OPTIMIZATION OF PROCESS PARAMETERS OF ELECTROCHEMICAL DISCHARGE MACHINING USING SDS POWDER

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ABSTRACT:

Electrochemical discharge machining (ECDM) is an emerging non-traditional processing technique that involves high-temperature melting and accelerated chemical etching under the high electrical energy discharged and has potential to machine electrically non-conductive materials such as glass, quartz, composite, ceramics. In ECDM, gas film and sparks are generated on a tool when voltage is applied between the tool and a counter electrode. Work-piece materials are removed mainly by the heat of the sparks. The spark generation is affected by both the voltage and electrolyte conditions. In this present work, The effect of process variables such as electrolyte concentration (EC), duty factor (DF), voltage (V), on response parameters such as Material Removal Rate (MRR), Tool Wear Rate (TWR), Diametric overcut (DOC) have been investigated using Sodium Dodecyl Sulfate (SDS) powder mixed (PMECDM) on soda-lime glass in electrochemical discharge machining (ECDM) using tungsten carbide electrode.

KEYWORDS: Electrochemical Discharge Machining, Material Removal Rate, Soda-Lime Glass, Sodium Dodecyl Powder, Tool Wear Rate

I.INTRODUCTION:

Nonconventional machining processes can be defined as the use of chemical, mechanical, thermal, electrical or combinations of these energies processes to machine a work-piece and remove material without contact between work-piece and tool material. Electrochemical discharge machining (ECDM) is a non-traditional machining method that has been firstly introduced for glass micro drilling by kurafuji and Suda [1]. This process are mainly used for micro-machining of hard and brittle non-conductive materials such as glass (mainly Pyrex, plexi and optical), ceramic, refractory bricks, quartz and composite materials. This has attracted extensive research interests because of additional advantage of machining electrically non-conductive materials.[2]

The ECDM process consists of a cathode tool and an anodic workpiece, which are separated by a gap filled with electrolyte (which is Depending upon the tool and workpiece material, the commonly used electrolytes are NaOH, NaCl, KOH, NaNO3, HCL, H2SO4, NaF etc.) and pulsed direct current (DC) power applied between them. And connected to a D.C. power supply, consequently when a voltage higher than a critical value is applied, electrolysis in the solution starts and hydrogen bubbles grow so dense on the tool electrode (cathode) that they coalesce into a gas film. The gas film acts as an insulating layer around the tool and provides electrical potential difference between the tool and electrolyte. This leads to electrical discharges between the electrodes, thus achieving both electro chemical dissolution and electro discharge erosion of the workpiece [1]. One of the major advantages of ECDM, over ECM or EDM, is that the combined metal removal mechanisms in ECDM, yields a much higher machining rate [2].Despite the considerable amount of research, which has been reported on the theoretical aspects and laboratory experiments, there are many aspects of the process control issues that are yet to be investigated for the achievement of improved productivity of the ECDM process. It is clear that the overall performance of the ECDM process can be increased by maintaining the electrode gap at an optimum value. Because the electrochemical discharge process is highly depended on the availability of the electrolyte in the machining zone, electrochemical discharge drilling with high aspect ratio faces various limitations.
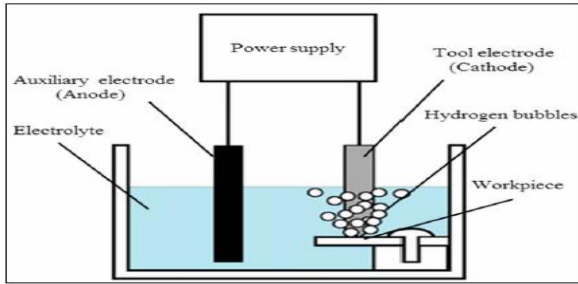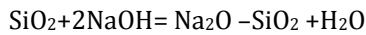
Figure 1 shows the principle of ECDM

The electrochemical reaction for soda-lime glass workpiece ECDM is,

$$SiO_2 + 2NaOH = Na_2O - SiO_2 + H_2O$$

The sodium ion (Na+) and the hydroxide ion (OH-) in the electrolyte are adsorbed on the glass surface; the -Si-O-Si- bond is broken and changed into the -Si-O-Na- bond.
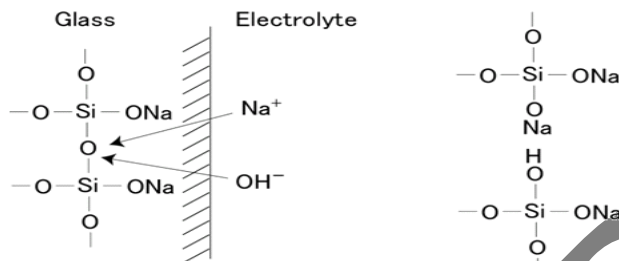

Figure 2 Chemical Reaction of Soda-Lime Glass Workpiece

The performance of the process depends on many parameters like tool-electrode material, electrode size and shape, wet ability characteristic of tool-electrode, feed-rate, work-piece material, applied voltage, current, duty cycle, pulse duration, electrolyte, its concentration and temperature, gap between tool-electrode and workpiece, distance between cathode and anode, anode material, etc.

II. LITERATURE SURVEY:

B. Mallick, M.N. Ali, B. R. Sarkar, B. Doloi, B. [1] (2014) - They carried out experimentation and presented parametric analysis, that ECDM can be used with great potential to machine electrically non-conducting harder brittle materials such as glass and can also be employed for micro-channel cutting applications. They draw the following conclusions ECDM system. Baoyang Jiang, Shuhuai Lan, Jun Ni, Zhaoyang Zhang [2] (2014) – studied the process modeling of ECDM with respect to spark generation and material removal. Tapered tool electrodes were employed as tool electrode whereas energy distribution curve and finite element method was used to study the outputs for spark generation and material removal rate. They concluded as tapered tool improved the consistency of spark generation and suppressed the generation of minor discharges prediction of material removal is reasonable in terms of diameter and maximum depth of machined holes. Y.S. Laio, L.C. Wu, W.Y. Peng [3] (2013) - They studied the effects of Sodium Dodecyl Sulphate (SDS) surfactant added electrolyte on machining quartz in electrochemical discharge machining (ECDM). Experimental results show that, as current density is increased, there is more bubble release around the electrode. The sparks become brighter and take place in a larger area and more stable pulse current is obtained. As a result, a less taper and a better quality but a little over size hole can be drilled with a higher engraving speed. Based on the observation of sparking process together with the experimental results, a new bubble forming mechanism during ECDM when SDS added electrolyte used is inferred. B. Bhattacharyya and J. Munda [11] (2004) – in this paper, the advantages of ECDM over other machining process as absence of burr, bright surface finish and ability to machine complex shapes regardless of its hardness is expressed. They also found that, the material for tool should be chemically inert and should have good electrical conductivity. Need to use freash electrolyte everytime is essential because precipitate of electrolyte may damage the tool and will affect MRR. Flow of electrolyte has effect on machining accuracy.

III. EXPERIMENTAL SETUP:

For this experimentation, we have selected Soda-lime glass as a work piece material. Tungsten Carbide with cylindrical geometry is used as a cathode tool. All experiments has been carried out on ECDM machine. For work-piece and tool preparation we used diamond cutter and cylindrical grinder. In pre-processing the work pieces and tools were weighing on the Citizon AX 220 digital weighing machine. It is having a least count of 0.1 mg. After machining had done, again we measured weights of tools and work-pieces on same machine for calculation of material removal rate and tool wear rate values. For diametric overcut, diameter of tool is measured by Digital Vernier Calliper and diameter of hole of work-pieces is measured on Machine vision measuring system unit.

Table 1 Chemical Composition of soda-lime glass[1]

Elements	SiO$_2$	Na$_2$O	CaO	MgO	Al$_2$O$_3$	K$_2$O	SO$_3$
Weight %	72	13	10.5	2.4	0.6	0.4	0.3

Table 2 Physical Properties of soda-lime glass[1]

Youngs Modulus (psi)	9.8×10^6
Coeff. Of Expansion	89×10^{-7} cm/cm/ oC
Poisson Ratio	0.22
Density (mg/mm3)	2.52 g/cm3
Hardness (Mohs)	5.5
Strain Point	511 ˚C
Anneal Point	545 ˚C
Soften Point	724 ˚C

Sodium Dodecyl Sulphate also known as sodium laurel sulphate and it is a surfactant have long chain alkyl (like fatty acid, etc.) is lipophilic group.

PHYSICAL AND CHEMICAL PROPERTIES OF SDS POWDER:
Chemical formula of SDS - $CH_3(CH_2)_{11}OSO_3Na$
Molecular weight - 288.38 g/mol
Odour -Slight fatty odour
Molar mass – 288.37 g/mol
Solubility -10g/100g water
Melting point – 206^0C
Density – 1.01 g/ cm^3
pH - 6.0-7.5

In electrochemical discharge machining, electrolyte is very reactive with metal. So we designed the machining chamber made of Acrylic material and bonded with chloroform which is chemically not reactive with NaOH and transparent enough to see level of electrolyte when poured in it. Special slider fixture made of SS (which is non-corrosive with NaOH electrolyte) material designed in chamber with allen bolt to fix work-piece in it. The chamber dimensions are (100 × 100 ×80) mm having 8 mm thickness. The figure shows the acrylic chamber.
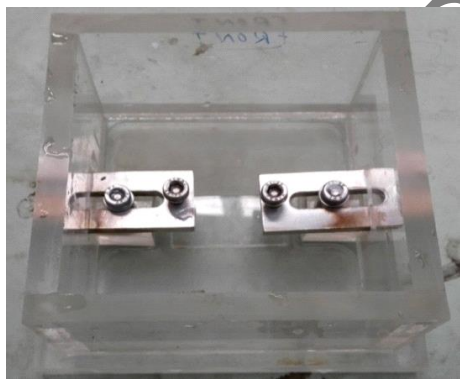

Figure 3: Acrylic chamber

IV. **EXPERMIENTAL CONDITIONS**:
Following machining parameters are kept constant selected on performance characteristics,

Sr. No.	Machining Condition	Specification
1	Work-piece material	Soda-lime Glass
2	Tool electrode material	Tungsten Carbide
3	Auxiliary tool material	Nickel
4	Machining time	20 min
5	Level of electrolyte	1 mm (above w/p)
6	Distance between anode to cathode	45 mm
7	Tool feed rate	1.67 μm/sec
8	Area ratio anode to cathode	50:1
9	Gap between cathode tool and workpiece	25 μm
10	Temperature	Ambient 27° C

With reference to literature survey, the following parameters were considered as variable input parameters,

1. **Voltage (V):** The D.C voltage is applied between cathode and anode from D. C. power supply system.
2. **Duty factor (%):** The ratio of the pulse on time to the pulse on and pulse off time (total pulse time) is called as duty factor.
3. **Electrolyte Concentration** (wt %): It is expressed in % by wt, which indicates the weight of the NaOH dissolved per 100 ml demineralised water to prepare the aqueous electrolyte.
4. **Sodium dodecyl sulphate powder Concentration (weight %):** It is expressed in % by weight, which indicates the weight of the SDS powder dissolved per 100 ml water. Electrolyte solution is prepared first and then it is allowed to cool down. SDS powder is added into that electrolytic solution. Size of the graphite powder particles is 12-15 μm (1200 mesh size).
The decision variables were,
1. **MRR (mg/min):** Material removal rate is calculated by taking weight work-piece before and after the machining and dividing it by machining time. Or "the ratio of the volume of material removed from the work-piece with respect to the machining time"

$$MRR \ (mg/min) = \frac{initial \ wt. of \ workpiece - final \ wt. \ of \ workpiece}{time}$$

2. Tool wear rate (mg/min) – Tool wear rate is calculated by taking weight tool before and after the machining and dividing it by machining time. Or "the ratios of the volume of material wear from the tool surface with respect to the machining time"

$$TWR \ (mg/min) = \frac{initial \ wt. of \ tool - final \ wt. \ of \ tool}{time}$$

3. Diametric over cut (mm) - It is the difference between machined hole diameter and tool diameter. It is measured on vision machine system.

DOC (mm) = Diameter of Hole – Diameter of Tool

As discussed above, the different input parameters were selected form the literature survey. The variation in the input parameters is done to carry out the experimentation and plackett burman method of design of experiment is selected to run the experiments.

Table 3: Input parameters for experiments[7]

Std Order	Run Order	PtType	Blocks	Volt	Duty Factor	Elec.Conc
4	1	1	1	75	75	35
5	2	1	1	75	85	25
10	3	1	1	75	75	25
1	4	1	1	75	75	35
11	5	1	1	65	85	25
6	6	1	1	75	85	35
3	7	1	1	65	85	35
12	8	1	1	65	75	25
2	9	1	1	75	85	25
7	10	1	1	65	85	35
9	11	1	1	65	75	25
8	12	1	1	65	75	35

After conducting various trails experiments, levels of input parameters with respective range are finalized.

Table 4: Levels of input parameters

Parameters	Levels		
	Level 1	Level 2	Level 3
Electrolyte Concentration 'EC' (gm/l)	25	30	35
Duty Factor 'DF' (%)	75	80	85
Applied voltage 'V' (V)	65	70	75
SDS powder (gm/l)	0.1	0.1	0.1

After finalizing range and levels of input parameters and required response parameters final experimentation is done. For final experimentation the D.O.E is preferred is RSM Box- Behnken design plan.

Table 5: Run Order of Experiments

Std Order	Run Order	Pt Type	Voltage	Duty Factor	Elect. Conc	SDS powder
9	1	2	70	75	25	0.1
14	2	0	70	80	30	0.1
8	3	2	75	85	30	0.1
2	4	2	75	80	25	0.1
13	5	0	70	80	30	0.1
4	6	2	75	80	35	0.1
12	7	2	70	85	35	0.1
11	8	2	70	85	25	0.1
1	9	2	65	80	25	0.1
7	10	2	65	85	30	0.1
6	11	2	75	75	30	0.1
5	12	2	65	75	30	0.1
10	13	2	70	75	35	0.1
15	14	0	70	80	30	0.1
3	15	2	65	80	35	0.1

Acrylic material is chosen for machining chamber because it is transparent so electrolyte level can be clearly seen. It does not react with NaOH solution.

V.RESULTS AND DISCUSSION

Experimentation is carried out by using Box-Behnken design with sodium dodecyl sulphate constant concentration and values of response parameters are noted down as below.

Table 6: Response table

Std. Order	Run Order	SDS Powder	Voltage	Duty Factor	Elec. Conce	MRR (mg/min)	TWR (mg/min)	DOC (mm)
9	1	0.1	70	75	25	0.59	1.8	0.2444
14	2	0.1	70	80	30	0.71	1.96	0.2593
8	3	0.1	75	85	30	0.76	2.035	0.3514
2	4	0.1	75	80	25	0.615	2.2	0.2573
13	5	0.1	70	80	30	0.71	1.93	0.2378
4	6	0.1	75	80	35	0.995	2.3	0.1996
12	7	0.1	70	85	35	1.075	1.94	0.2264
11	8	0.1	70	85	25	0.62	1.995	0.1993
1	9	0.1	65	80	25	0.385	1.84	0.1007
7	10	0.1	65	85	30	0.57	1.8	0.1462
6	11	0.1	75	75	30	0.89	2.09	0.2838
5	12	0.1	65	75	30	0.415	1.58	0.3916
10	13	0.1	70	75	35	0.78	1.755	0.2932
15	14	0.1	70	80	30	0.713	1.95	0.259
3	15	0.1	65	80	35	0.695	1.79	0.2933

GREY RELATIONAL ANALYSIS TO OPTIMIZE RESPONSE PARAMETERS:

In order to obtain the required output utilizing minimum resources, it is very much essential to follow optimal combination of process parameters. The optimal parameter setting for a particular response may be unfavorable for other responses. So, a multi-objective optimization needs to be carried out to obtain an optimal parameter setting. In GRA, the experimental values of the measured quality feature are normalized within a range of zero to one. This can be identified as "grey relational generation". The "grey relational coefficient (GRC)" is then computed. Overall performance characteristic depends on the computation of the "grey relational grade (GRG)".[5][6]

The highest GRG will be evaluated as the optimal parametric combination. For "grey relational generation", the MRR consequent to "higher the better" principle is given as:

$$x_i^*(k) = \frac{x_i^{(o)}(k) - max\ x_i^{(o)}(k)}{max\ x_i^{(o)}(k) - min\ x_i^{(o)}(k)} \qquad (1)$$

TWR and DOC subsequent to "lower the better" condition as specified as,

$$x_i^*(k) = \frac{max\ x_i^{(o)}(k) - x_i^{(o)}(k)}{max\ x_i^{(o)}(k) - min\ x_i^{(o)}(k)} \qquad (2)$$

Where $x_i(l)$ is obtained "grey relational generation", min $y_i(l)$ is the least value of $y_i(l)$ for the lth response and max $y_i(l)$ is the highest value for the lth response where l = 1,2,3,4 for the various output responses considered in a sequence. The data after normalization for "grey relational generation" GRC is computed to establish a correlation between the finest data and the definite normalized data. The GRC is calculated as:

$$\gamma(x_0(k), x_i(k)) = \frac{\Delta_{min} + \zeta\,\Delta_{max}}{\Delta_{oi}(k) + \zeta\,\Delta_{max}} \quad (3)$$

The GRG can now be formulated as:

$$\gamma(x_o, x_i) = \frac{1}{m}\sum_{i=1}^{m}\gamma(x_0(k), x_i(k)) \quad (4)$$

With n being the number of output responses. The higher is the value of GRG, the closer is the subsequent arrangement of parameters to the optimum solution.

Table 7: S/N ratio of response parameter

Run	MRR	S/N	TWR	S/N	DOC	S/N
1	0.59	-4.583	1.8	-5.1055	0.2444	12.238
2	0.71	-2.9748	1.96	-5.8451	0.2593	11.724
3	0.76	-2.3837	2.035	-6.1713	0.3514	9.08397
4	0.615	-4.2225	2.2	-6.8485	0.2573	11.7912
5	0.71	-2.9748	1.93	-5.7112	0.2378	12.4758
6	0.995	-0.0435	2.3	-7.2346	0.1996	13.9968
7	1.075	0.62817	1.94	-5.756	0.2264	12.9025
8	0.62	-4.1522	1.995	-5.9989	0.1993	14.0099
9	0.385	-8.2908	1.84	-5.2964	0.1007	19.9394
10	0.57	-4.8825	1.8	-5.1055	0.1462	16.7011
11	0.89	-1.0122	2.09	-6.4029	0.2838	10.9398
12	0.415	-7.639	1.58	-3.9731	0.3916	8.14315
13	0.78	-2.1581	1.755	-4.8855	0.2932	10.6567
14	0.713	-2.9382	1.95	-5.8007	0.259	11.734
15	0.695	-3.1603	1.79	-5.0571	0.2933	10.6538

From the S/N ratios of each response parameters, normalized values are obtained by using equation (1), [1- normalized value] gives deviation sequence value. By assuming =0 , =1 and =0.5 and referring equation (3) Grey relational coefficient is obtained for every run of experiment. Average of all GRC of same experiment run is calculated by using equation (4), that value is GRG of that particular experimental run. The values for GRC and GRG for each run with the rank order are furnished in table. Higher value of GRG leads to the optimum or close to the optimum combination of input parameters.

Table 8: GRG calculations

| Normalised S/N ratios			Deviation sequence			GRCoeff			GRG
MRR	TWR	DOC	MRR	TWR	DOC	MRR	TWR	DOC	
0.416	0.347	0.653	0.584	0.653	0.347	0.4611	0.4337	0.5902	0.4950
0.596	0.574	0.696	0.404	0.426	0.304	0.5531	0.5399	0.6222	0.5718
0.662	0.674	0.920	0.338	0.326	0.080	0.5969	0.6053	0.8624	0.6882
0.456	0.882	0.691	0.544	0.118	0.309	0.4790	0.8086	0.6179	0.6351
0.596	0.533	0.633	0.404	0.467	0.367	0.5531	0.5170	0.5765	0.5489
0.925	1.000	0.504	0.075	0.000	0.496	0.8691	1.0000	0.5019	0.7903
1.000	0.547	0.597	0.000	0.453	0.403	1.0000	0.5245	0.5534	0.6926
0.464	0.621	0.503	0.536	0.379	0.497	0.4826	0.5689	0.5013	0.5176
0.000	0.406	0.000	1.000	0.594	1.000	0.3333	0.4569	0.3333	0.3745
0.382	0.347	0.275	0.618	0.653	0.725	0.4473	0.4337	0.4080	0.4297
0.816	0.745	0.763	0.184	0.255	0.237	0.7311	0.6623	0.6784	0.6906
0.073	0.000	1.000	0.927	1.000	0.000	0.3504	0.3333	1.0000	0.5612
0.688	0.280	0.787	0.312	0.720	0.213	0.6155	0.4098	0.7012	0.5755
0.600	0.560	0.696	0.400	0.440	0.304	0.5556	0.5321	0.6216	0.5698
0.575	0.332	0.787	0.425	0.668	0.213	0.5407	0.4282	0.7014	0.5568
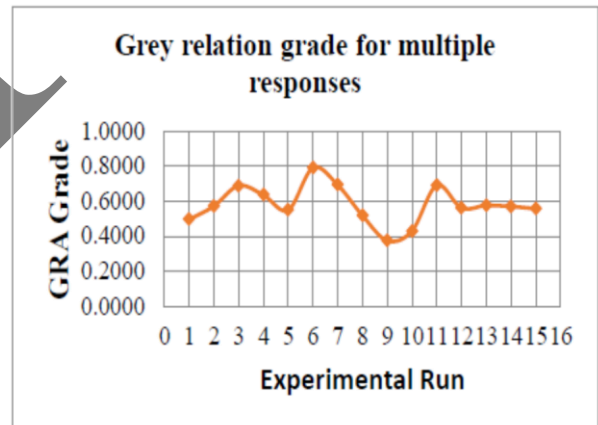
Figure 4: Grey relation grade for multiple responses

From the above table it can be seen that the experimental run 6 is the best multiple performance characteristics having highest preference order, hence it is optimum setting followed by run 7 and 11. The optimal parametric combination can be determined by higher values of preference number.

Table 9: Grey relational grade ranking

Run	Rank	GRG
6	1	0.790329
7	2	0.692634
11	3	0.690565
3	4	0.688208
4	5	0.635134
13	6	0.575465
2	7	0.571765
14	8	0.569777
12	9	0.561246
15	10	0.556772
5	11	0.548878
8	12	0.517625
1	13	0.495029
10	14	0.429669
9	15	0.374529

Table 10: optimum input parameters

	Level 1	Level 2	Level 3	Delta	Rank	Optimum Parameter
Voltage A	0.4479	0.5704	0.7473	0.2994	1	A3
Duty factor B	0.6349	0.5854	0.5340	0.1009	3	B1
Elec. Conc	0.5082	0.5699	0.6876	0.1794	2	C3

The optimal parametric combination can be determined by higher values of preference number. For all the levels, mean GRG can be given in the similar manner as shown in table

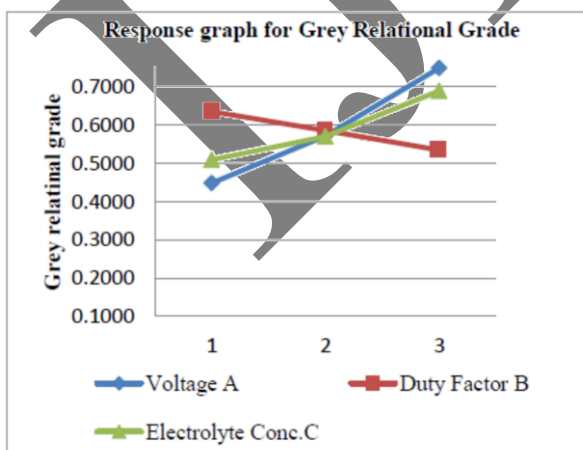| Optimum setting of parameter		
Voltage (Volt)	Electrolyte Conc. (wt%)	Duty Factor (%)
75	35	75

Figure 5: Response graph grey relation grade

After the estimation of optimum setting of parameters, prediction and confirmation for the development of quality attributes using the optimum setting experiment is carried out. The optimum setting obtained from the grey relational analysis gives an increased material removal rate (mg/min) range of 0.84 to 1.18 with low tool wear rate (mg/min).

Optimum setting	MRR (mg/min)	TWR (mg/min)	DOC (mm)
$V_3EC_3DF_1$	Range (0.8-1.18)	1.55–1.99	0.1464–444

VI. CONCLUSION:

From the conducted experiments and statistical analysis the following conclusion are made

1) The SDS surfactant effects on ECDM and the current density is enhanced due to the bubble structure shift.
2) Tungsten carbide is found to be suitable tool for machining soda-lime glass.
3) Material removal rate is increased with increase in voltage and electrolyte concentration by weight.
4) Voltage has large influence on tool wear rate and TWR increase with increase in voltage.
5) Duty factor has large influence on diametric over cut and DOC is highest at 75% decrease with increase in duty factor.
6) When 1 gm/l of sds powder is added, the material removal rate values are increased to a range of 0.38 to 1.075(mg/min) and the tool wear rate values decreased to a range of 1.58 to 2.3 (mg/min).
7) The optimal setting of process parameters is found to be SDS = 1 g/l, Duty factor = 75% Electrolyte concentration = 35 (wt %) and Voltage = 75 V from GRA for powder mixed machining.

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