up in order to establish a relationship between obtained emf during machining and the cutting temperature. Also, the most simplest and economical technique of temperature measurement i.e. tool-work thermocouple set-up was developed for the measurement of the cutting temperature in machining [13].

L. B. Abhang measured experimentally the tool-chip interface temperature during turning using a tool-work thermocouple technique. First and second order mathematical models are developed in terms of machining parameters by using the response surface methodology on the basis of the experimental results. The results are analyzed statistically and graphically. The metal cutting parameters considered are cutting speed, feed rate, depth of cut and tool nose radius [14].

3. Conclusion

In the literature review, there have been many experiments and reports about temperature measurement during metal cutting. In this work, the tool-chip temperature has been studied by using tool-work thermocouple technique. The tool-work thermocouple technique is the best method for measuring the average chip-tool interface temperature during metal cutting. The benefits of using the tool-work thermocouple are its ease of implementation and its low cost as compared to other thermocouples. The tool-chip contact area decreases with cutting speed and contact time in conventional cutting region. As the amount of heat removed by the chip increases, the fraction of heat flowing into the cutting tool decreases. The temperature of the tool rake face increases with the cutting speed. FEA results determines that the maximum temperature, at the tool-chip contact is increasing with cutting speed but not linearly due to the fashion of the heat flowing into the tool. A force has been found to be an important variable in generation of surface temperature.

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