DOE based investigation for C40 and C90 material to improve the surface attributes using EDM

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Abstract- The manufacturing sector has undergone a sea of change in the recent years. Several applications demanding modern machinery, technology, materials etc have been developed. This ever-changing radical scenario has led to the demand of materials for applications involving high temperatures, corrosion and oxidation resistance, better strength to weight ratio, hardness etc. These exotic materials possess properties that result in superior product performance; nevertheless, it becomes difficult to machine these materials by conventional methods. Hence Unconventional processes like EDM, ECM etc have been found suitable for machining of such materials. In EDM the Sink-EDM process has been the most preferred machining process for die making as surface attributes of dies such as surface finish, dimensional accuracy etc. are of great significance with respect to the products manufactured. The most important performance measure in EDM is the surface finish; among other measures material removal and tool wear rates could be listed. In the present work, experiments have been conducted to determine the parameters affecting Surface finish. The data obtained for performance measures have been analyzed using the proven Design of Experiments (DOE).

Index Terms- : EDM, MRR, RaT, RaW.

I. INTRODUCTION

The current manufacturing scenario has led to the demand of materials for applications involving high temperatures, corrosion and oxidation resistance, better strength to weight ratio etc. These newly developed materials have high strength and stiffness at elevated temperatures, extreme hardness, high brittleness and strength to weight ratio, high corrosion and oxidation resistance along with chemical inertness. Although such properties result in superior product performance; nevertheless, it is difficult to machine these materials by conventional methods. This situation has given a new impetus to the development of non-traditional machining processes since early 1940's, where in material have been removed by mechanical means (USM, AJM, WJM), thermal erosion (EDM, LBM, EBM), anodic dissolution (ECM), chemical reaction or combination of two or more than two processes called hybrid machining (EDAG, ECSM).

The Electro Discharge Machining (EDM) process can be compared with the conventional cutting process, except for the fact that, in this case a suitably shaped tool electrode with a precision controlled feed movement is employed in place of the cutting tool & cutting energy is provided by means of short duration electrical impulses.

The EDM process works on the principle of controlled erosion of the material by repetitive electric sparks between the work piece and the tool submerged in a bath of the dielectric medium. The work piece and electrode are separated by a spark gap across which the dielectric fluid flows. A servo system maintains the working gap for continuous operation. During the EDM process, a series of non-stationary, timed electrical pulses remove material from the work piece. The electrode and the workpiece are held by the machine tool, both of which remain submerged in the dielectric medium. A power supply controls the timing and intensity of the electrical charges of the electrode in relation to the workpiece.

In EDM, a power supply delivers high-frequency electric pulses to the tool and the workpiece. The gap between the tool and workpiece is flushed with a stream of dielectric liquid. When an electric pulse is delivered from the power supply, the insulating property of the dielectric fluid is momentarily broken down. This allows a small spark (discharge) to jump the shortest distance between the tool and workpiece. A small pool of molten metal is formed on the workpiece and the tool at the point of discharge. A gas bubble forms around the discharge and the molten pools. As the electric pulse ceases and the discharge disappears, the gas bubble collapses. The onrush of cool dielectric causes the molten metal to be ejected from the workpiece and the tool, leaving small craters. This action is repeated hundreds of thousands of times each second during EDM processing. This removes material from the workpiece in a shape complementary to that of the tool.

EDM has found its application in the machining of hard metals or alloys which cannot be machined easily by conventional methods. It thus plays a major role in the machining of dies, tools, etc. made of tungsten carbides, satellites or hard steels. Alloys used in the aeronautics industry for example hastalloy, nimonics, etc. could also be machined conveniently by this process. This process has the added advantage of being capable of machining complicated components.

The products produced from die casting using excellent quality dies will be a replica of the dies used for the process. Hence the dies should possess high dimensional accuracy and superior surface finish.

EDM process has been used in the present work to machine die casting dies used for producing superior product having high dimensional accuracy and superior surface finish. The reason for using EDM for machining die casting dies is because of the superior process control over surface finish and dimensional accuracy parameters [1-5].

II. RESEARCH METHODOLOGY

The present research work has been carried out by following the steps given below:

1) Identification of the important process parameters
2) Development of the design matrix and finding upper and lower limits of process parameters
3) Conduction of the experiments as per the design matrix and recording the responses
4) Evaluation of the regression coefficients and developing the mathematical models for MRR, TWR, Raw
5) Checking the adequacy of the mathematical models
6) Conformation of the experiments w.r.t the mathematical model.

The methodology followed has been clearly depicted in the form of a flowchart in the Fig 3.

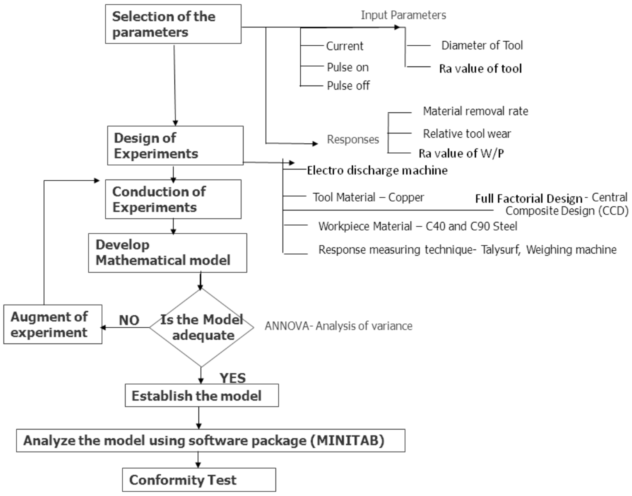


Fig.3 Methodology of Research work

III. EXPERIMENTAL SETUP

Experiments have been designed to develop empirical response models for MRR, RTW and RaW by investigating the effects of diameter of tool (Cross-sectional area) and Surface Roughness of the tool along with different Current, Pulse-On and Pulse-off levels and correlating the interactive and higher order influences of various sink-EDM process parameters using RSM.

The schematic diagram of the EDM setup has been depicted in Fig 1. The EDM machine used for the experimental work in this research has been shown in Fig 2.

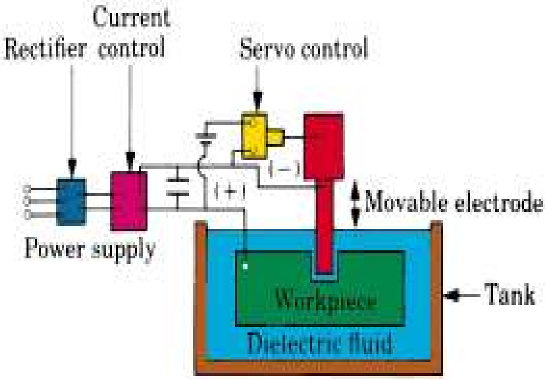


Fig.1 Schematic Diagram of EDM setup

Fig.2 EDM Machine

Workpiece materials used in the research work are C40 and C90 steels. C40 steel with a density of 7.859 gm/cc and hardness of 28 HRC obtained after water quenching has been used for the experiments. C-90 steel with a density of 7.84 gm/cc and hardness of 35 HRC obtained after water quenching has also been used.

IV. EXPERIMENTATION PROCEDURE

The following steps have been followed during the experimentation phase of the research work.

1) A simple experimental procedure has been used to understand the impact of controlled input parameters for an EDM process.
2) The workpiece(C-40 and C-90 steel) are ground on top and bottom face to a good level of surface finish.
3) Using CNC the bottom surface of the tool (99.7% Cu)) is finished to a desired level of surface finish.
4) The workpiece and the tool both are held in requisite positions on EDM setup.
5) The workpiece and tool have been connected to the positive and negative terminals of power supply, respectively.
6) The process is executed in the presence of dielectric fluid
7) The experiments have been conducted in a random order to remove the effects of any unaccounted factors.
8) At the end of each experiment, the work piece and tool has been removed, washed and dried.
9) An electronic balance is used to measure weights of tool and workpiece before and after machining.
10) The instrument Taly-Surf has been used to determine the surface finish of the work piece after conducting each experiment.

V. THE MATHEMATICAL MODEL

Forty-five experimental runs were conducted as per the design matrix at random to avoid any systematic error creeping into the system. The observed and calculated values of MRR, RTW and RaW for C40 steel have been indicated with symbols in design matrix as shown in Table 1. Similar design matrix has been created and analyzed for C-90 material also.

		Coded values					Natural values					Responses		
StdOrder	RunOrder	A	B	C	D	E	A	B	C	D	E	MRR(gm/min)	TWR(gm/min)	SF(µm)
1	6	-1	-1	-1	-1	-1	10	25	3	20	1.6	48.31047	7.6884	5.419
2	33	1	-1	-1	-1	-1	20	25	3	20	1.6	286.407	35.0448	5.842
3	20	-1	1	-1	-1	-1	10	75	3	20	1.6	292.33239	16.6284	6.705
4	17	1	1	-1	-1	-1	20	75	3	20	1.6	822.927	17.5224	6.905
5	10	-1	-1	1	-1	-1	10	25	7	20	1.6	150.9357	16.8966	6.194
6	44	1	-1	1	-1	-1	20	25	7	20	1.6	286.5648	53.4612	6.504
7	5	-1	1	1	-1	-1	10	75	7	20	1.6	74.955	10.9962	7.563
8	3	1	1	1	-1	-1	20	75	7	20	1.6	427.7958	27.8034	7.649
9	39	-1	-1	-1	1	-1	10	25	3	30	1.6	148.332	35.0448	5.689
10	34	1	-1	-1	1	-1	20	25	3	30	1.6	303.765	44.3424	6.218
11	37	-1	1	-1	1	-1	10	75	3	30	1.6	336.903	43.4484	5.889
12	28	1	1	-1	1	-1	20	75	3	30	1.6	695.1879	25.5684	6.194
13	13	-1	-1	1	1	-1	10	25	7	30	1.6	421.8783	44.4318	6.013
14	31	1	-1	1	1	-1	20	25	7	30	1.6	404.757	61.9542	6.429
15	19	-1	1	1	1	-1	10	75	7	30	1.6	198.2757	35.4918	6.473
16	23	1	1	1	1	-1	20	75	7	30	1.6	403.968	25.5684	6.458
17	8	-1	-1	-1	-1	1	10	25	3	20	4.8	22.881	7.6884	5.826
18	18	1	-1	-1	-1	1	20	25	3	20	4.8	82.6872	28.7868	6.686
19	15	-1	1	-1	-1	1	10	75	3	20	4.8	206.9547	25.8366	5.804
20	9	1	1	-1	-1	1	20	75	3	20	4.8	494.9397	16.6284	6.337
21	35	-1	-1	1	-1	1	10	25	7	20	4.8	344.004	16.8966	5.361
22	1	1	-1	1	-1	1	20	25	7	20	4.8	224.5494	42.1968	6.005
23	2	-1	1	1	-1	1	10	75	7	20	4.8	119.64396	16.6284	5.318
24	24	1	1	1	-1	1	20	75	7	20	4.8	225.5751	25.6578	5.813
25	38	-1	-1	-1	1	1	10	25	3	30	4.8	148.4898	25.5684	7.17
26	26	1	-1	-1	1	1	20	25	3	30	4.8	55.32468	25.5684	7.937
27	14	-1	1	-1	1	1	10	75	3	30	4.8	190.149	46.36284	5.862
28	11	1	1	-1	1	1	20	75	3	30	4.8	324.279	15.3768	6.54
29	42	-1	-1	1	1	1	10	25	7	30	4.8	565.78401	34.5084	6.054
30	43	1	-1	1	1	1	20	25	7	30	4.8	299.031	43.5378	6.804
31	36	-1	1	1	1	1	10	75	7	30	4.8	206.9547	33.2568	4.925
32	12	1	1	1	1	1	20	75	7	30	4.8	167.91498	16.6284	5.452
33	25	-1	0	0	0	0	10	50	5	25	3.2	151.7247	16.0026	5.78
34	29	1	0	0	0	0	20	50	5	25	3.2	283.251	16.7178	6.255
35	40	0	-1	0	0	0	15	25	5	25	3.2	163.9542	35.4918	6.154
36	45	0	1	0	0	0	15	75	5	25	3.2	251.7699	33.29256	5.98
37	27	0	0	-1	0	0	15	50	3	25	3.2	323.5689	16.6284	6.721
38	22	0	0	1	0	0	15	50	7	25	3.2	328.1451	16.8966	6.584
39	21	0	0	0	-1	0	15	50	5	20	3.2	202.2996	33.2568	5.955
40	30	0	0	0	1	0	15	50	5	30	3.2	263.9994	51.4944	5.76
41	41	0	0	0	0	-1	15	50	5	25	1.6	319.545	52.3884	6.042
42	32	0	0	0	0	1	15	50	5	25	4.8	269.6802	45.98736	5.779
43	7	0	0	0	0	0	15	50	5	25	3.2	219.1842	32.0052	6.106
44	16	0	0	0	0	0	15	50	5	25	3.2	247.4304	33.2568	6.106
45	4	0	0	0	0	0	15	50	5	25	3.2	247.4304	33.2568	6.106

Table 1: Experimental layout plan as per CCD and responses

The following models have been developed for MRR, RTW and RaW for C40 steel.

Material removal rate (MRR)
YMRR = -1593.70+ 107.43X1+20.22X2 -137.21X3 +60.767X4-25.53X5-1.25X12 --0.07X22 +19.27X32-0.63X42 + 17.90X52 + 0.46X1 X2 -4.10X1 X3+ -1.44X1 X4 -7.38X1 X5-1.96X2 X3 -0.26X2 X4 -0.79X2 X5 +2.72X3X4 -11.65X3X5 -1.12X4 X5.

Relative Tool Wear (RTW)
YTWR = -85.0865+ 27.3177X1 +0.6703X2+42.5399X3-13.7633 X4-34.0414X5-0.6487X12 +0.0029X22-3.9537X32 +0.3919X42 +6.4884X52 -0.0510X1 X2+ 0.2723X1 X3-0.2093X1X4 - 0.2852X1X5 -0.0747X2X3-0.0056X2X4+0.0527X2 X5 -0.0644X3 -0.1350X3 X5 -0.2708X5

Ra Value of Workpiece (RaW)
YRaw = -1.6234+0.094403X1 +0.086689X2 -0.84233X3+0.489682X4+0.424358X5 -0.001944X12+1.00E-06X22+ 0.146598X32-0.008344X42-0.060785X52-4.65E-04X1X2--0.003288X1 X3 +0.000545X1X4+0.011602X1 X5 +0.000543X2X3-0.002187X2X4 -0.008867X2X5 -0.0117X3X4 -0.10627X3X5+0.027273X4X5.

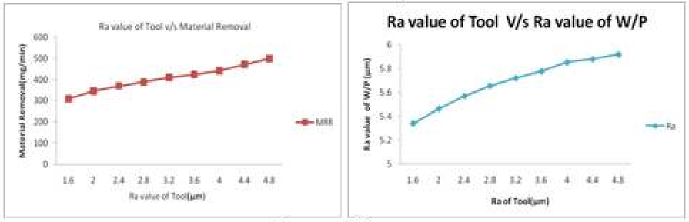
VI. RESULTS AND DISCUSSIONS

Comparison of the Interaction effect of various parameters (current, pulse on, pulse off, diameter of tool and surface roughness of tool) on the responses like Surface Finish of Workpiece (RaW), Material Removal Rate (MRR), Relative Tool Wear (RTW) and Tool Wear Ratio (TWR = MRR / RTW) have been carried out & their interpretations provided w.r.t. C-40 & C-90 material. Some of the important observations have been taken and discussed here on.

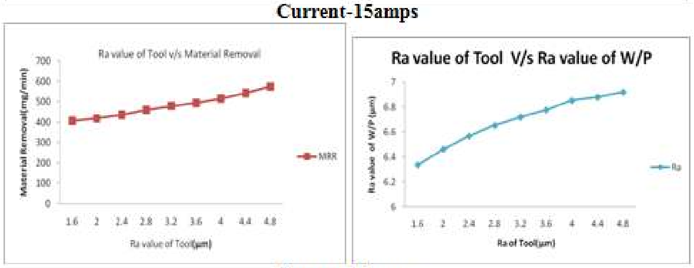
A. Interaction effect of current, Ra value on tool with reference to MRR and Surface Finish of the work for C40 material

The current varies from 10amps to 20amps and Ra value of tool from 1.6µm to 4.8µm, keeping pulse-on time, pulse-off time, and diameter of tool, at mid level (5µs, 50 µs and 25mm respectively) as shown in Fig 3.

Current-10amps



Current-15amps



Current-20amps

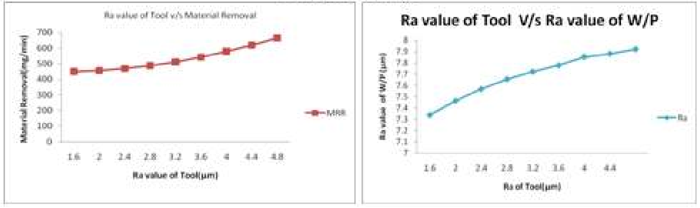


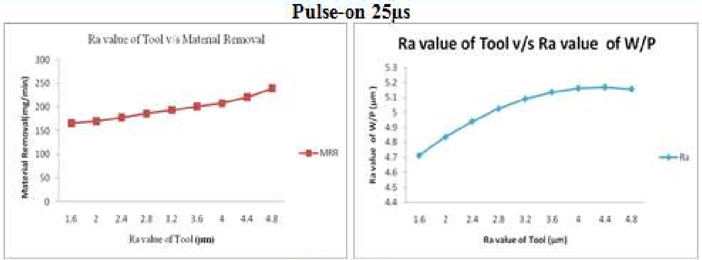
Fig 3: Variation of RaT w.r.t MRR, RaW at different current levels

It has been inferred that the maximum MRR at various values of current can be obtained with the tool having the rougher surface i.e higher Ra value. However it has been observed that the better quality work surface can be obtained with the tool having lower Ra value i.e. with a relatively lower MRR.

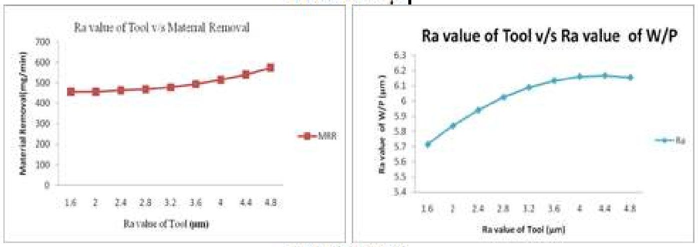
B. Interaction effect of Pulse-on and Ra value of the tool with reference to MRR and Surface Finish of the work for C40 material

The Pulse-on time varies from 25µsto 75µs and surface roughness of tool from 1.6µm to 4.8 µm. keeping pulse-off, diameter of tool, and current of tool at mid level (5µs, 25mm, and 15 amps respectively) as shown in Fig 4.

Pulse-on 25µs



Pulse-on 50µs



Pulse-on 75µs

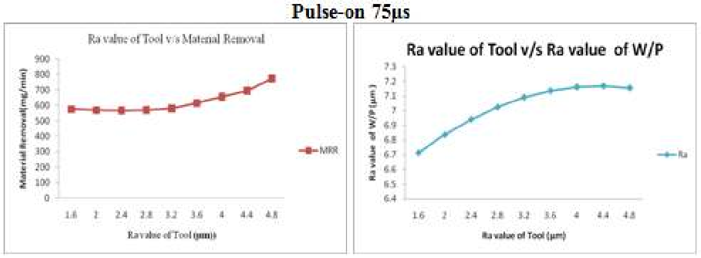


Fig 4: Variation of RaT w.r.t MRR, RaW at different Pulse-on levels

At a lower value of Pulse-on time i.e 25 µs and lower RaT value of 1.6 µm of the tool, good surface finish on the workpiece can be achieved. Thus Ra value of tool is directly proportional to Ra value of workpiece.

C. Interaction effect of current, Pulse-on with reference to MRR and surface Finish of the work for C90 material

The current varies from 10amps to 20amps and Pulse-on from 25µs to 75 µs, keeping pulse-off, diameter of tool and surface roughness, at mid level (5µs, 25mm and 3.2 µm respectively) as shown in Fig 5.

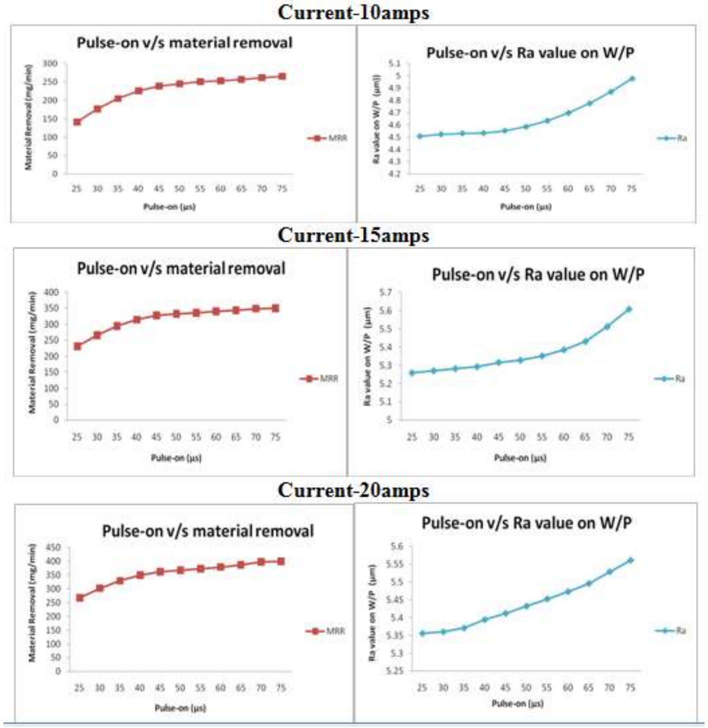


Fig 5: Variation of Pulse-on w.r.t MRR, RaW at different current levels

For finishing operation it is recommended to use lower current with lower pulse-on time thereby improving in Surface finish and compromising with MRR.

D. Interaction effect of current, surface roughness of tool with reference to MRR and SF for C90 material

The current varies from 10amps to 20amps and surface roughness of tool from 1.6µm to 4.8 µm, pulse-off, diameter of tool, and pulse-on at mid level (5µs, 25mm, and 50µs respectively) as shown in Fig 6.

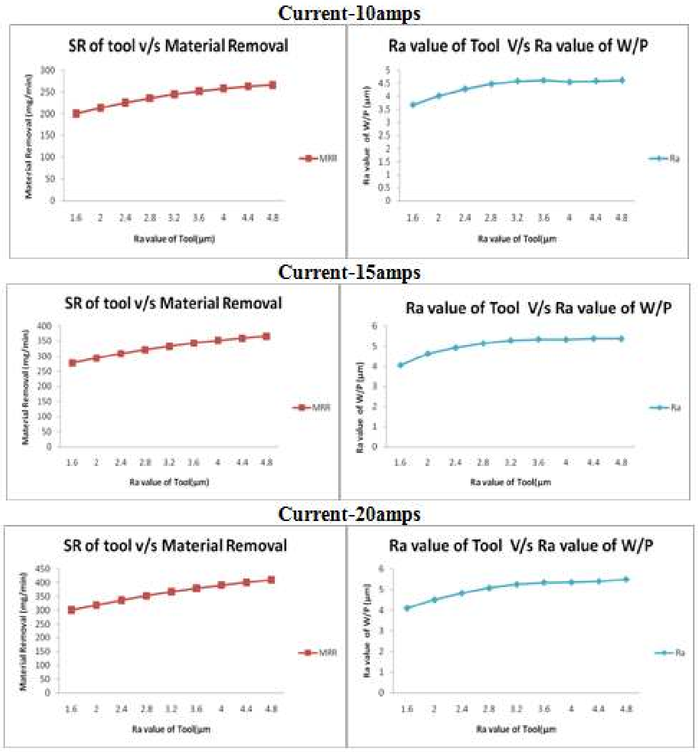


Fig 6: Variation of Pulse-on w.r.t MRR, TWR at different current levels

It has been inferred that the maximum MRR at various values of current can be obtained when the tool has the rougher surface i.e higher Ra value. However it has been observed that the better quality work surface can be obtained with the tool having lower Ra value with a relatively lower MRR.

VII. CONFORMITY EXPERIMENTS

In order to determine the accuracy of developed empirical models for C40 steel, the conformity experiments have been conducted using the same experimental setup. The process parameters have been assigned the intermediate values other than that used in the design matrix and the validation test runs have been carried out. The responses have been computed and compared with the predicted values for MRR, RTW, and Surface finish models respectively.

The percentage error of the developed RSM based empirical models is found to be within ± 5%, which clearly indicate the accuracy of the developed mathematical models. The experimental and the predicted values of MRR, RTW, and RaW for validation data set are illustrated in Graphs shown in Fig 7. Similar tests have been conducted for C-90 material also. The results obtained have been found satisfactory.

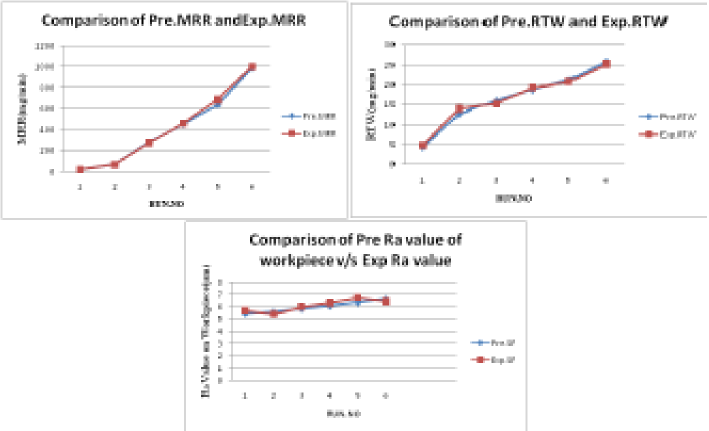


Fig 7: Conformity tests

VIII. CONCLUSION

The following general observations have been made with reference to the interaction effects of input parameters on the responses for C40 material.

1) Higher discharge current, pulse-on time and higher surface roughness of tool in combination with one another give good MRR and also better TWR which is more desirable. Higher material Removal can be achieved using higher discharge Current followed by Pulse-on time, Diameter of tool and surface roughness of tool.
2) The trend indicates that the interaction of moderate current and larger diameter of the tool does have a significant effect on Material Removal Rate (MRR) and Tool Wear Ratio (TWR).
3) A tool with lower Ra value (RaT) in combination with other Medium/ Low levels of input parameters yield good surface finish on the product.

To achieve good Surface Finish (SF) on the work component following combination of input parameters have to be used with reference to responses for C40 material.

1) Lower discharge current in combination with Lower pulse-on time, smaller diameter tool are preferred.
2) Lower discharge current in combination with lower surface roughness yield better Surface quality on the workpiece.
3) Smaller tool diameter with lower surface roughness of tool yields better Surface Finish.

The following are the observations made w.r.t. the interaction effects of input parameters on the responses for C90 material.

1) Higher discharge current, pulse-on time, and higher surface roughness of tool in combination with one another give good MRR and also better TWR which is more desirable. Higher material Removal can be achieved using higher discharge Current followed by Pulse-on time, Diameter of tool and surface roughness of tool.
2) The trend indicates that the interaction of higher current and larger diameter of the tool does have a significant effect on Material Removal Rate (MRR) and Tool Wear Ratio (TWR).

To achieve good Surface Finish (SF) on the work component following combination of input parameters have to be used with respect to responses for C40 material.

1) Lower discharge current in combination with Lower pulse-on time, smaller diameter tool are preferred.
2) Lower discharge current in combination with lower surface roughness yield better Surface quality on the workpiece.
3) Smaller tool diameter with lower surface roughness of tool yields better Surface Finish.

As C-90 material contains more percentage of carbon and also harder compared to C-40 material. From the above experimentation and analysis it is observed that with the same set and combination of input parameters higher MRR, TWR can be achieved on C-40 material. Higher surface Finish can be obtained on C-90 material with the same combination of input parameters.

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