Research Article

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Experimental Investigation of Drilling Small Hole on Duplex Stainless Steel (SS 2205) Using EDM

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Abstract: This work investigates drilling of small holes of 3 mm in diameter on duplex stainless steel. Its machinability index is very low (0.66) when compared to other steels; hence, electrical discharge machining is used. The input parameters are current, spark gap, and dielectric pressure. Each input parameter is considered for three levels. Therefore, the total number of experiments is 3 × 3 × 3 = 27. To reduce the number of runs, Taguchi L9 orthogonal array is used, which have the advantage of maximum and minimum trial runs in its design. The output response is metal removal rate (MRR). To find the best operating parameter, the regression model generated using ANOVA is given as input for MATLAB genetic algorithm (GA). The experimental results indicated that models are significant. The test result indicated that the contribution of the current on the MRR is 42.42%, dielectric pressure is 35.36%, and spark gap is 1.93%. From GA, it is observed that among these three factors, lower value of current and dielectric pressure produced the maximum MRR. The SS 2205 has wide variety of applications, such as high pressure components and control valves, which have large number of components attached to it. Hence, performing micro holes on such high hardness alloy is useful.

Keywords: electric discharge machine, SS 2205, ANOVA, MRR

1 Introduction

In modern manufacturing industries, electrical discharge machining (EDM) is widely used because of its ability to cut different materials with any desired shapes. The materials are removed by the etching technique in which an electrical energy is converted into a thermal energy because of the spark generated when the work piece came closer to the tool. It creates good surface structure because of its noncontact approach. Among various grades of stainless steel, the SS 205 is widely used in pressure vessels, fire walls, and sea water system because of its high resistance to corrosion and superior mechanical properties. These parts are having number of precise holes in order to hold various parts. Drilling of small hole on very hard material is diffcult. Hence, in this work, SS 205 is taken for analyzing the material removal rate (MRR) using EDM. In this work, brass rod of 3-mm diameter serves as electrode and distilled water is used as a dielectric medium. There is a narrow gap between the tool and the work. Material is removed from the work piece because of 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 its influence on MRR were studied [2]. Four different electrode diameters ranging from 1.6 to 1.9 mm are used to achieve the desired hole on D2 tool steel/Tool steel X153CrMoV12-1. The tool wear ratio was expressed in terms of number of different electrodes and work piece materials [3]. Stainless steel, titanium, magnesium, and brass are used as workpiece materials. Copper, brass, and tungsten carbide are used as electrode materials. The process parameters to achieve good surface finish, better dimensional accuracy, and small spark gap by drilling small hole in tungsten carbide using EDM were analyzed [4].

Two different types of pulse generator 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 and better surface finish rather than transistor type. Helix angle of 45° and flute depth of 50 and

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150 µm yielding good aspect ratio in machining of Ti6Al4V were studied [5]. Output responses achieved are machining time, material removal rate, electrode wear, and micro-hole quality. Tungsten electrodes and silicon electrodes were used to drill very small holes with a greater accuracy [6]. A hole of 2-µm diameter and 5-µm deep was drilled in brass using tungsten electrode, and holes of 1- and 0.5-µm were drilled in zinc using 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 its influence on the amount of MRR were investigated [8]. Four different electrode diameters ranging from 1.6 to 1.9 mm diameters are used to achieve the desired hole on D2 tool steel/Tool steel X153CrMoV12-1. High-speed whole drilling performed on nickel-based aerospace alloy using EDM and laser drilling machines was studied [9].

A two-level three-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 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 are the main influence factor on HAZ. Two dielectric mediums, oxygen–argon gases and deionized water, were compared in machining micro holes in Si3N4-TiN ceramic [11]. Axis displacement, voltage, and current have greater influence on the quality of hole. Study on electrodes with various diameters and dissimilar dielectrics for drilling micro hole on Be–Cu alloy was taken for analysis [12]. Using electrodes with different diameters and deionized water and kerosene as dielectrics improves the surface quality.

Brass rod the electrode that drills through blind hole on tool steel M2 was analyzed using EDM [13]. The output parameters are MRR, electrode wear ratio (EWR), and over cut (OC), and 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 (DOEs) 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 MRR, tool wear rate, surface roughness (Ra), and the hardness (HR). From the literature, it is observed that drilling of small holes on SS 205 received less attention to researchers. Hence, this work investigates drilling small holes (3 mm) on SS 205 using EDM.

3 Experimental Setup

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

Table 1: Specification of EDM

Specification	Parameters
Worktable size	436 mm × 316 mm
Worktable travel	400 mm × 300 mm
Machine dimensions	1,060 mm × 750 mm × 1,700 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	30 A
Z-axis travel control	Electric motor

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 lower bound of factor and upper bound factor are

Table 2: Specification of materials and electrodes

Serial No	Parameters	Specification
1	Workpiece material	Duplex stainless steel 2205
2	Workpiece dimension	150 × 150 × 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

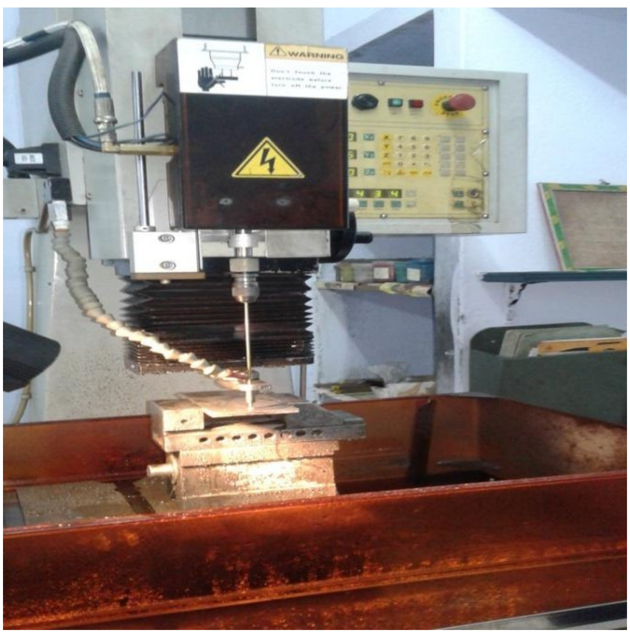

Figure 1: Electric discharge machine

always included in the sequences of experimental runs. In this work, three factors with three levels are selected to analyze the MRR. The input parameters are current, spark gap, and dielectric pressure, and the output parameters are MRR. Table 3 shows the L9 OA along with the input and output parameters. Table 4 shows ANOVA for MRR, and regression equation is given in Eq. (1).

From Table 4, the model value is 0.0343, which denotes that the model is considerable for MRR. 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, which indicates that the model terms are significant. In this case, the model term current is more significant than the dielectric pressure. The p-values larger than 0.1 indicate that model terms are not considerable for machining. Figures 2–4 show the effect of current, spark gap, and di-

Table 3: L9 orthogonal array

Serial No	Current (A)	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

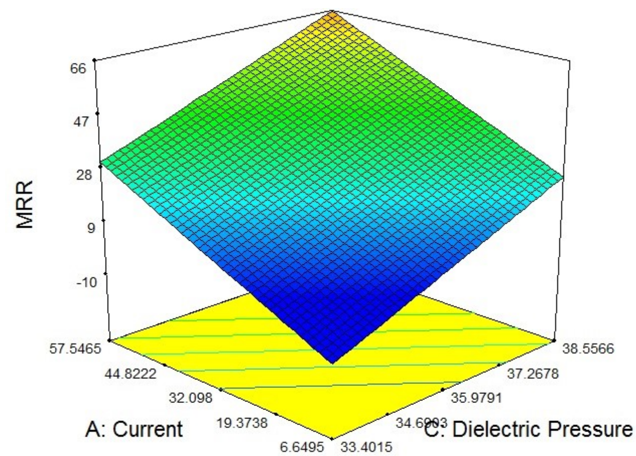

Figure 2: Effect of current versus dielectric pressure on MRR

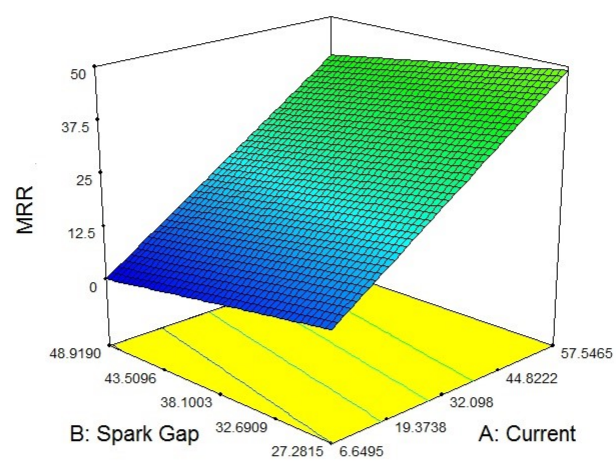

Figure 3: Effect of spark gap versus current on MRR

Table 4: ANOVA table for metal removal rate

Source	Sum of squares	df	Mean square	*F*-value	*p*-value Prob > F
Model	5,057.992	3	1,685.997	6.604782	0.0343
Current	2,691.554	1	2,691.554	10.54398	0.0228
Spark gap	122.5295	1	122.5295	0.480001	0.5193
Dielectric pressure	2,243.909	1	2,243.909	8.790364	0.0313
Residual	1,276.346	5	255.2692		
Correlation total	6,334.337	8			

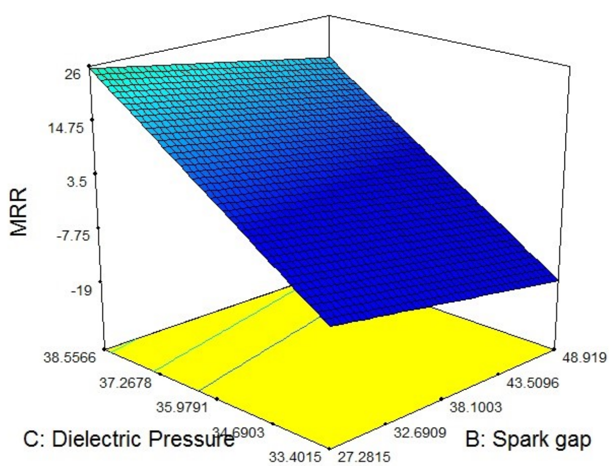

Figure 4: Effect of spark gap versus dielectric pressure on MRR

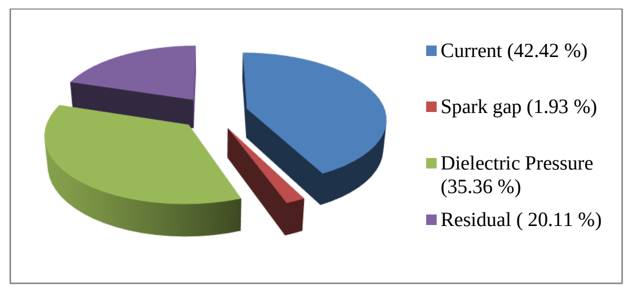

Figure 5: Interaction effect of various parameters on MRR

Table 5: Parameter setting of GA

Serial No.	Parameters	Value
1	Size of the population	100
2	Numbers of generations	100
3	Fitness scaling	Rank
4	Selection function	Roulette
5	Crossover	Two points
6	Crossover function	0.8
7	Elite count	2
8	Lower limits	6.6495 (C), 27.2815 (Sg), 33.4015 (Dp)
9	Upper limts	57.5465, 48.919, 51.0173

C, current; Sg, spark gap; Dp, dielectric pressure

electric pressure on the MRR.

$$\begin{aligned} MRR = & -233.015 \pm (0.795135 \times \text{Current}) \\ & -(0.40674 \times \text{Spark gap}) \\ & +(6.856061 \times \text{Dielectric pressure}) \end{aligned} \quad (1)$$

From Figure 2, it is revealed that low current and low dielectric pressure the material removal rate is low. When these factors increased, then MRR is also increased.

Figure 3 shows that spark gap has less effect on MRR than on current, and Figure 4 shows that dielectric pressure has more effect on MRR than on spark gap. Figure 5 shows the interaction effect of 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 crossover are the genetic operators that use the previous solutions to find the best results. The regession model given in Eq. (1) is solved using MATLAB GA to find best parameters for MRR. The parameter setting is given in Table 6.

The algorithm is run for 20 times, and the best iteration value is provided in Table 6; Figure 6 shows the graph of number of generations versus optimal MRR.

Table 6: Best parameters for metal removal rate

Current	Spark gap	Dielectric pressure	MRR
6.65	27.282	33.402	12.371

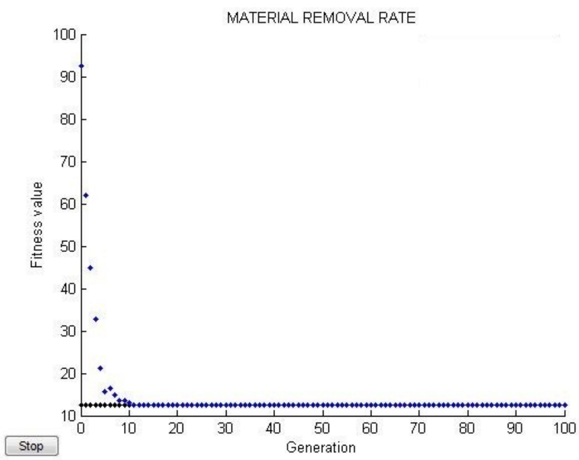

Figure 6: Number of generations versus MRR

6 Conclusion

In this work, MRR on SS 205 is investigated using EDM. To minimize the number of runs, Taguchi L9 orthogonal array is proposed. The machining parameters such as current, spark gap, and dielectric pressure are analyzed on metal removal rate using ANOVA. Using ANOVA, it is revealed that the contribution of current to metal removal rate is 42.42%, dielectric pressure is 35.36%, and spark gap is 1.93%. The regression model generated from ANOVA is given as input for MATLAB genetic algorithm (GA) to find the best machining parameter. The optimal MRR obtained using GA is 12.371 mm. In future, instead of single objective function (MRR), other parameters such as perpendicularity and surface roughness can be considered.

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