Comparative Study of Nanoelectrode Fabricated By AWJ Process with Graphene/CNT Coated Tools

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Abstract

Abrasive water jet (AWJ) machining is well known process for through cutting of materials irrespective of their hardness. However, channels and blind pockets can also be fabricated by controlled depth AWJ-milling process. Here, a strategy has been proposed and implemented to make miniaturised tools (die/ electrode) by AWJ process. The path strategy for jet movement was considered in a manner to selectively remove metal such that the resulting three dimensional features become the required die shape that can be used as tool for the EDM process. The dimensions of the fabricated tools were varied by controlling the step-over (SO) distance. These could be directly used as an electrode of EDM machine. Performance of these tools were analysed by conducting the experiments on EDM set-up. It was found that uniform cavity was obtained throughout the channels machined by these tools. Further, in order to enhance the EDM process and mechanical properties of these tools, CNT/graphene infused electrodes has been advocated on them. In the last, a comparative study of the die shaped tool with the graphene coated tool has been considered for investigation. Here conept ot produce any generic shaped electrode has been explained and the enhanced material properties of the eletrodes by CNT infused have been explained. The application of the current manuscript shows the potential of producing any complex shaped electrode by AWJ process and enhancement of electrode properties by CNT/Graphene infusement.

Keywords: AWJM, electrodes, EDM, CNT/Graphene

1. INTRODUCTION

In recent days, abrasive water jet (AWJ) appears to be a viable alternative for performing precision machining tasks because of its various advantages such as the ability to machine virtually all types of materials, the flexibility to produce different features without retooling, almost absence of heat affected zone (HAZ) on the target material and producing good surface quality at a faster production rate [1].

Initially, it was used for cutting of hard to cut materials such as super alloys and ceramics etc. AWJM is non-traditional machining process in which the small abrasive particles are added with a high pressurized water jet and which converted into a very velocity and able to cuts the range of materials from soft to hard like, inconel, titanium etc [2].

The very speed stream of the AWJM employed the erosion phenomenon for metal removal when the small abrasives along with high velocity water hit the work piece surface. AWJ contains the three phases consisting of air, abrasive particles and water [3]. These jets are developed by injection of these tiny particles in formed water jet, when air is added together with abrasive particles. In this process no electrical and thermal energy was involed and because of this many defects can be minimised. The working performance of AWJ process is depends on many parameters such as, abrasive flow rate, traverse speed, standoff distance (SOD) and jet pressure etc. [4] Finnie proposed mathematical model of metal removal by erosion phenomena. Later, extended a mathematical model for material removal for curved surfaces [5].

Hascalik et al. [6] found the effect of traverse speed on surface morphology during machining of Ti-6Al-4V alloy using AWJ by studying the profiles of machined surfaces, kerf geometries and microstructural features of the machined surfaces. It was found that the traverse speed of the jet was the most significant parameter affecting surface morphology. It was also observed that the kerf taper ratio and surface roughness increase with increase in traverse speed

AWJM process gained the wide acceptance in the manufacturing area because it gives s high material removal rate (MRR) than the other unconventional manufacturing process. Mostly AWJM applications are limited to shape cutting of variety of materials but form last two decades researchers have fabricated some blind features too. Turning, drilling and milling was attempted on hard materials and lot of scope was observed to produce some more complex shape blind features [7].

Objective of this work is to explore the capability of AWJ milling process to produce some more 3D features more complex shape features. Here an attempt has been made to produce EDM electrodes by controlling the process parameters involved in the process. The viability of the process of producing textured surfaces having micro features on larger area is to be experimentally investigated. Primary experiments were carried out to determine suitable range of process parameters, based on different step-over distance, pressure and traverse speed, features were fabricated. Electrodes of different shapes were fabricated on copper sheet. Further the CNC infused electrodes were synthesis and the performance of both type of electrodes was studied.

In the last, the performance of produced electrodes was examined by conducting experiments on EDM machine. The major advantage of this concept is that, one can use produce any complex shape electrode by the AWJ process and achieved the uniform channel width along its way. Overall purpose of the current study is to develop a best method to produce highly efficient electrodes (CNT infused) for EDM of any generic shape by AWJ.

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2. EXPERIMENTATION ON AWJM

2.1. AWJ Machining Setup

The Experiments were performed on AWJ machine. The machine and its fixture is shown in Fig. 1. The abrasive feed unit is to deliver a predetermined continuous flow of abrasive material to the jet. The abrasive jet system combines a high-speed flow of water with a flow of abrasives to create an abrasive jet flow. The abrasive is stored in a hopper on the moving head of the X-Y table. An air-controlled valve releases a stream of abrasive into a feed line where it flows to the nozzle. In the abrasive jet nozzle, water at high pressure is forced through a sapphire orifice to form a narrow stream moving up to 760 m/s. This stream causes a suction that draws the abrasive and air through the plastic feed tube. The water, abrasive and air then enter into a carbide mixing tube where they are combined to form a cutting stream moving at 300 m/s. This stream is then directed at the material to be cut. Table 1 shows the specification of the machine.

Table 1: Machine specification

Jet impingement angle	**90^0**
Orifice diameter	0.33 mm
Abrasive flow rate	0.226 kg/min
Mixing tube diameter	0.762 mm
Mixing tube length	101.6 mm
Maximum working pressure	310 MPa

The figure of the experimental setup is shown on the Figure 1 with their parameters.

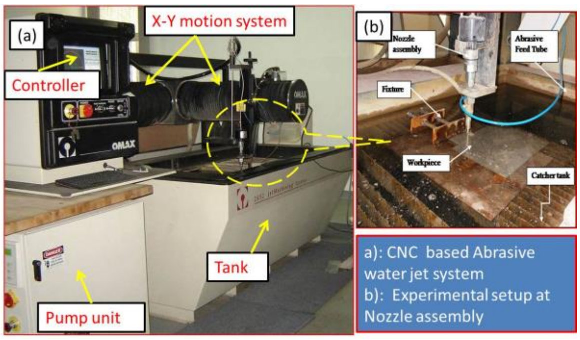

Fig. 1. Experimental setup of AWJ machining to produce electrodes

2.2. Methodology adopted to fabricate miniaturized tools (electrode/die) by AWJ process

It was available in literature that the geometrical features like, blind channels and the blind pockets those were produced by closed loop path can easily fabricated by AWJ milling process. These features were produced by overlapping of the consecutive AWJ nozzle passes of jet along the raster path. The stopover distance was kept less than the nozzle diameter (d). Fowler el. Al. (2005) used the different stopover distance (d/2, d/3 d/4 etc.) to perform controlled depth milling. However no attempt has been made to produce blind features of any generic shape [8].

Recently, Pal and Chaudhury [8-10] in 2014, introduced a novel path strategy to fabricate some small fins. Fig. 2 shows the path strategy used by them to produce small fins and the CAD model of the produced features. Based upon this strategy the small fins were produced in copper material sheet. These features were fabricated by using the concept of multi-pass linear traverse cutting leading to the milling strategy which is not based on the superposition of several kerfs. Here, the distance between the two parallel passes is kept more than the nozzle diameter (1200 µm), a nozzle is moved along two crossed (90 degree) raster passes to each other. These fins (on brass or copper material) would be used as an electrode (micro-tool) for an electrical discharge machining process to generate arrays of blind holes on large area.

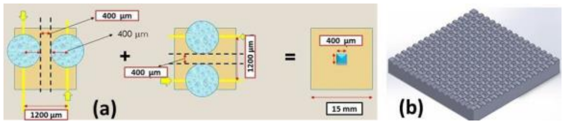

Fig. 2. (a)Path strategy to produce Micro Fins by AWJ milling (b) CAD model of produced features

In the present work, an AWJM based tool fabrication strategy has been proposed and implemented to make EDM tools. The goal is to produce a die-like tool which can create the entire channel geometry, hence, alleviating the requirement of a CNC control for tool traverse. This work is an extension of the AWJM based EDM tool fabrication method reported by Pal and Choudhury, 2014 [11]. The basic idea is to use AWJM process to selectively remove metal from a piece of material such that the resulting three dimensional features becomes the required electrode that can be used as tool in EDM process. In the previous work [11], it was shown that using parallel and perpendicular non-overlapping paths an array of square micro pillars can be fabricated. This tool was later used in an EDM process to get corresponding features on the work piece. Thus, the tool is actually made of the material left behind due to non-overlapping passes of AWJM.

Based on the state-of-art in the fabrication of three-dimensional complex features using AWJ milling, the process is characterized by three main input parameters

1. Step-over distance (SO): distance between two parallel consecutive machining passes, specified in terms of diameter of abrasive water jet,‘d’.

2. Traverse speed (TS): the speed of motion of nozzle along the path traversed by the nozzle.

3. Pressure (P): is the operating pressure of the AWJ machine, which in turn dictates the depth of metal removal

The step over specifies the nature of metal removal, i.e., overlapping passes will have SO less than‘d’ and non-overlapping passes will have SO greater than‘d’.

Figure. 3(a) explains the proposed path strategy. Let us first consider the generation of a tool to produce rectangular channel. As shown in the figure, to produce corresponding EDM tool, one needs to make a protruding rectangular feature on the work piece surface. First a non-overlapping pass surrounding the rectangular pillar is employed to produce the same. The width of the pillar will be determined by the step over distance and the height of the pillar will be based on a combination of traverse speed and jet pressure. This will in fact produce a rectangular slot on the work material block. To produce an EDM electrode with rectangular protrusion, one needs to remove remaining metal. This task is performed using CDM concept.

The idea could be easily extended to produce electrodes for curved channels (Fig. 3 (b)). For that the non-overlapping pass will be made up of two parallel curved paths, joined appropriately. Again overlapping passes will remove the unwanted material to finally give a curved protruding block feature on tool surface. Thus, the proposed strategy uses a combination of overlapping and non-overlapping passes to produce an electrode complementary to the de-sired channel shape. All the parameters were kept constant in all passes as to maintain tool accuracy on all sides. Micro tools of different shapes (straight, curved and generic complex) were fabricated.

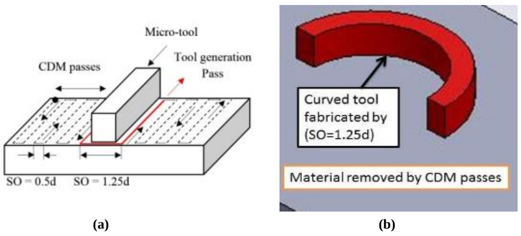

Fig. 3. Path strategy used to produce small tools by AWJ process to produce (a) straight (b) curved channel

Below is the image of some tools produced by AWJ milling process. Fig. 4 shows the optical images of the edges of the produced electrodes by AWJM.

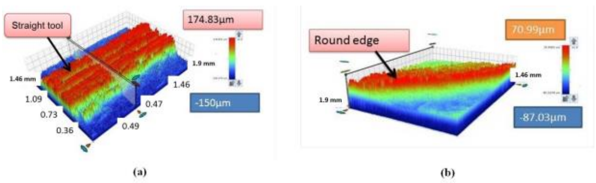

Fig. 4. Optical profilometer image of (a) straight tool T3 (b) An edge of a tool to produce curved channel T4

The generic shape of one of the electrode is presented in The Fig. 5. Different locations of the tools can be clearly seen in this figure.

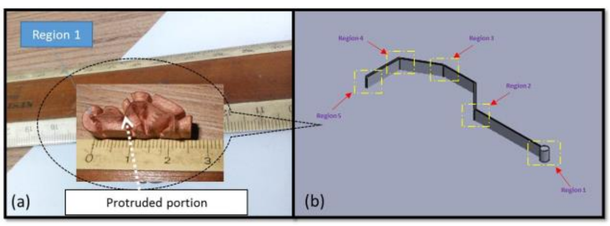

Fig. 5. (a) Real image of complex shape tool T5 (b) CAD model

3. CNT INFUSED ELECTRODE FABRICATION TECHNIQUES

3.1 Synthesis of CNT infused electrode

Section 2 demonstrated about the fabrication of any generic shaped electrode by AWJ process. In this section, in order to enhance the performance of EDM process, an attempt has been made to synthesis of CNT infused electrodes and their performance were analyzed. But, one of the major problem that is associated with CNTs is they quickly tend to form clusters because of the attraction of Van-Dar-Wall forces. This is the main reason of dispersion of CNTs in the matrix and becoming very challenging. The agglomeration of the CNTSs have to be solved before move for reinforcing, otherwise it gives a negative results.

In order to solve this problem CNTs were sonicated in acetone or ethanol and presented in Fig. 6. Vibrations of very high frequency were given and CNTs got separated up to a good extend. Sonication is a process in which sound waves are used to agitate particles in solution. Such disruptions can be used to mix solutions, speed the dissolution of a solid into a liquid (like sugar into water), and remove dissolved gas from liquids. The sound waves used in sonication are usually ultrasound waves with frequencies above what you can hear (above 20 kHz that is 20,000 cycles per second) and as frequency increases the strength of the agitation increases. These vibrations can disrupt molecular interactions (e.g. between molecules of water), break clumps of particles apart, and lead to mixing. Fig. 6 (b) shows the sample after sonication

Fig. 6. Images of a) Sonication bath and b) Sample after sonication

3.2 Stir Casting

Stir casting is usually used of stirring molten metals and continuous stirring particles into the metal alloys to melt and immediately pour into the sand mould and then it is cooled and allowed to solidify. In the stir casting process, the particles often tends to form agglomerates, which can be only dissolved by vigorous stirring with high temperature. However the other procedure or steps followed in the casting process remain the same. The steps followed in the process is in Fig. 7 are Mold making, Clamping, Melting of metal along with constant stirring, Pouring, Cooling and Removing and Trimming.

Fig. 7. Casting Process a) Mold making, b) Melting of metal, c) Continuous stirring, d) Pouring and cooling

4. SURFACE CHARACTERISTIC OF THE SAMPLES

The SEM images of the pure copper are shown in Fig. 8. It can be seen from this image d that there are lots of crystal grains in its microstructure which indicates that the forces of cohesion between molecules are weak and the material will have less hardness. Also this helps us in justifying the lower value of hardness of copper. Also the surface roughness value will be higher.

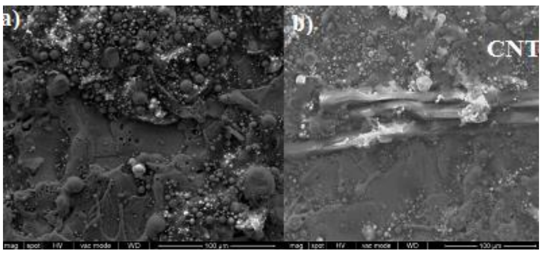

Fig. 8. SEM morphology image of pure Cu (a), Cu- CNT (b)

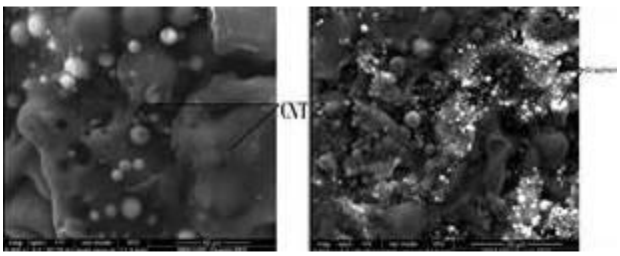

Fig. 9. SEM images of Cu+3g CNT (left) and Cu+ 3g Graphene (Right)

However, from the SEM images of the sample Copper plus 3g Carbon Nanotubes can depicted in Fig. 9 that less amount of crystal grains in its microstructure compared to those found in the pure copper which indicates that the forces of cohesion between molecules are better than those in pure copper sample.

Also this helps us in justifying the higher value of hardness compared to that of pure copper. From the SEM image of sample Copper plus 3g Graphene shows that there are lesser amount of crystal grains in its microstructure compared to those present in pure copper which indicates that the forces of cohesion between molecules are better than those in pure copper sample. Also this helps us in justifying the higher value of hardness compared to that of pure copper. Graphene can be identified as bright white spots seen in images. Fig. 10 shows the microstructure of copper wuth 4g CNT and Fig. 11 shows the Copper with 3 g Graphene.

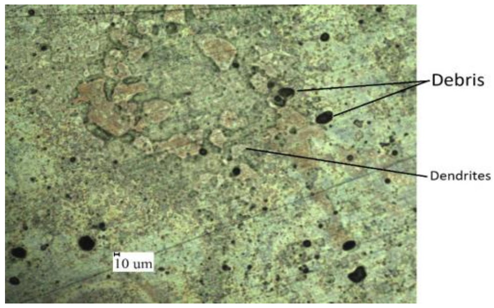

Fig. 10. Microstructure image of sample: Copper + 3g CNT

The below are the images of the samples those were produced at the different configuration.

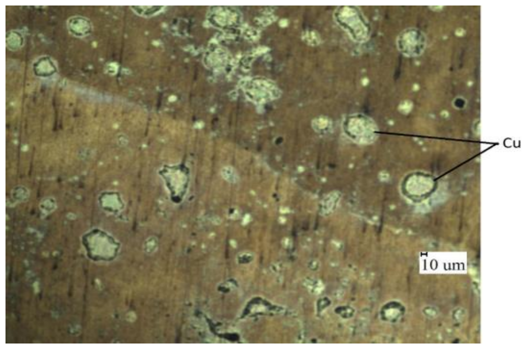

Fig. 11. Microstructure image of sample: Copper + 3g Graphene

In general the crystal particles in copper grow in preferred directions and form open, tree like structures called dendrites. The dendritic structure is very typical of cast metals as depicted in Fig.10. A lower melting point mixture of pure copper and cuprous oxide, called a eutectic, forms in the open spaces between the dendrites. The eutectic particles are usually dark, globular bodies dispersed in a copper background. The cuprous oxide particles form a network, outlining the dendritic cells. Pores, seen as dark spots in the microstructure, are also present in the as-cast material.

In Fig.11 the presence of dendrites (tree like structure) in microstructure can be clearly seen. Also it can be seen that in all samples except for pure copper the voids and micro-cracks are less, indicating that the Nano materials CNT and Graphene have filled up the voids. Also, in comparison to Copper-CNT composites the Copper-Graphene composites have lesser number of pores indicating uniform distribution of Graphene nano particles into microstructure.

5. EXPERIMENTS ON EDM MACHINE BY ELECTRODES FABRICATED BY AWJ PROCESS

The performance of the electrodes produced by AWJ process were analysed by conducting the experiments on EDM machine. The tool electrodes fabricated by AWJ milling of different shape and size were used for generating cavities through EDM process. A shank of a copper cylinder was inserted into the back side of the tools. The dimensions (depth and geometry) of the obtained cavities were examined through these experiments. The experimental details and results are discussed in the coming sections:

The parameters of EDM machine are listed are given in the table 2. The micro machining parameters were chosen.

Table 2. EDM parameters for brass and copper tools

S. No.	Parameter	Brass	Copper
1	Current	5 Amps	3 Amps
2	Voltage	75 volts	75 volts
3	Pulse on time	150 micro sec	150 micro sec
4	Duty Factor	72%	72%

The texture produced by EDM process are shown in Figure 12.

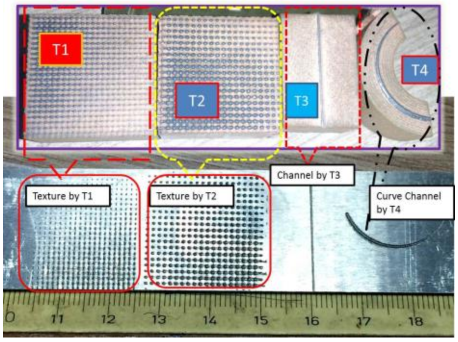

Fig. 12 Fabricated Electrode (T1, T2, T3, T4) on copper sheet by AWJ milling and Corresponding textured (cavity) produced by tools on stainless-steel sheet

Thus cavities are successfully produced by these tools. The concept to produce the texture by AWJ produced tools could be used directly in EDM process.

6. CONCLUSIONS AND FUTURE SCOPE

Due to recent development, the capability of AWJ milling can be explored to fabricate complex-shaped miniaturized features like micro-tools that can be used as an electrode for EDM/ECM. Copper is most commonly material used in the EDM electrodes. However, in order to enhance the properties of these electrodes, the CNT and grapheme infused electrodes have been produced. Once this infused material is synthesis, the desired profile could be produced by AWJM process. Hence, the current concept of producing any generic shape of electrode by AWJ process and enhancement of the electrode material by CNT infused has lot of potential in this area. The performance of the electrodes produced by AWJ shows the positive results. Moreover, in future, any complicated profiles could be produced on these infused electrodes.

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