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Original Article

Surface characteristics enhancement of MWCNT alumina composites using multi-pass WEDM process

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ABSTRACT

Machining of ceramic composites in electrical discharge machining process is often associated with high roughness, unwanted surface and subsurface defects. This situation is generally not desired as it will reduce the life of the ceramic components fabricated in this machining process. Thus, an improvement towards enhancement of surface characteristics is desired. Multi-pass wire electrical discharge machining process can serve as an effective means of enhancing the surface characteristics in machining of ceramic composite. The current work utilizes the multi-pass concept to improve the surface properties of multi-walled carbon nanotubes filled alumina composites. A decreasing nature of surface roughness is observed with increase in the number of machining passes. A lesser appearance of unwanted debris and cracks is observed at the end of the final pass on the machined surface. The spalling effect is found to be more dominant at the initial first pass while melting and evaporation effect is more dominating in higher passes. Also, a better subsurface characteristic with lesser porous recast layer is observed with increase in the number of passes.

1. Introduction

With advancement in materials and machining techniques, researchers have found an alternate means to machine ceramic composites using electrical discharge machining (EDM)/wire electrical discharge machining (WEDM) process. The ceramic materials are made machinable in EDM/WEDM process with the help of conducting filler [1–7]. The conducting fillers increase the net electrical conductivity of the ceramic composites that allows passage of current through it. TiC, TiN, TiCN, TiB_2, WC, SiC and NbC are the commonly used conducting fillers with a threshold value of 24 vol.% or more.

The incorporation of carbon nanotubes (CNT) and multi-walled carbon nanotubes (MWCNT) found that ceramic composites can be machined even with small concentrations of conducting filler, in order of around 5–10 vol.% [8–11]. The CNTs and MWCNTs have the capability to form strong electrical networks in the composites even with small concentrations. This improves the net passage of current through the composites, thus allowing more effective machining in EDM/WEDM process as compared to previously mentioned conducting fillers. The process was verified by Malek et al. [8] experimentally, where better machining characteristics were observed with 5.3 vol.% CNTs as compared to 40 vol.% TiN particles. Similar inferences were also brought forward by the authors with regards to machining of MWCNT alumina composites in the WEDM process [10–11]. The alumina composites with 10 vol.% MWCNTs was observed as the most optimum filler concentration that best relates to high material removal and appreciable surface finish [11].

The associated surface roughness value of ceramic composites in EDM/WEDM process is generally high. The situation is mainly brought forward by the dominance of spalling effect as compared to the normal melting-evaporation effect. This limits the direct application of machined ceramic components. Also, the observed porous recast layer and intense cracks formation have a tendency to further reduce the surface characteristics. Thus, removal of porous recast layer and cracks from the surface is of utmost priority in strengthening the machining process of ceramics in EDM/WEDM.

The multi-pass WEDM process has reported a reduction of the recast layer formation with nominal defects (cracks, pores, oxidisation effect *etc.*) [12–14]. In multi-pass process, the actual removal of material occurs at the first pass of the tool. From the second pass, the main focus is towards removal of unwanted debris, cracks etc. that resulted from the initial first pass. Thus, a much finer surface with fewer unwanted defects is observed with increase in the number of passes. A reduction in recast layer formation with increase in the number of passes was also

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Table 1
Properties of alumina composites with 10 vol.% of MWCNTs.

Theoretical density (kg/m^3)	3770
Actual Density (kg/m^3)	3672
Relative density (%)	97.35
Grain size (µm)	0.71 ± 0.11
Fracture toughness (MPa.m$^{1/2}$)	2.89 ± 0.11
Bending strength (MPa)	234.2 ± 16.1
Electrical conductivity (S/m)	1402.5
Thermal conductivity (W/m.K)	15.38

Table 2
Considered process parameters for (a) single pass; (b) three pass & (c) five pass.

a – Process parameters for single pass.

Wire pass no.	t_{on} (µs)	t_{off} (µs)	Current (A)	Wire speed (m/s)	Allowance (mm)
1	35	9	4	11.88	0

b – Process parameters for three pass.

Wire pass no.	t_{on} (µs)	t_{off} (µs)	Current (A)	Wire speed (m/s)	Allowance (mm)
1	35	9	4	11.88	0.02
2	8	9	3	4.72	0.01
3	2	9	2	2.32	0

c – Process parameters for five pass.

Wire pass no.	t_{on} (µs)	t_{off} (µs)	Current (A)	Wire speed (m/s)	Allowance (mm)
1	35	9	4	11.88	0.04
2	12	9	3	7.12	0.03
3	8	9	3	4.72	0.02
4	4	9	2	2.32	0.01
5	2	9	2	2.32	0

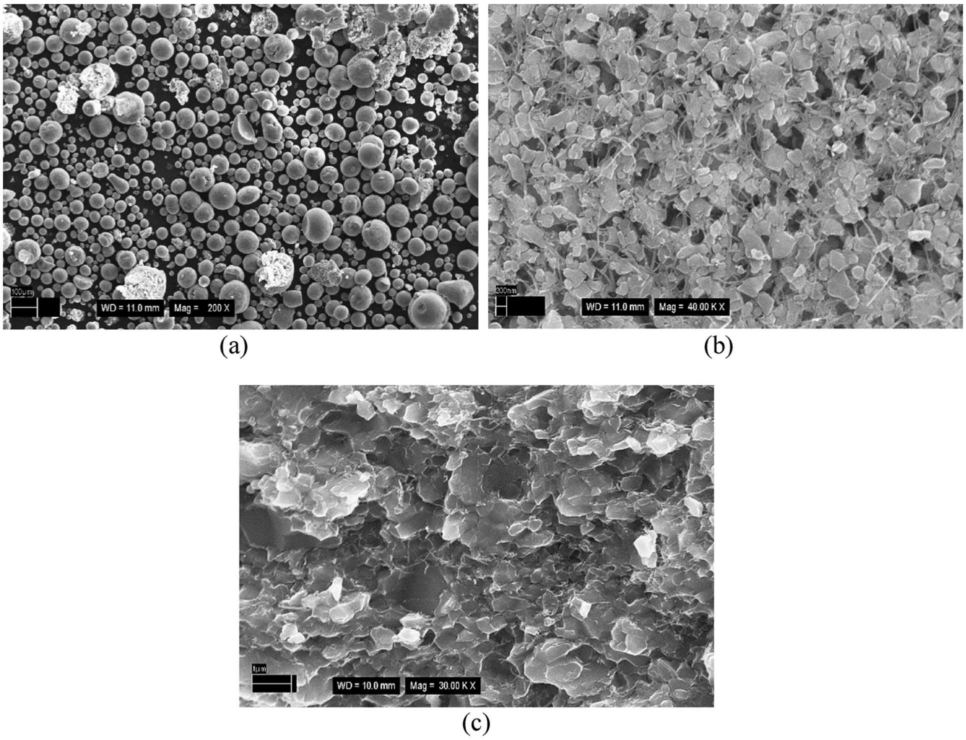
reported in previous work of multi-pass WEDM process [12–14].

The concept of multi-pass WEDM process will prove beneficial to reduce the surface imperfection associated with EDM/WEDM process of ceramic composites. The communicated work follows a means to reduce surface defects reported by Singh et al. [10] during machining of MWCNT alumina composites in WEDM. The porosity, cracks, debris particles and subsurface defects are compared and analysed using multi-pass concept.

2. Materials and experiments

The current work identifies a process to improve the surface characteristics of MWCNT alumina composites using the multi-pass WEDM process (DK7732C, Concord Limited, India). Alumina composites with 10 vol.% MWCNT filler concentration is considered as the workpiece for the current analysis (Table1). Here, in the fabrication process, the carbon nanotubes are initially mixed and ultrasonicated in mixture of sulfuric and nitric acid and then again in aqueous solution with surfactant sodium dodecyl sulfate [15]. After this, stable suspension with individually isolated carbon nanotubes is sprayed into the liquid nitrogen and subsequently, frozen granules are placed into the freeze dryer in order to remove water by sublimation without damaging integrity of granules. This approach leads to obtaining granulated composite powders with homogeneous distribution of MWCNTs (Fig. 1a and b). Also, the homogeneous distribution of MWCNTs is preserved in sintered composites (Fig. 1c). However, it is possible that in some areas there are agglomerates of MWCNTs especially when the content of carbon nanotubes are high as in this case.

Three different types of tool pass (one, three and five passes) are considered for the study. The process parameters are considered judiciously to reduce the net duty factor with increasing passes (Table 2). The current and pulse on time (t_{on}) are reduced with every successive pass while the pulse off time (t_{off}) is kept constant throughout. This is done to reduce the duty factor with every successive pass. This helps in surface smoothening characteristics of the uneven machined surfaces as lesser amount of sparks are produced over a specific duration (duty



(a) (b) (c)

Fig. 1. (a) Granulated composite powder alumina with 10 vol.% MWCNTs, (b) Surface granules with homogenous distribution of MWCNTs & (c) Fracture surface of sintered alumina composites with preserved homogenous MWCNT distribution.