A study on the vibration characteristics of the small diameter PCD coated milling tool

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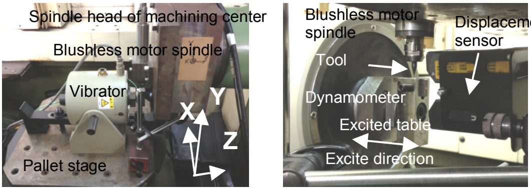
Abstract

In this report, vibration characteristics of the small diameter PCD coated carbide milling tool are discussed. The vibration tests are performed to determine the vibration characteristics of the small diameter (less than 1 mm) end mill such as modal parameters (mass, dumping, and stiffness) with experimental approach. The experimental setup is constituted with the vibrator, the dynamometer and the displacement sensor. Detected signals input on a FFT (fast fourier transform) analyser to measure the compliance curve. Modal parameters are determined with the measured compliance. In this report, the vibration tests for the PCD (poly-crystal diamond) coated carbide square end mill of which diameter of 0.5 and 1 mm are introduced. In addition the cutting tests on a tungsten carbide (JIS-K10) substrate with milling tools are also introduced to discuss the effects of the tool vibration on the surface finish.

1 Vibration tests

Figure 1 shows the measurment setup in vibration tests. The cutting edge of the milling tool is clamped on the excited table with the hole machined on the carbide tip. The cutting edge is clamped with the pre-displacement in tool radial direction to avoid the effect of the elastic defomation of the excited table. The pre-displacement is given by moving to the radial direction of the tool in a length of 0.02 mm. The excited load can be measured at the given displacement with piezoelectric dynamometer, which is mounted on the excited table. The displacement of the excited table is controlled by the sinusoidal wave generator without feedback control. The excited displacement is measured by the laser displacement sensor. The sensor measures the distance between the sensor head and the carbide chip. The compliance can be calculated with measuring the power spectrum of the load and that of the displacement on the FFT analyzer. The modal parameters in the vibrasion equation are estimated in the dynamic response.



(a) Over view (b) Excited table

Figure 1 Experimental setup for vibration tests

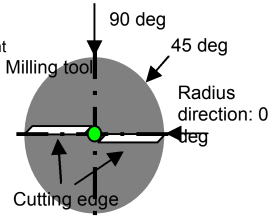
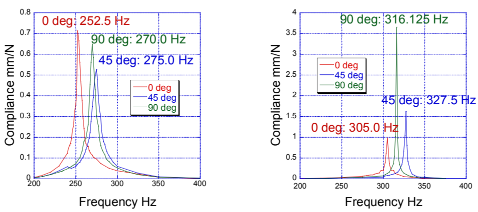


Figure 2 Excite directions on the milling tool

In vibration tests, PCD coated carbide square milling tools (OSG DIA-EDS) are evaluated. These tools have a different diameter of 0.5, 1.0 mm respectively. Both milling tools have the helix angle of 30 degree, the necklength of 1.0 mm (0.5 mm), and 2.4 mm (1.0 mm), and the edge roundness of about 3 μm. The tests are performed to ovserve effects of the tool size on the vibration characteristics. The excited force is applied to three directions of 0 (tool radius dierction), 45, and 90 degrees to determine the mode direction as shown in Figure 2. Figure 3 shows compliance curves at each exiting directions. In this figure, the natural frequency at the vibration directions are also shown. In each curves, peaks of the first vibration mode clearly, and the natural frequencey is changed with the vibration direction. Table 1 shows determined modal parameters. These parameters are determined with measured compliance curves. This table also shows the mode direcion and its modal parameters are calculated with measured parameters. The table shows that the mode direction and the stiffness of the small diameter milling tool can be determied with introduced measurement method.



(a) Tool diameter, 0.5 mm (b) Tool diameter, 1.0 mm

Figure 3 Compliance curves in vibration tests

Table 1 Modal parameters and natural frequency in vibration tests

Tool diameter	0.5 mm			1.0 mm		
Exited direction	0deg	45deg	90deg	0deg	45deg	90deg
Mass Ns^2/mm	0.0014	0.0009	0.0010	0.0014	0.0008	0.0009
Dumping Ns/mm	0.0054	0.0064	0.0065	0.0036	0.0020	0.0023
Stiffness N/mm	91.493	64.233	75.540	131.895	86.700	90.038
Natural frequency Hz	252.5	275.0	270.0	305.0	316.25	327.5
Mode direction deg	47.74			50.43		
Stiffness N/mm	64.52			84.01		

3. Cutting experiments

In this section, the cutting experiment with PCD coated carbide milling tools on the tungsten carbide (JIS-K10) are introduced. Figure 4 shows the experimental setup in the cutting tests. The milling tools mounted on the blushless motor spindle of which maximum rotational speed of 60,000 rpm. A runout of the motor spindle is garanteed less than a 1 μm with the specification. The motor spindle is mounted on the spindle

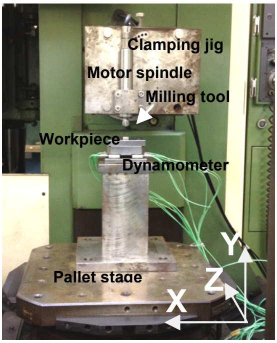
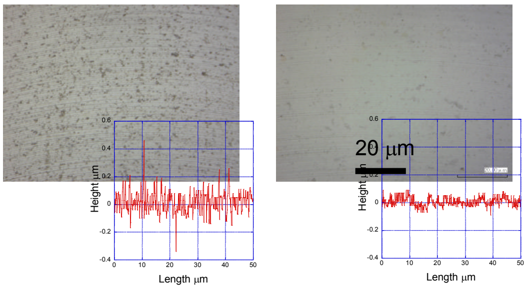


Fig. 4 Machine tool



(a) Tool diameter, 0.5 mm (b) Tool diameter, 1.0 mm

Figure 5 Machined surface and roughness curve

Table 2 Surface roughness

Parameters	Diameter of 0.5 mm	Diameter of 1.0 mm
Ra μm	0.06	0.02
Rz μm	0.82	0.17
Rq μm	0.08	0.03
RSm μm	0.78	0.63

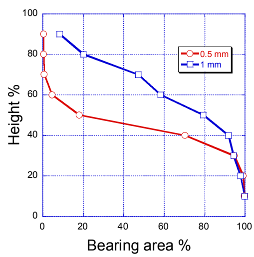


Figure 6 Bearing curves

head of the horizontal machining centre with clamping jig along to Y direction of the machine coordinate. The workpiece is mounted on the dynamometer to determine the contact point of the tool and workpiece in Y direction. In slotting operations, the milling tool is fed to the + X direction with numerical controller of machining centre at a cutting speed of 31.4 m/min, a feedrate of 0.48 mm/min, and depth of cut in Y direction of 0.02 mm respectively. All slotting operations are performed with dry cutting. Figure 5 shows the machined surface and surface roughness curve. The roughness curve was measured on the centre of the machind surface along to tool feed direction by conforcal laser micro scope. Table 2 shows the determined surface roughness. The surface roughness and the mean length of a roughness curve element RSm is much higher in the tool diameter of 0.5 mm. Especially, the root mean-square-average Rq is about 3 times higher than that of 1.0 mm. Figure 6 shows the bearing area ratio curve of roughness curves. In both curves, the reduced peak height Rpk is 14.67 % (0.5 mm) and 11.67 % (1.0 mm), respectively. It is considered that the deviation of the surface roughness is grown with decreasing of the tool diameter because the cutting depth varies widely with the excited tool displacement. According to this result, the surface finish depends on the tool stiffness in the micro milling process on the tungsten carbide.

4. Conclusion

In this report, vibration characteristics of the small diameter PCD coated carbide milling tool are discussed. The vibration characteristics such as modal parameters of PCD coated carbide square end mills were determined with vibration tests. Vibration tests show that the modal stiffness of the milling tool increases with the tool diameter. The cutting tests on a tungsten carbide with square end mills are performed to ovserve effects of the tool vibration on the surface finish. The surface roughness decreased with the increasing of the tool diameter in cutting tests. It is conclude that the tool stiffness changes the surface finish because it changes the excited tool displacment.

Reffernce

[1] T. Ono, Machining characteristics of micro milling process on the tungsten carbide with PCD coated carbide ball end mill , ASPEN 2011, 0003 (CD-ROM).
[2] T. Matsumura, Y. Miyahara, T. Ono, Dynamic characteristics in the cutting operations with small diameter end mills, Journal of Advanced Mechanical Design, Systems, and Manufacturing Vol.2, No.4, 2008, pp. 609-618.