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Surface & Coatings Technology 195 (2005) 29–40

SURFACE & COATINGS TECHNOLOGY

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Tool coatings influence on the heat transfer in the tool during machining

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Received 26 September 2003; accepted in revised form 3 January 2005

Abstract

Coatings influence on the thermal behaviour of a cutting tool was investigated. Heat transfer in a deposit–substrate system was analysed basing on a simple geometry example, and a steel turning experiment was realised in order to examine different coated inserts in real cutting conditions.

The heat flux in the tool was estimated by the sequential function specification method and the non-integer identified model. The parameters of this model are identified from the transient evolutions of the temperature in the tool due to the heat flux on the cutting edge. The temperature in the tool is measured by a sensor embedded at a certain distance from the zone of thermal load application. For this purpose a special experimental device was developed.

The results show that Al_2O_3 coating leads to a slight heat flux diminution in the tool whereas other used coatings do not influence its thermal behaviour.

Keywords: Tool coating; Machining; Thermal analysis; Heat diffusion; Non-integer differentiation; Inverse heat conduction problem

1. Introduction

The widespread techniques of synthetic material deposition on a substrate give numerous opportunities to improve the reliability of materials by its superficial reinforcement. Owing to improvement of mechanical properties, chemical and wear resistance, the market of coatings application permanently increases. The amelioration and possibility to strictly control coating process cause that synthesised films find wide-ranging applications from medicine, electronics and optics to industrial automotive, aerospace and microelectronics. The deposition techniques permit forming single layer films as well multilayer combinations of materials in order to improve the film adhesion and ameliorate required properties. Nowadays, a large range of materials (TiN, TiC, TiCN, Al_2O_3, HfN, Cr_xN_y, ZrN, CBN and diamond) is concerned by coatings in order to satisfy specific requirements.

The development of coatings has rapidly reached the machining process framework. Different types of metallic as well as non-metallic coatings are used for cutting inserts. Furthermore, multi layers deposits are also used. As it is represented in Fig. 1, the coating thickness for cutting applications is of several micrometers order.

Numerous explanations of coatings resistance from the mechanical point of view, i.e. abrasion, attrition etc. exist [1]. Nevertheless, few works treat on the influence of the coatings from the thermal point of view. It was well reported that a very important factor in tool wear process is the high temperature that occurs in the cutting zone [2], in fact the high temperatures occurring on the cutting tool lead to degradation of its mechanical properties.

As it has been viewed by Grzesik [3], the use of an appropriate coating decrease the friction coefficient at the tool–chip contact area. Klocke et al. [4] also indicate that the coating modifies the contact condition, reducing friction and adhesion. Consequently the mechanical power decrease,

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doi:10.1016/j.surfcoat.2005.01.007

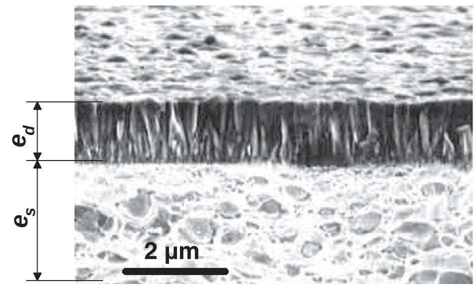

Fig. 1. Thin layer deposit–substrate system: cross-sectional electron micrograph of TiAlN coating on carbide substrate; e_d and e_s represents the deposit and the substrate thickness, respectively.

that naturally leads to decrease the temperature at the tool–chip interface. In Ref. [5], it was reported that the average tool–chip interface temperature and the fraction of heat transferred into the tool depend on the thermophysical properties of the workpiece and the coating. Thereby, an appropriate selection of metal-on-coating pairs reduces the cutting temperature and allows controlling heat transfer into the chip. In [6], Grzesik reports the aluminium oxide coating acts as a thermal barrier. Du et al. [7] basing on the boundary element method for steady-state conduction problem, concerning the influence of coatings on temperature fields in the tool, found very slight influence of Al_2O_3 coating on the temperature in the tool and explain this by its lower conductivity with respect to others coatings.

In front of such contradictory analysis, it seems that the influence of the thermophysical properties of the deposit on the heat transfer in the tool should be more precisely quantified. Thus, in the first stage, we present an analytical solution of heat diffusion in a coated tool. The sensitivity of the temperature at the surface of the deposit is analysed according to the thermophysical properties of the deposit and to the thermal resistance occurring at the deposit–substrate interface. In the second stage, we investigate the coatings influence on the heat flux in the tool. An inverse method that permits estimating the heat flux in the tool during machining is used. It requires temperature measurements at one or several locations in the tool and a model describing heat transfer in the tool. As it will be viewed this model is achieved using the system identification approach [8]. The application treats on the influence of several types of coatings on the tool used in turning process.

2. An analytical solution of the heat conduction problem in a coated insert

Heat conduction modelling in a deposit–substrate system is performed, as a first approximation, on the geometry represented in Fig. 2a. One consider thin deposit layer, thickness e_d, thermal conductivity λ_d and diffusivity α_d, deposited on a substrate of thickness e_s, conductivity λ_s and diffusivity α_s. The front face of the deposit is submitted to the uniform heat flux $\phi_0(t)$. The thermal resistance at the deposit–substrate interface is denoted R_{th}. It comes from the imperfect contact at the interface coating–substrate, resulting from the coating formation process.

A more realistic configuration, 3D axisymetric corresponding to a standard insert in metal turning, is represented in Fig. 2b. Applying Laplace and Hankel integral transforms, respectively on the time variable and the radial space variable, as described in Appendix A, leads to express the transformed temperature on the front face of the deposit according to the transformed heat flux as:

$$\overline{T}_0(\alpha_n, s) = H_{3D}(s)\overline{\varphi}_0(s) \quad (1)$$

where s is the Laplace variable and α_n the Hankel variable. It must be noticed that, in real machining, the temperature varies with space at the tool–chip contact area given to the sliding phenomenon. Here $T_0(t)$ represents the temperature in one point at r=0, on the heated surface.

The impulse response obtained from the transfer function can be assimilated to the temperature evolution on the insert during an interrupted cutting process, when the insert–chip contact is very short. In Fig. 3, the impulse response for

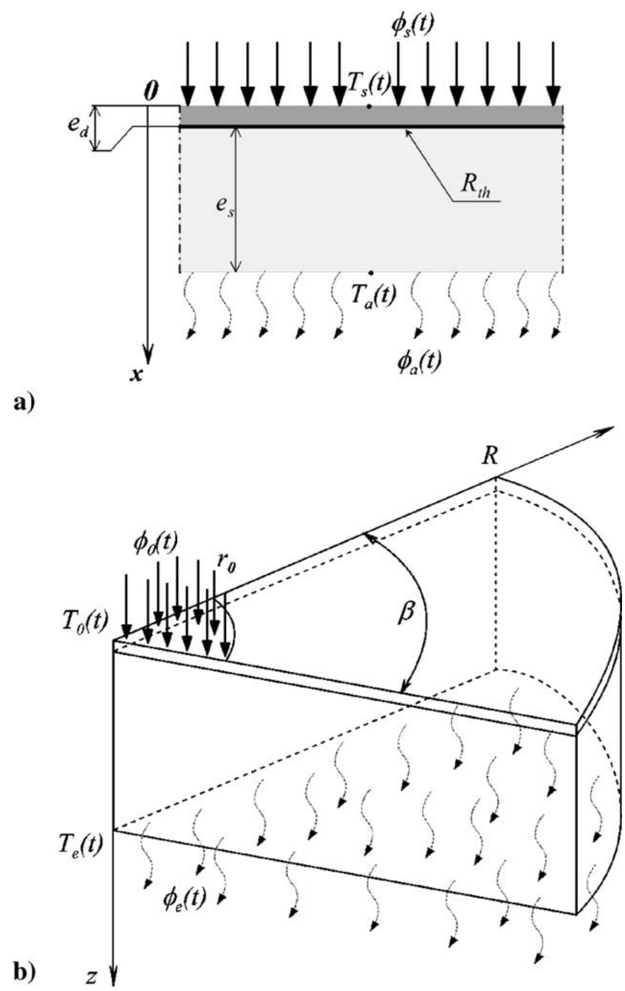

Fig. 2. (a) 1D and (b) 3D axisymetric configurations considered for the heat transfer modelling in a deposit–substrate insert.