EFFECT OF POWDER CONCENTRATION ON THE EDM PERFORMANCE OF AISI 304 USING CRYOTREATED POST TEMPERED ELECTRODES

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Abstract

Powder mixed electro discharge machining (PMEDM) is a hybrid machining process in which dielectric fluid is mixed with electrically conductive powder particles for enhancing surface quality and material removal rate. Cryogenic treatment was brought in this process to improve tool life and cutting tool properties. In this research, silicon carbide (SiC) powder mixed electro discharge machining (EDM) has been performed for AISI 304 machining. Experiments have been carried out to study the effect of powder concentrations (0 g/l, 4 g/l, 6 g/l, 8 g/l and 10 g/l) on the EDM performances viz. radial overcut (ROC), material removal rate (MRR), surface roughness (R_a) and tool wear rate (TWR) using three tungsten carbide electrodes (i.e. untreated, cryotreated single and double tempered). With addition of powder concentration material removal rate, radial overcut enhances and surface roughness and tool wear rate reduces. With the addition of powder concentration MRR, TWR, R_a and ROC decreased upto 10.60%, 37.08%, 15.95% and 9.31% for cryotreated single tempered electrode and decreased upto 16.64%, 42.10%, 26.58% and 12.19% for cryotreated double tempered electrode respectively. Microstructural analysis of machined surface has been carried out for the PMEDMed surfaces.

1 Introduction

Electrical discharge machining (EDM) is one of the popular non-traditional machining methods amid all the non-traditional machining processes. This process is extensively used to machine the conductive and difficult-to-machine materials used in aerospace, automobile, die and mold making industries [1]. Conventional EDM has some limitations such as poor surface quality and low machining efficiency. To overcome these limitations electrically conductive powder particles are suspended in the EDM dielectric fluid that improve surface finish and machining efficiency.

This hybrid material removal process is called powder mixed electro discharge machining (PMEDM) [2-4]. This PMEDM method was first studied by Erden and Bilgin [5]. Fong and Chen [6] used Cr, Cu, SiC and Al powders during PMEDM of SKD 11 mold steel and observed that Al powder produces good surface finish and lower recast layer. Tsai and Chang [7] added different type of polymer powders (Starch, PANI-emer, PANI-salt) in the silicon oil during PMEDM of stainless steel.

They reported that surface roughness is slightly decreased by using these powders and PANI-salt produces best surface finish among all the polymer powders. PMEDM of various workpiece material using different tools, powders and dielectrics revealed the significance of workpiece-tool-powder combination to

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reach the desire response level [8-11]. Sahu and Dutta [12] investigated the EDM performance of Inconel 718 by adding graphite powder in EDM dielectric. They have studied topological features and surface morphology of EDMed surface for powder mixed and conventional EDM and reported that PMEDM significantly reduces TWR and enhances MRR. Surekha et al. [13] investigated the influence of kerosene dielectric with Al powder by means of TWR and MRR during EDM of EN-19 alloy steel.

They found the optimum level for lower TWR and higher MRR. Bhaumik and Maity [14] investigated the effect of SiC powder concentration on the R_a of EDMed AISI 304 and found that SiC powder significantly reduces R_a. Later they investigated the influence of process parameters and powder concentration on the EDM performance characteristics. They showed that when SiC powder used MRR enhanced by 23.2%, TWR and R_a decreased by about 25% and 14.2%, respectively [15]. Abdudeen et al. [16] discussed about the recent advancement in the field on PMEDM.

They discussed about the various types of powder used in EDM process for achieving machining efficiency. A few decades ago, cryotreatment process had been introduced to lessen the tool wear and to cut down the machining process cost. Kumar et al. [17] performed powder mixed EDM of Inconel 718 using graphite powder and cryotreated double tempered (CT2) Cu electrode.

They showed considerable reduction of electrode wear ratio (EWR). During micro EDM of AISI 304, 58% reduction of tool wear has been found out using cryotreated WC electrode followed by brass and copper tool [18]. Again Singh and Singh [19] showed that cryotreated copper electrode exhibits lower TWR than the cryotreated brass electrode during EDM of AISI D3. Bhaumik and Maity [20] studied the influence of adding powder particles and CT2 WC electrode during EDM of AISI 304 and found that conventional EDM provides less radial overcut compare to powder mixed EDM and CT2 electrode gives less radial overcut than untreated electrode. Mohanty et al. [21] explored the effect of soaking period of deep cryotreatment and showed the effect of deep cryotreated brass electrode with different soaking periods on the EDM performance of Inconel 718.

They noticed that at 36 hours soaking duration TWR, R_a and ROC is reduced upto 48.29%, 31.72% and 88.33% respectively. From the above literature review, it is apparent that machining efficiency and surface quality is significantly improved by suspending conductive powder in the dielectric fluid. The machining efficiency further improved by introducing cryotreated electrode. Few significant studies has been reported regarding the effect of cryotreated post tempered electrodes in combination with dielectric powder concentration on the machining efficiency during EDM operation.

The objective of this investigation is to study the influence of SiC powder concentration and cryotreated post tempered WC electrodes on the EDM performances viz. surface roughness (R_a), tool wear rate (TWR), material removal rate (MRR) and radial overcut (ROC). The microstructural study also has been carried out for the PMEDMed surface.

2 Experimental details

2.1 Material selection and equipment

In this investigation, the EDM operation of AISI 304 stainless steel has been performed in die sinking type EDM machine (made by: Electronica-ElectraPlus PS 50 ZNC). Experiments have been performed using three tungsten carbide (WC) electrodes (i.e. cryotreated single tempered (CT1), cryotreated double tempered electrode (CT2) and untreated electrode (UT)). AISI 304 is most often used and malleable steel because of its excellent corrosion resistance. It is broadly used in kitchen appliances, heat exchangers, screw, bolts, chemical containers for transport and food processing equipments. Therefore, surface finish and dimensional accuracy play an important role in EDMed AISI 304 products. Chemical composition of AISI 304 is shown in Table 1.

Table 1. Chemical composition of AISI 304.

Element	C	Mn	Si	P	S	Cr	Ni	Fe
%	0.06	0.72	1.26	0.05	0.11	16.36	6.95	Balance

SiC powder (Figure 1) size of ~20 µm is considered for this experiment.

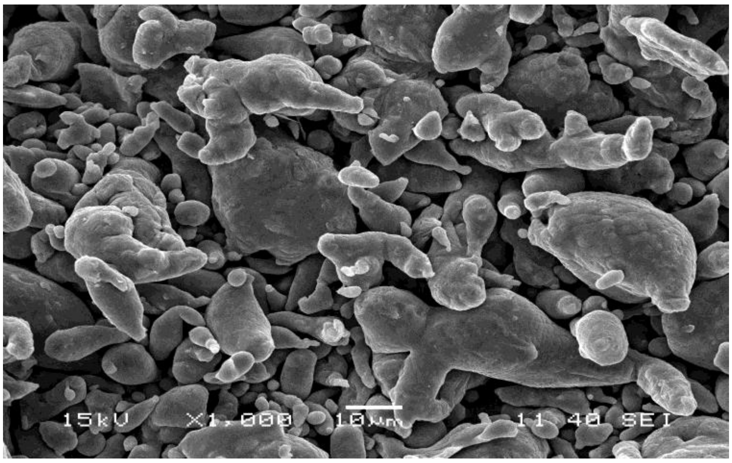


Figure 1. SiC Powder used in PMEDM.

2.2 Cryotreatment

The primary aim of cryotreatment and tempering cycle is to convert material from austenite to martensite for increasing hardness and thermal properties. WC electrode is subjected to the deep cryogenic treatment at a temperature of -193.15^{0}C for 24 hours. Then, one electrode is subjected to single tempering, and another one is subjected to double tempering for stress relieving induced by cryogenic treatment [20].

2.3 Selection of machining parameters

The process parameters are selected for this investigation because of having significant effect on EDM performances as evident from the literature [7, 12, 14, and 15]. The value of the fixed process parameters are selected in such a way that the process falls under semi finishing operation.
The selection of P_C is considered upto 10 g/l as the literature study has shown that adding more P_C causes an arching owing to a very thin effective gap [22]. Various experimental conditions and level of machining parameters are listed in Table 2.

Table 2. Experimental conditions.

Sl No.	Working Parameters	Description
1	Polarity (P)	Positive (+)
2	Workpiece material	AISI 304 Stainless Steel
3	Dielectric fluid	kerosene oil
4	Electrode material	Tungsten carbide
5	Machining time (min)	10
6	Gap voltage (V_g) (V)	45
7	Pulse on time (T_{on}) (µs)	50
8	Duty cycle (r) (%)	60
10	Peak current (I_P) (A)	5
11	Powder concentration (P_C) (g/l)	0, 4, 6, 8, 10

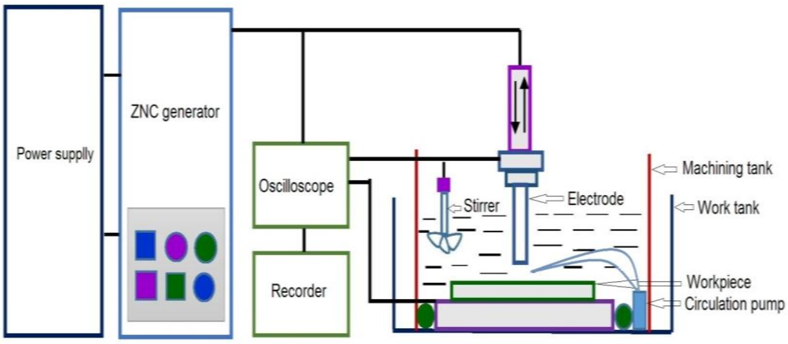


Figure 2. Schematic diagram of PMEDM set up [15].

2.4 Measurement of responses

The responses considered are material removal rate (MRR) (mm^3min^{-1}), surface roughness (R_a) (μm), radial overcut (ROC) (mm) and tool wear rate (TWR) (mm^3min^{-1}). Responses are calculated from the observed data using Eq.(1) - Eq.(4) [23-24].
Weight loss of the workpiece and tool was measured using an electronic balance (made by: Shinko Denshi, Japan; Model: DJ3000S)

$$MRR = \frac{Volumetric\ material\ loss\ from\ the\ workpiece\ (mm^3)}{Machining\ time\ (\min)} \tag{1}$$

$$TWR = \frac{Volumetric\ material\ loss\ from\ the\ electrode\ (mm^3)}{Machining\ time\ (\min)} \tag{2}$$

Radial overcut (ROC) is measured by Tool Maker’s Microscope (made by: Carl Zeiss, Germany).

$$ROC = \frac{D_h - D_t}{2} \tag{3}$$

The surface roughness (R_a) of the machined surface is measured by Talysurf (made by: Taylor Hobson, Model: Surtronic 3+). R_a is calculated by the following formula.

$$R_a = \frac{1}{L}\int_0^L |y(x)|\, dx \tag{4}$$

where x is the direction of profile, L is sampling length and y is height of peaks and valleys of roughness profile.
Microstructures of the EDMed surface machined by different type of electrodes were taken using scanning electron microscope (SEM) (made by: JEOL, Japan; Model: JSM-6480).

3 Results and discussion

Experimental results of using UT, CT1 and CT2 electrodes during PMEDM operation of AISI 304 are shown in Table 2.

Table 2. Experimental results.

Process parameter	Responses											
P_C (g/l)	MRR (mm^3min^{-1})			TWR (mm^3min^{-1})			R_a (μm)			ROC (mm)		
	UT	CT1	CT2	UT	CT1	CT2	UT	CT1	CT2	UT	CT1	CT2
0	3.917	3.575	3.282	0.127	0.115	0.104	6.76	6.19	6.1	0.0240	0.0230	0.0200
4	4.074	3.72	3.396	0.084	0.073	0.060	5.97	5.54	5.27	0.0248	0.0230	0.0222
6	4.263	3.811	3.558	0.071	0.053	0.048	5.63	5.38	4.63	0.0252	0.0238	0.0231
8	4.292	4.082	3.822	0.052	0.039	0.034	5.29	4.85	4.21	0.0264	0.0248	0.0240
10	4.369	4.147	3.926	0.042	0.026	0.024	4.89	4.11	3.59	0.0279	0.0253	0.0245

3.1 Effect of powder concentration on MRR

Effect of SiC powder concentration on EDM performance viz. MRR, TWR, R_a and ROC are shown in Figure 3, Figure 4, Figure 5, and Figure 6. When powder particles added in the kerosene dielectric enhancement of MRR is observed for all the three type of electrodes. This enrichment of MRR is credited to the drop of dielectric breakdown strength when powder particle are added into it. Therefore, in PMEDM, electrode gap between tool and workpiece expands extensively compared to the conventional EDM causing expansion of discharge passages. In the meantime, powder particles attempt to connect a bridge between the tool and workpiece.

This encourages the dispersion of discharge into several increments resulting increase in spark frequency. Consequently, MRR increases [25]. It is noticed that MRR is higher for UT electrode followed by CT1 and CT2 electrode. This may happen due to the cryotreatment effect of electrode. During sparking time because of higher thermal conductivity, spark ignition is continued for a less time.

This results the reduction of spark frequency in the discharge gap. Hence, MRR declines [15]. Tempering cycle has a considerable effect on the MRR. Using UT electrode MRR can be achieved upto 4.369 mm^3min^{-1} when SiC powder added upto 10 g/l by keeping the other parameters fixed. When powder concentration varies, MRR decreases upto 10.60% and 16.64% for CT1 and CT2 electrode respectively.

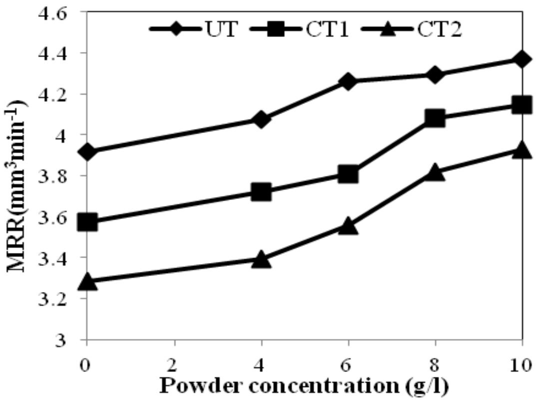


Figure 3. Effect of P_C on MRR.

3.2 Effect of powder concentration on TWR

TWR is one important factor that affects the dimensional accuracy of EDMed surface. As seen from the Table 2, TWR decreases with the increase of P_C for all the electrodes. It may happen due to the deposition of carbon layer on electrode surface which is generated from the decomposition of dielectric fluid. So the wear resistance of the electrode enhances resulting less TWR [26]. TWR is higher for UT electrode compare to CT1 and CT2 electrode because of superior thermal property of cryotreated tempered electrodes. During tempering, the martensite rejects carbon in the form of carbide phases that is responsible for increasing the thermal conductivity [27]. Increase in the thermal conductivity leads to a faster rate of heat conduction and results decrease in tool wear for the same heat load [15]. With the addition of P_C, TWR decreases upto 37.08% and 42.10% for CT1 and CT2 electrode respectively by keeping the other parameters fixed.

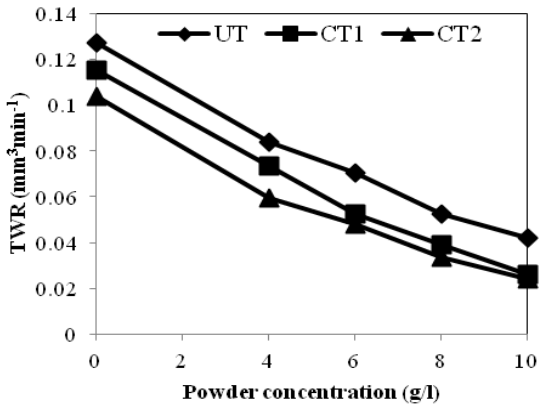


Figure 4. Effect of P_C on TWR.

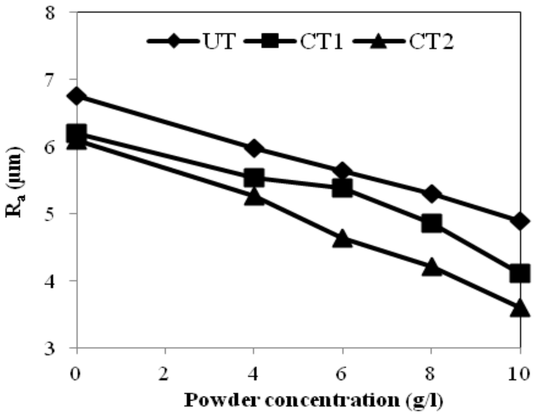


Figure 5. Effect of P_C on R_a.

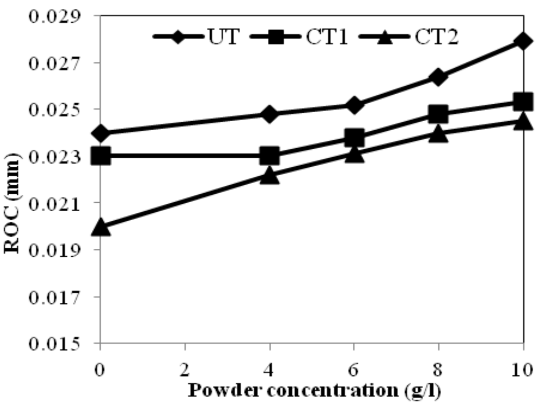


Figure 6. Effect of P_C on ROC.

3.3 Effect of powder concentration on R_a

When powder particles added in the dielectric fluid a substantial reduction in surface roughness occurs for the three electrodes. Plasma channel gets enlarged and widened after mixing the powder particles in the kerosene dielectric during EDM operation. So, spark energy is distributed over a large area amid the powder particles. Consequently, shallow and large crater formed on the EDMed surface [6]. Along with this, molten metal is not heavily compressed by gas babbles and plasma channel.

This situation lessens the entrapping of gas in the machining cavity. As a result, the surface turns out to be less concave, smooth and uniform [26]. Untreated electrode gives higher surface roughness followed by CT1 and CT2 electrode. This may happen because; during cryotreatment wear resistance property of electrode increases as the thermal conductivity enhanced. During spark on time, heat is easily dissipated from the electrode. Therefore, discharge energy density will be lower which causes the formation of less concave and smooth crater as compared to UT electrode. With addition of P_C, R_a declines upto 15.95% and 26.58% for CT1 and CT2 electrode respectively by keeping the other parameters fixed.

3.4 Effect of powder concentration on ROC

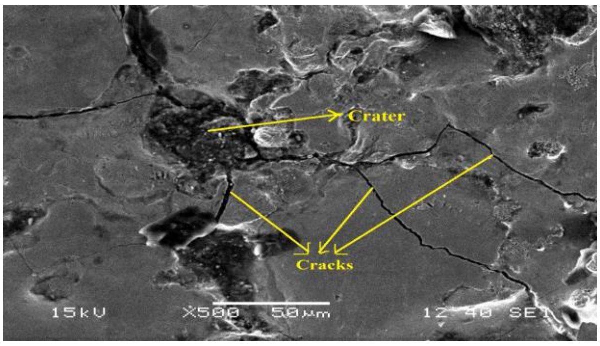
Precision of any component is significantly affected by overcut. ROC enhances with the increase of P_C for the three electrodes. After addition of P_C in the dielectric fluid, breakdown strength of dielectric is reduced severely. Therefore, low breakdown strength allows the spark to take place from a long distance [25]. As a result, ROC enhances. ROC significantly varies with the addition of powder particles. Untreated electrode gives higher ROC than CT1 and CT2 electrode.

The roundness of UT electrode gets affected owing to rise of local temperature and excessive heating as a result of poor thermal properties. The cryotreated electrode possesses higher thermal conductivity than the untreated electrode. As a result, electrode surface faces less vaporization and melting during sparking as compared to untreated electrode and the roundness of electrode is maintained [28]. As a result, dimensional accuracy of cryotreated electrodes is enhanced due to uniform sparking and proper maintenance of electrode shape than UT electrode. With the addition of P_C, ROC decreases upto 9.31% and 12.19% for CT1 and CT2 electrode respectively by keeping the other parameters fixed.

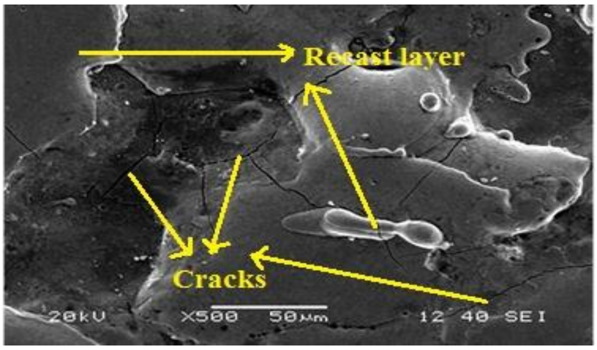
From the above study it is evident that CT2 electrode provides better result compared to CT1 electrode. During tempering, carbide phases formed owing to the rejection of carbon from the martensite. Better thermal property has been achieved for CT2 electrode compared to CT1 electrode. So, CT2 electrode provides better tool life, dimensional accuracy, surface finish compared to CT1 electrode.

4 Microstructural Analysis

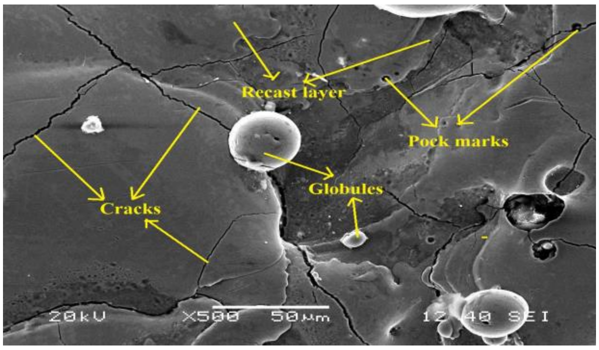
Surface characteristics of PMEDMed surface machined by UT, CT1 and CT2 electrodes are portrayed in Figure 7, Figure 8 and Figure 9. From the structures it is seen that, PMEDMed surface exposes the surface irregularities such as pock marks, deposition of re-solidified material, surface cracks and globules etc. Density of surface cracks also found to be less as the powder concentration increases up to 10g/l. PMEDMed surface machined by cryotreated electrodes provides comparatively smoother surface compare to the surface machined by untreated electrode. From all the micro structures, it is clearly visible that, the surface qualities machined by cryotreated tempered electrodes are better than machined by the untreated electrode.



(a) I_P=5A, T_{on}=50µs, Vg=45V,τ=60%, P_C=0g/l.

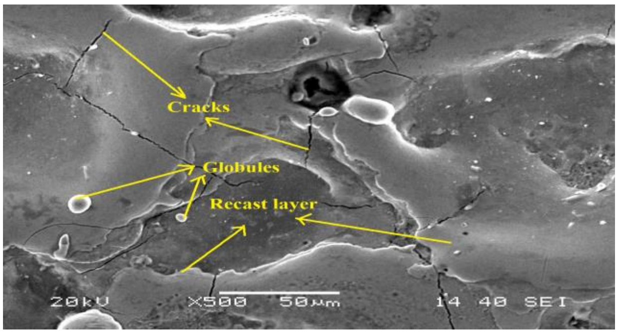


(b) I_P=5A, T_{on}=50µs,V_g=45V,τ=60%, P_C=6g/l.

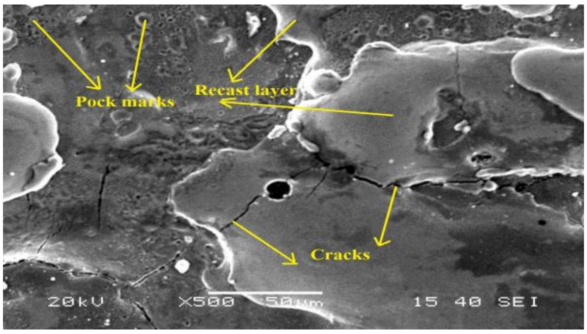


(c) I_P=5A, T_{on}=50µs, V_g=45V, τ=60%, P_C=10g/l.

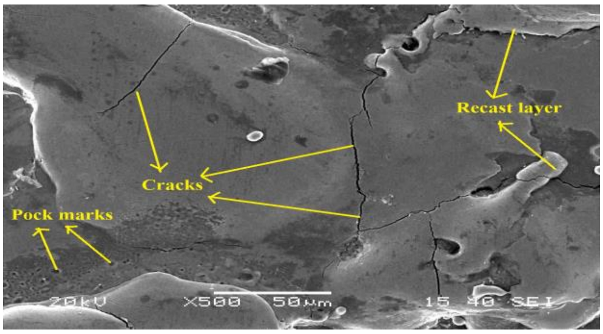
Figure 7. Microstructural analysis of machined surface for different machining conditions for untreated electrode.



(a) I_P=5A, T_{on}=50µs, V_g=45V, τ=60%, P_C=0g/l.

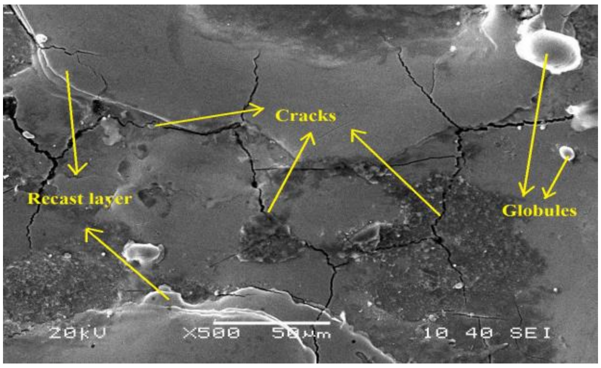


(b) I_P=5A, T_{on}=50µs, V_g=45V,τ=60%, P_C=6g/l.

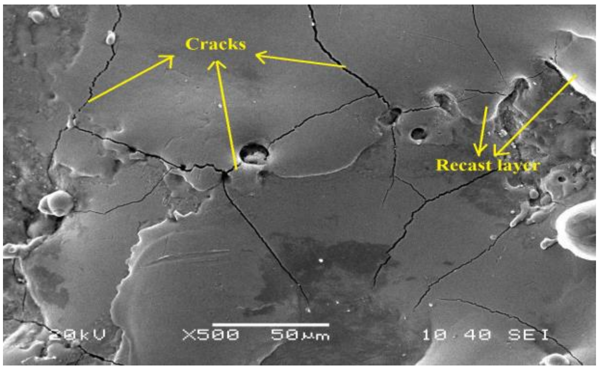


(c) I_P=5A, T_{on}=50µs, V_g=45V, τ=60%, P_C=10g/l.

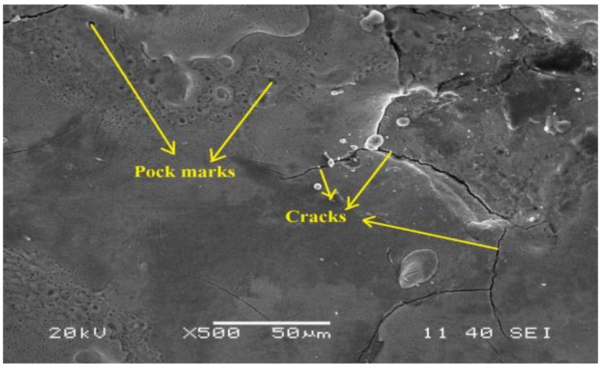
Figure 8. Microstructural analysis of machined surface for different machining conditions for cryotreated single tempered electrode.



(a) I_P=5A, T_{on}=50µs, V_g=45V, τ=60%, P_C=0g/l.



(b) I_P=5A, T_{on}=50µs, V_g=45V, τ=60%, P_C=6g/l.



(c) I_P=5A, T_{on}=50µs, V_g=45V, τ=60%, P_C=10g/l.

Figure 9. Microstructural analysis of machined surface for different machining conditions for cryotreated double tempered electrode.

5 Conclusions

In this research, influence of powder concentration on the EDM performances (tool wear rate, material removal rate, radial overcut and surface roughness) using three electrodes viz. UT, CT1 and CT2 WC electrode on AISI 304 stainless steel has been performed. The following conclusions have been drawn from the current study:

- MRR increases with the rise of P_C for all the electrodes. When P_C varies, MRR decreased upto 10.60% and 16.64% for CT1 and CT2 electrode respectively.
- TWR decreases with the increase of P_C for all the electrodes. UT electrode gives superior tool wear than two cryotreated post tempered electrodes. With the addition of P_C TWR decreased upto 37.08% and 42.10% for CT1 and CT2 electrode respectively.
- With the increase of P_C, R_a drops off for all the electrodes. By adding of P_C, surface finish enhances upto 15.95% and 26.58% for CT1 and CT2 electrode respectively.
- ROC increases with the increase of P_C. With the addition of P_C, ROC decreases upto 9.31% and 12.19% for CT1 and CT2 electrode respectively.
- Better surface characteristics have been observed for the cryotreated electrodes compared to untreated electrode.

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