IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Fabrication of Micro Dimples Pattern Using Ball End Mill

To cite this article: Muhamad Izdhar Bin Zaki *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **547** 012009

Fabrication of Micro Dimples Pattern Using Ball End Mill

Muhamad Izdhar Bin Zaki[1], Kushendarsyah Saptaji[1]*, Raden Dadan Ramdan[2], Tedi Kurniawan[3]
[1] 1Faculty of Manufacturing Engineering, University Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia
[2]Faculty of Mechanical and Aerospace Engineering, Institute Technology of Bandung, Indonesia
[3]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia

*Corresponding author (E-mail): kushendarsyah@ump.edu.my

Abstract. In this paper, the effect of workpiece tilt angle and feed direction in producing micro dimple pattern using ball end mill tools were studied. Experiments were conducted using carbide ball end mill tools, aluminium Al 6061-T6 workpiece and using CNC machine. Three workpiece tilt angles are selected 0^0, 30^0 and 45^0; and two feed directions z-axis and x-axis. Visual observations using Scanning Electron Microscope (SEM) and geometry measurements using laser scanning confocal microscope were conducted on the fabricated micro dimple patterns. The results show that the workpiece tilt angle produces less burr at the edge of the dimples compared to without tilt (0^0). In addition, the workpiece tilt angle can avoid the formation of undercut at the center of the dimple. The workpiece tilt angle of 30^0 and z-axis feed direction produced better result compared to 0^0 and 45^0 tilt angles with the value of ratio diameter/depth closer to the theoretical value.

Keywords: micro-dimple pattern, ball end mill, workpiece tilted angle, feed direction

1. Introduction

The surface profile modifications have been applied to reduce the friction in between two metal surfaces and to improve the oil lubrications especially in automotive engines. In automotive engines, most friction occurs between two slides surface inside the engine and directly affected energy consumptions and fuel savings [1,2]. One of the surface profiles that can improve the lubrication is micro dimple pattern. The micro dimple pattern can increase the performance of working surface and quality of surface [3]. Micro dimple pattern on the metal surface can act as water repellent or self-cleaning surface similar to the bio-inspired lotus leaf [1]. The micro dimple pattern creates small hydrodynamic pressure and produces less friction between the sliding surfaces [2,4-6]. At the end, the less friction sliding surfaces resulted in less energy consumption. Therefore, micro dimple pattern can be applied on the metal surfaces to increase the performance and mechanical properties of engineering components such as bearing [5]. In addition, the micro dimple pattern can also be applied in implants, bearings, turbine blades, aerofoil and also, micro lens.

Micro dimple structure can be defined as a geometric that have contour like square, circular, or elliptical with diameter of 20 μm – 4 mm and ratio of 7 to 40% and also depth of cut between 200 nm – 100 μm [7]. Micro dimple pattern can be classified into two arrangement patterns; linear / square arrangement and zigzag arrangement (Figure 1). The distance between dimples is important to ensure the surface effectiveness.

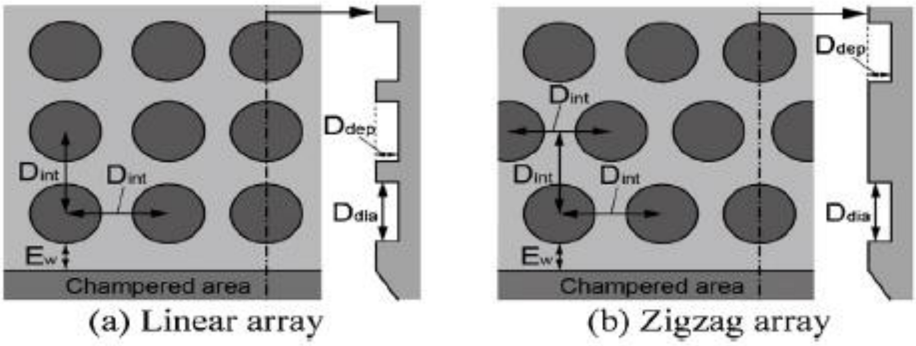

Figure 1. Two micro dimple patterns, linear / square (left) and zigzag (right) [8]**.**

The micro dimple pattern on the metal surface can be fabricated using several methods. Kurniawan et. al. [9] fabricated micro dimple using conventional texturing (CT) by sinusoidal motion tip of tool on surface. Dai et. al [10] used Masked Laser Ablation (MLA) method with pulse Nd:YAG laser to produce micro dimple pattern. The electrochemical machining (ECM) using a micro second pulse on-time toward the surface of material was used by Byun et. al. [6] in producing micro dimple pattern. Graham et. al. [2] used the ball end mill with inclined technique to produce effective and efficient fabrication of micro dimple pattern. Ball end mill method is simple and less expensive machining method that can be used to produce micro-dimple pattern. Ball end mill is also known for making three dimensional contour shape that can be found on moulds and dies products. Ball end mill usually operates on 3-axis machine. The ball end mill or the ball nose cutter is similar to the slot bit, but the end of the mill is hemispherical.

In this paper, the ball end mill tool will be used to fabricate the micro dimple pattern. The objective of this paper is to study the feasibility of fabricating micro dimple pattern using ball end mill tool in CNC milling machine and to determine the effect of workpiece tilt angle on the quality of the micro dimple pattern. The micro dimple pattern will be produced using three different workpiece tilt angles. The idea to tilt the tool is to find which angle can produce the best results in producing micro dimple pattern. The drawing software is used to sketch the pattern of micro dimple and to simulate the ball end mill process. This method becomes a quick and efficient way to create micro dimple pattern surfaces due to execution of G-code by the software. Finally, the micro dimple pattern is fabricated using CNC machine with the optimum machining parameters such as the spindle speed, feed rate and depth of cut.

2. Experimental Setup

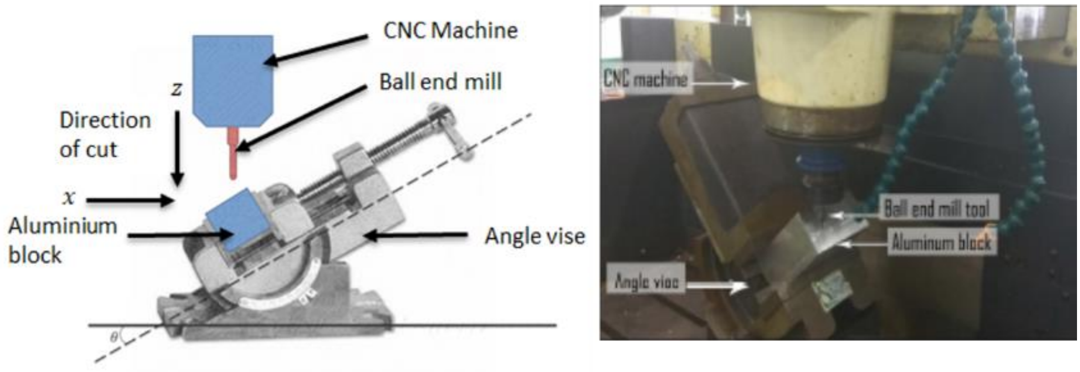

Figure 2. Schematic view (left) and experimental setup (right) for dimple pattern fabrication using workpiece tilt angle method

The cutting parameters used are depth of dimple 0.1 mm, feed rate 20 mm/min, spindle speed 4,000 rpm. These are the optimum parameters selected based on the preliminary results and machine capability. The carbide ball end mill tool having 1 mm diameter and 0.5 mm nose cutter radius is used in this experiment. The workpiece is aluminum alloys Al6061-T6. Prior to the fabrication of micro dimple patterns, the workpiece is polished to have a smooth surface with surface roughness of 0.476 µm. Experiments are conducted using Makino Ke55 CNC milling machine. The workpiece is clamped in vise to be able to tilt the workpiece (Figure 2). Three tilt angles of the workpiece are tested 0^0, 30^0 and 45^0. Two feed directions are used for the 30^0 and 45^0 which are x-axis and z-axis (Figure 3). Two dimple patterns are selected, square and zigzag. The distance between the dimples (pitch) for the square pattern is a = b = 1 mm and for zigzag pattern a = b = 1 mm and c = 0.5 mm (Figure 4).

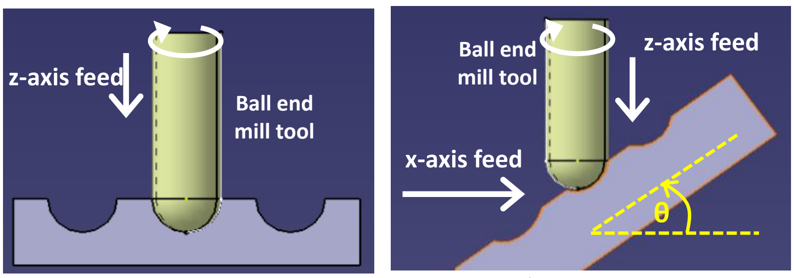

Figure 3. Illustrations for the feed direction (a) no tilt angle (0^0) (b) with a tilt angle θ (30^0 and 45^0).

The parameters used in the experiments are shown in Table 1. The CATIA software is used to design the dimple pattern and to generate the machining strategy to be used in Computer Numerical Control machine (CNC) for the machining of micro dimple pattern. Micro dimple patterns were fabricated with the size of 5 mm x 5 mm for each of combination of pattern, workpiece tilt angle and feed directions. The fabricated dimple patterns are observed visually using Scanning Electron Microscope (SEM) and analyzed using 3D Laser Scanning Confocal Microscope (Keyence).

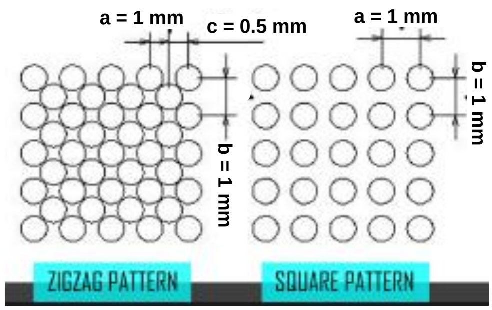

Figure 4. Distance between dimples used in this experiment for zigzag (left) and square (right) patterns

Table 1. Machining parameters used in the experiment

Tool	Carbide ball end mill tool with 1 mm diameter and ball nose radius 0.5 mm
Workpiece	Aluminum Al6061-T6
Spindle speed	4,000 rpm
Feed rate	20 mm/min
Depth of dimple	100 µm
Type of patterns	– Square (pitch = 1 mm) – Zigzag (distance between dimples a = 1 mm, b = 1 mm, c = 0.5 mm)
Workpiece tilt angle (θ)	0^0, 30^0, 45^0
Feed directions	z- axis and x-axis

3. Results and Discussion

In total 10 different micro-dimple patterns were fabricated (three tilt angles, two feed directions and two patterns). Surface quality observations are conducted using SEM and optical microscope. Dimple depth, circular diameter, and pitch are measured on a selected dimple for each of the combination of tilt angle, feed direction and pattern.

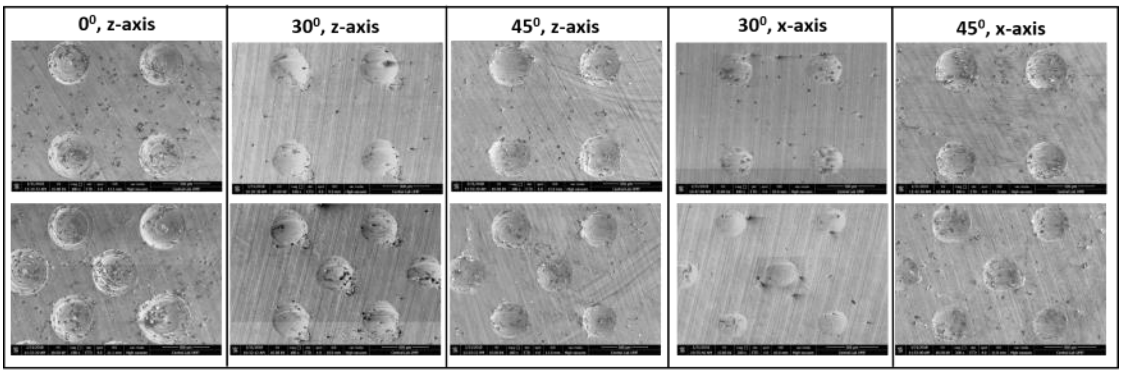

Figure 5. SEM images of the micro dimple pattern for various workpiece tilt angles and feed directions for square pattern (top) and zigzag pattern (bottom).

3.1. Visual Observations

Visual observations on the micro dimple patterns are mainly conducted on the morphology of the micro dimple pattern, edge quality and the dimple surface quality based on the workpiece tilt angle and feed direction. Figure 5 shows SEM images of the 10 fabricated micro dimple patterns for various workpiece tilt angle, feed directions, and patterns. Optical microscope images taken by 3D Laser Scanning Confocal Microscope (Keyence) on a selected dimple show some burrs existed on the edges for all patterns (Figure 6). It can be seen that the 0^0 tilt angle is seen to have more burrs compared to other tilt angle and the 45^0 tilt angle shows the shape is not perfectly circular. This can be occurred due to the material removal mechanism by the ball end mill when the workpiece is tilted at 45^0. The 30^0 workpiece tilt angle is seen to have less burrs and more precise circular shape compared with the other two tilt angles.

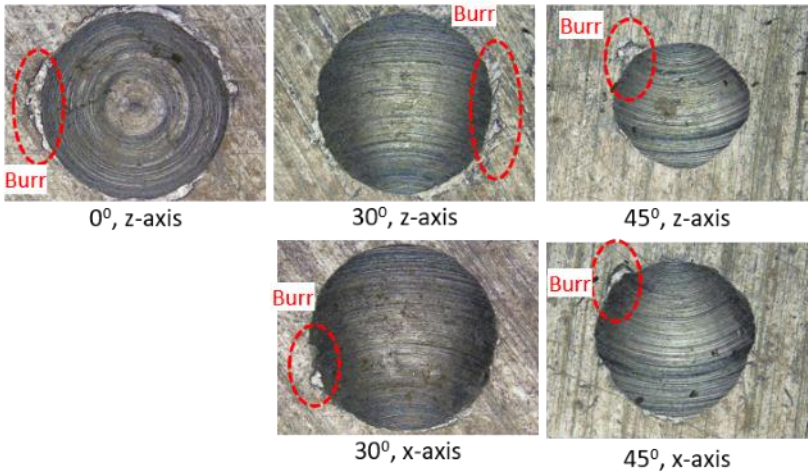

Figure 6. Optical Microscope Images for one of dimple for various workpiece tilt angle and feed direction.

3.2. *Geometrical Analysis*

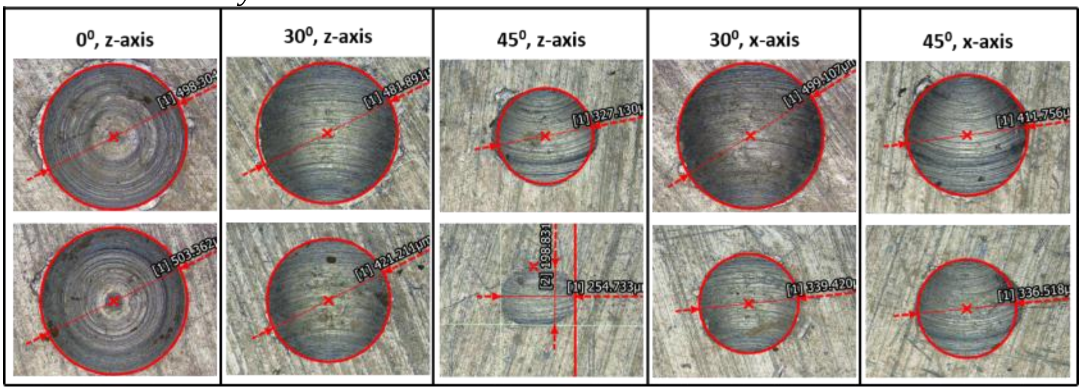

Figure 7. Dimple diameter measurement for various workpiece tilt angle and feed direction for square pattern (top) and zigzag pattern (bottom).

Table 2. Measured dimple diameter and depth for square and zigzag patterns

	Theoretical Dimple diameter (µm)	Measured Dimple diameter (µm)	Theoretical dimple depth (µm)	Measured Dimple depth (µm)	Aspect ratio (diameter/depth)
Square pattern					
0^0, z-axis	600	498.30	100	68.49	7.27
30^0, z-axis	600	481.89	100	65.06	7.41
45^0, z-axis	600	327.13	100	26.81	12.20
30^0, x-axis	600	499.11	100	67.53	7.39
45^0, x-axis	600	411.76	100	38.79	10.62
Zigzag pattern					
0^0, z-axis	600	503.36	100	73.22	6.87
30^0, z-axis	600	421.21	100	53.33	7.90
45^0, z-axis	600	254.73	100	13.34	19.10
30^0, x-axis	600	339.42	100	26.07	13.02
45^0, x-axis	600	336.52	100	29.49	11.41

Dimple diameter measured using Laser Scanning Confocal Microscope (Keyence) is shown in Figure 7. Table 2 summaries the measured diameter, depth and aspect ratio (diameter/depth) of the selected dimples for square and zigzag patterns respectively. The theoretical diameter is 600 µm based on the theoretical depth of the dimple which is 100 µm. Hence the expected aspect ratio is 6. It can be seen that dimple depth for all the combinations are less than 100 µm resulted the diameter to be less than 600 µm. This can be occurred due to the limitation of the CNC machine in achieving precision at micro meter scale. However, the optimum results are achieved for 0^0 and 30^0 workpiece tilt angle with z-axis feed direction with aspect ratio in between 7 – 8.

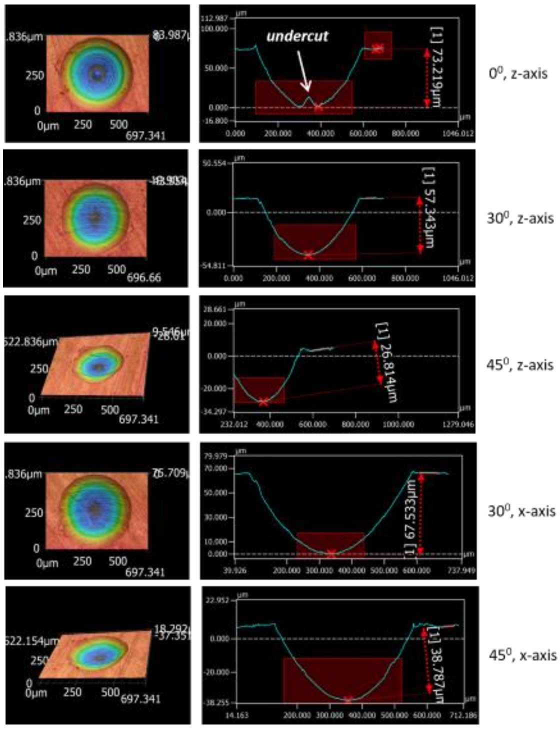

Figure 8. Depth measurement result for various workpiece tilt angle and feed direction.

Figure 8 shows the 3D profile of the dimple and 2D cross section profile of the dimple depth measured using confocal laser microscope (Keyence). It can be seen that there is a small bulge at the center of the dimple for 0^0, z-axis as a result of undercut. The other tilt angle and feed direction show no undercut at the center of dimple.

4. Conclusions

In this initial experiment, micro dimples pattern with the depth of dimple of 100 µm can be fabricated by using ball end mill, however better machining center is needed in order to have better precision and accuracy. The workpiece tilt angle produces less burr at the edge of the dimples compared to without tilt (0^0) and it can avoid the formation of undercut at the center of the dimple. The workpiece tilt angle of 30^0 and z-axis feed direction produced better result compared to 0^0 and 45^0 tilt angles with the diameter/depth ratio closer to the theoretical value. Follow-up work is currently on-going in order to improve the accuracy and precision of the fabrication of dimple pattern using ball end mill.

5. Acknowledgements

This research is supported by research grant RDU 180324 from Universiti Malaysia Pahang, Malaysia

6. References

[1] A. Malshe, K. Rajurkar, A. Samant, H. N. Hansen, S. Bapat, and W. Jiang, "Bio-inspired functional surfaces for advanced applications," *CIRP Annals*, vol. 62, no. 2, pp. 607–628, 2013.

[2] E. Graham, C. I. Park, and S. S. Park, "Fabrication of micro-dimpled surfaces through micro ball end milling," *International Journal of Precision Engineering and Manufacturing*, vol. 14, no. 9, pp. 1637–1646, 2013.

[3] T. Pratap and K. Patra, "Micro ball-end milling—an emerging manufacturing technology for micro-feature patterns," *The International Journal of Advanced Manufacturing Technology*, vol. 94, no. 5, pp. 2821–2845, 2018.

[4] T. P. and K. Patra, "Micromilling of Ti-6Al-4V Titanium Alloy Using Ball-end Tool," *IOP Conference Series: Materials Science and Engineering*, vol. 229, no. 1, p. 12011, 2017.

[5] T. Ibatan, M. S. Uddin, and M. A. K. Chowdhury, "Recent development on surface texturing in enhancing tribological performance of bearing sliders," *Surface and Coatings Technology*, vol. 272, pp. 102–120, 2015.

[6] J. W. Byun, H. S. Shin, M. H. Kwon, B. H. Kim, and C. N. Chu, "Surface texturing by micro ECM for friction reduction," *International Journal of Precision Engineering and Manufacturing*, vol. 11, no. 5, pp. 747–753, 2010.

[7] S. G. and D. C. and T. R. and A. B. M. and H. H. M. and B. Pingguan-Murphy, "Tribological investigation of diamond-like carbon coated micro-dimpled surface under bovine serum and osteoarthritis oriented synovial fluid," *Science and Technology of Advanced Materials*, vol. 16, no. 3, p. 35002, 2015.

[8] T. Sugihara and T. Enomoto, "Performance of cutting tools with dimple textured surfaces: A comparative study of different texture patterns," *Precision Engineering*, vol. 49, pp. 52–60, 2017.

[9] R. Kurniawan, G. Kiswanto, and T. J. Ko, "Micro-dimple pattern process and orthogonal cutting force analysis of elliptical vibration texturing," *International Journal of Machine Tools and Manufacture*, vol. 106, pp. 127–140, 2016.

[10] F. Z. Dai, D. P. Wen, Y. K. Zhang, J. Z. Lu, X. D. Ren, and J. Z. Zhou, "Micro-dimple array fabricated on surface of Ti6Al4V with a masked laser ablation method in air and water," *Materials & Design*, vol. 84, no. Complete, pp. 178–184, 2015.