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Micro-texture at the coated tool face for high performance cutting

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ABSTRACT

This paper describes the effect of micro surface texture on the lubrication conditions at the tool rake face in machining aluminum alloy. For this purpose, four types of micro surface texture were fabricated at the tool faces of cemented carbide through spattering, photolithography and wet etching, and the micro-textured tool faces were coated with diamond like carbon (DLC) or TiN. Then, orthogonal cutting experiments of aluminum alloy were conducted using the coated tools with and without micro-texture. The normal and friction forces and the coefficient of friction were obtained from the measured cutting forces. In addition, tool surface conditions were inspected with a CCD microscope after machining. As a result, it was found that parallel type and square-dot type of micro-textures improved effectively the lubrication conditions in machining aluminum alloy A6061-T6. It was also found that micro-texture was likely to improve the lubrication conditions more effectively as the pattern of texture became smaller and deeper.

1. Introduction

Nowadays, development of high-performance and intelligent tools is needed for high speed, high efficiency and trouble-free cutting. Tool coating is the most effective in enhancing the performance of a tool. Therefore, various types of coated tools with high hardness, high oxidation temperature, low friction coefficient and long tool life have been developed so far: fine diamond coating [1,2], superlattice coating [3,4], nanocomposite coating [5,6] and diamond like carbon (DLC) coating [7,8]. Some of coated tools have contributed to environmental conscious machining, such as dry and minimum quantity lubrication (MQL) machining [1,9]. However, development of new coating materials is getting more and more difficult. By contrast, it is known that micro-textured surface as well as surface coating change the friction characteristic of solid surface [10,11]. Thus, machining micro-textured surface was applied to micro die for decreasing the coefficient of friction in drawing [12]. Accordingly, the combination of the micro-textured surface and the surface coating seems to take a synergic effect on the performance of cutting.

Surface texture was applied to cutting tools for decreasing the friction coefficient at the rake face [13,14]. Sugihara and Enomoto [13] fabricated micro texture and shallow grove on a DLC-coated tool by irradiating the rake surface with a femto-second laser. They found that the textured and grooved tool reduced the adhesion of the work material A5052 to the tool face and decreased the coefficient of friction at cutting speed 6 m/s. Kawasegi et al. [14] fabricated nano and micro-scale grooves at uncoated cemented-carbide tool faces by laser irradiation. They also applied these tools to machining of A5052 aluminum alloy. Grooves fabricated on the tool had a favorable effect only in a range of cutting speeds faster than 7.0 m/s. However, the effect of the micro shapes of surface texture on the cutting performance of a coated tool has not yet been investigated.

Some authors made intelligent tools with thin film thermocouples in coating layers using photolithography, wet etching and hard coating, and applied these tools to machining of aluminum alloy [15] and carbon steel [16] for measuring cutting temperature and tool condition monitoring. In future, a tool with intelligent sensors and particular functional surfaces will be made for high performance cutting. For this purpose four types of micro-textures were fabricated in this study at tool surfaces using a process of photolithography followed by hard coating. Then, orthogonal cutting experiments of aluminum alloy A6061-T6 were conducted using the coated tools with and without micro-textures and the effect of micro-texture on the cutting performance was investigated.

2. Experimental methods

2.1. Fabrication of coated tools with micro-textured surfaces

Four types of micro-texture fabricated at flat rake faces are shown in Fig. 1 schematically: (a) one-directional grooves perpendicular to the cutting edge, (b) one-directional grooves parallel to the cutting edge, (c) a matrix of square pits and (d) a matrix of square dots, which are called "perpendicular," "parallel," "pit"

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and "dot" types, respectively. The grooves and ridges of the four types of micro-textures have width $w=25$ or 50 μm and depth and height $h=0.5$, 1.0 or 1.2 μm; thus a cross section of a micro-texture perpendicular to a groove has a shape of square wave ideally. Distance from the cutting edge to the area of surface texture δ was set at 100 and 150 μm. In other words, there is no texture over a distance of 100 or 150 μm from the cutting edge. A photo mask for each texture pattern was made of a blank glass plate coated with chromium film and photo resist using an electron beam lithography system and associated apparatuses.

A schematic of the fabrication process of a coated tool with micro-texture is shown in Fig. 2. The process was similar to that of cutting tools with built-in thin film thermocouple sensors [15,16]. SPGN120408 and SNGN120408 types of K10 cemented-carbide inserts were used for tool substrates. The four types of micro-texture were fabricated on SPGN120408 inserts, while only parallel type was fabricated on SNGN120408 inserts. First, the top surface of an insert was finished by polishing until the surface roughness became less than 0.01 μm Ra. Polishing removed the chamfer along the cutting edge and sharpened the cutting edge lowering the cutting edge roundness to a value less than 10 μm. Thus, non-textured inserts were also polished. The polished insert was cleansed and degreased through ultrasonic cleaning with acetone as well as alkaline detergent; it was rinsed with pure water and dried completely using isopropyl alcohol.

The polished surface of an insert was coated with nickel using helicon DC magnetron sputtering. The thickness of coated nickel layer was 1 μm for a SPGN120408 insert, and 0.5 and 1.2 μm for a SNGN120408 insert. Then, photoresist was spin-coated over the tool surface, prebaked and exposed to ultraviolet light through a photo mask with a specific pattern of micro-texture. After development of photoresist, unnecessary part of nickel was chemically etched for leaving a specified micro-texture at the tool face. Finally, SPGN120408 inserts with and without micro-texture were coated with DLC using plasma chemical vapor deposition (PCVD), while SNGN120408 inserts with and without micro-texture were coated with TiN using reactive helicon DC magnetron sputtering.

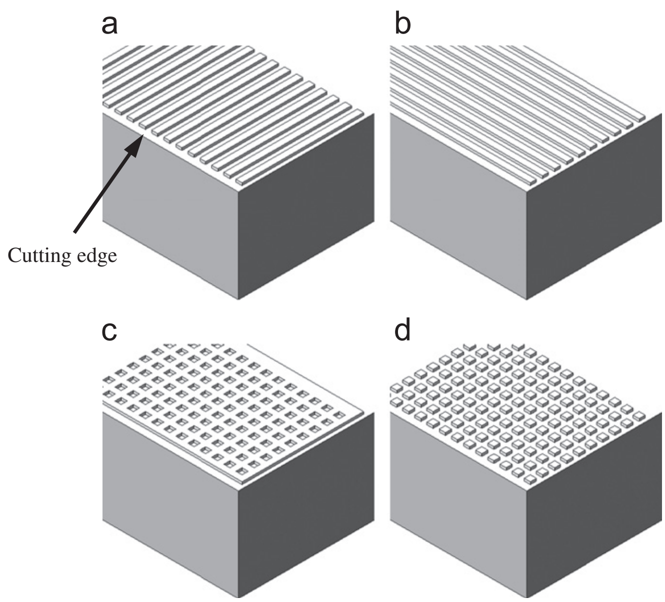

Fig. 1. Four types of micro-texture fabricated at the flat rake face: (a) perpendicular; (b) parallel; (c) pit and (d) dot.

2.2. Cutting experiment

Two types of tool shanks for clamping SPGN120408 and SNGN120408 inserts were made for orthogonal machining with

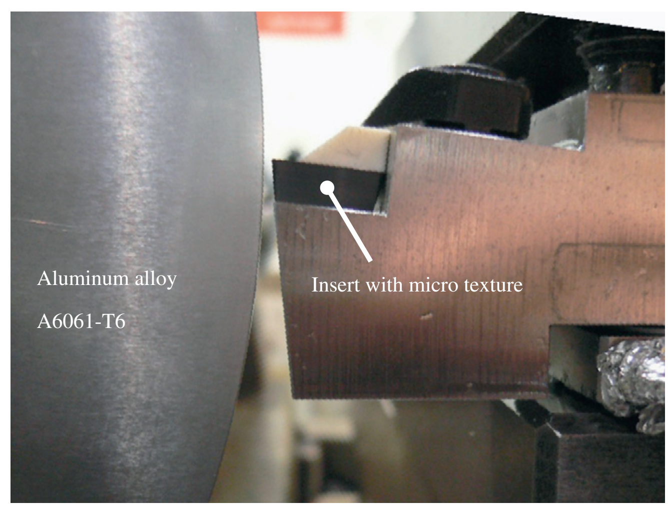

Fig. 3. Orthogonal cutting experiment using a tool with micro surface texture.

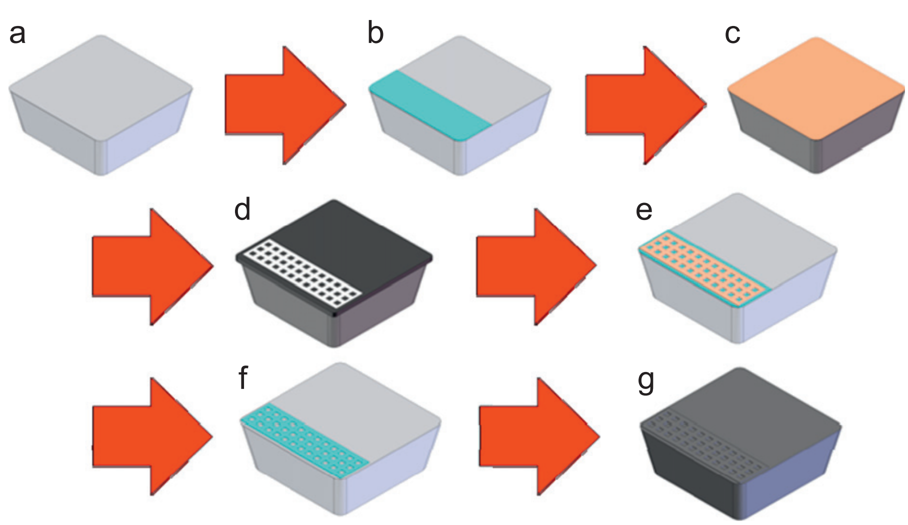

Fig. 2. Schematic of the fabrication process of a DLC coated tool with micro-texture: (a) lapping and cleansing of rake face; (b) deposition of Ni; (c) spin-coating of photoresist; (d) UV exposure through a mask; (e) development; (f) chemical etching of Ni and (g) DLC coating.