Abstract of Dissertation (論文の要旨)

Title (題 目): The Effect of Laser Assisting for Milling Process of Difficult-to-cut Materials

(難削材へのレーザ援用ミリング加工の効果)

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This dissertation presents the effect of laser assisting for milling process of difficult-to-cut materials. Milling is a generally accepted that a machining process has been widely used for manufactured part in various industries such as plastic mold, die forging, automobile and aerospace. The basically mechanic of milling process is the cutting tool directly interface with the workpiece, tool rotating to cut work material in the direction of cutting velocity leaded to initialed deformation in the primary shear zone, which the shearing region occurred in front of the cutting tool, the continuously movement of cutting tool also leaded to work material deformed in secondary shear zone and flow-off on the tool rake face as a chip. Therefore, the requirement of cutting forces is strongly depended on the cutting conditions such as cutting speed, depth of cut, feed rate and the machinability of materials is strongly depended on cutting tool and workpiece. Whereas, the high requirement of cutting forces which is caused that the low machinability cannot be avoided when machined difficult-to-cut materials such as nickel base super alloys as well as Inconel 718 and high hardness of surface hardening materials such as well as nitrided die steel.

Recently, lasers have been widely applied in various machining process to reduce refractory of difficult-to-cut materials. This is because the laser is a rapid heat source which has high energy concentration to heat materials locally in the machining zone. Although increase in initial temperature of workpiece leaded to softened work material and improved machinability, the effects of atmosphere in laser assisting on the machinability of difficult-to-cut materials has not investigated clearly. Therefore, the first objective of dissertation is an experiment to investigate the influence of cutting speed, preheating temperature and atmosphere on the improved machinability in the laser assisted for milling Inconel 718 with uncoated carbide inserts.

In addition, the pulsed laser surface treatment is well established to treat the surface of work materials as a report of laser surface hardening, polishing, cleaning and so on. On the other hand, the excessive thermal heat must be resulted in the damage on the work surface due to remelting process. This is potentially expected to reduce the hardness layer of nitrided die steel which is possible leading to improved machinability for reformed worn dies. However, a few of researcher was addressed on the pulsed laser surface treatment to reduce mechanical properties of nitrided die steel and the machinability of irradiated surface. Therefore, the second objective of dissertation is an experiment to fulfill knowledge on the application of pulsed laser surface treatment in order to improved machinability for milling process.

In this work, uncoated carbide tool (WC-Co) was used as a cutting tool. Therefore, the cutting temperature must be measured to avoid cutting conditions which leaded to temperature softening of carbide tool (1100°C). Tool-work thermocouple method is powerful to measure

cutting temperature in the region of tool-chip/tool-workpiece interface. However, it is difficult to use for milling process because the cutting tool is rotating and thermal electromotive force (EMF) generates in the rubbing area (cold junction). Therefore, carbon brush was designed to use as a sliding contact to connect signal of EMF from the rotating part to oscilloscope. And, electromotive force generated in the rubbing area and the measuring circuit were investigated to compensate EMF in cutting test. The obtained results show that the EMF in the cutting test must be compensate before convert to cutting temperature because the difference ratio of calibration curves for the difference couple of material. For example, the ratio of EMF to temperature for carbon brush and tool holder was approximately 1 mV : 100^{o}C. but EMF to temperature for carbide tool and Inconel 718 was approximately 1 mV : 54^{o}C. Whereas, the compensate value increased with the rotating speed due to more heat generated at higher rubbing speed. The cutting temperature increased with the cutting speed due to more heat generated at higher cutting velocity.

The experimental results with various cutting speed and preheating temperature for milling Inconel 718 were found that the requirement of laser power for preheating workpiece proportionally increased with the particular heating temperature (300, 500, and 700^{o}C) and table speed (30, 50, 75 and 100 mm/min). In addition, the highest temperature in the primary shear zone occurred at the highest preheating temperature which could maximally reduce in shear stress of workpiece approximately 20, 30, 35 and 34% to compare with conventional machining at the same cutting speed of 30, 50, 75 and 100 m/min, respectively. Tool wear in laser assisted machining was higher than conventional machining at the low cutting speed of 30 and 50 m/min, but the wear could be improved at relatively high cutting speed of 75 and 100 m/min.

The obtained results from laser assisted milling for Inconel 718 to investigate the influence of atmosphere on the performance of laser assisting showed that the higher laser power was required to particular heating temperatures in the argon gas, while the atmosphere containing oxygen (compressed air blow and dry machining) required lower laser power. This is because the oxygen in the air accelerated oxidation and burning on the irradiated surface which increase the optical absorptivity of laser. The experimental results from cutting tests showed that the specific cutting force decreased with the preheating temperature in any atmospheres, and the lowest specific cutting forces was obtained in the argon atmosphere due to the increase in friction coefficient leaded to higher cutting temperature and work material more softening.

An application of pulsed laser surface treatment improved machinability in the shape correction process by ball end-milling for forging dies. The die steel with high hardened layer by ion nitrided process was used as a workpiece that was irradiated by pulsed laser. Then, inclined milling experiments were performed on the irradiated workpieces which was simulated machining for walls of the dies with a draft. The machinability was evaluated from specific cutting force, actual depth of cut, tool deflection and uncut chip thickness. The result of improved machinability was found that the hardness of nitride layer can be reduced by the laser irradiated. Therefore, the laser irradiated surface responded to increase the actual depth of cut and uncut chip thickness, while the tool deflection and specific cutting force were small compared with those for non-irradiated surface.