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Precision machining of microholes and microwalls on ultra-hard materials and analysis of mechanical signals using electro-discharge and mechanical machining system

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Abstract

Demands on ultrafine mechanical components; such as nozzle, filter, bio-reactor, ultra-precise masters, increases rapidly in electronic, biological and manufacturing industries. For those applications, ultra-hard materials have drawn attention by high productivity, thermal resistance and wear resistance. Despite of high demands and superior properties, ultra-fine structure on ultra-hard materials are difficult to manufacturing using conventional machining process. Laser machining has limitation of roundness and straightness, and electrodischaging machining shows discharge mark and wear of electrode. Especially, in mechanical machining those materials into ultra-fine feature size under 100 µm, errors in size or shape can be occurred by run-out during tool-setting.

In this research, we introduce a newly developed ultra-precision machining system with both electro-discharge and mechanical machining modules for hard but brittle materials using PCD(polycrystalline diamond) and PCBN(polycrystalline boron nitride) tools and suggest optimized machining conditions using a machining signal analyzing system. Force and acoustic emission data were obtained and correlated with resulting morphologies on material surfaces. By using developed system, microholes with diameter under 20 µm and microwalls with width under 10 µm have been machined successfully on tungsten carbide surface, which is well-known as ultra-hard alloy.

Micromachining, Ultra-precision, Electrical discharge maching (EDM), Mechanical

1. Introduction

Recently, ultra-fine structures such as microscale holes, , channel, and freeform of 10 µm-scale have been required to manufacturing nozzle, filter, bio-reactor and master mold for flexible display, IT/electronics/semiconductor devices and bio diagnostic device industries. As a constituent material, ultra-hard material such as tungsten carbide, silicon carbide, titanium alloy and sappire have got limelight due to their high productivity, thermal and wear resistance. Ultra-hard materials have been machined using polycrystalline diamond(PCD) or polycrystalline boron nitride(PCBN) tools, which is also known as ultra-hard material.

Machining those fine features at 10 µm-scale on ultra-hard materials have great difficulties in securing surface quality and errors using conventional machining techniques. Laser machining could cause poor out-of-roundness and straightness. Electrodischaging machining also have limitation of discharge mark and wear of electrode. Also, mechanical machining can produce good surface quality but error in size and shape due to run-out of tool.

To overcome those limitation of conventional machining systems, new machining system should be consider and collect the advantages of conventional system; 1) tools are made by electro-discharging process, 2) hole and channel structure are manufactured by mechanical machining, 3) tool making and structure manufacturing should be in one system to avoid run-out of tool which generates errors in shape and size.

In this research, ultra-precision machining system with both electro-discharge and mechanical machining modules is introduced for machining hard-to-machine ultra-hard materials using PCD and PCBN tools. Force and acoustic emission data were obtained and correlated with resulting morphologies on material surfaces. By using developed system, microholes with diameter under 20 µm and microwalls with width under 10 µm have been machined successfully on tungsten carbide surface, which is well-known as ultra-hard alloy.

2. Materials and Methodology

Tool material is polycrystalline diamond(PCD) (SINJIN Diamond Corp.) which is sintered from PCD particles with size of 2 to 10 µm and bonded to tool steel. Cylinderical PCD is brazed to tool shank and machined to have diameter under 1 mm by using laser machining. Then, further decrease in diameter of PCD tool is proceeded by using wire electro-discharging machining module in developed machining system. The diameter of PCD tool under 20 µm is obtained by stepped electro-discharging from 90 V to 55 V. To minimize run-out of micro-PCD tools, final tool machining is proceeded in same spindle rotation speed with hole and channel machining, while differenct spindle rotation speed can results in vibration.

After tool fabrication, PCD tool moves without tool changing and setting above tungsten carbide (WC) and glass thin plate workpiece with thickness of 100 and 200 µm mounted on the dynamometer(9256C, Kistler) with acoustic emission sensor(8252C, Kistler) and accelerometer sensor (8763B, Kistler) to obtain machining signals. Three signals are displayed in real time and collected with data acquisition module (Kidaq, Kistler) during machining microholes and microwalls.

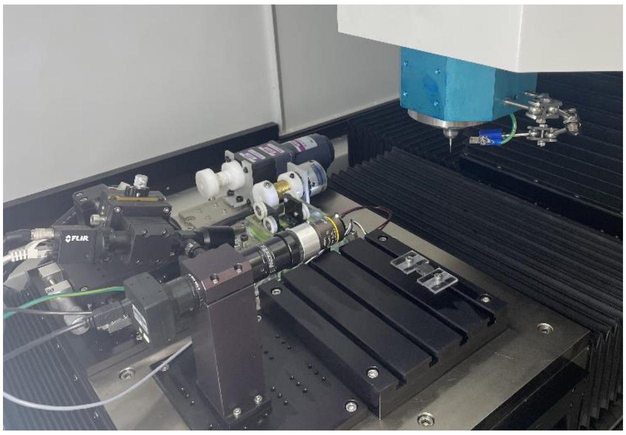

Figure 1. (Experimental set-up in developed electro-discharging and mechanical machining system)

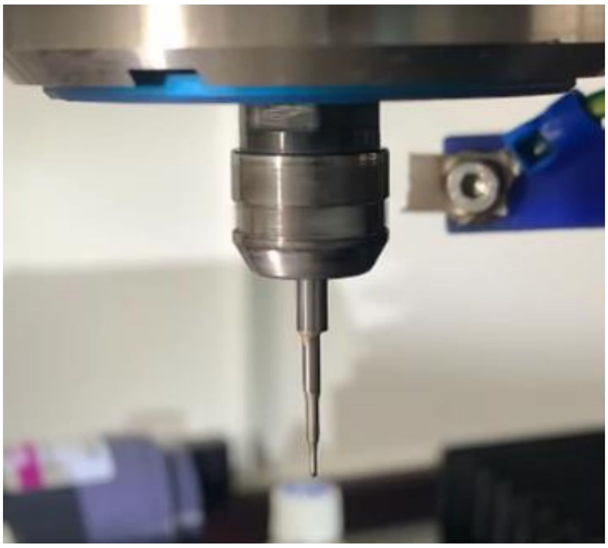

Figure 2. (Tool shank-tool steel-PCD microtool after electro-discharging machining)

3. Results and Discussion

Machining results are closely related with feed rate of tool, spindle rotation speed, depth of cut and so on. Effects of each factors were investigated with obtained signals and morphology of holes and walls. Diameter of microhole can be down under 20 µm at spindle rotation of 68000 rpm, feed rate of 0.2 µm/s and depth of cut of 5 µm by using PCD tool made of PCD particle size of 2~3 µm developed mechanical machining system. The voltage given during tool fabrication was also important factor to make microscale holes because electrodischarge voltage controls the roughness of the PCD tool and microcracks inside of tool. When PCD tool is about to break due to abnormal conditions, AE signal at specific frequency was generated comparing with normal conditions.

Vibration generated by machining shows relevance with resultant surface of microwalls. The intensity of AE signal is increased when the amount of surface crack at the edge of wall increases. By optimizing machining conditions, microwall with width under 10 µm is fabricated on tungsten carbide workpiece.

Also, the location accuracy of developed machining system is accomplished under 1 µm by measuring distance between 5 microholes in both x-axis and y-axis.

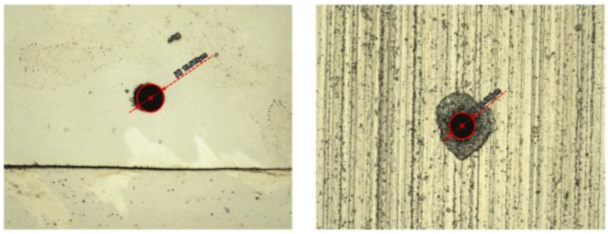

Figure 3. (Entrance(diameter of 13.5 µm) and exit(diameter of 12.7 µm) of microhole on tungsten carbide thin plate)

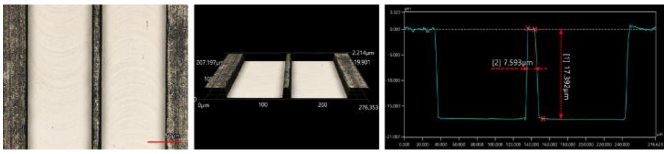

Figure 4. (Microwall structure with width of 7.6 µm on tungsten carbide thin plate)

4. Conclusion

Ultra-hard material such as tungsten carbide or glass have difficulty in machining due to brittleness and high hardness. They requires low feed rate and optimized spindle rotation speed to minimize machining errors like crack at the edges. In this research, microholes with diameter under 20 µm, microwalls with width under 10 µm and location accuracy under 1 µm are achieved by using developed electro-discharging and mechanical machining system and customized PCD tools. The machining results and obtained signals are correlated with each other and the possibility of real-time estimation for machining results is suggested.

Acknowledgement

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