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Micro Hardness Measurements on Machined Surface of PH17-4 Stainless Steel during EDM with Surfactant and Graphite Powder Mixed Dielectric

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Abstract—*In this work, an investigation is made into electrical discharge machined surface of PH17-4 stainless steel when graphite powder and surfactant mixed dielectric fluid is used during electrical discharge machining. The Taguchi method is used to formulate the experimental layout, to analyze the effect of process parameters namely peak current, surfactant concentration and graphite powder concentration on the responses such as white layer thickness (WLT) and depth of heat affected zone (DHAZ), and to predict the optimal combination of process parameters. It is found that these parameters have a significant influence on responses such as white layer thickness (WLT), and depth of heat affected zone (DHAZ). Experiments are conducted on modified experimental setup and micro hardness measurements are carried out on machined samples to obtain response values such as white layer thickness and depth of heat affected zone. Further, the analysis of variance (ANOVA) is performed to identify the significance of parameters on measured responses. Confirmation experiments are conducted at their respective optimum parametric settings to verify the predicted optimal values of responses.*

Keywords*: Electrical discharge machining, Taguchi method, surfactant, graphite powder, white layer thickness, depth of heat affected zone.*

1. INTRODUCTION

Electrical Discharge Machining (EDM) is extensively used in manufacturing industry to make dies of complex cavities. In EDM, the material removal takes place through the conversion of electrical energy into thermal energy through a series of discrete electrical sparks occurring between electrodes when both are immersed inside a dielectric medium and are separated by a small gap. The material is removed from the work piece by localized melting and even vaporization of material by high temperature spark. This leads to many defects namely micro cracks, porosity, residual stress, and the white layer that are originate on the machined surface due to rapid high temperature melting and subsequent rapid cooling during machining process.

Soni J.S et al (1996) have stated that considerable amount of material transfer takes place between electrode and work piece during EDM of die steel with rotating copper tungsten electrode. This transferred material is observed in the re-solidified layer of the work piece [1]. Ghoreishi et al (2002) have reported that the effect of axial vibration of tool along with rotation on MRR and TWR during EDM and observed the significant increase in MRR for specified surface roughness by provide high frequency axial vibration to the tool along with rotation [2]. H.K.Kansal et.al (2006), proposed the parametric optimization of powder mixed EDM through Taguchi method and utility concept [3]. P. HS Payal et al (2008) have studied the effect of parameters on SR, MRR during EDM of EN31 tool steel using copper, brass and graphite as electrodes. Different patterns of the HAZ are observed for all the specimens machined by three different electrodes. HAZ is deeper in case of graphite electrode compared to brass and copper [4]. Mohammadrezashabgard et at (2011) have studied the influences of EDM input parameters (pulse on time and pulse current) on the characteristics of EDM process (MRR, EWR and SR) as well as white layer thickness and depth of heat affected zone of AISI H13 tool steel as work piece using Cu as electrode [5]. BehzadJabbaripour et al (2013) have studied PMEDM of γ-TiAl by means of adding different powders (aluminum, chrome, silicon carbide, graphite and iron) to the dielectric to find its effect on surface roughness, topography, metal removal rate, electro chemical corrosion resistance of machined samples [6]. Anirban Bhattacharya et al (2013) have reported the improvement of surface properties (improved surface roughness, increased micro hardness) with Si, W and graphite powders mixed in dielectric in powder mixed EDM process. Further the mixing of powders in dielectric lower the surface roughness however powder concentration, current and pulse on time were found to be major significant factors affecting SR. Mixing of powders also increase the micro hardness of the machined surface and observed the significant amount of material transfer from added powder, tool material and dielectric, being deposited on the machined surfaces [7].

From the literature survey, it is observed that no extensive work has been carried out so far in the field of EDM of precipitation hardening stain less steel PH17-4 using surfactant and graphite powder mixed dielectric fluid. Based on literature survey and our preliminary investigations the parameters chosen as input parameters are peak current I (A), surfactant concentration SC (g/lt.) and graphite powder concentration PC (g/lt).The aim of the present work is to identify the significant affect of the above chosen process parameters on white layer thickness (WLT), and depth of heat affected zone (DHAZ). Also find the optimal parametric settings to minimize the WLT and DHAZ.

2. EXPERIMENTAL SETUP, PROCEDURE AND EQUIPMENT:

The work material PH17-4 stainless steel pieces with the dimensions of 80 X30 X6 mm are used to conduct experiments. The electrolyte copper of diameter ø14 mm and length 70 mm is selected as tool. Considering safety and pollution issues, the surfactant with least irritation non-ionic SPAN20 is chosen to add into the dielectric for all the experiments. The graphite powder (particle size 20 to 30µm) is chosen to add into the dielectric with surfactant SPAN20. All the experiments were conducted on die sinking EDM machine of FORMATICS 50 model which is equipped with ELECTRONICA PRS 20 controller and modified working fluid circulating system designed for experimentation for better circulation of graphite powder and surfactant mixed dielectric fluid. Taguchi L9 Orthogonal array was chosen for experimentation. The chosen input factors and corresponding levels for this study are presented in Table1. The selected experimental conditions were presented in the Table2

Table 1: Input process parameters and their levels

Parameter	Level1	Level2	Level3
Peak current I(A)	10	15	20
Surfactant concentration SC(g/lt)	4	6	8
Powder concentration PC(g/lt)	4.5	9	13.5

Table 5: Experimental conditions

Working Conditions	Description
Work piece	PH17-4 stainless steel(80mm×30mm×6mm)
Electrode	Electrolyte copper Ø 14mm and length 70 mm
Dielectric	Commercial EDM Oil grade SAE 450+Gr.powder+surfactant SPAN20
Flushing	Side flushing with pressure 0.5MPa
Gr. Powder particle size	20-30µm
polarity	Normal
Supply voltage	110 V
Gap voltage	70 V
Pulse duration	65 µs
Pulse off time	48 µs
Machining time	3 minutes

Micro hardness (HV) measurements are carried out on the machined specimens to determine the white layer thickness (WLT) and depth of heat affected (DHAZ) after conducting experiments. The machined specimens are sectioned transversely by wire cut EDM and polished subsequently with silicon carbide papers to obtain mirror image finish. Further, micro hardness (HV) measurements are carried out on mirror finish polished transverse sectioned surface of machined samples along the depth from the machined surface from 0 to 100 µm at 11 positions. These measurements are repeated on the samples of all experiments and average values are calculated. The micro hardness measurements were carried out on a computer interfaced micro Vickers hardness testing machine (Mitutoyo Japan make, model: HM-113) with 10gf load applied for 10 seconds duration with 250X magnification. MINITAB16 software is used to analyze the data.

3. RESULTS AND DISCUSSION

It is possible to sort out each process parameter on response at different levels since the experiments are designed in orthogonal nature. The raw data of various responses are collected after conducting experiments were transferred in to their respective S/N ratio values using MINITAB 16 software.

3.1. Effect of process parameters on white layer thickness (WLT)

The characteristics of electrical discharge machining (EDM) such as large spark energy range, variation of surface finish, extreme cooling rates, chemical surface impurities from electrode and dielectric (carbon is more important contaminant), a recast layer which intern creates more anxiety on surface integrity of electrical discharge machined surfaces. The heat affected zone produced by the EDM is comprised of an upper layer, called as white layer or recast layer followed by phase transformation zone and conversion zone. The micro hardness values are measured by micro hardness tester at two different locations of same depth and average of two values is calculated for each trial of experiments. The variation of micro hardness profiles with depth from the machined surface of all experimental runs is presented in the Fig1.

It is observed from Fig1 that the hardness value decreases up to the depth of white layer then increases further in the region of heat affected zone with increasing depth from the machined surface. WLT is estimated as the depth up to which the micro hardness decreases from the machined surface, where as DHAZ is estimated as the depth in the region in which micro hardness increases up to base metal hardness. The WLT values of all experimental samples are calculated with above procedure from respective micro hardness profiles and their corresponding S/ N ratio values are presented in Table3.Response curve shown Fig2presented the individual effect of peak current, surfactant concentration and Graphite powder concentration on the values of WLT. It is observed from Fig2 that white layer thickness increases significantly with increasing peak current. This can be due to the increase in peak current increases discharge energy density causes more available heat energy at the work surface. This increases the amount of molten metal formation that makes more re-solidified material resulting increase in white layer thickness. Whereas WLT initially increases then it decreases further with increasing surfactant concentration. This may be due to that the addition of surfactant in to dielectric improves its conductivity causes increase in spark energy that increases molten metal formation resulting increase in WLT. On the other hand surfactant concentration improves conductivity of the dielectric causes more heat energy may dissipate into the dielectric that may lowering the available heat energy at the work surface. In addition, lowers dielectric viscosity with increasing in surfactant concentration results more easily flow of dielectric into the inter-electro gap causes improved dreg removal rate that improves flushing conditions which lowers resolidified material on machined surface resulting decrease in WLT. However decreased in WLT was observed initially with increasing in powder concentration but slight increase in WLT was noticed with further increasing in powder concentration. This may be due to the addition of graphite powder improves dielectric conductivity causes widening the inter electrode gap resulting uniform distribution of discharge energy and lowers the discharge energy for single spark that increases sparking frequency which lowers the amount of heat available at work surface resulting reduced WLT.

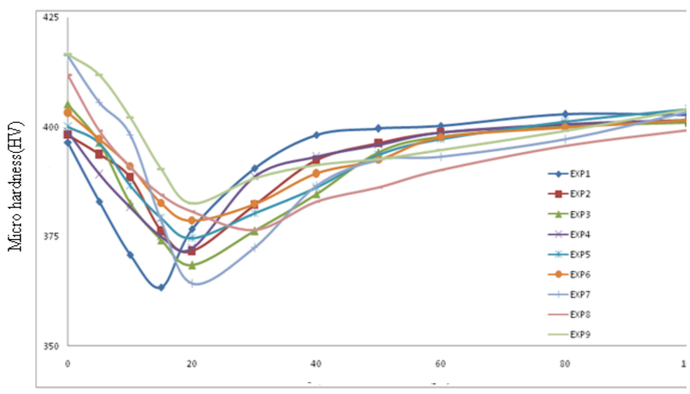

Fig. 1: variation of micro hardness along depth from the machined surface on all experimental samples

Fig 2 suggests that WLT value was found to be minimum when process parameters are peak current is at 10A (level 1), surfactant concentration is at 4g/lt (level 1) and graphite powder concentration is at 9g/lt(Level2). Further optimum value of white layer thickness was calculated at above optimal parametric setting as 12.111 μm and corresponding S/N ratio as -22.2883. Analysis of variance (ANOVA)has been performed to find significance of input parameters. From ANOVA calculated values of F and P reveals that peak current and surfactant concentration have significant effect on WLT whereas graphite powder concentration has less significant effect on WLT.

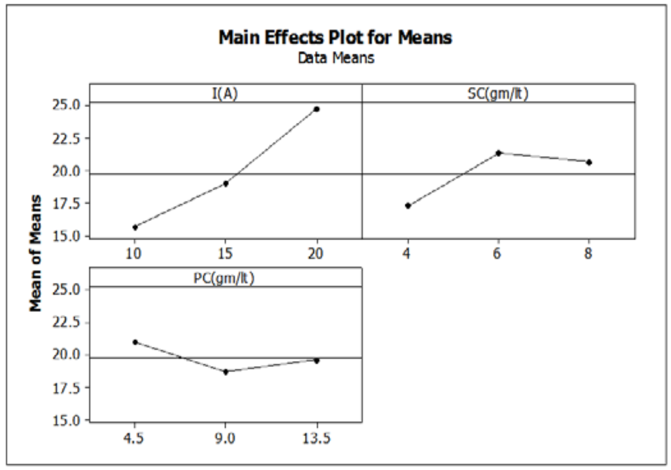

Fig. 2: The effect of process parameters on WLT

Table 3: Experimental results for the EDM responses SR, WLT, SH and DHAZ

Exp. No.	I(A)	SC (g/lt)	PC (g/lt)	WLT (μm)	S/N WLT	DHAZ (μm)	S/N DHAZ
1	10	4	4.5	14	-22.92	32	-30.10
2	10	6	9	16	-24.08	34	-30.10
3	10	8	13.5	17	-24.60	37	-31.12
4	15	4	9	16	-24.08	36	-31.12
5	15	6	13.5	20	-26.02	42	-32.46
6	15	8	4.5	21	-26.44	45	-33.06
7	20	4	13.5	22	-26.84	46	-33.25
8	20	6	4.5	28	-28.94	56	-34.96
9	20	8	9	24	-27.60	50	-33.97

3.2. Effect of process parameters on depth of heat affected zone (DHAZ)

Underneath the re-solidified white layer a second layer lies which is not melt but is affected by heat conducted into the work piece. For steel during cooling cycle, solid state transformation occurs in this heat affected zone (HAZ) because the highest temperature reaches behind the austenite transformation temperature. This heat affected layer transforms mostly to martensite along with some retained austenite [8].The estimated values of DHAZ for all experimental samples which are calculated from respective micro hardness profiles and their corresponding S/ N ratio values are presented in Table3. The individual effect of peak current, surfactant concentration and Graphite powder concentration on the response values of DHAZ is presented in Fig3.

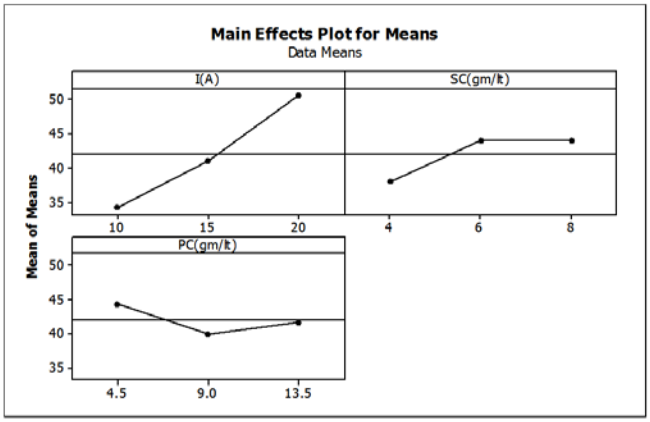

Fig. 3: The effect of process parameters on DHAZ

From the Fig3 it is observed that DHAZ increases with increasing of peak current. This can be due to increase of peak current causes spark energy increases that makes more amount of heat energy conducted in to the work piece results more depth of heat affected zone. However DHAZ increases initially with increasing of surfactant concentration but no change was found in it with further increasing surfactant concentration. The addition of surfactant into the dielectric fluid increases dielectric conductivity, which shortens the relay time of discharge. Thisimproves heat conducted in to the work resulting increase in DHAZ. Further it is also noticed from the Fig3 that DHAZ decreases with increasing in graphite powder concentration from 4 to 9 g/lt whereas increase in it was noticed with increasing of powder concentration from 9 to 13.5 g/lt. Increasingof powder concentration reduces insulating strength of dielectric in the gap that causes more uniform distribution of spark energy and decrease in amount of energy per spark which resulting less amount of heat penetrated into the work piece makes decrease in DHAZ. On the other hand a higher powder concentration causes more accumulation of powder particles in the gap resulting unstable machining that increases DHAZ.

Fig3 suggests that DHAZ is observed to be minimum when the input parameters are peak current is at 10 A (level 1), surfactant concentration is at 4 g/lt (level 1) and graphite powder concentration is at 9 g/lt (level 2). Further the optimum DHAZ value is calculated at optimal parametric settings as 28.333 µm and corresponding S/N ratio value is-29.4497. The significance of each individual process parameter on the DHAZ is identified by analysis of variance of DHAZ values and it is identified as all the three parameters having significant effect on depth of heat affected zone. From the calculated F value and P values it is noticed that peak current is the most significant parameter follows surfactant concentration is significant parameter and then graphite powder concentration is less significant parameter affecting of DHAZ.

4. CONFIRMATION EXPERIMENTS

To verify the predicted optimal values of WLTand DHAZ, confirmation experimentwas conducted at their optimal parametric setting .The data from the confirmation experiment and its comparisons with respective predicted values and the deviation of predicted results from experimental results are calculated as percentage error and are presented in Table4..

$$\%error = \frac{experimentalvalue - predictedvalue}{experimentalvalue} \times 100$$

Table 4: confirmation tests and their comparison with results

S. No.	Optimum parameters			Response	Experimental value	Predicted value	%error
	I(A)	SC(g/lt)	PC(g/lt)				
1	10	4	9	Min.WLT (µm)	13	12.111	6.84
2	10	4	9	Min .DHAZ (µm)	30	28.333	5.55

5. CONCLUSIONS

Based on the experimental results in the present study, the following conclusions are drawn:

1. WLT and DHAZ are increasing with increase of peak current.
2. WLT values first increases till reaching maximum value then it decreases further with increasing of surfactant concentration. Whereas DHAZ increases with increasing of surfactant concentration form 4 to 6 g/lt but no change in DHAZ was noticed with further increase of surfactant concentration from 6 to 8 g/lt.
3. WLT and DHAZ are decreasing with increase of powder concentration from 4.5 to 9 g/lt, then increase in WLT and DHAZ were noticed with further increase in powder concentration from 9 to 13.5 g/lt.
4. Based on the results of ANOVA analysis, peak current is most significant parameter affecting WLT and DHAZ. Whereas surfactant concentration has less significant effect on DHAZ and has most significant effect on WLT. However powder concentration has less significant effect on WLT and DHAZ.
5. Further optimal parametric settings are established for WLT and DHAZ and corresponding optimum values are calculated. Confirmation experiment is conducted at respective optimal parametric setting to verify predicted optimum values.
6. One more observation made from this study is material having lower hardness than base material hardness in the region of HAZ. Hence possibility of crack initiated in the machined surface is penetrated in to the base metal through HAZ is very less.

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