



Experimental Investigation of Material Removal Rate of H11 Die Tool Steel Using Copper Tungsten and Cryogenically Treated Copper Tungsten Electrode During EDM.

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Abstract: During World War II the field of cryogenics was advanced when scientists found that metals showed more resistance to wear when frozen to low temperature. Enhancement in the abrasion resistance hardness and fatigue resistance of the materials is observed. To attain high accuracy in difficult to machine materials, the nonconventional machining has become the lifeline of any industry. Advanced machining processes can be categorized in to three categories, viz. Mechanical, Thermoelectric and Electrochemical or chemical processes based on the type of energy utilized for performing energy. Electric discharge machining is one of the most important non-conventional machining methods. In this research work, experimental investigations have been made to compare the machining characteristics of H11 tool steel using PM CuW and Cryogenically treated CuW through Electric discharge machining (EDM). A L_{18} Taguchi's standard orthogonal array is used for experimental design by varying different input machining parameters such as discharge current, gap voltage, duty cycle, polarity, and their effect on Material Removal Rate (MRR). It was found that Material Removal Rate is maximum in negative polarity with CuW electrode, 14amp current, voltage of 60V and duty cycle of 0.72.

Keywords: Electrical Discharge Machining (EDM), Material Removal Rate (MRR) Powder Metallurgy (PM), Taguchi method, Copper tungsten(CuW).

I. INTRODUCTION

Electrical Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. Work material to be machined by EDM should be electrically conductive. This method usually employed in production of die cavities via the erosive effect of electrical discharges between a tool electrode and a work-piece.

CRYOGENICS

Cryogenic processing has been traced back to Germany where the Junkers Company used it in aircraft engines

built in the late 1930's. It was also used in the early 1940's by a company in Massachusetts on knives. Cryogenic processing is used on racing engines, tooling, brakes, stereo equipment. Cryogenic treatment is an extension of the

heat-treating process that further enhances metals in the following ways

- Relieves residual stresses.
- Promotes a more uniform micro-structure.
- Precipitates eta-carbides in steels for increased resistance to wear.

CRYOGENICS AS A PROCESS

It is a process that uses cryogenic temperatures to modify materials to enhance their performance. Cryogenic Processing involves the slow reduction in temperature of the material to at least -300°F (-185°C) and holding the material at that temperature for some period of hours followed by a slow increase of temperature back to room temperature. In some instances, the material is tempered at elevated temperatures to finish the process. The process is distinct from a process named "cold treating" used by heat treaters to convert retained austenite in hardened steels to a martensitic structure.

II. LITERATURE SURVEY

Kuriakose S. et.al., 2005 [5] presented the methodology and data from an experiment that measures the normal force and friction force directly in an altered machining setup. The procedure simulates the pure frictional behaviour of the tool-chip interface in cryogenically cutting. The results show that LN2 cooled condition has a significantly lower coefficient of friction than dry conditions in all cases. The data also shows that the friction is lower for Ti-6Al-4V but mixed results obtained for mild steel AISI 1018 when LN2 is applied properly as in the experiment setup as compared to traditional emulsion flooding. Based on the unique pattern of the friction behaviour in the sliding tests,

possible lubrication mechanisms using liquid nitrogen are proposed.

Duowon D. et.al., 2006 [3] suggested that in EDM operation the work piece as well as the tool (electrode) experience an intense local heating in the vicinity of plasma channel. The high power density would result in the erosion of a part of material both from the work piece and the electrode by the local melting and heating. When high material removal rate is desirable with good surface quality, erosion of electrode is unwanted. So a proper selection of tool materials and choice of parameters like pulse power, width and polarity were investigated.

Beri N. et.al., 2008[1] Studied electric discharge machining of AISI D2 steel with copper tungsten (30% Cu and 70%W) electrode and conventional copper electrode by using kerosene. The input factor studied are current, duty cycle, and flushing pressure and output parameters are material removal rate and surface roughness. They concluded that conventional copper electrode gives high MRR and copper tungsten made through powder metallurgy gives higher surface finish

Sohani et. al.,2009 [11] presented the application of response surface methodology (RSM) for investigating the effect of tool shapes such as triangular, square, rectangular and circular with size factor consideration along with other process parameters like discharge current, pulse on time, pulse off time and tool area. The investigation revealed that the best tool shape for higher MRR and lower TWR is circular, followed by triangular, rectangular and square cross-sections. From the parametric analysis, it was also observed that the interaction effect of discharge current and pulse on time is highly significant on MRR and TWR, whereas the main factors such as pulse off time and tool area are statistically significant on MRR and TWR. The ANOVA was employed along with Fisher's test (F test) at 95% confidence interval to verify the lack of fit and adequacy of developed model

Tomadi, S.H. et. al., 2009[12] Investigated the effect of process parameters like Pulse on time, Pulse off time, Supply Voltage, peak current on material removed rate (MRR) and electrode wear (EW). The Tungsten Carbide was used as the work piece material and Copper Tungsten as electrode. The full factorial design of experiment was used to analysis the optimum condition of machining parameters. Author concluded that for surface roughness the most influential factor were voltage followed by pulse off time, peak current and in case of material removal rate, it was seen that the pulse on time factor was the most influential, followed by voltage, peak current and pulse off time.

Singh, R. et.al., 2010[10] Investigated the effect of cryogenic treatment for enhancing life of EDM tool while machining titanium alloys using taguchi technique. The output parameters selected are tool wear rate (TWR) and surface roughness. They concluded that with the help of cryogenic treatment, the machining

parameters like TWR and surface roughness improved by 58.778% and 8% respectively.

Kumar, D. et.al., 2010 [4] investigated the effect of hastalloy steel on sintered tool electrode of copper chromium (Cu-Cr) with reverse polarity in standard EDM oil. The input parameters analyzed are current, voltage, duty cycle, pulse on time, and flushing pressure with MRR, TWR, SR, % wear rate as output parameters. While during experiment current and voltage are varied by keeping other parameters constant on average value. They concluded that MRR and TWR increases with increase in current and voltage but surface roughness and % wear rate decreases with the increase in current and at low value of voltage.

Sharma, S. et.al., 2010[8] studied the effect of aluminium powder on machining hastalloy using EDM with reverse polarity by evaluating MRR, TWR, % wear rate, SR. The input parameters selected for the study are concentration and grain size of aluminium powder. They found that with the increase in the concentration of aluminium powder, surface roughness and % wear rate decreases but TWR and MRR increases.

Beri, N. et.al., 2011[2] experimentally investigated AISI D2 steel in kerosene with CuW (25% Cu and 75% W) powder metallurgy electrode. An L18 orthogonal array was used to identify the best process parameters (Viz. electrode material, duty cycle, flushing pressure, and current etc.) for MRR, SR, and surface hardness. Grey relational analysis was used to solve the EDM process with multiple performance characteristics which was obtained through grey relation grade. They concluded that EDM process performance can be improved efficiently through this approach and they also concluded that copper tungsten PM electrode gives better multi objective performance than conventional copper electrode

Majumder, A. et.al., 2012[6] derived quadratic mathematical model to represent the process behaviour of Die-Sinking Electrical Discharge Machining. Experiments has been conducted with three process parameters viz. discharge current, pulse on time and pulse off time and to relate them with process responses viz. material removal rate (MRR) and electrode wear (EW). Experiment was performed with mild steel as work piece and copper as electrode sand finding that the effect of supply current on material removal rate is higher than the other machining parameters while in case of electrode wear (EW) the most influential factor was the intensity of the pulse-on time

Singh, H et. al., 2013[9] studied the influence of operating parameters like pulse-on-time and pulse-off-time for responses such as Metal removal rate (MRR) and Tool Wear Ratio (TWR) on the EDM using steel as work piece and cryogenic and non-cryogenic electrode of copper material. The cryogenic treatment is used for increasing the material removal rate and lowering the tool wear rate. It was found that with increase in pulse on time tool wear rate is decreased in both electrode

cryogenic treated and non -cryogenic copper electrode. Tool wear rate is increased with increase in pulse off time. Material removal rate is decreased with increased in pulse on time from 50 μ s to 100 μ s and Material removal rate is increased with increased in pulse off time from 15 μ s to 20 μ s.

Mathai, V.J. et.al., 2013[7] has been made to study the effect of cryogenic treatment of tool electrodes on various responses during Electro Discharge Machining It has been observed that cryogenic treatment of tool electrodes result into reduction in tool wear rate. Relatively lesser influence of the same has been

observed on material removal rate and surface roughness.

III. DESIGN OF EXPERIMENT

Design of experiment is the primary step before starting the experimental work. Design of experiments (DOE) is used to study the effect of multiple variable simultaneously, which is a powerful statistical technique introduced by R.A.Fisher in England in 1920's. Table 2.1 shows selected input machining parameters with their designation and values assigned to them at different levels

Table 3.1: Designations of input Machining Parameters and their assigned values at different levels.

| Factor Designation | M/c ing Parameters | Levels and corresponding values of M/c ing Parameters (units) | | |
|--------------------|--------------------|---|---------------------------|---------|
| | | Level 1 | Level 2 | Level 3 |
| A | Electrode type | CuW | Cryogenically treated CuW | |
| B | Peak Current(A) | 4 | 9 | 14 |
| C | Gap Voltage (V) | 40 | 50 | 60 |
| D | Duty Cycle | 0.72 | 0.82 | 0.92 |

The next step is to select an appropriate array keeping in mind that the total DOF for the orthogonal array should be greater than (or) at least equal to those for the process parameters. L18 (33 x 21) orthogonal array is selected for the present study. This orthogonal array has 4 columns and 18 rows. One machining parameter is assigned to each column. Total 18 rows give the parametric combination for each set of experiment. The experimental combination of the machinery parameters using the L18 orthogonal array are presented in Table 2.2.

| Exp. No | Electrode Type A | Peak Current (Amp) B | Gap Voltage (Volt) C | Duty Cycle D |
|---------|------------------|----------------------|----------------------|--------------|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 2 | 2 |
| 3 | 1 | 1 | 3 | 3 |
| 4 | 1 | 2 | 1 | 1 |
| 5 | 1 | 2 | 2 | 2 |
| 6 | 1 | 2 | 3 | 3 |
| 7 | 1 | 3 | 1 | 2 |
| 8 | 1 | 3 | 2 | 3 |
| 9 | 1 | 3 | 3 | 1 |
| 10 | 2 | 1 | 1 | 3 |
| 11 | 2 | 1 | 2 | 1 |
| 12 | 2 | 1 | 3 | 2 |
| 13 | 2 | 2 | 1 | 2 |
| 14 | 2 | 2 | 2 | 3 |
| 15 | 2 | 2 | 3 | 1 |
| 16 | 2 | 3 | 1 | 3 |
| 17 | 2 | 3 | 2 | 1 |
| 18 | 2 | 3 | 3 | 2 |

Table3.2: Design Matrix of L18 (21 x 33)

IV. EXPERIMENTAL PROCEDURE

Experiments are conducted on SMART ZNC EDM, Electronica Machine Tools, India (Pune). In the machine, Z axis can be programmed to follow an NC code which is to be fed through the control panel and is also servo controlled. The gap voltage between the work piece and tool electrodes is responsible for servo control feedback. A constant gap distance will be maintained during machining and tool is fed in to the work piece. In this machine gap distance cannot be independently controlled and X and Y axis are manually controlled. All three axis have an accuracy of 5 μ m. Machining can be programmed to occur up to a fixed depth of cut through an NC code. Stop watch is used to note down the machining time., Work piece was perfectly cleaned with pressurized air jet before starting the experiment so that dust (or) unwanted particles can be removed. At first tool electrode and work piece was weighed on a precision weighing machine and work piece mounted on the T-slot table of the EDM machine. Ensure that work piece is properly held on the fixture assembly and clamp it properly. A micrometer of range 0 to 25mm; with a

least count of 0.01 mm made by Mitutoyo, Japan was used to measure the diameter of electrodes. Then the tool was clamped on the V-block tool holder of the EDM machine, and its alignment was checked with the help of tri square. The tool holder has a facility to make adjustments for the alignment of the electrode with respect to the work piece. The depth of cut was set at 0.50 mm for each cut. The gap between tool and work piece was automatically maintained with the help of beep sound. Flushing should be done, since during machining both tool and work piece should be immersed in dielectric fluid. Then machining should be started, as the desired depth is reached, machining operation stops automatically. However, the actual depth of cut achieved may not be 0.50 mm because electrode wears out during the machining operation and the decrease in the length of the electrode also gets added in the depth of cut. Hence in order to calculate the MRR, the loss in the weight of the work piece was taken as the criteria, which gives more accurate results. The input values of discharge current, pulse on time, duty cycle and gap voltage was set by using the hand held keyboard for each experiment. The values were noted as per the

design of experiment trial conditions using Taguchi method (Table 2). The stop watch was also stopped at that very instant and time of cut (t in seconds) was noted. The drain valve of the tank was opened to flow out the dielectric to the storage tank. Eighteen experiments were performed (as per table 3) and at the each end of the experiment work piece was weighed to find out final weight, so that MRR can be calculated.

Work piece material

For the present study H11 hot work tool steel is selected as work piece material. Work piece of size 65 X 30 X 7 mm is used here. H11 is basically 5% chromium hot work steel. The 1.5% molybdenum imparts very high hardenability to this grade and makes difficult to machine by traditional machining methods. It has good resistance to softening at elevated temperatures, but its outstanding characteristics are high toughness. A slight modification of this grade has been widely used for aircraft and structural applications requiring good ductility and notch strength at high strength levels. The chemical composition of H11 is shown in Table 3.1.

Table 4.1: Chemical composition of H11 (wt %)

| Carbon | Copper | Silicon | Chromium | Nickle | Manganese | Molybdenum | Sulphur | Vanadium |
|--------|--------|------------|------------|--------|-----------|------------|---------|-----------|
| 0.35 | 0.25 | 0.80- 1.20 | 4.75- 5.50 | 0.3 | 0.20-0.50 | 1.10-1.60 | 0.03 | 0.03-0.60 |

Electrode Material

The electrode material selected for the present investigation is copper tungsten (75% Cu and 25% W) electrode and cryogenically treated copper tungsten. CuW electrodes are made through powder metallurgy technique by mixing weight of copper and tungsten in blenders. The mixture is then compacted in a die to form green compact. This compact is sintered in a sintering furnace to the temperature of 16000c and sintering time is kept between 3 to 6 hrs. The diameter and length of electrode are kept constant at 8.00 mm and 90 mm respectively. Cryogenic treatment of the electrode is carried out at CTR Ludhiana.

V. RESULT AND DISCUSSIONS

The results obtained after experimentation on Electrical Discharge Machining of H-11 Die Tool powder

metallurgy copper-tungsten and cryogenically treated copper-tungsten tool electrodes CuW (75%Cu and 25%W) and the analysis and discussion on the Material Removal Rate (MRR). The experimental plans for EDM process were based on Taguchi method and for analyzing the data; analysis of variance (ANOVA) is performed using MINITAB software The requirement is to maximize the MRR so the criteria selected using the software is larger is better. An ANOVA (Analysis Of Variance) Table 5.2 is used to summarize the experimental results. The table concludes information of analysis of variance and case statistics for further interpretation. Response for SN ratios is shown in table 5.3 which is clearly indicates that the, electrode type and gap voltage are relatively less influencing factors to MRR. Peak current and duty cycle are the most influencing factors for MRR.

Table 5.1 Experimental observations for MRR

| Exp. No | Electrode Type | peak Current | Voltage | Duty Cycle | Wt of w/p before M/cing (gm) X | Wt of w/p after M/cing. (gm) Y | Time (t) In mints | M.R.R = X-Y/t | MRR |
|---------|----------------|--------------|---------|------------|--------------------------------|--------------------------------|-------------------|---------------|-------------|
| 1 | A | 4 | 40 | 9 / 0.72 | 55.265 | 55.077 | 66.43 | 0.002830047 | 0.002830047 |
| 2 | A | 4 | 50 | 10 / 0.82 | 55.077 | 54.873 | 71.46 | 0.002854744 | 0.002854744 |
| 3 | A | 4 | 60 | 12 / 0.92 | 54.719 | 54.549 | 120 | 0.001416667 | 0.001416667 |
| 4 | A | 9 | 40 | 9 / 0.72 | 54.549 | 54.394 | 85.08 | 0.001821815 | 0.001821815 |
| 5 | A | 9 | 50 | 10 / 0.82 | 54.394 | 54.194 | 81.13 | 0.002465179 | 0.002465179 |
| 6 | A | 9 | 60 | 12 / 0.92 | 54.194 | 54.001 | 39.12 | 0.004933538 | 0.004933538 |
| 7 | A | 14 | 40 | 10 / 0.82 | 54.001 | 53.778 | 59.52 | 0.00374664 | 0.00374664 |
| 8 | A | 14 | 50 | 12 / 0.92 | 53.778 | 53.616 | 37.53 | 0.004316547 | 0.004316547 |
| 9 | A | 14 | 60 | 9 / 0.72 | 53.616 | 53.436 | 61.30 | 0.002936378 | 0.002936378 |
| 10 | B | 4 | 40 | 12 / 0.92 | 53.436 | 53.257 | 115.12 | 0.001554899 | 0.001554899 |
| 11 | B | 4 | 50 | 9 / 0.72 | 53.257 | 53.070 | 117.51 | 0.001591354 | 0.001591354 |
| 12 | B | 4 | 60 | 10 / 0.82 | 53.070 | 52.883 | 113.28 | 0.001650777 | 0.001650777 |
| 13 | B | 9 | 40 | 10 / 0.82 | 52.883 | 52.636 | 95.19 | 0.00259481 | 0.00259481 |
| 14 | B | 9 | 50 | 12 / 0.92 | 52.636 | 52.431 | 32.56 | 0.006296069 | 0.006296069 |
| 15 | B | 9 | 60 | 9 / 0.72 | 52.431 | 52.243 | 40.05 | 0.004694132 | 0.004694132 |
| 16 | B | 14 | 40 | 12 / 0.92 | 52.243 | 52.005 | 20.26 | 0.011747285 | 0.011747285 |
| 17 | B | 14 | 50 | 9 / 0.72 | 52.005 | 51.771 | 59.11 | 0.003958721 | 0.003958721 |
| 18 | B | 14 | 60 | 10 / 0.82 | 51.771 | 51.613 | 47.12 | 0.003353141 | 0.003353141 |

Table 5.2 Analysis of Variance for SN Ratios for MRR (Larger is Better)

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|--------------------------|----|---------|---------|---------|-------|-------|
| Electrode | 1 | 6.000 | 6.100 | 6.0999 | 1.94 | 0.236 |
| Current | 2 | 138.172 | 138.172 | 69.3559 | 22.09 | 0.007 |
| Voltage | 2 | 4.450 | 4.519 | 2.2597 | 0.72 | 0.541 |
| Duty cycle | 2 | 14.412 | 18.278 | 9.1390 | 2.91 | 0.166 |
| Electrode* Current | 2 | 6.359 | 6.359 | 3.1797 | 1.01 | 0.441 |
| Electrode* voltage | 2 | 11.650 | 11.650 | 5.8249 | 1.86 | 0.269 |
| Electrode* Duty cycle | 2 | 1.862 | 1.862 | 0.9312 | 0.30 | 0.758 |
| Residual error | 4 | 12.560 | 12.560 | 3.1399 | | |
| Total | 17 | 196.105 | | | | |

Table 5.3 Response Table for SN ratio for MRR (Larger is Better)

| Level | Electrode | Current | Voltage | Duty cycle |
|-------|-----------|---------|---------|------------|
| 1 | 12.252 | 8.300 | 11.117 | 12.430 |
| 2 | 11.088 | 11.611 | 11.570 | 12.166 |
| 3 | | 15.099 | 12.323 | 10.414 |
| Delta | 1.164 | 6.799 | 1.206 | 2.016 |
| Rank | 4 | 1 | 3 | 2 |

It is clear from figure 1 that MRR is maximum at the 1st level of electrode type, 3rd level of peak current, 3rd level of gap voltage, 1st level duty cycle.

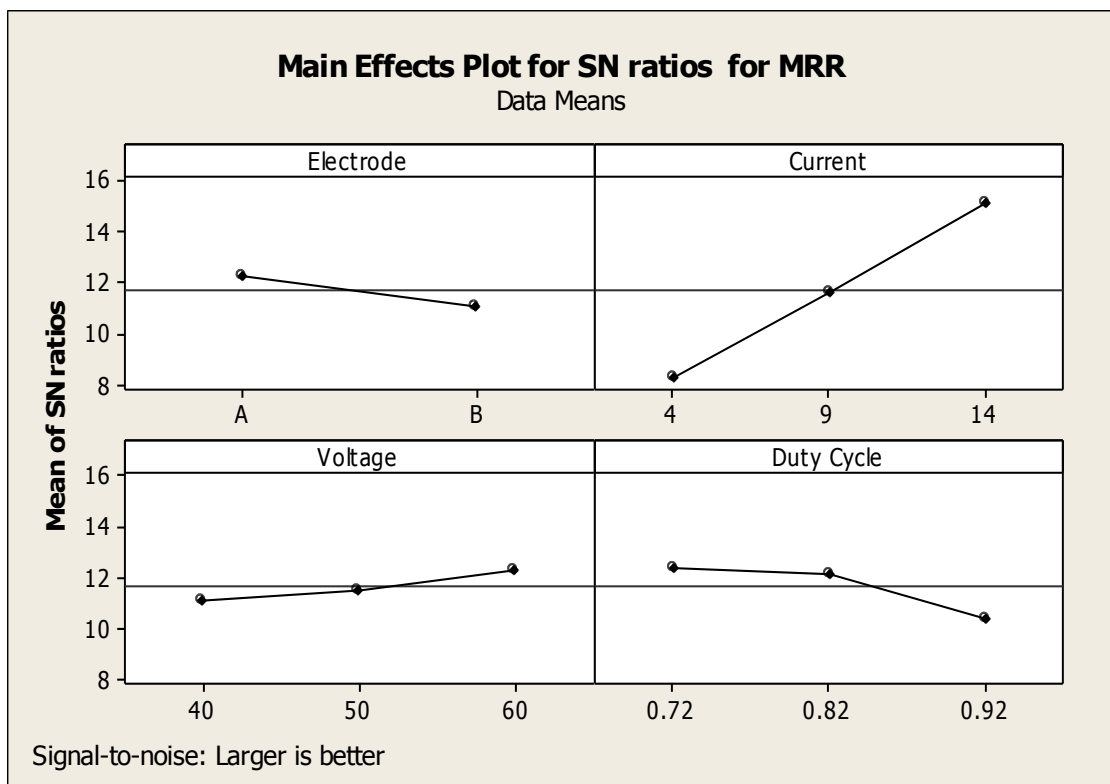


Fig. 1 Main effects plot for SN ratios (MRR)

The best levels of parameters at maximum MRR are shown in table 5.4.

Table 5.4 Best levels of parameters at maximum MRR

| Factor | A | B | C | D |
|--------|---|---|---|---|
| Level | 1 | 3 | 3 | 1 |

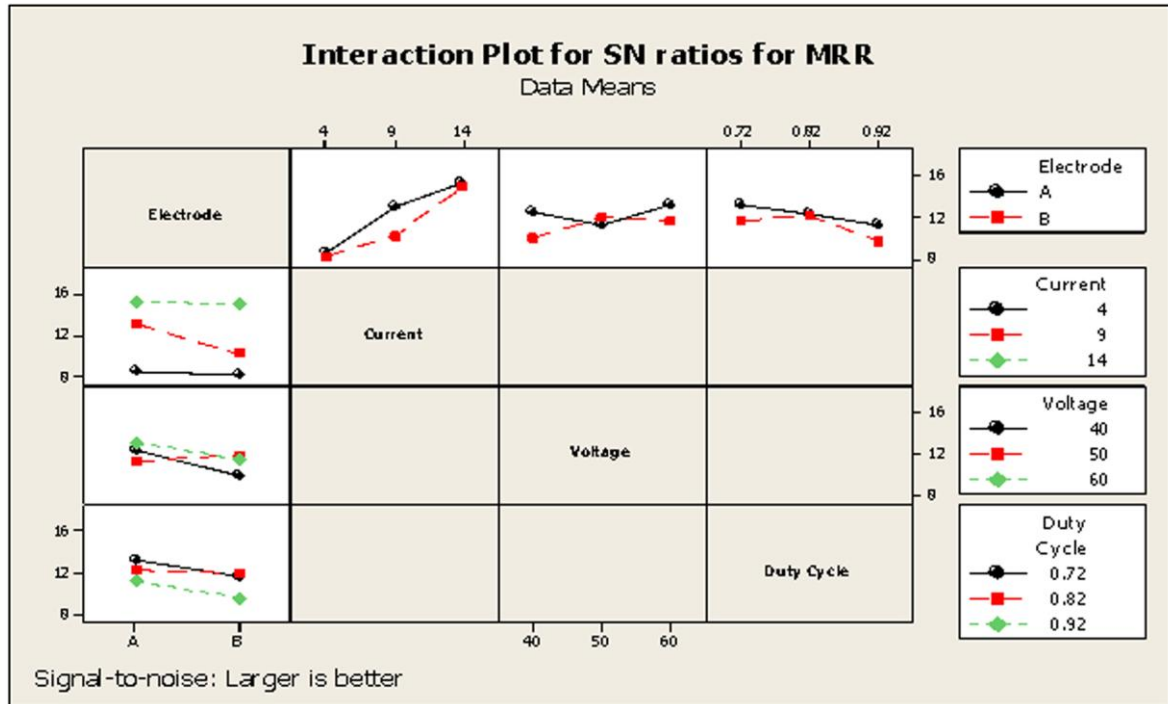


Fig. 2 Interaction Plot for SN ratios for MRR

The interaction plot for SN ratio for MRR is shown in fig.2 which clearly indicates the following results

1. MRR increases Continuously with the increase in current for both electrodes.
2. MRR decreases with increase in gap voltage from 40 to 50 Volt, after that it increases with increase in gap voltage from 50 to 60 Volt for PM CuW tool.
3. MRR increases with increase in gap voltage from 40 to 50 Volt, and decreases with further increase in gap voltage from 50 to 60 Volt for cryogenically treated CuW tool.
4. MRR decreases continuously with the increase in duty cycle PM CuW tool.
5. MRR increases slightly with increase in duty cycle from 0.72 to 0.82, and decreases with further increase in duty cycle from 0.82 to 0.92 for cryogenically treated CuW tool.

VI. CONCLUSIONS

Following conclusions can be drawn from the analysis of the results:

1. It has been observed from experimental work that Electric discharge machining of H-11 die tool Steel is feasible with PM CuW electrode at negative polarity.
2. It is found that electrode type is less significant factor for output parameters.
3. Machining rate increases with the increase in current due to predominant increase in spark energy.

4. Negative polarity with 14amp current, voltage of 60V and duty cycle of 0.72 gives the best results for MRR i.e. A₁, B₃, C₃, D₁.

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