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Review

Hybrid micro-machining processes: A review

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ABSTRACT

Micro-machining has attracted great attention as micro-components/products such as micro-displays, micro-sensors, micro-batteries, etc. are becoming established in all major areas of our daily life and can already been found across the broad spectrum of application areas especially in sectors such as automotive, aerospace, photonics, renewable energy and medical instruments. These micro-components/products are usually made of multi-materials (may include hard-to-machine materials) and possess complex shaped micro-structures but demand sub-micron machining accuracy. A number of micro-machining processes are therefore, needed to deliver such components/products. The paper reviews recent development of hybrid micro-machining processes which involve integration of various micro-machining processes with the purpose of improving machinability, geometrical accuracy, tool life, surface integrity, machining rate and reducing the process forces. Hybrid micro-machining processes are classified into two major categories namely, assisted and combined hybrid micro-machining techniques. The machining capability, advantages and disadvantages of the state-of-the-art hybrid micro-machining processes are characterized and assessed. Some case studies on integration of hybrid micro-machining with other micro-machining and assisted techniques are also introduced. Possible future efforts and developments in the field of hybrid micro-machining processes are also discussed.

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Nomenclature

BUE	built-up edge
CCM	conventional cutting method
CIRP	college international pour la recherche en productique
CUSM	chemical-assisted ultrasonic machining
DC	direct current
ECAM	electrochemical arc machining
ECDM	electrochemical discharge machining
ECM	electrochemical machining
ECSM	electrochemical spark machining
EDM	electrodischarge machining
EMM	electrochemical micro-machining
ERP	electrorheological fluid-assisted polishing
EVC	elliptical vibration cutting
EWR	electrode wear rate
FEM	finite element method
FTS	fast tool servo
HAZ	heat-affected zone
HF	hydrofluoric
HFDG	high frequency dither grinding
JECM	jet electrochemical machining
LAJECM	laser-assisted jet electrochemical machining
LAMM	laser-assisted micro-milling
MRR	material removal rate
PET	polyethylene terephthalate
PMMA	polymethyl methacrylate
RC	resistor–capacitor
R-MEDM	reverse micro-electrical discharge machining
ROC	radial overcut
SACE	spark-assisted chemical engraving
SEDCM	simultaneous micro-EDM and micro-ECM
SEM	scanning electron microscope
TBC	thermal barrier coating
USM	ultrasonic machining
UV	ultraviolet
WC	tungsten carbide
WEDG	wire electrodischarge grinding
WEDM	wire electrodischarge machining

1. Introduction

In recent years, the demand for micro-components/products has increased at a rapid pace in various areas such as electronics, bio-medical, aviation, energy and optical industries [1]. The characteristics of these micro-components/products are: (1) size of functional features in micrometre level, from few micrometres up to 100 μm; (2) high precision tolerances, typically better than 1 μm; (3) good surface finish, in general surface roughness R_a smaller than half micrometre; (4) 3D or complicated structures; (5) use of a variety of materials such as ceramics, hard steels, titanium alloys, etc. [2]. Many surface or bulk micro-machining processes based on lithography, chemical or plasma etching, printing, moulding, transfer and assembly techniques have been proposed for micro/nano-device batch fabrication [3,4]. They can provide components with small feature sizes in inorganic and organic materials and even 3D shapes. Micro-machining techniques reviewed in this paper are fully complementary techniques able to provide complex geometries in a large range of materials with a high relative accuracy. They constitute a promising technology for bridging the gap between macro and micro/nano domains [5–7].

Although traditional stand-alone (single function) machine tools have been used as a major means to fabricate micro-components/products, it still remains a big issue in the predictability, producibility and productivity of fabrication of micro-components/products, especially for those with complex surface forms/shapes [8]. In recent years some multifunctional machine tools have been developed to implement several mechanical machining operations on one machine in order to rapidly and economically fabricate those components/products while research has also been drawn on the development of hybrid machines which will integrate conventional and non-conventional machining processes on them [9]. Some hybrid micro-machining processes have been approved to be able to improve machinability of hard-to-machine materials, tool life, geometrical accuracy, surface integrity and machining efficiency.

There is no exact description for hybrid machining processes [10]. From time to time a number of definitions for hybrid machining processes have been proposed by researchers like Rajurkar et al. [11], Kozak and Rajurkar [12], Aspinwall et al. [13], Curtis et al. [14], Lauwers [15], etc. Aspinwall et al. [13] explained that the combination of machining operations can be considered either