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An investigation of temperature and heat partition on tool-chip interface in milling of difficult-to-machine materials

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Abstract

It is particularly of importance to determine temperature and heat partition on tool-chip interface in milling of difficult-to-machine materials, because they have great effect on machining process. In this paper, a new analytical method is presented to investigate temperature and heat partition on tool-chip interface in milling of difficult-to-cut materials. Besides single wire thermocouple is used to measure temperature on tool-chip interface. The tool is discretized into axial differential elements to model temperature of each differential element. The tool and chip temperature is worked out by integrating temperature of each differential element along axial direction. Secondly, Response Surface Method, an optimization method, is employed to solve heat partition on tool-chip interface. The objective function is described by matching tool and chip temperature, and the constraint condition is that heat partition cannot beyond 1. After all, the prediction temperature is compared with measurement temperature to verify this method.

Keywords: temperature; heat partition; difficult-to-machine materials; tool-chip interface; milling

1. Introduction

Temperature on tool-chip interface has great impact on machining operations because of its contributing to deteriorate tool wear, and reducing both the tool life and strength, especially in milling. Milling, an interrupted machining operation, is extensively used to manufacture aviation engines key parts. Tools suffer more severe thermal stress in milling than turning because they experience combination of heating-cooling and fatigue (load-unload) cycles. In milling of difficult-to-cut materials, excessively high temperature on tool-chip interface results from low thermal conductivity and intensive friction. This inevitably worsens tool wear and shortens its life to affect machining accuracy and productivity. Understandably, it is necessary to study temperature and heat partition on tool-chip interface to improve cutting condition in milling of difficult-to-machine materials.

Trigger and Chao [1] conducted pioneer research on the cutting temperature. They considered the friction heat source on tool-chip interface as moving heat source for the chip and stationary for the tool. Then using Blok' principle [2], the average temperature on contact surface for mutually contact bodies is equal, they calculated the average heat partition and temperature on tool-chip interface. Subsequently, using similar method, Loewen and Shaw [3] studied the average temperature on varying contact area. However, Trigger and Chao [4] found that the assumption about heat source uniform distribution results in inappropriate use of Blok's principle. Then they proposed a functional analysis method instead of Blok's principle to solve heat partition.

Komanduri and Hou wrote detailed review on temperature modeling. Based on heat source method, developed by Jaeger, they calculated the temperature of chip and workpiece only caused by the shear plane heat source [5]. Later, they modified Hahn and Jaeger's model to calculate the chip temperature only

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considering the friction heat source in a moving coordinate system. In order to calculate the tool temperature more accurately, they considered flank face as adiabatic boundary and imaginary heat source which are no taken into account before [6]. Finally, they combined the shear plane and friction heat source to analyze the temperature on tool-chip interface and shear plane [7]. Considering the determination of heat partition, they simplified the functional analysis method developed by Trigger and Chao. After their simplification, this method becomes much faster to use [8].

Stephen and Ali [9] analyzed tool temperatures in interrupted cutting. In their work, the analytical solution in a semi-infinite rectangular corner heated by time-varying heat flux with different spacious distributions is used to investigate the tool temperature distribution.

Huang and Liang [10, 11] researched the cutting temperature under the effect of flank wear. They calculated the chip temperature considering primary shear zone as uniform moving oblique band heat source. The second deformation zone and rubbing caused by flank wear are regarded as non-uniform stationary heat source to calculate the tool temperature.

Grzesik and Nieslony [12] studied the interface temperature with multilayer coated tool at cutting speed 50-210 m/min. They analyzed heat partition to tool with various methods, including Shaw, Kato and Fuji, and Reznikov. Grzesik [13] used a hybrid analytical-FEM (finite element method) technique, i.e. boundary conditions for temperature distribution simulation are determined by analytical model, to study the temperature distribution on the cutting zone.

Abukhshim et al. [14] investigated the heat partition in high speed turning of high strength alloy steel using orthogonal cutting experiment and FEM. They found that the heat partition on tool-chip interface changes dramatically with cutting speed. Jen et al. [15] modified Stephenson's model to analyze the tool temperature under transient conditions. They used a fixed-point iteration method to work out heat partition which modified quasi-steady partition method developed by Loewen and Shaw. G.List et al. [16] researched the interface temperature and its dependency with crater wear mechanism in high speed machining. They calculated the friction shear stress and heat partition on rake face using Shaw's method, and analyzed temperature distribution under crater wear by FEM. Lazoglu and Altintas [17] developed a temperature model for tool and chip in continuous and uncontinuous machining based on finite difference method. Lin et al. [18] investigated temperature variation of workpiece in end milling, and proposed practicable algorithm of periodic temperature rise function series.

Temperature and heat partition on tool-chip interface in milling of difficult-to-machine materials have not been researched sufficiently, because of difficulties of complex tool geometry, interface area and heat flux varying dynamitic. In order to overcome these difficulties, the tool is discretized into differential elements along axial direction to model its temperature. Secondly entire tool temperature is figured out by integrating all temperature of differential elements. Finally a function of heat partition is built by matching the tool and chip temperature, and solved by Response Surface Method, an optimization method.

Nomenclature

B	Heat partition to tool
α	Thermal diffusivity
λ	Heat conductivity
h_c	Deformed chip thickness
l_s	Shear plane length
l_c	Tool-chip contact length
v	Cutting speed
v_c	Velocity of chip flows
f_z	Feed per tooth
ap	Axial depth of cut
ae	Radial depth of cut
α_n	Normal rake angle
φ	Normal shear angle
dz	Axial integration height
K_0	Zero order modified Bessel function of the second kind
Ei	Exponential integral
Q_f	Heat generated in tool-chip interface
Q_s	Heat generated in shear plane
q_f	Heat flux on tool-chip interface
q_s	Heat flux on shear plane
T_t	Tool temperature
T_c	Chip temperature
r	Distance from any point to heat source

2. Materials and methods

2.1. Temperature modeling of tool

Some factors, including complex tool geometry and varying uncut chip thickness, make temperature modeling in milling to be more difficult. In order to overcome those, the tool is discretized into tool differential element (TDE) axially like modeling of milling forces. Fig.1 presents the analytical method carried out to determine the temperature field in the tool.

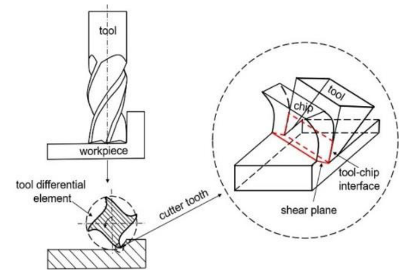

Fig. 1. Diagram of tool differential element in end milling

When the tool performs end milling, TDE independently performs oblique cutting due to helical angle. Without considering flank wear, the tool temperature is mainly affected by the friction heat source on too-chip interface, in spite of little