International Journal of Machine Tools & Manufacture 105 (2016) 1–13

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

journal homepage: www.elsevier.com/locate/ijmactool

Developments in electrochemical discharge machining: A review on electrochemical discharge machining, process variants and their hybrid methods

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ARTICLE INFO

Article history:
Received 24 September 2015
Received in revised form
3 March 2016
Accepted 7 March 2016
Available online 9 March 2016

Keywords:
Electrochemical discharge machining
Micromachining
ECDM variants
Triplex hybridization

ABSTRACT

Electrochemical discharge machining (ECDM) is a hybrid non-conventional machining process, used to machine electrically conductive and non-conductive materials. It is a preferred process to fabricate micro scale features like micro holes, micro channels, microgrooves and 3-dimensional intricate shapes on variety of materials. In order to improve the efficacy of ECDM process, certain technical augmentations are provided with basic configuration of ECDM. These augmentations result in developments of ECDM process variants. Further, research community has developed ECDM based triplex hybrid methods for further process enrichment. This review article presents a comprehensive review of these recent developments in ECDM process, its variants and their triplex hybrid methods. The future research possibilities are identified and presented as research potentials.

Contents

1. Introduction

Exponential evolution of micro level products has grabbed

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http://dx.doi.org/10.1016/j.ijmachtools.2016.03.004

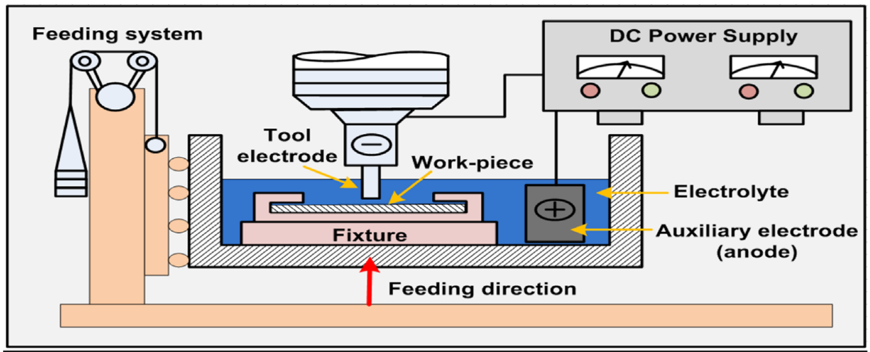

Fig. 1. Schematic of ECDM set-up.

great attention, because of their tremendous applications in various fields like micro electro mechanical systems, micro fluidics, bio medical testing systems etc. [1–3]. Manufacturing of these products has put huge pressure on industries to come out with efficient and economical solutions. In order to facilitate the real goals of industries, researchers have been using either of non-conventional or lithography based micro machining techniques. For small lot sizes, non-conventional machining processes are economical over lithographic techniques [4]. These non-conventional machining processes use either of, thermal, mechanical and chemical energies or their combinations for material removal. The thermal energy based processes include laser beam machining (LBM) and electric discharge machining (EDM). LBM uses thermal energy for machining of ceramics, polymers and metals. But it requires expensive equipment and has a high maintenance cost. Further, the existence of heat affected zone (HAZ) limits its industrial usages [5]. The thermal energy has also been used in the form of discharges in micro electric discharge machining (μ-EDM) [6] and wire-cut electric discharge machining (W-EDM) [7]. However, these processes can be used for machining of micro features on conductive materials only. By using mechanical energy, micro USM and AJM can produce complex micro features on hard and brittle materials, irrespective of their electrical conductivity [8,9]. Their incapability to machine ductile materials results in limited applications. The chemical energy based machining methods develop intricate micro profiles on a variety of materials with smooth surface finish. But low processing speed, low dimensional accuracy and low aspect ratio structures are the limitations of chemical process [10]. There was a need for a machining process that can machine micro features over a wide variety of work materials, irrespective of material hardness, strength and conductivity. Thus electrochemical discharge machining (ECDM) was developed by Kura Fuji in 1968 s [11].

Electrochemical discharge machining (ECDM) is a combination of two non-conventional machining processes, namely electrochemical machining (ECM) and electric discharge machining (EDM) [12]. Simplicity and small sized set-up make ECDM a very attractive technology for micro machining. In literature, the ECDM process has been presented through several names: viz. spark assisted chemical engraving [13], electrochemical spark machining [14], micro electrochemical discharge machining [15], electrochemical discharge machining [12], electrochemical arc machining [16], discharge machining of non-conductors [17] and electro erosion dissolution machining [18].The advantage of ECDM, compared with other processes, is that it can machine conductive/non-conductive, hard/brittle and ductile materials. Initially, this method was attempted to drill on glass substrates [11], subsequently this method was employed in the drilling of ceramics [19], composites [14] and stainless steel materials [18]. In order to explore the capabilities of ECDM process, the electrochemical discharge energy was manipulated for the development of ECDM variants. By using these variants researchers had been performing various operations like the fabrication of complex and intricate micro profiles [20], micro dies [18], deep drilling [21], machining of cylindrical parts [22], dressing of micro-grinding tools [23] and slicing of glass rods [24]. In general, ECDM variants have proved their usefulness for micro fabrication. However, ECDM is also associated with limitations like low aspect ratio structures, low accuracy etc. To overcome these limitations several external energies have been applied to the ECDM. This resulted in development of several ECDM process variants. Recently, the simultaneous involvement of these external energies with ECDM process, further developed new triplex hybrid methods. These triplex hybrid methods enhanced the performance meaningfully. Nonetheless research is still continuing to get the better results. The present paper attempts to report the developments in variants of ECDM process and their triplex hybrid methods. This paper also includes the findings and the future scope for further research work.

1.1. Electrochemical discharge machining (ECDM)

Electrochemical discharge machining (ECDM) is one of the widely accepted hybrid non-conventional micro machining techniques, which is used to fabricate miniaturized products on electrically conductive [25] and non-conductive materials [26]. ECDM set-up consists of two electrodes immersed in an electrolytic solution, namely, tool electrode (cathode) and auxiliary electrode (anode). The work piece is placed below the tool electrode as shown in Fig. 1. A DC power source is used to provide the voltage across these two electrodes. Thus, an electrochemical cell (ECC) is formed. The electrolysis occurs in ECC due to the potential difference across the two electrodes and results in the formation of hydrogen and oxygen gas bubbles at the tool electrode and at the auxiliary electrode respectively. Beyond the critical voltage, the generation rate of hydrogen gas bubbles near the tool electrode exceeds the generation rate of bubbles floating on the electrolyte surface that ensures the staying of hydrogen gas bubbles around the tool electrode. The physical contact of hydrogen gas bubbles with each other formed big sized single gas bubble and gets converted into hydrogen gas film around the tool electrode [27]. The hydrogen gas film behaves like a dielectric medium between the cathode tool and the electrolyte and acts as an insulator around the tool electrode. This insulation of tool electrode, almost ceases the flow of current and develops high electric field (10 V/μm) across the dielectric film and that results in arc discharge. The existence of high current densities at the sharp edges of tool results in spark initiation at these tool edges [28]. Subsequently, discharge location changes over entire face of tool electrode [26]. During the discharge period, tool electrode bombards a large number of electrons on the workpiece surface kept close to the