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Experimental Investigation of Drilling Small Hole on Duplex Stainless Steel (SS2205) Using EDM

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This work investigates drilling of small holes of Ø 3 mm on duplex Stainless Steel. Its machinability index is very low (0.66) as compared to other steels, hence Electrical Discharge Machine is used. The input parameters are Current, Spark Gap & Di electric Pressure. Each input parameter is considered for 3 levels. Therefore total number of experiments is 3x3x3 – 27. To reduce the number of runs, Taguchi L9 orthogonal array is used, which is having advantage of maximum and minimum trial runs in its design. The output response is metal removal rate. To find the best operating parameter, the regression model of ANOVA is given to input of MAT Lab-Genetic Algorithm. The experimental results indicated that models are significant. The test result indicated that the contributions of current is 42.42%, Di electric pressure is 35.36% and Spark gap is 1.93% on metal removal rate. From Genetic Algorithm it is observed among three levels of factors, lower value of current and Di electric pressure produced maximum metal removal rate. The SS 2205 has wide variety of applications such as high pressure components, control valves etc., which are having large number of components to it. Hence performing micro holes on such high hardness alloy is useful.

Keywords: electric discharge machine, SS2205, ANOVA, MRR.

1. Introduction

In modern manufacturing industries, Electrical Discharge Machining is widely used to create desired shapes due to ability to cut different materials with any desired shapes. The materials are removed by the etching technique in which electrical energy is converted into thermal energy as the spark generated when the work piece came closer to the tool. It creates good surface structure due to its non-contact approach. Among various grades of stainless steel, the SS 205 is widely used in pressure vessels, fire walls and sea water system due to its high resistance to corrosion and superior mechanical properties. These parts are having number of precisie holes in order to hold various parts. Drilling of small hole on very hard material is diffcult. Hence in this work, SS205 is taken for analyzing material revmoval rate using electirc dischage machining. In this work brass rod of 3 mm diameter serves as electrode & distilled water is used as a dielectric medium. There is a narrow gap in between the tool and the work. Material is removed from the work piece due to erosion caused by rapidly recurring electrical spark discharged between the work piece and the tool electrode.

2. Literature review

Aluminum MMC reinforced with Zrb2 and Tib2 was investigated [1]. In this work, authors analyzed the influence of Zrb2 and Tib2 in machinability using EDM. The machining parameters are Pulse On, Pulse Off and current. The geometrical accuracy by adjusting discharge energy and electrode diameter and influences on MRR was studied [2]. Four different electrode diameters ranged from 1.6 mm to 1.9 mm diameters are used to achieve the desired hole on D2 Tool steel/Tool steel X153CrMoV12-1. The tool wear ratio in terms of number of different electrodes and work piece materials was expressed [3]. Workpiece materials are stainless steel, titanium, magnesium and brass. The electrode materials are copper, brass and tungsten carbide. The process parameters to achieve good surface finish, better dimensional accuracy, small spark gap by drilling small hole in Tungsten carbide using EDM was analyzed [4]. Two different type pulse generators such as Transistor type and RC type are used to generate the spark in machining EDM. RC type pulse generator produce micro holes with good accuracy, better surface finish rather than Transistor type. Helix angle of 45o and flute-depth of 50 and 150 micrometer yields good aspect ratio in machining of Ti6Al4V was studied [5] .Output responses achieved are machining time, material removal rate, electrode wear and micro-hole quality. Tungsten electrodes and silicon electrodes to drill very small holes with a greater accuracy was achieved [6]. 2 micrometer diameter and 5 micrometer deep hole was drilled in brass by Tungsten electrode of 1 micrometer &0.5 micrometer holes were drilled in zinc by silicon electrode. The Positive polarity has more machining efficiency and low relative wear in short pulse and moderate electrical parameters are suggested [7]. The geometrical accuracy by adjusting Discharge energy and electrode diameter and influences on the amount of MRR was investigated [8]. Four different electrode diameters ranged from 1.6 mm to 1.9 mm diameters are used to achieve the desired hole on D2 tool steel/Tool steel X153CrMoV12-1. High speed whole drilling done on nickel based aerospace alloy using EDM and laser drilling machines was studied [9]. A 2-level 3-factor full factorial design was used to identify the ideal operating parameters. The input parameters are drilling speed, recast layer thickness and hole taper. In Inconel 718, drilling and shaping process are made into a single progression with identical electrode found that Shape accuracy is affected by Relative tool wear [10]. MRR, Relative tool wear and surface reliability are the objective parameters. Discharge current and duration has main influence factor on HAZ. Two dielectric mediums oxygen – argon gases and De-ionized water were compared in machining micro holes of Si3N4-TiN ceramic [11]. Axis displacement, Voltage, and Current has greater influence in the quality of hole. Study on various diameter electrodes with dissimilar dielectrics are used to micro a hole on Be-Cu alloy was taken for analysis [12]. Using different diameter electrodes with dielectrics as deionized water and kerosene improves the surface quality. Brass rod is the electrode to drill through blind hole on tool steel M2 was analyzed by EDM machine [13]. The output parameters are metal removal rate (MRR), electrode wear ratio (EWR) and over cut (OC) & the Input parameters are tool revolution speed, voltage and spark time. Grey relational analysis with a L9 orthogonal array is generated. The electrode rotation speed main parameter that affects output parameters followed by voltage and the spark time. Full factorial design with three central point Design of Experiments (DOE) is developed with a mathematical regression equation to predict the process parameters on machining Stainless steel [14]. Input parameters are current, voltage, pulse on, and duty factor. Output parameters are material removal rate, tool wear rate, surface roughness (Ra) and the hardness (HR). From the literature it is seen that drilling of small holes on SS205 received less attention to researchers. Hence this work investigates drilling small holes (3 mm) on SS205 using EDM.

3. Experimental setup

Electro Discharge Machining is an unconventional process which uses electrical spark to remove metals. Spark produced at a region of tool and work piece. High pulsating current density developed through the electrode to work piece. This removes very tiny metal particles at faster rate in a controlled manner. Dielectric fluid medium which are water based bath in which the tool and work piece submerged so that it lubricates the tool and removes the heat generated and avoids catching fire. In this work, Distilled water is used as dielectric medium that flushes away the metal. A hole of diameter 3 mm and depth of 5 mm are drilled. The EDM consists of EDM generator, electric holder, High pressure pump, Servo mechanism, Dielectric chamber. The Table 2 and 3 shows the specification EDM & work piece materials in which small holes are drilled. The Figure 1 shows the electric discharge machine in which experimental work is carried out

Table 1 Specification of EDM

Specification	Parameters
Worktable size	436x316 mm
Worktable travel	400x300 mm
Machine dimensions	1060x750x1700 mm
Control type	ZNC:Z-axis NC Control
Drilling depth	0-300 mm
Z-axis Travel	270+(300) Mm
Max. drilling speed	60 mm^2/Min
Max. working current	30A
Z-axis Travel control	Electric Motor

Table 2 Specification of materials and electrodes

S. No	Parameters	Specification
1	Work Piece Material	Duplex Stainless Steel 2205
2	Work Piece Dimension	150 X 150 X 5
3	Electrode	BRASS ELECTRODE 3 Mm
4	Dielectric Fluid	Distilled Water
5	Input Parameters	Current, Spark Gap, Dielectric Pressure
6	Output Parameters	Material Removal Rate

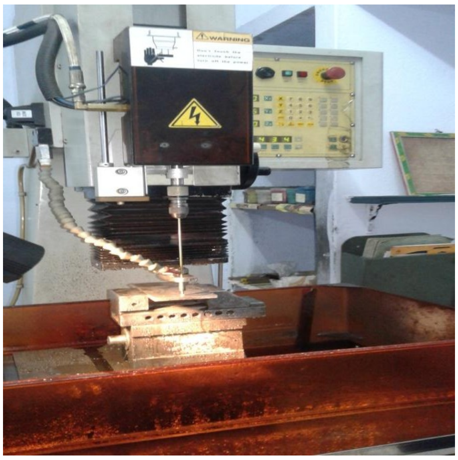

Figure 1 Electric Discharge Machine

Table 3 L9 Orthogonal array

S. No	Current (Amps)	Spark Gap (mm)	Dielectric Pressure (psi)	MRR (mm)
1	6.6495	27.2815	33.4015	1.4882
2	6.6495	33.7208	37.9633	2.3056
3	6.6495	48.919	38.5566	17.5192
4	45.7254	33.7208	38.5566	78.0194
5	45.7254	48.919	33.4015	6.3177
6	45.7254	27.2815	37.9633	53.6467
7	57.5465	48.919	37.9633	57.3782
8	57.5465	33.7208	33.4015	24.1332
9	57.5465	27.2815	38.5566	51.0173

4. Experimental work

Taguchi Design is an alternate method of performing the experimental analysis. Selections of machining parameters are the main control of the experiments. Taguchi Orthogonal Array (OA) Design always gives the minimum numbers of experimental run in a Full Factorial Design. At the same time the in the sequences of experimental runs it always includes the lower bound of factor and upper bound factors. In this work, three factors with three levels are selected to analyze metal removal rate. The input parameters are Current, Spark Gap & Di electric Pressure & output responses are metal removal rate. The Table 3 shows the L9 orthogonal array along with input and output responses. The Table 4 shows the ANOVAs for MRR and regression equation is shown equation – 1.

Table 4 ANOVA table for Metal Removal Rate

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F
Model	5057.992	3	1685.997	6.604782	0.0343
current	2691.554	1	2691.554	10.54398	0.0228
Spark gap	122.5295	1	122.5295	0.480001	0.5193
Dielectric pressure	2243.909	1	2243.909	8.790364	0.0313
Residual	1276.346	5	255.2692		
Correlation total	6334.337	8			

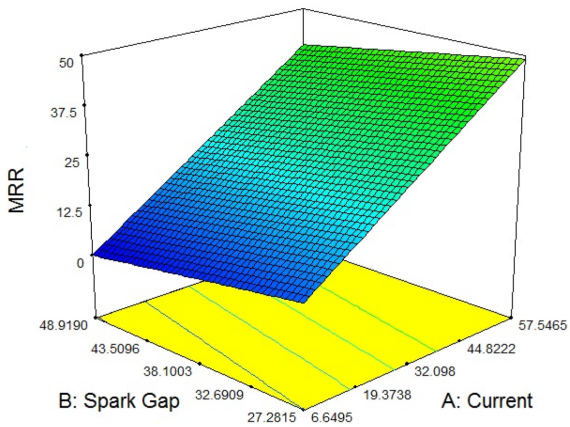

Figure 2 Effect of Spark Gap Vs Current on MRR

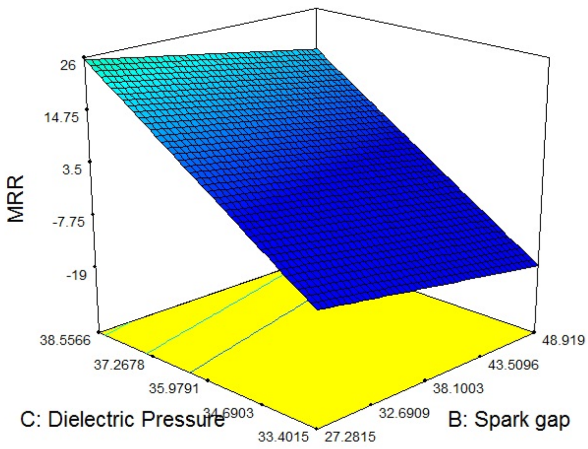

Figure 3 Effect of Spark Gap Vs Dielectric pressure on MRR

From Table 4, it is shown that the model value is 0.0343 which denotes that model is considerable for metal removal rate. There is only a 0.01% change that the model F value could be large due to noise. The value of Prob > F is less than 0.05 indicates that model terms are significant. In this case, model term Current is more significant than Dielectric pressure. The p-values larger than 0.1 indicate that model terms are not considerable for machining. The Figure 2-4 shows the effect of Current, Spark Gap & Dielectric pressure on metal removal rate.

$$\begin{aligned} \mathrm{MRR} = &-233.015 \pm (0.795135 \times \mathrm{Current}) - (0.40674 \times \mathrm{Spark\,Gap}) \\ &+(6.856061 \times \mathrm{DielectricPressure}) \end{aligned} \tag{1}$$

From the Figure 2, it is revealed that low current and low Dielectric pressure the material removal rate is low. When these factors increased then MRR also increased. The Figure 3 shows that Spark gap has less effect on MRR than Current & Figure 4 shows that dielectric pressure has more effect than spark gap on MRR. The figure 5 shows the interaction plot various input parameters on MRR.

5. MatLab based Genetic Algorithm

Genetic Algorithm (GA) is the commonly used evolutionary computing optimization technique.In GA a set of solutions as chromosomes are considered as Population.Previous populations are base for the creation of new population to which new solutions are formed.Mutation and cross over are the genetic operators which uses the previous solutions to find the best results. The regession model shown

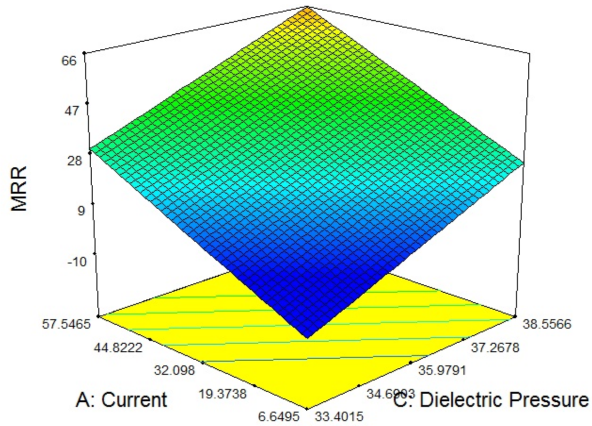

Figure 4 Effect of Current Vs Dielectric Pressure on MRR

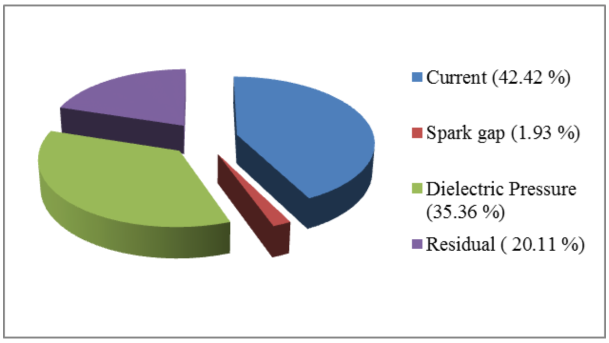

Figure 5 Interaction effect of various modules on MRR

Table 5 Parameter setting of GA

S. No.	Parameters	Value
1	Size of the population	100
2	Numbers of Generations	100
3	Fitness Scaling	Rank
4	Selection function	Roulette
5	Cross Over	Two Point
6	Cross over function	0.8
		2
7	Elite Count	6.6495 (C), 27.2815 (Sg)
8	Lower Limits	33.4015 (Dp)
9	Upper Limts	257.5465,48.919,51.0173

C – current, Sg – spark gap, Dp – di-electric pressure in Equation (1) is solved using matlab GA to find best parameters for MRR. The parameter setting are shown in Table 6.

The algorithm is run on 20 times and best iteration value is shown in Table 6 and Figure 6 shows the graph of number of iterations Vs optimal MRR.

Table 6 Best Parameters for Metal Removal Rate

Current	Spark gap	Dielectric pressure	MRR
6.65	27.282	33.402	12.371

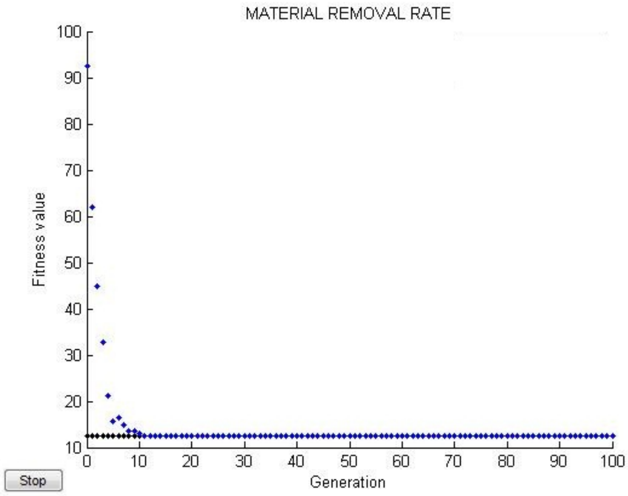

Figure 6 No. of generations Vs MRR

6. Conclusion

In this work, metal removal rate on SS 205 is investigated using electric discharge machine. To minimize the number of runs, Taguchi L9 orthogonal array is proposed. The machining parameters such as current, spark gap, di-electric pressure are analyzed on metal removal rate using ANOVA. From ANOVAs, it is revealed that contributions of current is 42.42%, Di electric pressure is 35.36% & Spark gap is 1.93% on metal removal rate. The regression model generated from ANOVAs is given as input of Mat lab Genetic Algorithm to find best machining parameter. The optimal MRR 12.371 mm is obtained using genetic algorithm. In future, instead of single objective function (MRR), other parameters can such as perpendicularity, surface roughness etc., can be considered.

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