Surface modification using micro-nano sized powder metallurgical green compact electrode in EDM

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KEYWORDS

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ABSTRACT

This work addresses the process of surface modification of aluminium workpiece in EDM process. Powder metallurgical green compact of macro-sized powders of copper (Cu) and nano-sized multi-walled carbon nanotube (MWCNT) are used throughout the surface modification process. The EDM process is carried out by varying the tool parameters, such as the compaction pressure of the green compacts, and process variable settings such as, peak current and pulse on-time setting. The experiments are planned and performed utilizing the Taguchi L9 orthogonal array. The highest MDR value of 0.36 mg/min and the lowest R_a *of 2.5 μm achieved in the experimentation. The XRD analysis confirms the tool material's presence in the modified surface.*

1. Introduction

Material deposition using electric discharge machining (EDM) under reverse polarity has gained popularity in last few years. The advancement of research has introduced various surface modification techniques such as ion implantation, laser cladding, physical and chemical vapor deposition, etc. (Tyagi et al., 2019). But one of their significant drawbacks is that these techniques require a special setup and controlled environment, which increases the overall cost of manufacturing. In this scenario, deposition using EDM has emanated as a favoured approach over alternative deposition techniques. The surface modification using EDM can be achieved either using a green compact/sintered/semi-sintered tool or using powder mixed dielectric (Rahang & Patowari, 2020). The tool which are fabricated in PM process readily wears out as a result of thermal energy generated during the EDM process, which aids the addition of more powdered materials onto the workpiece surface. Furthermore, the PM technique is more efficient than powder-mixed EDM in regards to cost-effectiveness, lack of extra equipment needed for the circulation of powder, minimal arcing, homogeneous coating, and so on. Surface modification using EDM has been carried out by many researchers over time. The surface of carbon steel is modified by depositing hard layers of TiC using green compact of titanium powders in EDC process (Wang et al., 2002). The research revealed that compact TiC ceramic coatings with improved hardness of more than three times may be formed on metal work surface. The surface modification of C-40 steel is carried out using sintered tool of W-Cu (Patowari et al., 2015). The experimental results showed deposition of thick coatings of WC with improved surface hardness. (Sarmah et al., 2020) deposited a layer of Inconel 718 powder is deposited over Al-7075 workpiece. They observed that the deposited layer hardness and thickness increases with increase in peak current and pulse on-time.

While machining mild steel using aluminium tool coated with Cu-MWCNT, (Mandal & Mondal, 2019) found increased microhardness of 139.48 % with micro-crack reduction in the modified surface. (Tyagi et al., 2019) developed a solid lubricating surface over mild steel using hBN-Cu green compact tool. They observed a reduction in microhardness along with reduced wear and friction coefficient of the deposited lubricating layer. (Mazarbhuiya et al., 2021) reported the modification of Al-6061 workpiece using Si-Cu green compact tool. The results showed the highest deposited layer thickness of 18.73 μm and increased hardness of

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268 HV. It was reported that the surface roughness increases with increased peak current and pulse on-time. Thus, from the existing literature, it can be perceived that surface modification using EDM is an effective technique for improving the surface properties, i.e., hardness, corrosion resistance, etc. of a base material.

MWCNT, which is an allotrope of carbon, holds exquisite thermal, mechanical and electrical properties and possesses structural stability even at elevated temperatures (Mandal & Mondal, 2019). For deposition, the thermal and electrical conductivity of the tool material plays a major role and MWCNT is a perfect candidate for improving these properties. (Barua & Rahang, 2022) reported the use of Cu-MWCNT green compact tool in reverse polarity to modify the surface of Al-7075. However, the work reported was in a preliminary stage and required more experimentation and study. Thus, the fundamental aim of this study is to observe the effect of pulse on-time (T_{on}), compact load (CL) and peak current (I_p) with respect to the output responses i.e., material deposition rate (MDR) and surface roughness (R_a).

2. Materials and methods

The surface modification process has been carried out in a die-sinking EDM (Make: Sparkonix India Pvt. Ltd., Model: S25) with the dielectric medium of DEF92 grade EDM oil. The Al-7075 workpieces were cut into the specific dimension (20mm×25mm×3mm), followed by surface grinding and cleaning with acetone. The PM green compact powder mixture consisting of MWCNT (10-30 nm dia.) and Copper (44 µm) in stoichiometric ratio are mixed rigorously for one and half hours. The powder blend is then transferred in a handheld compaction machine with a single punch and die configuration to fabricate green compact pellets. The final tool is obtained by mounting the green compact pellets to cylindrical copper rods using conductive paste.

The Taguchi method has been employed in this study to determine the optimal settings and the influence of key variables on the performance, such as material deposition rate (MDR) and surface roughness (R_a). Taguchi's L9 orthogonal array comprising of three factors with three levels has been considered for this experimentation. The experimental conditions and the levels of input parameters are shown in Table. 1. The MDR has been evaluated by taking the weight difference of the initial and final workpiece. The MDR is calculated using Eq. (1).

Table 1
EDM operation parameters.

Parameter	Value
Operation time (min)	5
Voltage (V)	40
Duty cycle (%)	84-89
Pulse on-time (µs)	200, 400, 600
Peak Current (A)	2, 3, 4
Compact load (t_{on})	6, 9, 12

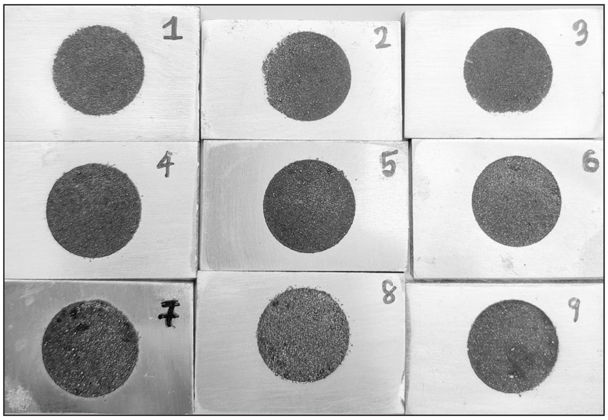

Fig. 1. Surface modified workpieces.

$$MDR = \frac{Weight\ of\ the\ workpiece\ after\ (mg) - Weight\ of\ the\ workpiece\ before\ (mg)}{Operation\ time\ (min)} \quad \text{................(1)}$$

The R_a pattern has been recorded using a surface roughness tester (Make: Taylor Hobson Surtronic, Model: S100).

3. Results and Discussion

The primary focus of this experimental investigation is to deposit a layer of Cu-MWCNT onto Al-7075 and observe the effect of input parameters with respect to output responses, which has not been carried out so far. The surface modified workpieces with the respective experiment numbers are shown in Fig. 1.

3.1. Analysis of material deposition rate

The MDR is a critical performance measure that is affected by process parameters. The main effect plot of MDR is depicted in Fig. 2. MDR values that are negative indicate material removal, whereas positive values imply material addition.

Table 2
Input parameters and output responses.

	Input			Output	
Exp. No.	Peak Current (A)	Compact Load (ton)	Pulse on-time (µs)	MDR (mg/min)	R_a (µm)
1	2	6	200	0.14	2.5
2	2	9	400	0.32	2.6
3	2	12	600	0.36	2.8
4	3	6	400	-0.48	4.1
5	3	9	600	-0.38	3.9
6	3	12	200	-1.20	4.4
7	4	6	600	-1.40	4.7
8	4	9	200	-8.20	5.0
9	4	12	400	-7.08	4.6

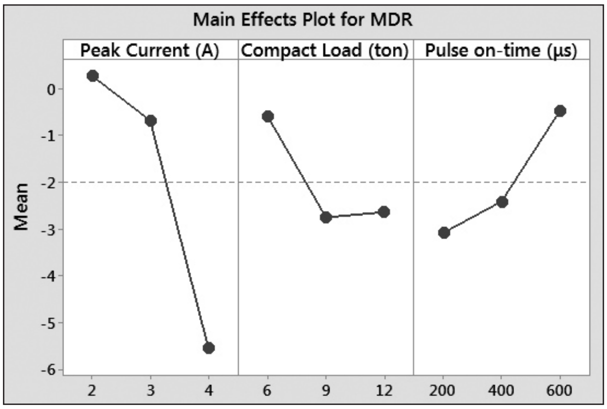

Fig. 2. Main effect plot for MDR.

In Fig. 2 it can be observed that the MDR value declined as the value of I_p increased from 2A to 3 A. With further increase of I_p the MDR value keeps following the negative trend; this is because MWCNT is highly conductive and as the I_p is increased, higher thermal energy is generated which aids in the removal of material from workpiece surface. The effect of the compact load is also similar to that of peak current, as the compact load is increased the binding strength between the particles increases, raising the possibility of the PM tool behaving as a solid electrode. As a result, the PM compact tool fabricated with a low compaction load results in improved material transference. Pulse on-time plays a major role in material deposition, in the instance of T_{on} variation, TWR (Tool Wear Rate) rises with an increase in T_{on} from 200 to 600 µs owing to the heat energy's prolonged persistence.

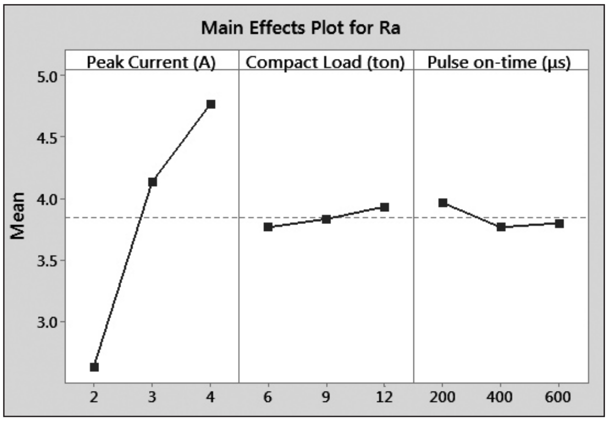

Fig. 3. Main effect plot for R_a.

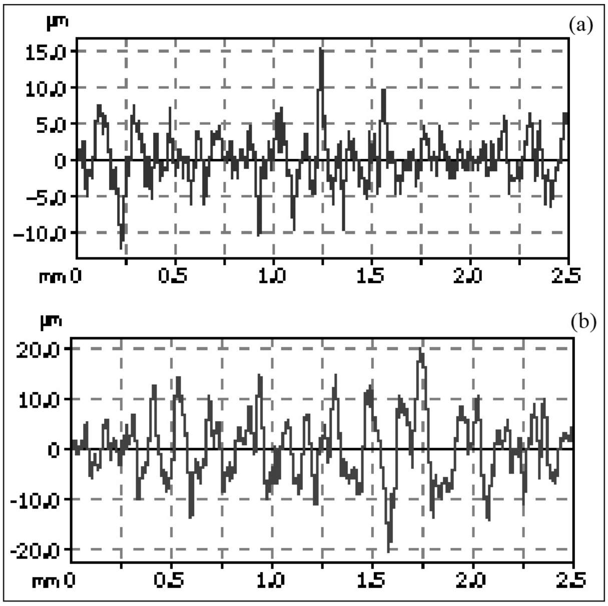

Fig. 4. Roughness profile showing
(a) minimum and (b) maximum roughness.

3.2. Analysis of surface roughness

The amount of energy emitted during the EDM process determines the form of the machined surface.

The sum of the maximum valley depth and maximum peak height is used to calculate surface roughness. The main effect plot of R_a is shown in Fig. 3. The peak current and pulse duration influence the R_a. As I_p and T_{on} increase, the craters get more prominent and profound as the strength of the spark increases. In Fig.3, it can be observed that the R_a value increases as the I_p increases. The increase in CL also affected in the same manner but the influence of CL and T_{on} is not much effective compared with I_p. The roughness profile of the highest (5.0 µm) and lowest (2.5 µm) values of R_a are shown in Fig. 4.

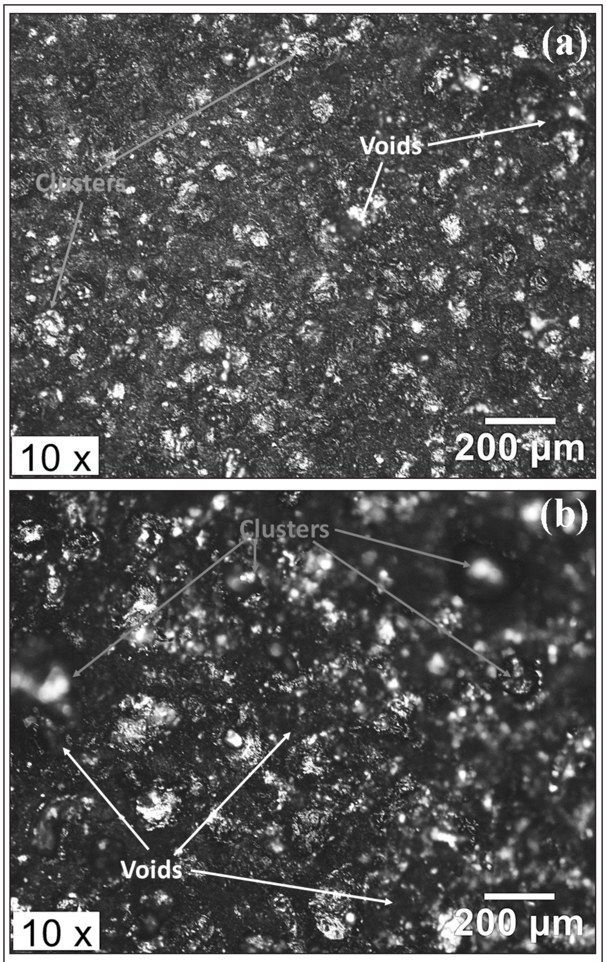

Fig. 5. Optical microscopy images of (a) Experiment No. 1 (b) Experiment no. 8.

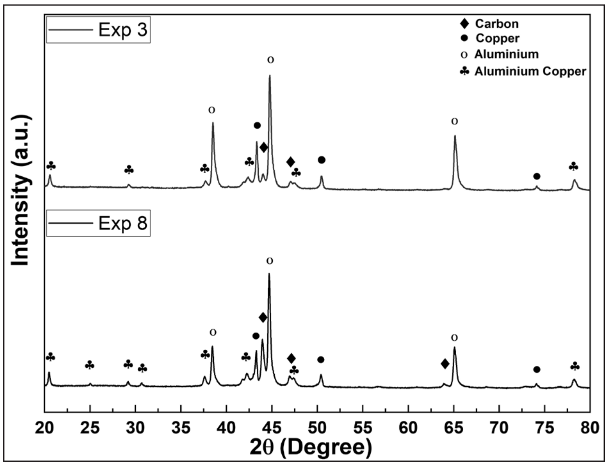

Fig. 6. XRD plot of maximum and minimum MDR samples.

3.3. Optical microscopy

To examine the surface morphology of the deposited layer, a microscopic investigation has been conducted using Olympus BX51 M metallurgical microscope. The micrographs of some modified surfaces are shown in Fig. 5.

The micrographs reveal, as the particles are deposited because of the solidification of pools of molten materials, some distinct craters and voids are produced due to succession of sparks. The size of craters and voids also depends on the input parameters. Tests performed with less peak current and compact load produce a more uniform surface with less inhomogeneity, while tests performed with more peak current and compact load produce deeper craters and voids in the deposited layer. In Fig. 5(a), fewer clusters and voids are present as compared to Fig. 5(b). The inhomogeneity in the modified layers results a surge in surface roughness.

3.4. XRD analysis

X-ray diffractograms for all the samples are recorded using XRD (Make: MIS Rigaku Corporation, Model: Rigaku SmartLab). The peaks with respect to the 2θ angles give traces of the elements and compounds formed due to the interaction of tool and electrode materials during the discharge process.

Compounds of aluminium and copper, such as Al_4Cu_9 and Al_2Cu are found at different peak positions, shows cubic and tetragonal structures. Aluminium and copper alone showed cubic structure and carbon exhibited a hexagonal structure. Fig. 6 shows the XRD plots of minimum and maximum MDR surfaces. At experiment 8 though material removal takes place, peaks with respect to exp. 3 can be observed along with the addition of compounds. During exp. 8, the I_p setting was very high, resulting in the formation of additional compounds.

4. Conclusions

In this work, the surface of Al-7075 is modified using Cu-MWCNT PM green compact tool. The following inferences can be drawn from this present study:

1. The powder metallurgy tool exhibits significant material migration (Cu and MWCNT). The migration of tool particles will enhance the surface properties of the base material.
2. The highest MDR value of 0.36 mg/min is obtained at a setting of I_p at 2 A, CL at 12 ton and T_{on} at 600 µs, while the lowest R_a of 2.5 µm is attained at a setting of I_p at 2 A, CL at 6 ton and T_{on} at 200 µs.
3. The presence of tool particles is confirmed by XRD analysis. The XRD analysis exhibited

different structures of compounds such as aluminium copper and elements such as aluminium, copper and carbon.

Therefore, it can be concluded that there is a lot of potential for surface alloying using the suggested approach. However, the modified layer microhardness and optimization studies have to be carried out in future.

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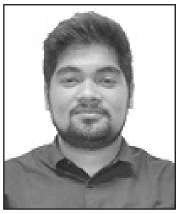

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