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Effect of Alloying Content on Surface Roughness of Die Materials at Optimal Parametric Condition using WEDM

[1] U. K. Vates, [2]N. K. Singh and [3]R. V. Singh

[1]Research Scholar Deptt of Mech Engg, ISM Dhanbad India;
[2]Deptt of Mech Engg ISM Dhanbad;
[3]Deptt of Mech Engg, MRIU Faridabad India

Abstract

In this paper, the effect of process parameters in Wire Electrical Discharge Machining (WEDM) process like gap voltage (V_g), dielectric flush rate (F_r), pulse on time (T_{on}), pulse off time (T_{off}) have been investigated to determine their impact on surface roughness using single variable at a time approach (SVATA) on different tool and die steels (EN31, D2 and HSS T42), which having different chemical compositions. The optimal selection of influencing process parameters of steels (on the basis of Carbon and Chromium %) was predicted to minimize the surface roughness (R_a) at corresponding material removal rate (MRR) during WEDM. It is difficult to determine better chemical combinations among three different steels to improve its surface finish during complex WEDM process. WEDM process was developed to generate precise cutting and fine finishing work on complicate, hard and difficult to machine die and mould materials. It is also evident that electrical conductivity of materials, total alloying contents and few of their interactions have significant effect on R_a as well as MRR. Therefore, a new way has been achieved for selecting the carbon & chromium composition in steels to optimize the surface roughness under WEDM. It is observed that surface roughness decreases with increase in the pulse off time and gap voltage, and it decreases with decrease in the pulse on time but moderate and sometimes high flush rate leads to improve surface finish at optimal MRR. Cold worked hard die steel D2 has been selected as best performing die steel on the basis of its high Carbon and Chromium combination among three steels to get optimal values of surface roughness (R_a) with corresponding MRR under WEDM.

Keywords: WEDM, Surface Roughness, MRR, SVATA.

INTRODUCTION:

Wire Electrical Discharge Cutting (WEDC) is the metal removal process by means of repeated spark created between the wire electrode and work piece. It is considered as unique adaptation of the conventional EDM which uses an electrode to create sparks within kerfs. WEDC process utilizes a regular travelling wire anode made up of very thin copper, tungsten and brass materials of diameter ranging 0. 05- 0. 35, which is used to find very good edge sharpness (Ho K. H et al., 2004). The thermal erosion mechanism during WEDC, primarily makes use of electrical energy and then turns into thermal energy through a series of discrete electrical discharges occurring between thin wire electrode and conductive material work piece immersed in a dielectric medium (Tsai, H. C et al., 2003). The thermal energy generates a channel of plasma between wire electrode and the conductive and hard work material (Shobert, E. I. et al., 1983). However, conclusions from literature have been drawn as very high temperature ranging 8000° C - 12000° C is created within the kerfs gap during machining so that material removal may takes place by not only melting but directly vaporization also (Boothroyd, G.; Winston, A. K. et al., 1989). WEDM Resistance and Capacitance (R-C) circuits deals to convert electrical energy to generate the pulsating or intermittent discharge in the form of sparks with maintaining the desire gap between the electrodes (Bawa, H. S. et al., 2004). The electrically charged wire has the provision to perform the movement in X-Y direction to remove the work piece after each runs of experiment (Qu et al., 2002a, b). The concept of WEDC is illustrated in Fig. 1.

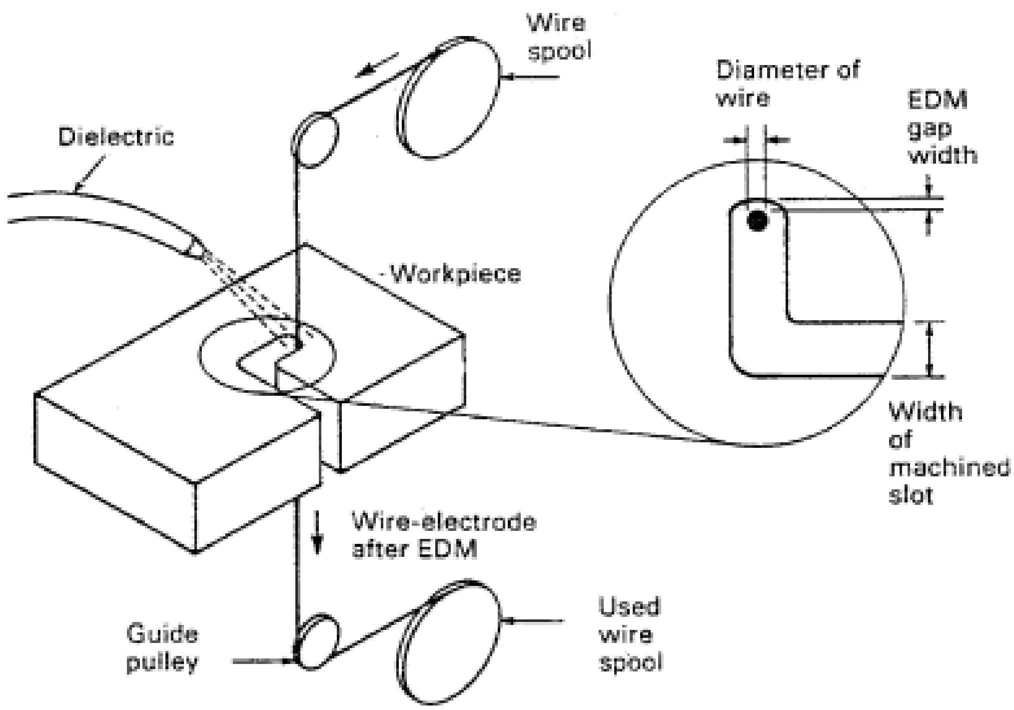


Fig. 1: Schematic Diagram- Wire EDM

Present investigation based on WEDC process parameters (surface roughness, MRR, EWR, Kerfs) affecting with variations of chemical compositions in steel materials, most influencing parameters V_g, F_r T_{on}, T_{off}, and very crucial alloys such as Carbon and Chromium have been selected in hard die steels to obtain the best performing material at optimal parametric combinations for surface smoothness under WEDC. Manufacturing processes (WEDM) has been chosen depending on the material characteristics and the type of responses (SR & MRR with alloys) required to be evaluated. The present investigation aims to optimize responses using SVATA. Scatter plot of surface roughness vs Carbon-Chrome percentage have been plotted for EN31, D2 and HSS T42 steels under the influence of independent variables Vg, F_r T_{on} and T_{off}. R_a and corresponding MRR has been predicted at controlled parametric condition to select one of the best material work pieces for mould and die steels machining using WEDC, where D2 was observed as best performing among others EN31& HSS T42 as for as surface smoothness is concern.

EXPERIMENTAL SETUP

Selection of Materials of Wire Electrode & Work piece:

Chrome coated pure copper electrode wire having 0. 25mm in diameter and high tensile strength of 250 N/mm^2 was selected for conducting machining operation on three die (EN31, D2 and HSS T42) material rods having each 18 mm in diameter and 0. 7 m in length to cut 5 mm thickness of disk under WEDC travelling under controlled conditions. The steel materials selected on the basis of varying alloying elements to observe its effect on R_a with MRR at same input condition on each of the steel material rods.

Machining Conditions:

The experiment was performed on ELECTRONICA-MAXICUT, SL NO-250, (F:09:0002:01), WEDM machine to determine the effect of process parameters on responses to achieve optimal parametric combination for the best surface roughness of steels by WEDM. Specially, SVATA was used for four most influencing input parameters at 5 level variations of each factor to observe its effect on surface roughness and corresponding MRR by keeping others three influencing parameters constant during that set of experiment. The machine setup has been shown in Fig 2. Table. 1 indicates the chemical composition, hardness and conductivity of three different steels.

Fig. 2: WEDM Process

Table 1: Composition and hardness of die materials

Die. Materials	C%	Cr %	HRC	Conductivity (W/mK)
HSS T42	1. 23	3. 80	66	16
D2	1. 50	11. 5 8. 2	56	22
EN31	1. 00	1. 40	63	19

EXPERIMENTAL OBSERVATION ON DIES UNDER WEDC PROCESS:

1st set of reading:

In this experiment gap voltage (V_g) is varied from 20V to 100V with regular increments of 20 units, where the optimum combinations of other parameters; F_r = 6 Lit/min, T_{on} = 1. 05µs and T_{off} = 170 µs are kept constant during each variation in gap voltage.

Table 2: V_g vs. R_a with corresponding MRR values

Vg (v)	EN31		D2		HSS T42	
	R_a (μm)	MRR (mg/min)	R_a (μm)	MRR (mg/min)	R_a (μm)	MRR (mg/min)
20	1. 6536	117	1. 5283	142	1. 7553	183
40	1. 5682	118	1. 4781	122	1. 5663	149
60	1. 3163	98	1. 4135	91	1. 3101	115
80	1. 1680	75	1. 1956	78	1. 1628	112
100	1. 1318	68	1. 0438	62	1. 1314	76

Table. 2 is evident that the values of surface roughness decreases with increase in V_g and also R_a and MRR vary proportionally. The value of R_a in D2 steel is most preferred among other two die materials work piece; which is indicated in Fig. 3. It is also clear that high value of V_g responsible to get minimum R_a.

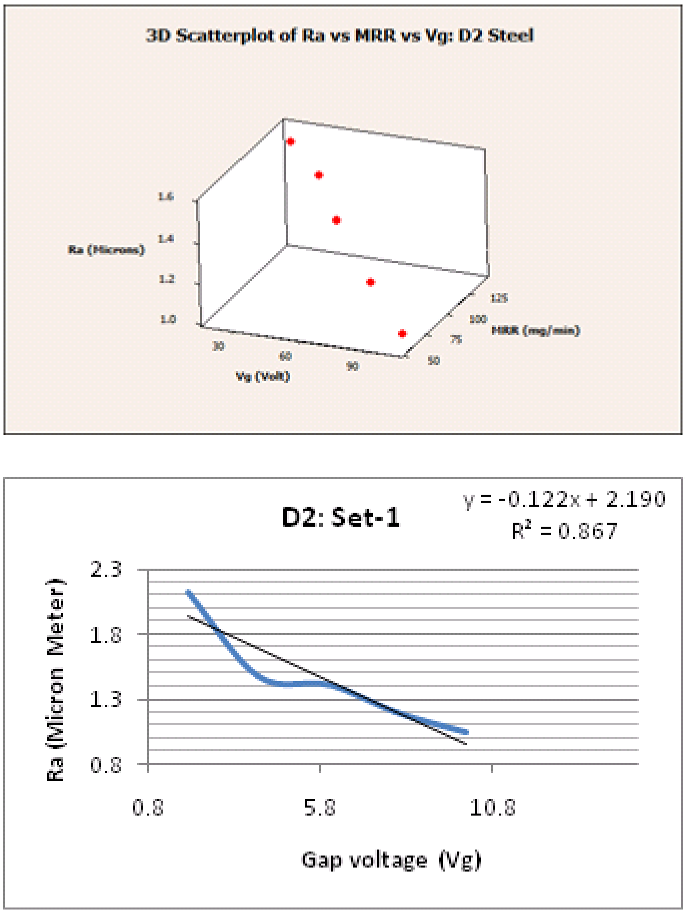


Fig. 3: V_g vs. R_a vs. MRR

2nd set of reading: In this experimental set, flush rate (F_r) is varied from 4 to 8 (L/min) with regular increments of 1 unit, where the values of V_g = 100 V, T_{on} = 1. 05μs, T_{off} = 170μs are kept constant during each variation in flush rate.

Table. 3 indicates the surface roughness decreases with increases the flush rate and lowest R_a in D2 steel has been achieved than others at same inputs.

Table 3: F_r and R_a with corresponding MRR values

Fr (L/min)	EN31		D2		HSS T42	
	R_a (μm)	MRR (mg/min)	R_a (μm)	MRR (mg/mi)	R_a (μm)	MRR (mg/min)
4	1. 6458	119	1. 4325	133	1. 5538	223
5	1. 5734	128	1. 3956	97	1. 5823	168
6	1. 1543	98	1. 1135	103	1. 2141	146
7	1. 1857	112	1. 1464	101	1. 3628	118
8	1. 2318	103	1. 0281	63	1. 3250	143

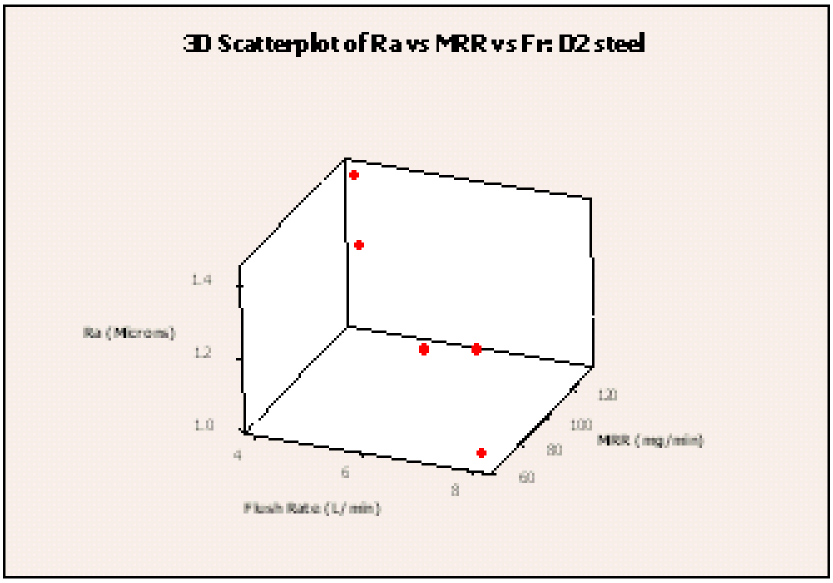


Fig. 4: R_a vs. MRR vs. Flush rate for D2

It is clear from Fig. 4 that the lowest value of surface roughness achieved at high flush rate.

3rd set of reading

In this experimental set pulse-on-time (T_{on}) is varied from 1. 05μs to 1. 25μs with regular increments of 0. 05μs units, where the values of V_g = 100 V, F_r =6 L/min and T_{off} =170 μs are kept constant during each variations in pulse-on-time.

Table 4: T_{on} and R_a with corresponding MRR values

Ton (μs)	EN 31		D2		HSS T42	
	R_a (μm)	MRR (mg/min)	R_a (μm)	MRR (mg/min)	R_a (μm)	MRR (mg/min)
1. 05	1. 146	101	1. 055	79	1. 178	108
1. 10	1. 242	118	1. 125	67	1. 342	145
1. 15	1. 154	124	1. 114	85	1. 255	146
1. 20	1. 186	143	1. 395	97	1. 366	168
1. 25	1. 232	122	1. 513	105	1. 673	193

In the above Table. 4, it is clear that the D2 steel is most preferred than others as for as surface smoothness is concern. Minimum values of R_a achieved on lowest $T_{on.}$ Fig. 5, indicates that better surface finish may be achieved on D2 material at lower T_{on} under design parameters using WEDC.

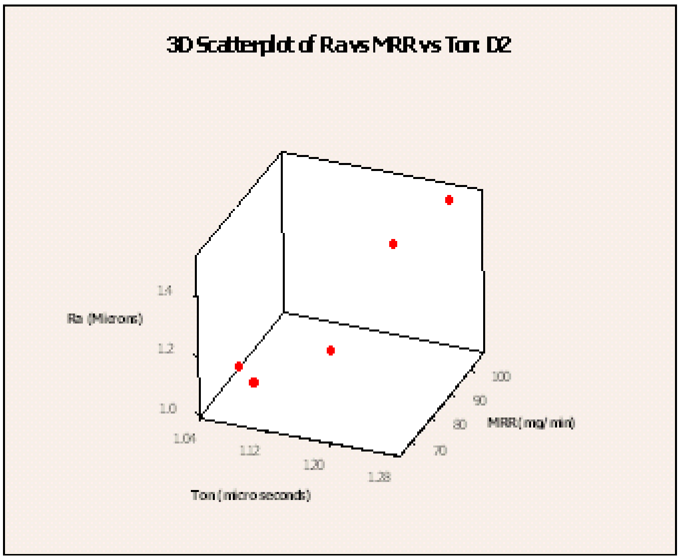


Fig 5: R_a vs. MRR vs. Spark on time for D2

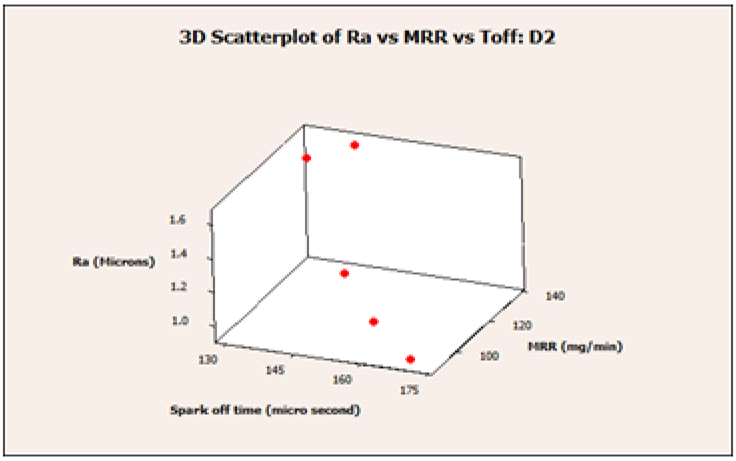
4th set of reading:

In this experimental set pulse off time (T_{off}) is varied from 130 to 170μS (SVATA) with regular increments of 10 units, where the values of Vg = 100 V, Fr =6 L/min, and T_{on} = 1. 05μs are kept constant during each variations in pulse off time.

Table 5: T_{off} and R_a with corresponding MRR values

Toff (µs)	EN 31		D2		HSS T42	
	R_a (µm)	MRR (mg/min)	R_a (µm)	MRR (mg/min)	R_a (µm)	MRR (mg/min))
130	1. 6530	163	1. 5546	135	1. 5272	173
140	1. 2812	135	1. 6453	138	1. 4729	155
150	1. 1932	116	1. 2372	103	1. 4926	156
160	1. 1117	112	1. 0839	93	1. 2683	153
170	1. 0654	103	0. 9438	88	1. 1528	134

In this above Table 5, it is clear that the D2 steel is most preferred due the minimum values of R_a corresponding to the variations in T_{off}. Fig.. 6 indicates the lowest R_a has been achieved at higher value of T_{off}.



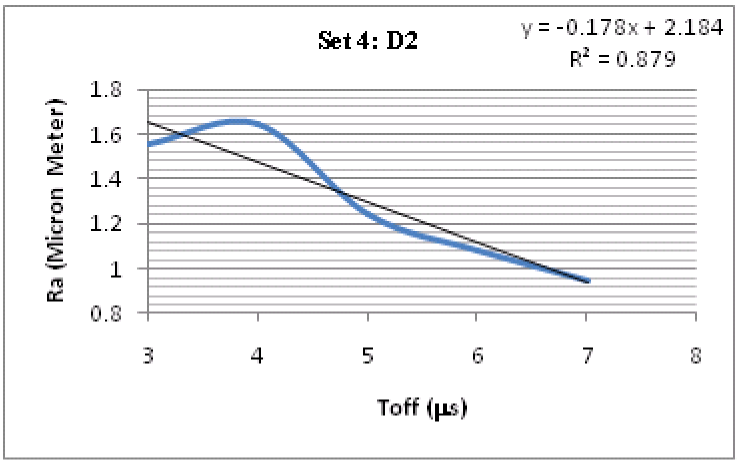


Fig 6: R_a vs. MRR vs. Pulse off time for D2

RESULT:

Analysis of the each Figures (3-6) have been made using SVATA and by keeping the values of other three input parameters constant. Single point has been selected in each Fig. (3-6) at which minimum possible surface roughness is achieved at most likely MRR values. Carbon percent in each steel material is analyzed vs. surface roughness against possible MRR.

The most optimal conditions for different three steels are presented in Table. 6.

Table 6: Optimal parametric conditions using SVATA.

Optimum Combination	EN 31			D2			HSS T42		
	R_a (µm)	MRR (mg/mi)	C%	R_a (µm)	MRR (mg/m	C%	R_a (µm)	MRR (mg/mi)	C%
V_g =100	1. 1318	68	1. 00	1. 0438	62	1. 5	1. 13	76	1. 23
F_r= 8	1. 1543	98	1. 00	1. 1135	63	1. 5	1. 2141	146	1. 23
T_{on}= 1. 05	1. 1458	101	1. 00	1. 0547	79	1. 5	1. 1782	108	1. 23
T_{off} =170	1. 0654	103	1. 00	0. 9438	88	1. 5	1. 1528	134	1. 23
Aver.	1. 12	92. 5	1. 0	1. 035	73	1. 5	1. 165	116	1. 23

It is evident from Table 6 (SVATA) that average R_a of D2 steel (C% = 1. 5) is 1. 035 (µm) at MRR 73 (mg/min), which is lower than other two materials so the effect of C% and Cr% has been observed on surface roughness of each steel in Figures 7-10. Contour plots in figures 6-9 show that high carbon chrome percentage, hardness of materials material and conductivities of die materials (EN31, HSS T42 &D2) play an important role to get the best surface roughness under WEDM at possible optimal conditions.

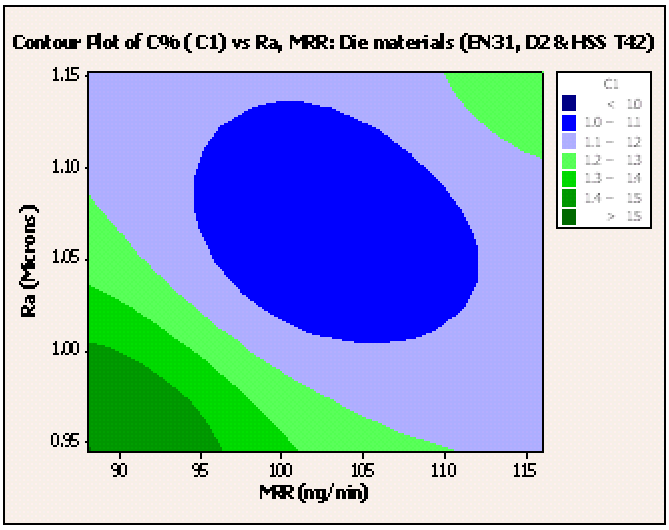


Fig. 7: Contour plot of die steels at Vg = 100, Fr = 6, Ton = 1. 05µs & Toff =

170µs: C% vs. Ra vs. MRR

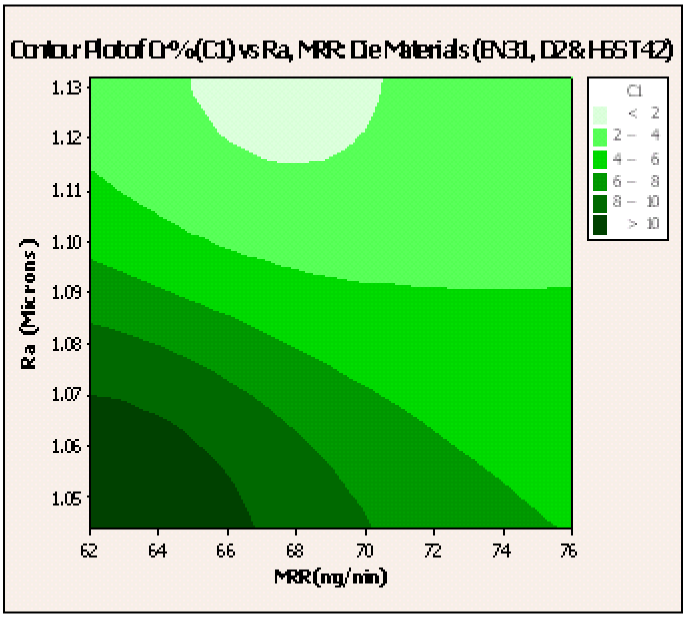


Fig. 8: Contour plot of die steels at Vg =100, Fr = 6, Ton = 1. 05µs & Toff = 170µs: Cr% vs. Ra vs. MRR.

It is very clear that Fig. 7 indicated that lowest values of surface roughness has been achieved at high values of C% in three selected steels (EN31, D2 and HSS T42), similarly high values of Cr % also responsible for lowest R_a as Fig. 8.

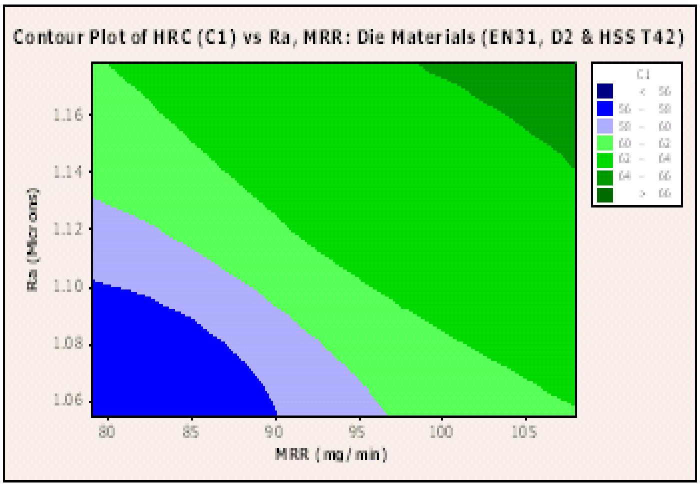


Fig. 9: Contour plot of die steels at Vg =100, Fr = 6, Ton = 1. 05µs & Toff = 170µs: HRC vs. Ra vs. MRR.

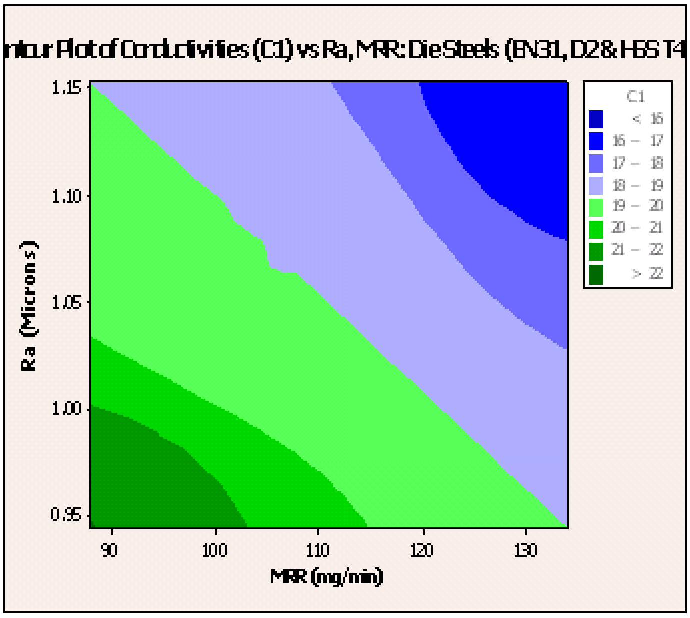


Fig. 10: Contour plot of die steels at Vg = 100, Fr = 6, Ton= 1. 05µs & Toff= 170µs: Conductivities vs. Ra vs. MRR.

Fig. 9 indicated that surface roughness is proportional to the hardness of the steel materials. Lowest R_a has been achieved at D2 soft material than others EN31 and HSS T42. Fig. 10 also indicated that higher the value of electrical conductivity deals the very smooth surface using WEDC.

5. CONCLUSIONS:

The following conclusion has been drawn by analysing experimental results in Tab. 6 and Fig. 7-10:

The D2 steel gives best surface smoothness than EN31, and EN31 gives better surface than HSS T42 at same input parametric conditions.

Surface roughness of die steels decreases with increase of gap voltage, dielectric flush rate and pulse off time whereas surface roughness decreases with decrease of pulse on time under WEDC.

Optimum combinations of individual independent variables are V_g = 100 V, F_r = 8 (L/min), T_{on} = 1. 05µs, T_{off} = 170µs which have been predicted using SVATA. By using this optimum input parametric combinations the best lowest value of surface roughness obtained as 1. 03895µm which is 4. 32% less than average value of R_a and highest possible MRR is 73 mg/min on D2 steel.

Surface smoothness of D2 steel may be further improved by introducing more carbon and chrome content keeping others components and characteristics constant at the same parametric combinations.

Lower hardness (HRC) of die materials (D2 steel among EN31 & HSS T42), having good electrical & thermal conductivity, mostly leads to give more surface smoothness using WEDM under optimal parametric combinations.

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