OPTIMIZATION OF ELECTRICAL DISCHARGE MACHINING (EDM) PROCESS PARAMETERS USING RSM: A REVIEW

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Abstract

In this day and age the fabricated item requires high exactness and quality, yet in addition ought to be created in least time. In this way it is required to accomplish the ideal yield by controlling the procedure parameter according to the necessity. It offered ascend to circumstance which requires the learning of ideal estimations of different info factors to amplify or limit a specific yield. Response Surface Methodology is best of the productive technique of demonstrating in this circumstance. The basic center of attention is progression parts of various factors of the electrical Discharge machining frames using Response Surface Methodology and from now on simply such investigate tasks are consolidated into this task where Response Surface Methodology is utilized to advance the electrical discharge machining procedure. The review take a shot at such an expansive scale was not endeavored before by thinking about these procedures at once, and henceforth, this survey work may turn into the prepared data at on a spot and valuable for consequent scientists to choose their course of research.

Keywords: RSM, Process Parameters, Optimization, Electric Discharge Machining

1. Introduction

The electrical Discharge machining innovation has grown quickly in the ongoing years and has turned out to be imperative in accuracy producing applications like, smaller scale machining, die and mold making and so forth. It is an entrenched Non-traditional machining process for assembling hard material and geometrically intricate surface that are incredibly hard to-machine by customary machining forms. Due to this, electrical Discharge machining the has been broadly connected in the cutting edge fabricating manufacturing for creating intricate employments in dies and moulds, which are hard to make by customary machining as of late [1]. In this process, there is no physical contact between work piece and tool. Limitation of this EDM process is that it is only used for machining electrical conductive materials. Material is evacuated in EDM by a sequence of electrical releases happening between work piece and cathode and both placed in the dielectric fluid for example, kerosene oil, paraffin 0r refined water [2]. The fundamental guideline utilized in EDM is the change of electrical vitality into warm vitality through a progression of discrete electrical releases happening between the tool and work piece submerged in the dielectric medium. In EDM, dielectric medium or fluid used are insulating properties. The release vitality amid machining produces extremely high temperatures at the purpose of the sparkle on the work piece surface, evacuating the material by melting and vaporization [3, 4]. Along these lines, it is hard to build up an explanatory model with ideal situation that can precisely anticipate the execution and ideal reaction by associating the procedure factors. The EDM procedure includes countless parameters, for example, wire feed rate, duty cycle, dielectric liquid, powder focus, powder estimate , wire pressure, tool material, polarity of electrode, wire tension, servo voltage, capacitance, pulse off time, open circuit voltage, pulse on time, electrode material, tool-work piece gap and so on [5]. EDM has surprising nature of using harm vitality to machine electrically conductive parts paying little regard to hardness have been its unmistakable leeway for assembling of careful segments [6, 7].

These procedure parameters can influence the different reactions of the procedure like tool wear rate, curve deviation, radial over cut, material removal rate, cutting width, surface roughness, cavity measure etc. By changing the various input parameters values, we can find out the desire objective. For example when we increases the current intensity, the metal removal rate is increase and at same time surface roughness and tool wear rate also increases. The procedure needs to amplify the MRR and in the meantime advances, for example, tool wear rate, surface roughness, Surface crakes and so forth ought to be limited. By changing the values of these process parameters through trail endeavors may fulfill just a single target at any given moment and may prompt either decreased generation rate or low quality dimension. For this purpose, most favorable process parameters optimization is required to find out the predetermined objective. RSM optimization technique is best technique to find out predetermined objective. The past, comparable endeavors were completed by a few scientists and the equivalent is introduced which highlighted in table 1, 2. In this research work, we are focused on RSM optimization technique which was used by various researchers for selecting the various EDM and its version process parameters for find out desired objective.

Nomenclature Table

EDM	Electrical Discharge machining
PMEDM	Powder Mixed EDM
MRR	Metal Removal Rate
RL	Recast Layer
WEDM	Wire EDM
WR	Wear Ratio
K_W	Kerf Width

TWR	Tool Wear Rate
SR	Surface Roughness
WLT	White Layer Thickness
EWR	Electrode Wear Rate
ROC	Radial Over Cut

Various EDM parameters are used for optimization of over research work. Electrical Discharge Machining factors extensively characterized in to two classifications:

- Performance parameter
- Process parameter

Process Parameters: Process parameters are those parameters in Electrical discharge machining with the help of which optimum output is achieved by varying the values of these parameters in a effective manner. These parameters are given below in tabular form:

Table 1. Various EDM process parameters used.

Electrode Based factors	Size of Electrode, shape of Electrode, material of Electrode
Non-Electrical factors	Working time, Dielectric type, Nozzle flush, size of grains, gap
Powder Based factors	Size of powder used, type of powder, concentration of powder, density of powder, powder conductivity
Electrical factors	Current, voltage, electrode polarity, servo motors, pulse frequency, pulse on time, pulse off time, duty factor

Performance parameter: Performance parameters are those parameters in EDM which are useful to find out its desired objective by varying the values of process parameters in effective manner. These parameters are given below in tabular form:

Table 2. Various EDM performance parameters used.

Performance Parameters	Process presentation effect
Surface Roughness	Surface roughness is the measurement of finely spaced micro- irregularities on the surface of work piece which is consists of three parts, namely roughness, waviness and form. Arithmetical mean surface hardness, greatest top to-valley surface spitefulness, root mean square surface hardness are the surface roughness terms used in EDM.

Tool wear rate	Tool wear rate is defined as the rate with which the material is removed from electrode 0r tool surface. It is articulated as volume of material removed from tool or electrode surface per unit time.
Wear Ratio	It is the ratio of amount of machining of work piece and amount of electrode wear. It is very important ratio which is find out before the selection of tool and work piece for the process because different wear ratio is given by using different material combination. We want minimum wear ratio with optimum MRR by proper combination of tool and work piece material.
Surface quality	Surface quality is used to explain the condition of the machined surface of the work piece. Various factors like recast layer thickness, area of heat affected zone, surface roughness etc. are affects the surface quality of work piece.
Material removal rate	The rate with which the material is removed from the surface of work piece is known as MRR and it is used to measure the speed with which material is removed from surface.

2. **Response Surface Methodology (RSM)**

RSM technique depends on test plan with the last objective of assessing the ideal working of mechanical offices, utilizing least trial exertion. Here, the inputs are called factors or variables and the outputs represent the response that generates the system under the causal action of the factors. Afterwards, the use of the RSM was shown in the design of new processes and products. As of late, it is being connected effectively in other logical fields, for example, science, prescription, vehicle, and planes, and so forth this is all so the goal is to improve the reaction.

Response surface methodology (RSM) is used to investigate the interaction between several illustrative variables and one or more response variables. Box and Draper [8] were introducing RSM in 1951.The most important purpose of RSM is to use a series of designed experiments to attain an optimal response.RSM approach is the methodology for deciding the connection between different procedure parameters with the different machining criteria and investigating the impact of these procedure parameters on the coupled reactions. In this work, RSM is used for deciding the relations between the different EDM process parameters with the different machining criteria and investigating the impact of these procedure parameters on the reactions, for example the MRR, EWR, hole estimate and the surface finish. So as to think about the impacts of the EDM parameters on the previously mentioned machining criteria, second request polynomial reaction surface scientific models can be created [9]. RSM is a gathering of numerical and measurable methods that are valuable for the displaying and investigation of issues in which a reaction of premium is influenced by a few factors and the goal is to advance this reaction [10, 11]. It is a sequential experimentation strategy for empirical model building and optimization. By leading tests and applying relapse investigation, a model of the reaction to some free information factors can be gotten. In view of the model of the reaction, a close ideal point would then be able to be derived. RSM is regularly connected in the portrayal and advancement of procedures. In RSM, it is possible to represent independent process parameters in quantitative form as:

$$Z=f[X_1, X_2, X_3 \ldots X_n] \pm \varepsilon \qquad (A)$$

Where Z is the output factors, f is the response function; ε is the experimental error, and X_1, X_2, X_3,………..X_n are independent parameters. If the response can be well modeled by a linear function of the independent factors, the function Equation (1) can be written as:

$$Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \beta_n X_n \qquad (B)$$

However, if a curvature seen in the arrangement, then a higher order polynomial such as the quadratic model of Equation may be used

$$Z = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum\sum_{i<j} \beta_{ij} X_i X_j + \sum_{i=1}^{k} \beta_{ij} X_i^2 + \varepsilon \qquad (C)$$

Where Z is the target or output value, Xi is the input factors, X^2_{ii} and X_i Xj are the squares and communication terms of the input factor. β_o, β_i, β_{ij} are unknown second order Regression which are find out by using the second-order model. The last equation (D) includes the interactive effects of the process factors. In this work, Eq. (3) can be rewritten according to the four factors used as:

$$Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{11} X_{12} + \beta_{22} X_{22} + \beta_{33} X_{32} + \beta_{44} X_{42} + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \cdots \beta_n X_n \quad (D)$$

X_1, X_2, X_3 and X_4 are Input factors. B_iX_i is the interaction between various factors.

2.1 EDM process performance factors optimization and enhancement using RSM optimization Technique (Table.3)

Year	Author	Process version	Work material	input variables	Objective	Remarks
2019	Bhupender et.al. [12]	WEDM	Nimonic 263	pulse-on time, pulse-off time, peak current, spark gap voltage	SR, recast layer thickness (RLT)	BPNN (Back propagation neutral network) has higher accuracy than RSM, showing lower value RMSE and percentage error.
	Anantha et.al. [13]	Plasma arc welding	Monel 400	Standoff distance, cutting speed, current, gas pressure	MRR, Heat effected zone	Microstructure examination is led to discovering the morphologies of cut surface at different cutting conditions.
2018	Shalini et.al. [14]	Powder Mixed EDM	AlSiCp	Pulse on time , flushing pressure, current, high voltage, pulse-off time	MRR, SR, TWR	Molecule swarm streamlining was actualized for foreseeing the outcomes and consequently blunder examination was accomplished for the arrangement of analyses.
	Amit et.al. [15]	Powder Mixed	Inconel alloy	gap voltage , pulse on time	MRR SR	Surface methodology of the created surface has been

		EDM		and peak current	TWR	examined by taking FESEM pictures, which demonstrates a similarly improved surface.
2017	Sourabh et.al. [16]	EDM	Incoloy 800HT	current, voltage and pulse on-time	TWR MRR	The exploration demonstrates that current is a critical parameter, as though the present increments, there is an expansion in material expulsion rate. Device wear rate limits when the voltage provided is high.
	Shiva et.al. [17]	Wire EDM	Titanium Alloy	pulse off time, constant voltage, Pulse on time, input power, Tension in wire	SR, Kerf width, MRR,	The exploratory outcomes uncover that the kerf width increments as the input control, beat on schedule, wire strain increments, server voltage and and the metal removal rate increments as information control increments and beat on schedule and It is seen that as the beat on schedule and info control builds, the surface unpleasantness additionally increments.
	Gaitonde et.al. [18]	Wire EDM	HCH Cr steel	pulse off time feed rate in wire, Pulse on time	TWR MRR SR	The built up numerical models were later utilized with differential development (DE) to improve the machining element.
2016	Sounder et.al.[19]	Wire EDM	A413 alloy	pulse off time, beat current, Pulse on time	SR MRR	The numerical models were created to anticipate the outcomes which are inside the breaking points of pleasant normal mistake for surface harshness and material evacuation rate through additivity test..
2015	Tiwary et al. [20]	EDM	Ti-6Al-4v	Pulse-off-time, Flushing pressure, Pulse-on time, Gap voltage,	MRR	CCD has been utilized and RSM is utilized to delineate connection between the procedure factors with the machining yield.
	Sarkar et a. [21]	EDM	AISI P20	Pulse Duration, Current, Duty cycle	MRR	Used to fit a quadratic scientific model for every one of the reactions
	Raj Amrish et al. [22]	Wire EDM	Titanium alloy	Pulse-off time, feed rate of wire Pulse-on time	SR MRR	The most favorable condition was found to be at wire feed rate 3.85 mm/min, pulse off time 17 µs and pulse on time 1 µs
	M. M. Rahman [23]	EDM	Ti-5 Al-2. 5Sn	Pulse-off Time, Servo voltage, Pulse-on Time, Peak Current	MRR	It is observed that the formulating model is within the limits of the delightful error (about 9%) when compared to investigational results.
	Zhang et al. [24]	Wire EDM	SKD 11	Pulse-on- time, Pulse current, Pulse-off-time	SR MRR	Pareto- optimal solutions can be used to find out best possible process-parameter arrangement.
	Balbir et al. [25]	Powder Mixed EDM	AA6061/10% Sic composite	Gap voltage, Pulse- off-time Current, Pulse-on time	SR	Machined with powder material EDM, surface hardness is increased and Thickness of white recast layer is decreased.

2014						
	Sivaprakasm et al. [26]	Micro Wire EDM	Ti-6,Al-4v	Capacity of voltage, Wire feed rate,	MRR SR	The most favorable machining performance of surface roughness are 0.789 µm and MRR0.01802 mm 3/min.
	Dewangan et al. [27]	EDM	AISI P20 tool steel	Current, Time of tool work, Pulse-on-time lift time of tool	SCD, Surface Roughness WLT	Best results were obtained by regular confirmation test in proper order.
	Hourm et al. [28]	EDM	Al-Mg2-Si	Current, Duty factor, Voltage, Pulse- on-time	TWR MRR	Investigation of microstructure of the EDM procedure on Al-Mg-Si tests uncovered that beat on-time, current, voltage, and extensively affect profile of machined surface.
	Gopalakannn et al. [29]	EDM	Sic	Current, Pulse-off-time Voltage, Pulse-on-time,	TWR MRR SR	Find out those factors which affect the output characteristics.
	Shashikant et al.[30]	EDM	EN 19	Pulse-off-time, Voltage, Pulse-on time, current	Surface roughness	Approximately 0.02% error was found when a test was performed.
2013	Kumar et al. [31]	Wire EDM	Pure titanium material	Electrode type, Pulse-on time, Duty cycle, Electrode Polarity, current Gap voltage	TWR , Surface roughness, MRR	Over cut is minimized by machining parameters optimization so that quality is improved.
	Tzeng et. al. [32]	EDM	Material SKD61	Pulse-off-time, Servo voltage, current, Pulse-on-time	REWR , Surface roughness, MRR	Best possible process parameters adjustment was achieved by using a hybrid technique.
	Assarzadeh et al. [33]	EDM	Cobalt-bonded tungsten carbide composite WC/6%Co)	Pulse- on-time, Duty cycle, Voltage Discharge current,	TWR, MRR, Surface roughness	The research is focused on benefit of selecting the adopted approach for increasing the metal removal rate.
	Khanna et. al. [34]	Wire EDM	D-3 material	Pulse-off-time, Current, Pulse-on- time, Servo Voltage	MRR	Voltage, current, pulse-on-time and pulse-off-time are the factors in their decreasing order which affects MRR.
	Ayesta et al.[35]	EDM	C1023 aeronautical alloy	Pulse time, Voltage, Current	EW MT	Low voltage, low current, high pulse time are the process parameters which decrease electrode wear and lower machining time.
	Khalid et. al.[36]	Powder Mixed EDM	W300 Die Steel material	concentration of Al powder, current, Pulse-on-time	WLT	Low peak current of 6A and Low thickness of WLT at high concentration of powder show Optical microscopy results.

	Rajendra et al. [37]	EDM	Mn2W50,T90 Cr45 tool steel material	Pulse -off-current Pulse-on-time	EWRL	The current is directly proportional to current density and resolidify layer.
	Modi M et al. [38]	Powder Mixed EDM	Ti-6, Al-4V	Pulse duration, Wheel-speed, Powder concentration, Current, Duty cycle,	SR MRR	Most favorable combination values of MRR and Ra. was obtained by WPC method.
	Muthu kumar [39]	EDM	Material Inconal 800	Beat-off time, Voltage, Current Beat-on time	ROC	Mathematical technique was used for correct the machining factors and ROC.
2012	Solhjoei et al. [40]	EDM	AISI H13	Pulse-on time ,Voltage, Current	SF MRR	MRR and various input factors like voltage, pulse-on-time and current are inter related to each other by use of mathematical technique.
	Patel et al. [41]	EDM	Steel material AISID2	Gap, Pulse-on-time, Current, Pulse-off time, Voltage	Surface roughness	For correlate the influences and interactive between EDM process factors, a comprehensive mathematical technique was created
	Baraskar et al. [42]	Die-sinking EDM	EN-8 carbon steel material	Pulse-off-time, Current, Pulse-on-duration, Pulse-on time, Current	SR MRR	RSM technique was used to find out the best possible Results.
	Lin et al. [43]	Micro-wire EDM	SK3 carbon tool steel material	Pulse-of- time, current, Electrode rotation speed, Pulse-on-time,	OC, Surface Roughness EWR	Highest consideration factor affecting the process performance was Peak current.
	Rajesh et. al. [44]	EDM	Aluminum Alloy with HE9 grade	Pulse-off time, voltage , Oil pressure, Pulse-on time, Current, Spark gap,	SR MRR	By using a designed experiment, a empirical models was create for analysis of MRR and SR
	Yang et al. [45]	Wire EDM	Pure tungsten	Pulse-off- time, Servo voltage, Wire feed rate, Water pressure, Pulse-on-time, Arc of time, Wire tension	SR MRR	Effective Process parameters setting were achieved by a hybrid method.
2011	Treng et al. [46]	Wire EDM	Pure tungsten material	Wire feed rate, Pulse-off-time, voltage, Wire tension, pressure of Water, Pulse-on-time, Arc-off time,	SR MRR	Optimization of wire EDM process factors was obtained by using integrated approach.
	Ojha et al. [47]	EDM	EN-8steel material	Duty cycle, Diameter of tool, current	TWR MRR	Quadratic equations are creating for performance factors with the help of empirical modeling.
	Rahman et al. [48]	EDM	Al-4 ,Ti-6	Pulse-off-time, current, Pulse-on- time	MRR	Research developed a mathematical model for correlates manipulate of various factors and find the output in the form of increasing MRR.

2010	Raman et al. [49]	EDM	Al-4 V, Ti-6	Pulse-on- time, current, Pulse-off-time	MRR	In this research work, created model is within the restrictions of the satisfying error (about4.01%) when compared with the experimental outcome.
	Iqbal et. al. [50]	EDM	AISI 304 material	Feed rate, Rotational Speed of electrode, Voltage,	Surface roughness, MRR EWR	By using rotary electrode, RLT and micro cracks was removed from the surface.
	Abdul et. al. [51]	EDM	Al-4 V, Ti-6	Pulse-on-time , voltage gap, Current, Pause-off-time,	Electrode wear	Research was examination of electrode wear due to the effects of electrode cooling.
2009	Patel et al. [52]	EDM	Ceramic composite Al2O3/Sic W/Tic	Discharge Current, Pulse-on time, Duty cycle, Gap voltage	SR	SR was dominated by pulse- on-time.
	Habib [53]	EDM	MMC Al/Sic	Gap voltage, Pulse-on-time, Peak current	Tool wear rate, RGS, MRR	For correlate the influences and interactive between EDM process factors, a comprehensive mathematical technique was created
	Kung et al. [54]	Powder Mixed EDM	Cobalt-bonded tungsten carbide	Pulse-on-time, Discharge Current, Grain size,	EWR MRR	Experimental technique was used to find out the best possible Results.
	Saha et. al. [55]	Dry EDM	Mild steel EN32 material	Discharge Current, Duty factor, Spindle Speed, Gap Voltage, Pulse-on-time, Air Pressure	Electrode wear rate, MRR, SR	Research focused on creating a experiment based on the CCD of experiments for develop a practical models for Ra, tool wear rate and MRR.
	Sohani et al. [56]	EDM	Medium carbon steel material	Current, Pulse-on-time, Tool wear area, volume fraction of Sic, Pulse-off-time,	Surface roughness, EWR, MRR	Research found that lower tool wear rate and higher MRR were achieved by using circular tool shapes.
	Taweel [57]	Die sinking EDM	Steel material CK45	Flushing pressure, Beat-on-time Peak current,	TWR MRR	Tool wear rate and material rate was the main process factors to achieve the goal.
2008	Chiang et al. [58]	EDM	Cast iron material	Pulse-on-time, Open discharge voltage, Discharge current, Duty factor,	Electrode wear rate, SR, MRR	Area fraction of spheroidal graphite particle and diameter were second phase process factors.
	Chiang. [59]	EDM	TiC Mixed Ceramic+Al2O3	Duty Factor, Voltage, Discharge Current, Pulse-on-time	EWR Surface Roughness MRR	Process characteristics were developed by using mathematical model.
	Kung et.al. [60]	Wire EDM	Aluminium oxide based Ceramic material	Duty factor, Peak current, Pulse-on-time, Wire speed	Surface roughness, MRR	Peak current affects the surface roughness and duty factor and pulse on time affects MRR.

	Tao et al. [61]	Dry EDM Milling Process	liquid-gas mixture	Current, Pulse Duration, Pulse interval, Polarity, Gap voltage, OCV	SR MRR	Good surface finish and machining stability were found under low discharge input current.
	Kanagarajan et al.[62]	Die-Sinking EDM	WC/Co cemented carbide	Pulse-on- time, Flushing Pressure, current, Electrode Rotation,	Surface roughness, MRR	Process characteristics were developed by using Statistical form.
	Kuppan et al. [63]	EDM	Inconel 718 material	Electrode speed, current, Duty factor, Pulse-on- time	Duty cycle, SR, MRR	Desirability function approach was used for optimized required surface finish and maximum MRR.
2007	Çaydas et al. [64]	EDM	Al-4V , Ti-6	Pulse-on time, Current	WLT Electrode wear rate	Electrolyte flow rates, feed rate, machining voltage are the various parameters to Investigate improvability of surface reliability.
	Chiang et. al. [65]	EDM	TiC, Al2O3+30%	Voltage, Current, Pulse duration	SR_{max} Electrode wear rate, MRR	Ridge density and WLT are affected by quantity and area fraction of graphite particle.
2006	Kensal et. al.[66]	Powder Mixed EDM	SiCP Al 10%	Duration of pulses, current	Surface roughness, MRR	Research was focused on finding the various factors like SR, MRR with significant values.
	Petropoulos et al.[67]	EDM	Material AISI D2	Beat -on- time, current	SF	To find out the good surface finish and precision, best fit conditions was developed by a model.

3. Concluding Remarks

After a point by point writing literature identified with parametric advancement of Electrical discharge machining forms utilizing Response surface methodology starting time 2019 to 2006 is arranged and abridged. In this article, various non conventional machines like electrical discharge machining (EDM), powder mixed EDM, wire EDM and small scale EDM are optimized with their process parameters. With the help of a table author name, various objective(s), procedure factors and work materials utilized by various analysts are likewise featured. Different research works are also additionally introduced and the accompanying perceptions are come dependent on survey work.

- There should arise an occurrence of EDM and its partnered procedures, most of the enhancement related works depended upon Response Surface methodology. The benefits of various working or input parameters are independently affect the all response or output parameters by investigation of the various reaction parameters utilizing Response Surface methodology.
- By using the data from practical work, mathematical models can be produced with the help of Response Surface methodology. Study of various control factors were used to control the parameters like electrode wear rate, MRR, surface roughness, gap and so on. The widespread

models develop by using various factors have influential, relatively distinctive and goal oriented. With the help of these models, one can differentiate between important and most important factors utilized in a specific application. Peak current, voltage, gap, pulse on time, pulse off time are important factors but MRR, electrode wear rate, surface finish, gap size are most important factors of EDM and appropriate technique is selected for these parameters.

- When the material removal rate is increased, at the same time electrode wear rate and tool wear rate is also increased. This can be found in Response surface methodology optimization method used in Electrical discharge machining process

References

[1]. Ho, K. H., & S. T. Newman. "State of the art (EDM)." Int. J. of Machine Tools & Manufacture 43.13 (2003): 1287-1300.

[2]. Shu, K. M., & G. C. Tu. "Study of electrical discharge grinding using metal matrix composite electrodes." Int. J. of Machine Tools & Manufacture 43.8 (2003): 845-854. .

[3]. Guu, Y. H. "AFM surface imaging of AISI D2 tool steel machined by the EDM process." Applied Surface Science 242.3 (2005): 245-250.

[4].Ramakrishna, R., & L. Karunamoorthy. "Multi response optimization of wire EDM operations using robust design of experiments." The Int. J. of Advanced Manufacturing Technology 29.1-2 (2006): 105-112.

[5].Sanjeev, et al. "Surface modification by electrical discharge machining: A review." J. of Materials Processing Techn209.8 (2009): 3675-3687.

[6]. Ponappa, K., et al. "The effect of process parameters on machining of magnesium nano alumina composites through EDM." The Int. J. of Advanced Manufacturing Technology 46.9-12 (2010): 1035-1042.

[7]. Majhi, Sanjay Kumar, M. K. Pradhan, & Hargovind Soni. "Optimization of EDM parameters using integrated approach of RSM, GRA & entropy method." Int. J. of Applied Resea.Mecha.Eng 3.1 (2013).

[8].M.Yan, Y.Lai, "Surface quality improvement of wire-EDM using a fine-finish power supply," International Journal of Machine Tools & Manufacture., Vol. 47, Feb. 2007,pp. 1686–1694.

[9].Cochran, G. "GM Cox in: Experimental Design." (1962).

[10].C Montgomery, Douglas. "Montgomery Design & Analysis of Experiments." (1997).

[11].Ebeid, S. J., et al. "Towards higher accuracy for ECM hybridized with low-frequency vibrations using the RSM. "J. of materials processing technology 149. 1 (2004): 432-438.

[12]. K. Ananthakumar et. al., " Measurement and optimization of multi-response characteristics in plasma

arc cutting of monel 400TM using RSM And TOPSIS ” Volume 135, March 2019, Pages 725-737

[13]. Bhupinder Singh et. al., "Surface finish analysis of wire electric discharge machined specimens by RSM and ANN modeling” Volume 137, April 2019, Pages 225-237

[14]. Shalini et. al., "Multi-objective parametric optimization of nano powder mixed electrical discharge machining of AlSiCp using response surface methodology and particle swarmoptimization” Alexandria Engineering Journal,Volume 57, Issue 2, June 2018,Pages 609-619

[15]. Amit kumar et. al., " Investigation of powder mixed EDM process parameters for machining Inconel alloy using RSM” Volume 5, Issue 2, Part 1, 2018, Pages 6183-6188

[16]. Sourabh et. al., "Investigation of Material Removal Rate and Tool Wear Rate on Electrical Discharge Machining of Incoloy 800HT by using RSM” Volume 4, Issue 9, 2017, Pages 10603-10606

[17]. Shiva et. al., "Parametric optimization in Wire Electrical Discharge Machining of Titanium Alloy using RSM” Volume 4, Issue 2, Part A, 2017, Pages 1434-1441

[18]. Gaitonde et. al., " Modeling and optimization of electrical discharge machining process using RSM” Volume 4, Issue 2, Part A, 2017, Pages 1752-1761

[19]. Soundararajan et. al., " An investigation of material removal rate and surface roughness of squeeze casted A413 alloy on WEDM by multi response optimization using RSM” Journal of Alloys and Compounds, Volume 685,15 November 2016, Pages 533-545

[20].Tiwary, A. P., B. B. Pradhan, & B. Bhattacharyya. "Study on the influence of micro-EDM process parameters during machining of Ti– 6Al–4V super alloy.”The Int. J. of Advanced Manufacturing Technology 76.1-4 (2015): 151-160.

[21].Sarkaret et. al. "Optimization of Machine Process Parameters on Material Removal Rate in EDM for AISI P20 tool Steel Material using RSM."

[22]. Raj, D. A, & T. Senthilvelan. "Empirical Modeling & Optimization of Process Parameters of machining Titanium alloy by Wire-EDM using RSM.”Materials Today: Proc 2. 4 (2015): 1682-1690.

[23].Khan, MdAshikur Rahman, M. M. Rahman, & K. Kadirgama. "An experimental investigation on surface finish in die-sinking EDM of Ti-5Al-2.5 Sn.” The Int. J. of Advanced Manufacturing Technology 77. 9-12 (2014): 1727-1740.

[24]. Zhang, Guojun, et al. "The multi-objective optimization of medium-speed WEDM process parameters for machining SKD11 steel by the hybrid method of RSM & NSGA-II.” The Int. J. of Advanced Manufacturing Technology 70.9-12 (2014): 2097-2109.

[25].Singh, Balbir, Jatinder Kumar, & Sudhir Kumar. "Experimental investigation on surface characteristics in powder-mixed electro discharge machining of AA6061/10% Sic composite.” Materials & Manufacturing Processes 29.3 (2014): 287-297.

[26].Sivaprakasam, P., P. Hariharan, & S. Gowri. "Modeling & analysis of micro-WEDM process of titanium alloy (Ti–6Al–4V) using response surface approach." Engineering Science & Technology, an Int. J. 17.4 (2014): 227-235.

[27].Dewangan, Shailesh Kumar. Multi-objective optimization & analysis of EDM of AISI P20 tool steel Diss. 2014.

[28].Hourm & , Mehdi, et al. "Investigating (EDM) parameter effects on Al-Mg2Si metal matrix composite (MMC) for high material removal rate (MRR) & less EWR–RSM approach." The Int. J. of Advanced Manufacturing Technology 77.5-8 (2014): 831-838.

[29].Gopalakannan, Subramanian, & ThiagarajanSenthilvelan. "Optimization of machining parameters for EDM operations based on central composite design & desirability approach." J. of Mechanical Science & Technology 28.3 (2014): 1045-1053.

[30].Shasikant et al. 2014"Effect & optimization of various machine process parameters on the surface roughness in EDM for an EN 19 material using Response surface Methodology Int. conference on Advances on manufacturing & material Engineering AMME 2014,Proceeding Material Science 5(2014) 1702-1709

[31].Kumar, A, V Kumar, & Jatinder Kumar. "Investigation of machining parameters & surface integrity in wire electric discharge machining of pure titanium." Proc. of the Institution of Mechanical Engineers, Part B: J. of Engineering Manuf. acture 227. 7 (2013): 972-992.

[32]. Tzeng, Chorng-Jyh, & Rui-Yang Chen."Optimization of electric discharge machining process using the response surface methodology & genetic algorithm approach. "Int. J. of precision engineering & manufacturing 14.5 (2013): 709-717. . .

[33].Assarzadeh, S., & M. Ghoreishi. "Statistical modeling & optimization of process parameters in electro-discharge machining of cobalt-bonded tungsten carbide composite (WC/6% Co)." Procedia CIRP 6 (2013): 463-468.

[34].Khanna, Rajesh, & Hari Singh. "Performance analysis for D-3 material using response surface methodology on WEDM." Int. J. of Machining & Machinability of Materials 14.1 (2013): 45-65.

[35].Ayesta, I., et al. "Influence of EDM parameters on slot machining in C1023 aeronautical alloy." Procedia CIRP 6 (2013): 129-134.

[36].Syed Khalid Hussain, & P. Kuppan. "Studies on Recast-layer in EDM using Aluminum Powder Mixed Distilled Water Dielectric Fluid." Int. J. of Engineering & Technology 5 (2013): 1775-1780.

[37].Rajendran, S., K. Marimuthu, & M. Sakthivel. "Study of crack formation & re solidified layer in EDM process on T90Mn2W50Cr45 tool steel." Materials & Manufacturing Processes 28.6 (2013): 664-669.

[38].Modi, M, & G Agarwal. "Powder-Mixed Electro-Discharge Diamond Surface Grinding Process: Modeling, Comparative Analysis & Multi-Output Optimization Using Weighted Principal

Components Analysis." J. of Mechanical Engineering 59.12 (2013): 735-747.

[39].Muthukumar, V., et al. "Mathematical Modeling for Radial Overcut on Electrical Discharge Machining of Incolol 800 by Response Surface Methodology." Materials Science 6 (2014): 1674-1682.

[40]. Solhjoei, Nosratollah, et al. "Investigation on Electro Discharge Machining of H13." Research J. of Applied Sciences, Engineering & Technology 4.17 (2012): 3005-3014.

[41].Patel, M. B.,et al. "Application of Response Surface Methodology for Determining MRR & TWR Model in Die Sinking EDM of AISI 1045 Steel."Pulse 40.50: 60.

[42].Baraskar, Sunil Sheshrao, S. S. Banwait, & S. C. Laroiya. "Multi objective optimization of electrical discharge machining process using a hybrid method."Materials & Manufacturing Processes 28.4 (2013): 348-354.

[43].Lin, Y. C. , et al. "Evaluation of the characteristics of the micro electrical discharge machining process using response surface methodology based on the central composite design. " The Int. J. of Advanced Manufacturing Technology 62.9-12 (2012): 1013-1023.

[44].R.Rajesh M.Dev An & 2012 The Optimization of the Electro-Discharge Machining Process Using Response Surface Methodology & Genetic Algorithms Int. Conference on Modeling, Optimization & Computing (ICMOC - 2012) Procedia Engg38 (2012) 3941 – 3950

[45].Yang, Rong Tai, et al. "Optimization of wire electrical discharge machining process parameters for cutting tungsten." The Int. J. of Advanced Manufacturing Technology 60.1-4 (2012): 135-147.

[46].Tzeng, C. J., et al. "Optimization of wire electrical discharge machining of pure tungsten using neural network & response surface methodology."Proc. of the Institution of Mechanical Engineers, Part B: J. of Engineering Manufacture (2011): 09544054JEM2021.

[47].Johan Kildee, R. K. Garg, & K. K. Singh. "Experimental investigation & modeling of PMEDM process with chromium powder suspended dielectric."Int. J. of Applied Science & Engineering 9.2 (2011): 65-81.

[48]. Rahman, M. M., et al. "Optimization of machining parameters on surface roughness in EDM of Ti-6Al-4V using Response surface method." Advanced Materials Research.Vol. 213.2011

[49].Rahman, M. M. , et al Modeling of Material Removal on Machining of Ti-6Al-4V through EDM using Copper Tungsten Electrode & Positive Polarity Int. J. of Mechanical & Materials Engineering 1:3 201

[50].Iqbal A. K.M, & Ahsan Ali Khan. "Influence of process parameters on electrical discharge machined job surface integrity." American J. of Engineering & Applied Sciences 3.2 (2010): 396-402.

[51].Abdulkareem, Suleiman, Ahsan Ali Khan, & Mohamed Konneh. "Cooling effect on electrode & process parameters in EDM." Materials & Manufacturing Processes 25.6 (2010): 462-466.

[52].Patel, K. M., Pulak M. P & ey, & P. Venkateswara Rao. "Determination of an optimum parametric combination using a surface roughness prediction model for EDM of Al2O3/Sic/Tic ceramic composite." Materials & Manufacturing Processes 24.6 (2009): 675-682.

[53].Habib, Sameh S. "Study of the parameters in electrical discharge machining through response surface methodology approach." Applied Mathematical Modeling 33.12 (2009): 4397-4407.

[54].Kung, Kuang-Yuan, Jenn-TsongHorng, & Ko-Ta Chiang. "Material removal rate & electrode wear ratio study on the powder mixed electrical discharge machining of cobalt-bonded tungsten carbide" The Int. J. of Advanced Manuf.Technology 40.1-2 (2009): 95-104.

[55].Saha, Sourabh K., & S. K. Choudhury. "Experimental investigation & empirical modeling of the dry electric discharge machining process."Int. J. of Machine Tools & Manufacture 49.3 (2009): 297-308.

[56].Sohani, M. S., et al. "Investigations into the effect of tool shapes with size factor consideration in sink electrical discharge machining (EDM) process." The Int. J. of Advanced Manufacturing Technology 45.11-12 (2009): 1131-1145.

[57].El-Taweel, T. A. "Multi-response optimization of EDM with Al–Cu–Si–Tic P/M composite electrode." The Int. J. of Advanced Manufacturing Technology 44.1-2 (2009): 100-113.

[58].Chiang, Ko-Ta. "Modeling & analysis of the effects of machining parameters on the performance characteristics in the EDM process of Al2O3+ Tic mixed ceramic." The Int. J. of Advanced Manufacturing Technology37.5-6 (2008): 523-533.

[59].Chiang, Ko-Ta. "Modeling & analysis of the effects of machining parameters on the performance characteristics in the EDM process of Al2O3+ Tic mixed ceramic." Int. J. of Advanced Manufacturing Technology37.5-6 (2008): 523-533.

[60]. Kung, Kuang-Yuan, & Ko-Ta Chiang. "Modeling & analysis of Machinability evaluation in the wire electrical discharge machining (WEDM) process of aluminum oxide-based ceramic." Materials & Manufacturing Processes 23.3 (2008): 241-250.

[61].Tao, Jia, Albert J. Shih, & Jun Ni. "Experimental study of the dry & near-dry electrical discharge milling processes." J. of Manufacturing Science & Engineering 130.1 (2008): 011002.

[62]. Kanagarajan, D., et al. "Optimization of electrical discharge machining characteristics of WC/Co composites using non-dominated sorting genetic algorithm (NSGA-II)." The Int. J. of Advanced Manufacturing Technology 36.11-12 (2008): 1124-1132.

[63].Kuppan, P., A. Rajadurai, & S. Narayanan. "Influence of EDM process parameters in deep whole drilling of Inconel 718." The Int. J. of Advanced Manufacturing Technology 38.1-2 (2008): 74-84.

[64].Hasçalık, Hamlet, & UlaşÇaydaş. "A comparative study of surface integrity of Ti–6Al–4V alloy machined by EDM & AECG." J. of Materials Processing Technology 190.1 (2007): 173-180.

[65].Chiang, Ko-Ta, Fu-Ping Chang, & De-Chang Tsai. "Modeling & analysis of the rapidly resolidified layer of SG cast iron in the EDM process through the response surface methodology." J. of Materials

Processing Technology182.1 (2007): 525-533.

[66].Kansal, H. K., Sehijpal Singh, & Pradeep Kumar. "An experimental study of the machining parameters in powder mixed electric discharge machining of Al–10% SiCP metal matrix composites." Int. J of Machining & Machinability of Materials 1.4 (2006): 396-411.

[67].Petropoulos, G., et al. "Multi-parameter modeling of surface texture in EDMachining using the design of experiments methodology." Materials science forum. Vol. 526. 2006.