Development of Indentation Machining Technology for Precise Discontinuous Micro Pattern

Eun-chae Jeon[1], Tae-Jin Je[1], Doo-Sun Choi[1]
[1]*Dept. of Nano Manufacturing Technology, Korea Institute of Machinery and Materials (KIMM), Daejeon 305-343, Korea*

jeonec@kimm.re.kr

Abstract

As dot-type light sources (LED, OLED) become more popular, the need for discontinuous micro pattern in which means the pattern density varies depending on location of the dot-light source is increasing. Indentation machining technology was adapted to manufacture discontinuous micro patterns in this study. However, severe non-uniform plastic deformation known as pile-up occurred around the pattern after indentation machining. Based on a survey of previous researches, it was presumed that the amount of pile-up is inversely proportional to the ductility of the material. A very simple and powerful method to increase the ductility of a material is an annealing heat treatment which untangles dislocations. A copper mold and a brass mold were respectively annealed at 600℃ and 575℃ for two hours and then cooled in a furnace slowly as an annealing heat treatment. Discontinuous patterns were machined by indentation machining technology again, and there was no pile-up around any of the patterns on the two materials. Small optical components having the discontinuous patterns were made by injection molding technology using the annealed metal mold. The annealed metal mold had sufficient hardness, though the annealing heat treatment reduced the hardness of the metal mold. Nonetheless, discontinuous micro patterns were molded successively.

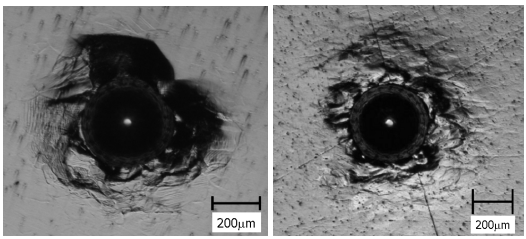
1 Indentation machining with the pile-up effect

Indentation machining technology originated from the conventional hardness test and the instrumented indentation test. These two tests measure the force and the size of a residual indentation (or depth). The main idea of the indentation machining technology is that residual indentations can be used as discontinuous patterns. The shape of the patterns can vary with the indenters whose shapes include pyramid, half-

sphere, cylinder shape and so on. The general size of the patterns is on a micro-scale; however, nano-scale and macro-scale patterns are also possible.

Pure copper and 6:4 brass (Muntz alloy) were selected as the molds in this study because the two materials are widely used as metal molds for injection molding. Indentation machining was performed with an AIS2100 instrument and a spherical indenter of 250μm radius produced by Frontics, Inc. Korea. Ten rows of indentations were performed at indentation depths from 10μm to 100μm with 10 indentations in each row. Optical observation was performed in order to check machining quality.

Severe non-uniform plastic deformation was created around the discontinuous micro patterns on the two materials, as shown in Figure 1. The same phenomenon was also observed around all patterns of other indentation depths. This phenomenon is generally known as pile-up which is a critical issue in the field of the instrumented indentation testing [1]. The pile-up phenomenon arises due to the absence in a volume change in the metals (as it is a non-compressive material) theoretically during plastic deformation [2]. However, the amount of the pile-up is inversely proportional to work-hardening exponent [1] because there is no compressive material practically. The work-hardening exponent is an index of the ductility of the materials. Therefore, it was assumed in this study that the pile-up phenomenon could be eliminated by increasing the ductility of the metals.



(a) (b)

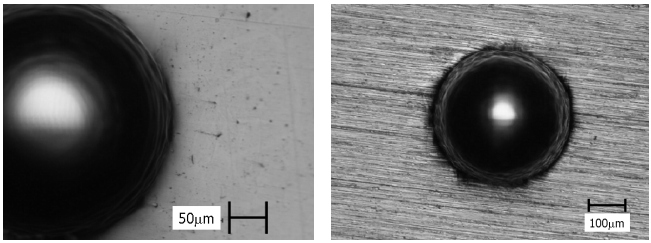
Figure 1: Severe non-uniform plastic deformation around patterns of (a) pure copper and (b) brass at an indentation depth of 100μm

2 Indentation machining without the pile-up effect

A simple and powerful method to increase the ductility is an annealing heat treatment which untangles dislocation in metals. The temperature, which is the main condition

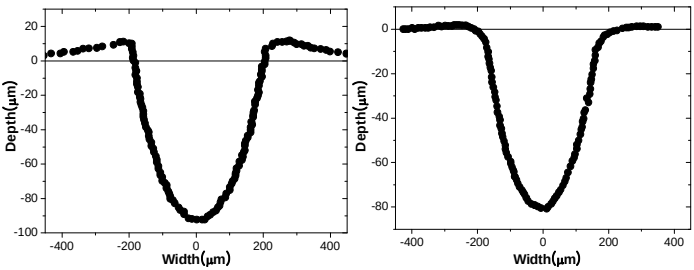
of the treatment, can be determined easily from textbook or internet sources because the annealing heat treatment has been used extensively. A copper mold and a brass mold were annealed at 600℃ and 575℃, respectively, for two hours and were then cooled slowly in a furnace. Indentation machining was performed under the same conditions used in the first experiments and the shapes of the patterns were observed optically.

There was no pile-up around the discontinuous micro pattern with an indentation depth of 100μm as shown in Figure 2. This was also the case in all of the patterns of the other nine types of indentations. The maximum heights of the pile-up of non-annealed pure copper and the annealed pure copper were 11.9μm and 1.8μm, respectively, as shown in Figure 3.



(a) (b)

Figure 2: No pile-up around the pattern of (a) pure copper and (b) brass at an indentation depth of 100μm



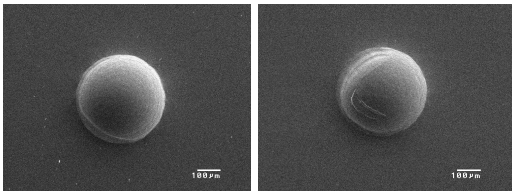
(a) (b)

Figure 3: Pattern profile on (a) non-annealed pure copper and (b) annealed pure copper

3 Molding discontinuous pattern by injection molding

A discontinuous micro pattern can be molded by injection molding technology using indentation-machined metal molds. The metal molds should have sufficient hardness so as to endure the high pressure during the injection molding process. However, the annealing heat treatment decreases the hardness. Therefore, discontinuous micro patterns were molded in this study in order to confirm whether or not the annealed metal molds can be used for an injection molding process.

The two types of resins (Polypropylene and Cyclic Olefin Copolymer) were used for the creation of discontinuous patterns, and high-quality micro patterns were obtained, as shown in Figure 4. The radius of the patterns varied from 50μm to 200μm, and all molded patterns were of a high quality. This demonstrates that the annealed metal molds had sufficient hardness and that they can be used for injection molding process.



(a) (b)

Figure 4: Molded discontinuous micro patterns of (a) PP and (b) COC

4 Conclusions

Indentation machining technology was developed without a pile-up effect for the manufacturing of discontinuous micro patterns.

(1) The pile-up effect around discontinuous micro patterns on metal molds can be eliminated through an annealing heat treatment.

(2) The annealed metal molds can be used in the injection molding process to mold discontinuous micro patterns.

References:

[1] Y.T. Cheng et al., “Effects of ‘sinking in’ and ‘piling up’ on estimating the contact area under load in indentation”, Phil. Mag. Let., **78,** pp.115-120, 1998.

[2] G.E. Dieter, Mechanical Metallurgy, McGraw Hill, 1998.