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Development of novel cutting tools with dimple textured surfaces for dry machining of aluminum alloys

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Abstract

Dry machining of aluminum alloys is one of the most challenging machining operations because these materials severely adhere to the tool surface without the use of cutting fluids, leading to deterioration of the surface integrity of the workpiece and tool failure. In order to overcome this problem, we newly developed cutting tools with dimple-shaped textures having different dimensions and arrays, generated on the tool rake face by using a femtosecond laser. A series of experiments demonstrated that the dimple textures significantly suppress the aluminum adhesion on the tool rake face by facilitating the flaking of the adhesion layer from the tool surface, and they exhibit a superior performance compared with those with groove textures, which were developed in our previous study, in dry machining of aluminum alloys. Furthermore, the relationship between texture dimensions and anti-adhesive properties was discussed to establish a guideline for optimizing the dimensions of the dimple textured surface.

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Keywords: Dry machining; cutting tool; tribology; surface textrure

1. Main text

In recent years, the movement towards minimizing or eliminating the use of cutting fluids; namely near-dry/dry machining, is one of the most important challenges in the field of metal cutting, because the use of cutting fluids increases costs for waste disposal and environmental loads [1-3]. In particular, aluminum alloys are well known as critical materials with regard to dry machining [1, 2]. Without the use of any cutting fluids, these materials severely adhere to the tool surface and form a built-up edge due to their low melting point and high ductility, leading to deterioration of the surface integrity of the workpiece and tool failure. Therefore, a wide range of studies related to cutting tool technologies, including tool materials, geometry, surface coating and surface finishing, have been

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conducted. For instance, diamond-like carbon (DLC) coated tools are considered to be suitable for dry machining of aluminum alloys [4, 5]; however, a flooded cutting fluid is required in practical use to avoid adherence of aluminum chips to DLC-coated tools [6].

In contrast to the conventional approaches described above, we adopted a surface engineering approach; namely, a functionalization of tool surfaces by textures [7, 8]. We introduced this technology to cutting tool surfaces to improve cutting tool performances and developed several types of cutting tools with various textured rake and flank faces. For example, cutting tools with periodical stripe-grooved rake and flank faces successfully decrease the crater and flank wear in steel machining [9, 10]. In addition, recently, several studies have been conducted on cutting tools with textured surfaces[11–19]. These studies reported that surface textures on tool surfaces can improve cutting performances in various metal cutting operations, including decreasing the cutting forces [11–19], reducing the cutting temperature [15, 16, 18], and improving the wear resistance [14, 15, 18, 19]. With regard to the dry machining of aluminum alloys, our previous study clarified that the micro-grooves generated on the tool rake face significantly improved anti-adhesiveness of the tool surface [20]. However, the anti-adhesive properties of the grooved-surface strongly depend on the groove direction, and this type of textured surface adversely promotes the chip adhesion when the groove direction coincides with the chip flow direction.

In the present study, we newly developed cutting tools with dimple-shaped textured surface which has lower direction dependency compared with the groove-shape textures, and evaluated the cutting performances in dry machining of aluminum alloys. Furthermore, the influences of the texture dimensions and the mechanism for suppressing the chip adhesion were also discussed.

2. Experimental details

2.1. Development of cutting tools with dimple-shaped textured surface

To generate micro-dimples on the tool surface, laser surface texturing using femtosecond laser [19, 20] was employed. A micro-dimple array was generated on the rake face of a WC-Co cemented carbide cutting tool (ISO K10-type, Non-coated tool) by a Yb:KGW-based laser system (L.P.S Works Co. Ltd., PiCooLs4; wavelength = 515 nm, pulse width = 190 fs, cyclic frequency = 400 kHz). Figure 1 shows a scanning electron microscope (SEM) image, a 3-dimensional image and a sectional profile of the rake face of a developed tool. The micro-dimples, which have a rectangular cross-section, were fabricated on the rake face of the WC-Co cemented carbide cutting tool.

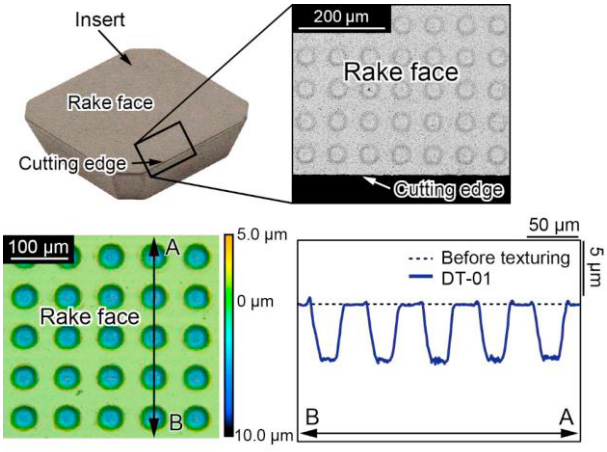
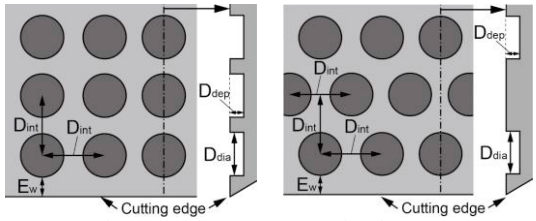


Fig. 1. Cutting tool with dimple-shaped textured surface



(a) Linear array (b) Zigzag array

Fig. 2. Parameters of dimple textures

Table 1 Characteristics of developed tools

Tool name	D_{dia} (μm)	D_{int} (μm)	Array	A_r (%)
Conv. tool	-	-	-	0
DT-01	50	75	Linear	35.0
DT-02	30	75	Linear	12.6
DT-03	70	75	Linear	68.3
DT-04	50	95	Linear	22.0
DT-05	50	55	Linear	64.9
DT-06	50	75	Zigzag	35.0
DT-07	30	75	Zigzag	12.6
DT-08	70	75	Zigzag	68.3
DT-09	50	95	Zigzag	22.0
DT-10	50	55	Zigzag	64.9