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Fabrication and analysis of micro-pillars by abrasive water Jet machining

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Abstract

Now-a-days, fabrication of 3-D features employing Abrasive Water Jet (AWJ) milling by partially superimposing two consecutive passes is a major research interest. This paper presents an innovative water jet path strategy to fabricate micro-pillars with good geometrical accuracy. These micro-pillars can be used as fins (cooling purpose) and tool fabrication for Electro Discharge Machining and Electro Chemical Machining (EDM/ECM). The novelty of the paper relies on the proposal of path strategy for jet movement that moves along two crossed (90 degree) raster path and keeping the Step Over (SO) more than the diameter of nozzle (1.25d). Micro pillars were fabricated by varying the process parameters; pressure and abrasive size, respectively on three different work materials, namely, Al6061 (Aluminium alloy), SS304 (Stainless steel) and Ti6Al4V(Titanium alloy). Pillars of different aspect ratios were achieved varying height in the range of 265 to 720 micronsand taper ratio in the range of $10\text{-}15^0$. Geometry and surface roughness of micro-pillars were measured by 3-D optical profilometer and processed using scanning probe image software (SPIP).Digital and scanning electron microscopes (SEM) were used to observe and analyse the microscopic behaviours of machined surface.

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Keywords: AWJ Milling; Micro-fins; Novel path strategy; Aspect ratio; 3-D Optical profilometer.

1. Introduction

Increase in power dissipation for high performance electronic devices is a major problem in electronics industry. Electroniccomponent requiresquick transferof heat to reduce work temperature and hence, to improve the characteristics and the reliability of the appliances (Gromoll, 1992(a); 1993(b)).Process or power consumption and heat dissipation has become the key challenges in the design of high performance system. Increase power consumption typically leads to higher costs for thermal packing.

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Fins are widely used to enhance heat transfer in many engineering applications which offers a practical mean for achieving a large heat transfer surface area without the use of excessive amount of primary surface area. Fins are mainly used in electrical/electronic application such as computer power supply, heat exchanger, air conditioning, transformer sub-stations, IC engines cooling (radiator) etc.

Miniaturization due to severs space and weight limitations like heat sink leads to application of micro fins are continuously increasing (Peterson and Ortega, 1990). Fabrication of these miniature components is a major problem in manufacturing industries. Machining of hard metals by conventional processes is not only time and energy consuming but also becomes more expensive in terms of tool wear and loss of quality in the product owing to induced residual stresses during manufacture. Non- conventional machining processes like ultrasonic machining (USM), electro chemical machining (ECM), electric discharge machining (EDM), laser beam machining (LBM), electron beam machining (EBM), water jet machining (WJM), abrasive water jet machining (AWJM) etc., are used to fabricate micro-dimensional features. Manufacturing technologies including micro electric discharge machining and lithography were employed in micro-parts for high accuracy. Currently in commercial applications micro-machining is mostly performed by lasers, electro-discharge machining (EDM) and chemical etching (Masuzawa et al., 1985). However these processes present several major limitations such as surface damage (recast layer) to the machined material, poor edge quality, require special material property (Electrical conductivity –for EDM/ECM), tool design problem (micro-ECM). In addition to that these processes have low material removal rate and Low efficiency becomes main disadvantage of these processes.

AWJM is one of the most promising non-conventional machining processes, which has capacity to machine any material ranging from soft to hard without considering any special material property (Electrical conductivity) and having no tool design problem etc. It is a non-conventional machining process in which a mixture of abrasive particles with high pressure water is converted to a high velocity jet for cutting. The high speed abrasive water jet machining employs the erosion phenomenon for material removal when the abrasive particles along with high velocity water hit the target surface (Finnie,1960). Minimal fixture requirements and the absence of heat affected zones due to no contact between the cutting tool and work piece are the some of the major advantages of this technique. The major parameters of AWJM process are characterized by hydraulic parameters, cutting parameters, mixing- and- acceleration parameter and abrasive parameters. Process primarily depends on the following input parameters – abrasive flow rate, traverse speed, standoff distance (SOD), water jet pressure, shape and size of abrasive particles. This process is well established for through cutting and most of the works reported was based on through cutting by AWJM. But of later, researchers have also started experimenting on generating blind features using AWJM.

For generating blind features like pockets and channels, several authors used the multiple passes linear traverse cutting as milling strategy. This principle is based on the superposition of several kerfs to obtain a cavity of defined geometry. It is reported that the lateral distance between the single kerfis the main parameter in this process (Laurinat et al., 1993). Hashish (1994) used the principles of rotary table and masking to perform a practical application of controlled depth milling of iso-grid structures. However, they observed substandard process performancedue to inefficient mixing of the abrasive grains and the rotating water jets (Ojmertz and Amini,1994). The strategy used by them for abrasive water jet milling was based on the concept of multi pass linear traverse cutting (Laurinat, 1995). Superposition of several kerfs to obtain a cavity of desired geometry has been developed. However, process parameters influence the geometry and efficiency of the process. Experimental studies on ceramic material revealed that material removal rates increases with pressure. MRR is related to process parameters mostly on abrasive mass flow rate and flow rate of water (Laurinatet al., 1993). In waterjet milling the pump pressure was found to be more prominent parameter and quality of surface generated defined by depth of cut, tolerance and roughness of bottom (Momberet al., 1996). Model of milling process shows that, geometry of the cavity depends on the traverse speed and standoff distance. Shape of the milled cavity was determined as type of cosine function (Ojmertz, 1993).

Fowler et al.,(2005(a)-(c); 2009)developed controlled depth milling (CDM) process. They studied the effect of various parameters like traverse speed, jet impingement angle, milling direction, grit size, etc. on the surface roughness, material removal rate and surface characteristics while machining titanium alloy.They observed that the machined surface get affected due to level of the grit embedment and hardness/shape of the abrasive particle. They found that the level of grit embedment was 40% at high jet impingement angles and approximately 10% at low