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Flank wear of multi-layer coated tool

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ABSTRACT

Flank wear analysis on the multi-layer (TiCN/Al_2O_3/TiCN) coated carbide inserts has been performed after turning AISI 1045 steel. Using advanced microscope and image processing techniques including wavelet transform, we have obtained the flank wear profiles and analyzed the surface roughness and groove sizes on the coating layers to understand the progress of flank wear and its wear mechanisms. The dominant wear mechanism was found to be the abrasion by the cementite phase in the work material. The adhesion took over after carbide substrate was exposed as the notch wear also became more significant. Based on the experimental result, it was concluded that the hardness of the coating is the most important requirement to resist flank wear due to its high wear resistance against abrasion. Therefore, the multilayer coating scheme does not provide any significant benefit to resist flank wear.

1. Introduction

Flank wear is one of the most important aspects that affect tool life and product quality in machining. However, only few works were published to identify the mechanism behind flank wear mainly due to the complexity in metal cutting process. At the present time, the most dominant flank wear mechanism is believed to be the abrasion by the hard inclusions in a work material, which results in the scoring marks on the flank surface [1]. Recently, 2-body and 3-body abrasion models have been identified for the tool wear prediction in turning of pearlitic and spherodized steels with various coated carbides [2]. It was observed that the 3-body wear model shows an excellent agreement with the experiment results of spherodized steels while the 2-body model predicts the flank wear trend for pearlitic steel with some deviations due to the phase transformation during cutting. The flank wear was predicted by the 2-body abrasive model along with FEM simulation (the details are shown in [3]), which provided the cutting temperature on the flank surface. The wear prediction based on the 2-body abrasive model showed very similar results compared to the experimental data.

Another important wear mechanism for flank wear is adhesion. This type of wear can take place when one solid material is sliding over the counteracting surface. The interaction between two surfaces can be represented by the metallurgical weld or adhesion joint. Adhesive wear takes place when discrete pieces are pulled out from the tool surfaces during sliding [4].

Excessive localized wear at the depth of cut line on the flank surface is called notch wear. The main concern is that the notch wear often leads to catastrophic tool failure. Chandrasekaran and Johansson [5] investigated the mechanisms for notch wear in machining of various austenitic stainless steels with cemented carbide tools. They concluded that the sequence of the severe shear deformation and lateral extension of the chip leads to excessive abrasion or adhesion wear between the deformed chip and the tool surface at the notch region.

To identify the wear mechanisms that can be verified through the experiments, accurate measurement techniques are needed. The standard wear measurement techniques such as toolmaker's microscopy and scanning electron microscopy (SEM) are inadequate for such purpose. Recently, three dimensional (3D) measurement techniques such as stereo microscopy, stylus profilers and interferometer, capable of analyzing tool wear pattern, have been used [6–8]. Among these techniques, confocal laser scanning microscopy (CLSM) has been successfully used to generate the 3D crater wear patterns of multi-layer coated carbide tools in combination with wavelet transform [9]. The height encoded (HE) image of the tool surface obtained from CLSM, with a set of height value or z-matrix as a function of x and y, inherently possesses noises and artifacts, which can be eliminated by the wavelet-filtering technique. In addition, the micro features on the tool surface such as the scoring marks by abrasion can be extracted and isolated using the wavelets [10], which enable us to analyze wear mechanisms.

Olortegui-Yume and Kwon [9] have conducted a combined experimental and analytical study to reveal the benefit of mul-

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tilayer coatings for crater wear based on a series of turning experiments with multilayer (TiN/Al_2O_3/TiCN) coated carbide, the followings have been concluded,

1. The effectiveness of the multilayer comes from the changes in interface conditions as each layer is exposed. As each layer is exposed, the maximum wear location changes instead of concentrating on one location. This extends the tool life substantially.
2. The middle layer, Al_2O_3, resisted tool wear at relatively high cutting speeds due to the excellent resistance against dissolution wear while the hard TiCN layer provided an excellent resistance against abrasive wear. Therefore, the multilayer coating made of Al_2O_3 and TiCN provides an excellent resistance against crater wear as the wear mechanism is a combination of abrasive and dissolution wear.

Does the multilayer coating scheme deter the progress of flank wear as it did for crater wear? It was reported that the benefit of the multilayer coating is realized by the crack propagation through the coating interfaces, rather than right into the cutting tool [12,13]. This conjecture is proved to be false for the crater wear [9]. This paper explores if this conjecture is a plausible possibility for the progress of flank wear by studying the flank wear of multi-layered coating using the various microscope techniques and 2D wavelet transform. The flank wear rate and wear evolution are analyzed and the relationship between the roughness of the flank surface and flank wear are investigated.

2. Image processing technique

A JEOL JSM-6400 SEM, which includes both secondary electrons (SE) and backscattered electrons (BSE), and a CLSM (Zeiss LSM210) were used for the flank wear analysis at various cutting times. The flank wear images taken by SEM can be mainly used for the measurement of flank wear land (V_B). CLSM can provide the height information (3D surface profile) of the tool surface with high axial resolution (50 nm) by an axial optical slicing process [11,14]. For each optical section, the maximum brightness associated with the surface profile is detected at a focal plane and stacked each section up to construct the 3D HE image with a series of these optical sections. In this study, for the 3D topography of the flank surface, HE images, corresponding to each maximum bright (MB) images, were obtained with an objective of 50× as shown in Fig. 1(a) and (b). The 200 optical sections with a step size of 200 nm were used for a high accurate surface profile.

Many works have been reported for the surface analysis using wavelet transform [9,15,16]. The key advantage of the wavelet transform is the capability of decomposition of the surface profile to various wavelength regimes, which represent the surface conditions such as roughness, waviness and form, while maintaining the surface details [9,10]. During the decomposition process, the mother wavelet determined based on the characteristic of the surface texture is required. Using the chosen mother wavelet, for example, 1D discrete wavelet transform (DWT) can bring out the two coefficients, approximation and detail, at each level through a decomposition process with two channel filter banks, low-pass and high-pass filters in multi-resolution (MR) scheme. Through a reverse process of the decomposition called reconstruction or inverse discrete wavelet transform (IDWT), the coefficients obtained can be transformed into the approximation and detail, which are related to the "filtered" surface profile, "form", (low frequency) and surface waviness/roughness (medium to high frequency), respectively [14,17,18]. For 3D topography, in a similar way, 2D DWT analysis decouples the raw 3D data to 4 sets of wavelets coefficients, which are called approximation (cA), horizontal details (cH), diagonal details (cD) and vertical details (cV). The surface can be transformed as many levels as possible without losing the original shape. Then, 2D IDWT or 2D wavelet analysis reconstruction for these coefficients are needed to obtain the approximation (*A*), horizontal (*H*), diagonal (*D*) and vertical (*V*) details (see Fig. 3(b)). For the surface roughness analysis, the rough-

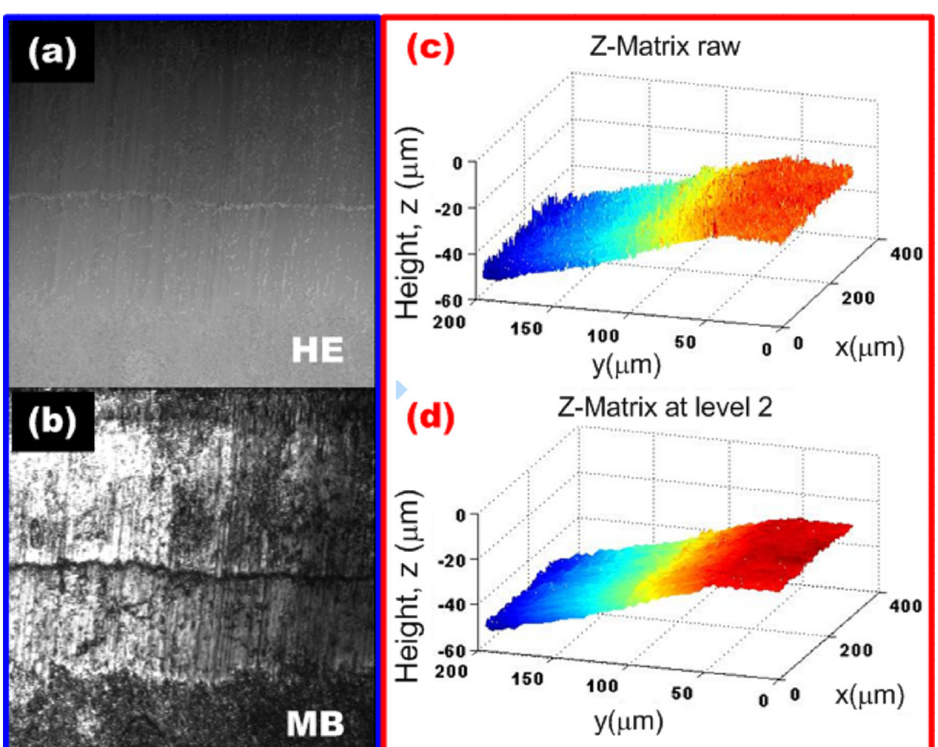

Fig. 1. (a) HE and (b) MB images from CLSM at 7 min cutting time and (c) raw *z*-matrix and (d) wavelet filtered images from HE image.