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Short communication

Application of X- ray diffraction to study the grinding induced surface damage mechanism of WC/Co

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ABSTRACT

X-ray diffraction was utilized to examine the WC/Co surface after high spindle speed grinding (HSSG) to get a further insight into the machining induced surface damage mechanism. The results showed that grinding induced reorientation and preferred {100}/{10−10} growth of WC particles occurred in the deformed surface, while the crystallinity of WC(001) increased. Based on the analysis of the penetration depth of X ray in WC and Co, grazing incidence X-ray diffraction (GIXRD) showed that the grinding induced preferred crystal growth occurred only in the outmost layer (~3.324 nm), but the compressive stress was caused to a certain depth of the subsurface (> 756.18 nm).

1. Introduction

Grinding of cemented carbides has been widely conducted for the extensive application of WC/Co in molding industry, automatic field and cutting tools [1–5]. To improve the life span of the devices or tools, the (sub-)surface damage induced during the machining is of great concern. It has been reported that the varied worn modes occurred for the machined surface, such as surface deformation, fracture, grain pull-outs, and residual stress [3,5–7].

To characterize the surface damages, different methods have been applied to examine the machined surface, such as Electron Backscattering Diffraction (EBSD) [7,8], Transmission Electron Microscope (TEM) [9–12], Scanning Electron Microscope (SEM) equipped with Energy Dispersive Spectra (EDS), Focused Ion Beam (FIB) [6], as well as X-ray Diffraction (XRD) [1,13,14]. In comparison, X ray diffraction (XRD) technique provides us an effective and nondestructive approach to detect the structure transformation of the machined surface.

In the present work, XRD (Bragg-Brentano X-ray diffraction and Grazing incidence X-ray diffraction) is utilized to characterize the grinding induced crystallinity change and preferred orientation of WC/Co, and the corresponding theoretical analysis is given based on the specific crystal structure of WC.

2. Experiments

High spindle speed grinding (HSSG) of WC/Co (~10 wt.%Co) composites was conducted on an ultra-precision grinding machine (Moore Nanotech 450UPL, USA), with minimum quantity of oil coolant (CLAISOL 350). Detail information of the materials properties and grinding setup could be found in our previous studies [5,15]. The micro-structure change of the machined WC/Co surface was characterized by Bragg-Brentano X-ray diffraction (BBXRD) and Grazing Incidence X-ray diffraction (GIXRD) with CuK_{α} radiation (Rigaku SmartLab) in a scanning angle range of 20 to 80°. The spectra was analyzed by Jade 6.5, compared with the standard PDF2-2004 database, and the reference number of the powder diffraction file for WC is PDF#73-471.

3. Results and discussion

To eliminate the impact of the rough surface after sintering, the WC/Co was firstly polished with the diamond paste of 1 μm diameter to remove the surface layer and reduce the impact of the surface defects. The surface morphology, as shown in Fig. 1(a), of the polished WC/Co composites indicates that there are no obvious defects in the original bulk material and the average grain size of WC is about 2 μm. The obtained surface roughness (R_a, arithmetic mean of the departures of the profile) was about 3 nm for the workpiece after polishing, as shown in Fig. 1(b). Fig. 1(c) and Fig. 1(d) shows the surface morphology and surface topography of WC/Co after grinding. It can be readily seen that the machined surface is covered by scratching grooves, WC grain dislodgement, as well as the extrusion of binder. In addition, the surface roughness

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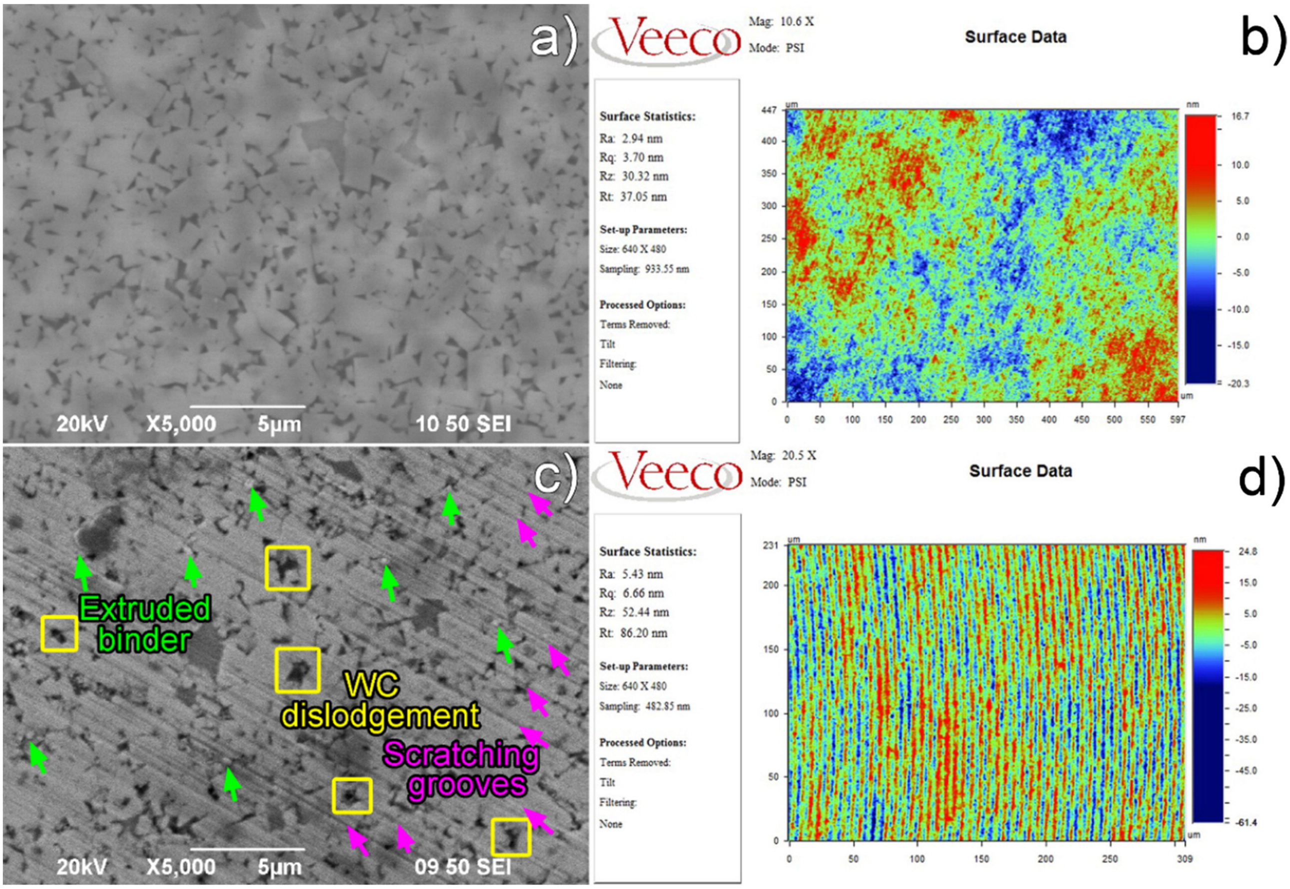

Fig. 1. Surface morphology and topography of WC/Co after polishing and grinding: (a) and (b) after polishing, (c) and (d) after grinding.

reached 5.43 nm (R_a). Compared with the original surface, the XRD pattern of the machined surface, as shown in Fig. 2, shows some reduction in the peak intensity, which is firstly attributed to the formation of a densified layer that is seriously deformed under the dynamic pressure of diamond grits [16]. Specifically, due to the extrusion of cobalt binder, the surface deformation was induced during grinding, where the mean free path of WC grains decreased, resulting in the densification of the deformed surface [1,14,15]. In addition, amorphization of WC could be induced under the shear stress of the dynamic diamond grits during grinding, which has been reported by Stoyanov et al. [17], and this could also lead to the decreasing peak intensity.

Crystallinity is specified as a percentage of the volume of the material that is crystalline, and the crystallinity of the different crystal planes for WC is calculated by Eq. (1):

$$Crystallinity = I_{\text{Intensity of crystalline peaks}}/I_{\text{Total intensity of spectrum}} \times 100\% \quad (1)$$

In the present work, the calculated crystallinity of WC, as shown in Fig. 2(c), indicated that the crystallinity for WC(001), WC(100) and WC(101) all decreased, and this is attributed to the formation of amorphous WC [17]. In addition, the texture coefficient of different crystal planes for WC could also be obtained referring to [18,19], which was calculated based on Eq. (2),

$$T_C = \frac{nI_{hkl}/I^0_{hkl}}{\sum I_{hkl}/I^0_{hkl}} \quad (2)$$

where I_{hkl} is the measured peak intensity of (hkl) plane, $I^0_{hkl}$is the peak intensity of the same plane as indicated in the standard sample (PDF#73-471), n is the total number of reflections observed ($n = 3$). Based on the crystal structure of WC, as shown in Fig. 2(e), it can be easily seen that the close-packed crystal plane is {0001}, and the close-packed orientation is ⟨−12−10⟩. To low the system energy, preferred WC{0001}/⟨−12−10⟩ growth is expected during sintering, so the preferred orientation for the original workpiece is WC(001), as shown in Fig. 2(d).

However, the preferred orientation of WC(100)/(10−10) appeared for the machined surface, as indicated in Fig. 2(d). As far as the high grinding temperature and dynamic pressure of the diamond grits were concerned, the grain growth of WC could be induced, which promoted the further growth of WC grains, leading to the preferred growth of WC(100)/(10–10) for the machined surface. The surface topography of the machined WC/Co measured by AFM in a range of 1 μm × 1 μm is shown in Fig. 2(f). It can be readily seen that the machined surface is covered by many nano grains. According to the previous experimental and theoretical study, the instantaneous temperature of the grinding zone, which is called 'spike' or 'flash' temperature, could be close to the melting point of the workpiece material with minimum quantity lubrication, especially at a very small depth of cut where the friction heats resulted in the high temperature [20–22]. Therefore, the preferred growth for the nano grains could be induced during the grinding process under this consideration.

Previous studies have also shown that reorientation of grains could be induced in the seriously deformed layer [23–25], and the reaction indicated by Eq. (3) occurred [26]. In addition, a tendency of fracture path occurred on {10–10} has been proposed during the indentation of WC/Co [27]. Therefore, the expected orientation alignment and grain fracture could lead to the increasing amount of prismatic planes