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Numerical modelling, simulation and fabrication of 3-D hemi-spherical convex micro features using Reverse Micro EDM

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ABSTRACT

Reverse Micro Electrical Discharge Machining (RMEDM), a variant of Micro Electrical Discharge Machining (MEDM) is a non-contact thermal micro machining process extensively used for fabrication of high aspect ratio single or multiple 2.5-D features with different cross-sections like square, circular, triangular etc. The process capability is limited by difficulty in debris ejection through the small inter-electrode gap (few μm) which causes debris sticking to electrodes and thereby creating unwanted secondary and higher order erosion that affects the features generated. In this paper, an attempt has been made to numerically model, simulate and experimentally investigate the fabrication of 3-D convex hemi-spherical micro feature by taking advantage of the effect of secondary and higher order erosion of debris. Array of 3-D hemispherical shaped micro features finds application in the field of micro lens let arrays, solar cells etc. Results indicate that use of taper ended blind hole leads to debris accumulation towards the corners and edges of cathode which enhances the possibility of secondary and higher order erosion at those areas leading to generation of 3-D convex hemi-spherical micro feature on the anode. Also, the relation between material removal by secondary and higher order erosion to that of primary erosion during machining was derived. Different values of k_0 (averaged for entire machining depth) were found affecting the shape of generated micro feature. In this study, material removal by secondary and higher order erosion was found to be five times that of primary erosion.

1. Introduction

Surface texturing has led to many advancements in the field of surface engineering. Micro and nano scale textures are being used extensively for enhancement of various properties of engineering surfaces. Fields of application include tribology, micro fluidics, surface wettability, tool design, bio-medical and many more. The effect of shape of micro feature has found to play a key role in enhancing surface properties required for specific application. Imran et al. [1] compared the effect of different geometrical shapes of micro features on the performance of friction reduction. Their study led to the conclusion that triangular shaped micro features produced the lowest co-efficient of friction. Geometric shape of micro features also effect the hydrodynamic pressure generated between conformal contacting surfaces [2]. Yu et al. found that the best load carrying capacity of contacting surfaces was shown by ellipse dimples perpendicular to the sliding direction. Friction performance on laser textured steel surfaces can be improved by incorporating by incorporating multi-dimple textured patters viz. circles and triangles, and circles and squares as compared to un-textured or single textured patterns on surfaces [3]. Obikawa et al. [4] studied the effect of four different types of micro features on coated tool face in order to have better lubrication conditions thereby improving machinability. Results indicated that one-directional grooves parallel to the cutting edge and square dot shape of micro features on the tool face effectively improved the machining conditions. Triangular shaped cross-section of micro pillars fabricated on micro channels were found to enhance heat transfer co-efficient particularly at high velocities as compared to circular, diamond shaped cross-section of pillars or on micro channel without pillars [5]. The effect of different cross sectional shapes viz. rectangular, circular, triangular and cross shaped micro pillars on PDMS surface on the contact angle was studied by theoretical and experimental techniques [6]. It was found that apparent contact angle monotonically increases with a decrease in surface area at the top of micro feature. Most of the geometrical shape discussed are 2.5-D micro features (constant cross-section along length). However, application of 3-

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Nomenclature

E	Electric field (V/m)
E_{th}	Threshold electric field (V/m)
$\boldsymbol{V}$	Electric potential (V)
$\boldsymbol{D}$	Electric displacement (C/m^2)
ρ_V	Space charge density (C/m^3)
ρ_f	Density of fluid (kg/m^3)
ρ	Density of solid (kg/m^3)
$\boldsymbol{u}$	Flow velocity (m/s)
t	Time (s)
t_{on}	Pulse on time (ns)
t_{off}	Pulse off time (ns)
$\boldsymbol{I}$	Identity matrix
p	Pressure of fluid (Pa)
μ	Dynamic viscosity (Pa s)
$\boldsymbol{F}$	Volume Force (N)
r_{hf}	Heat flux radius (μm)
r	Position
z	Cylindrical coordinate in vertical direction
R	Resistance (Ω)
C	Capacitance (F)
q_0	Heat flux (W/m^2)
C_p	Specific heat capacity (J/kg K)
F_D	Drag force (N)
F_B	Buoyancy force (N)
F_E	Electrostatic force (N)
F_{P-P}	Particle – particle interaction force (N)
F_{P-W}	Particle – wall interaction force (N)
F_M	Weight of particle (N)
d_p	Diameter of debris particle (μm)
r_p	Radius of debris particle (μm)
u_p	Debris velocity (m/s)
$\boldsymbol{T}$	Temperature
T_{melt}	Melting temperature
σ	Finite distance at which the inter-particle potential is zero
p_{plasma}	Plasma implosion pressure (Pa)
n	Charge multiplication factor
Z	Charge number
e	Charge on an electron (C)
δ	Dirac delta function
r_j	Position vector of jth particle
ε	Depth of the potential well
ε_0	Permittivity of free space
k	Thermal conductivity (W/mK)

D micro features viz. hemispherical shaped convex micro features finds application in micro lens let arrays [7], solar cells [8] etc. Fabrication of 2.5-D positive micro features (protruding from the surface) is mostly carried out using bottom up processes like chemical deposition, layer by layer deposition, sol-gel method, etc. Also, there are certain top down processes that can fabricate 2.5-D positive micro features viz. LIGA, photolithography, micro milling, etc. However, it is difficult, if possible to fabricate positive 3-D micro features using any of the above mentioned techniques.

Apart from the above mentioned techniques for generating positive micro features, reverse micro electrical discharge machining (RMEDM) is also extensively used for fabricating 2.5-D positive micro features. This process has the advantage of generating features of various shape and size simultaneously with moderate to high aspect ratios. Peng et al. [9] fabricated complex micro features of high aspect ratio using a combination of deposition using RMEDM followed by selective removal using MEDM. Mujumdar et al. [10] fabricated micro rods of similar length but different diameters using RMEDM process wherein, the work piece on which features are to be generated is made as anode and is plunged into cathode which has single or multiple through holes on it.

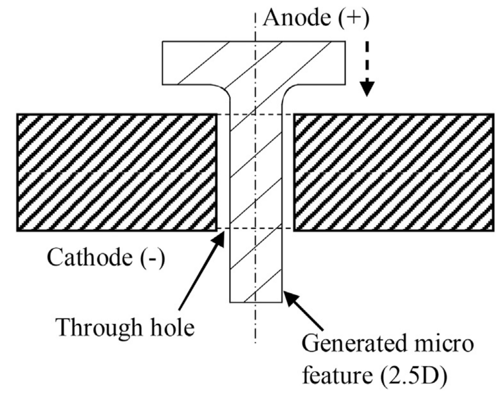

Fig. 1. RMEDM with through hole.

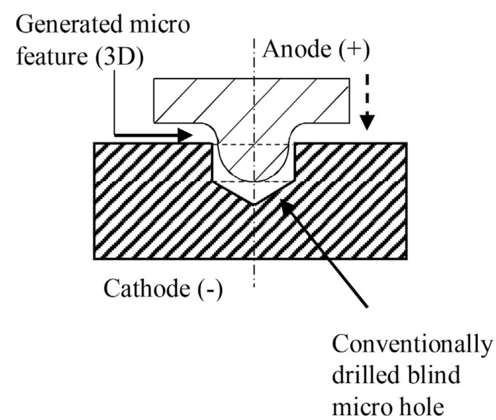

Fig. 2. RMEDM with tapered blind hole.

Literature survey indicates that most of the research work is done for generating 2.5-D micro features and generation of 3-D micro features like hemi-spherical shapes using RMEDM are not known to be published till date. Therefore, in this paper, an attempt has been made to analyse numerically, simulate and fabricate 3-D hemi-spherical convex micro features using RMEDM and parameters affecting the shape is discussed in this paper. Numerical modelling of eroded hole obtained after machining is not included in this study.

2. Mechanism of micro feature generation by RMEDM

2.1. General mechanism

RMEDM is a variant of MEDM and is used for the fabrication of medium to high aspect ratio positive micro features. Cylindrical pillars (2.5-D micro features) with high aspect ratio are fabricated by this process as shown in Fig. 1. Primary erosion is the main mechanism for material removal in RMEDM.

2.2. Proposed mechanism

In the RMEDM process shown in Fig. 2, cathode is made with a taper ended blind hole instead of through hole. This restricts the flow of debris out of the gap through the bottom of the hole which is easier in case of RMEDM with through hole (Fig. 1). The aspect ratio of micro feature formed with respect to a taper ended blind