Response Surface Methodology – A Review

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Abstract— Response Surface Methodology (RSM) is a technique which involves some statistical and mathematical calculations and helps developing, improving and optimizing product and process. Although various optimization methods are available in literature such as one-factorial method, Taguchi design of experiments etc., RSM has its own benefits when compared to other conventional techniques of optimization. The main drawback of one-factorial method lies in is lengthy and time consuming process. Also in one-factorial it is not possible to detect parameter interactive impact on response. Taguchi approach of optimization is very familiar and popular in the field optimization which minimizes the number of experiments by using the concept of Design of Experiments. It uses the concept of signal-to-noise ratio and analysis of variance for finding the optimal parameter combination and its effect on the response. But in Taguchi method the results cannot be fitted in regression equation for locating the optimum level. In this perspective, RSM is best suitable and sufficient method for multiple variable optimizations to find the optimal conditions with minimum number of experiments. This paper reviews the concept of RSM and previously conducted experiments which got published in international journals. Although, lot of literature is available on optimization methods, there is no specific literature written on RSM. In this study a total of 27 RSM papers were reviewed which got published between 2000 and 2018 in various reputed international journals.

Keywords: Optimization, Response Surface Methodology (RSM), Design of experiments (DOE)

I. INTRODUCTION

The design of experiments is a series of techniques to optimize product/process design and process operation, and limiting the effect of noise (uncontrollable) factors. [1] This technique is very helpful in determining the most desirable design of product, the best parameter combination of process and the most effective data collection plan. The optimization of process parameters by DOE provides the evaluation of the effect of individual independent parameters on the identified quality characteristics. [2] DOE is useful to make product and process more robust. A few methods used as Design of experiments are Taguchi Method, Response Surface Method and Factorial Designs.

– Response surface methodology

Response surface methodology is a statistical and mathematical method which explores relationship between input process parameters and response variable (output). This method was introduced by George. E. P .Box and K. B. Wilson in 1951. RSM uses sequential order of design of experiments in order to achieve optimum response. This is the methodology helps in developing, improving and optimizing the process parameters. The design procedure of RSM involves the following steps:

1) Designing a set of experiments,
2) Determination of the mathematical model with best fits,
3) Finding the optimum set of experimental factors to produce maximum or minimum of the response and
4) Representing the direct or interactive effects of process variables on the surface quality of machined surface.

For "n" number of measurable input variables, the response surface given by:

$$Y = f(x_1, x_2, x_3, x_4 \ldots x_n) + \varepsilon$$

Where, $x_1 \ldots x_n$ are the independent input parameters, ε is the random error and Y is the output or response variable.

RSM is generally employed through multiple regression models. Our goal is to find a suitable approximation for the response function which can be achieved by the regression models.

For example, the first order or linear multiple regression model can be used –

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon$$

For better approximation, interaction terms can be included

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon$$

The second order or quadratic regression model includes the square terms in addition to the terms above –

$$Y= \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x12 + \beta_{22} x22 + \beta_{33} x32 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon$$

In RSM, Central Composite design and Box-Behnken design are effective designs for fitting quadratic model.

A. *Central Composite Design:*

The central composite design (CCD) is a well known design for setting a quadratic model. This design consists of full-factorial or fractional factorial design with center points and axial points.

The number of tests required for CCD is given by:

$N=2k+2k+nc$

Where,

N = total number of runs or experiments

k = number of independent variables or factors

nc = number of center points

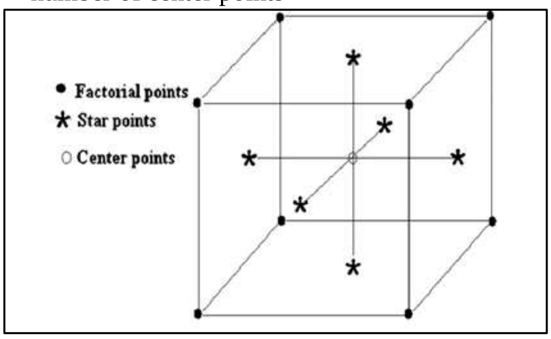

Fig. 1: Structure of central composite design

If the distance from the center of the design space to a factorial point is ±1 unit for each factor, the distance from the center of the design space to a star point is $|\alpha| > 1$.

The precise value of α depends on certain properties desired for the design and on the number of factors involved.

1) Types of CCD:

Central composite circumscribed design (CCC): These designs are the original form of the central composite design. The star points are at some distance "α" from the center based on the properties desired for the design and the number of factors in the design. The star points establish new extremes for the low and high settings for all factors. This requires 5 levels for each factor.

Central composite inscribed design (CCI): The CCI design uses the factor settings as the star points and creates a factorial or fractional factorial design within those limits. This design also requires 5 levels of each factor.

Central composite face centered design (CCF): In this design the star points are at the center of each face of the factorial space, so α= ± 1. This variety requires 3 levels of each factor.

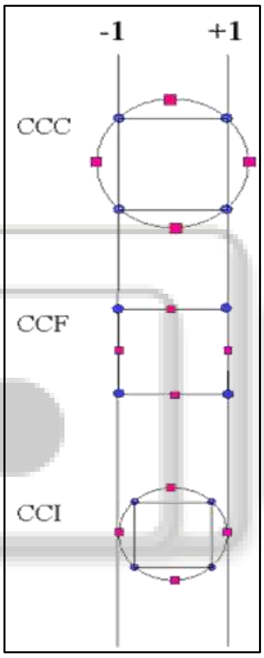

Fig. 2: Three types of central composite design for two factors.

B. box-behnken design:

Box-Behnken design is one with points lying on a sphere of radius √2. This design contains only the points on the mid edges of the process space and at the center. They require 3 levels.

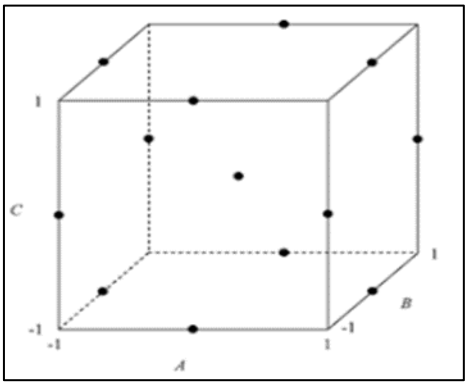

Fig. 3: Box-Behnken design for three factors

The number of tests required for Box-Behnken design is given by:

$$N=2k(k-1)+nc$$

Where,

N = total number of runs or experiments

k = number of independent variables or factors

nc = number of center points

II. Terminology Used in RSM

1) Factor: All the input variables that affect the output of a system are factors.
2) Response: The output obtained from trial runs of experiment.
3) Center points: They are the trial runs whose values of each factor are the medians of the values used in the factorial portion. This helps in enhancing the precision of the experiment.
4) Axial points or star points: They are which will take on values both below and above the median of the two factorial levels.
5) Alpha (α): It is the distance of each axial point from the center. It is α = (2k) 1/4 for a rotatability design.
6) Rotatable design: A design produces contours of standard deviation of predicted response.

III. Literature Review

Sudhir Kumar, Pradeep Kumar and H.S.Shan [3] studied the effect of process parameters such as degree of vacuum, pouring temperature, grain fineness number, amplitude of vibration and time of vibration on the solidification time of Al-7%Si alloy produced by vacuum assisted evaporative pattern casting process. The central composite rotatable design has been used to conduct experiments. As there are 5 factors or variables, number of experiments to be conducted are 32 and a second order response mathematical model is constructed using RSM. Here, the solidification time decreases with increase in the degree of vacuum, amplitude of vibration and time of vibration is noticed.

Mohan Kumar Pradhan and Chandan Kumar Biswas [4] submitted a work on establishing a relationship between the three control variables such as discharge current, pulse duration and pulse off time on material removal rate of AISI D2 tool steel in EDM process. The second order model is built using response surface method and they used the central composite design to estimate the coefficients of model. They are validated using ANOVA at 5% level of significance and found that the three parameters have a significant effect on material removal rate.

Gökhan Orhan1,Gökçe Hapçı1,Özgül Keleş [5] presented the study on the effects of deposition parameters such as current density, electrolyte composition (Cu/Zn mole ratio), mechanical stirring speed, and temperature on the Cu content of alloy powder and cathodic current efficiency of Cu-Zn alloy powders formed in electrodeposition process in which pyrophosphate-based electrolytes are used. The empirical models developed in terms of deposition parameters have been found statistically adequate to describe the process responses and experiments were considered using central composite design(CCD). Their study revealed that as far as the copper content was concerned in the alloyed powders; all parameters selected have positive correlations. However, high stirring speed and low current density lead a greater current efficiency. From SEM analysis it is inferred that the powder morphology is considerably affected by the cathodic current density and stirring speed. The alloy powder morphology changes from spongy-like to cauliflower-like structures with increasing stirring speed. With increasing current density, highly branched dendritic particles are formed. These powders are highly branched dendrites, consisting of corncob-like structures.

Dr.M.Naga Phani Shastry, K.Devaki Devi and Dr.k.Madhava Reddy [6] presented a study on analysis and optimization of machining process parameters like feed, cutting speed and depth of cut of Al alloy in turning process. In order to construct the fine model, quadratic effects and interaction effects of the variables are considered here. They conducted 20 experiments as they considered three factors and two different materials. Material removal rate is calculated and with the help of DESIGN EXPERT-8 optimized value is obtained and later analysis of variance is carried out to validate the values.

Ashvin J.Makadia and J.J.Nanavati [7] used response surface methodology to study the effect of turning parameters such as feed rate, tool nose radius, cutting speed and depth of cut on the surface roughness of AISI 410 steel. They selected a design based on response surface methodology and conducted 81 experiments. They found that the feed rate is great influencing on surface roughness followed by tool nose radius and cutting speed. Depth of cut has no significant effect on surface roughness.

Norasiah Muhammad and Yupiter HP Manurung [8] used central composite design based response surface methodology to study the effect of input parameters such as weld current, weld time, electrode force and hold time while developing a weld zone in resistance spot welding which focuses on weld nugget and heat affect zone. They developed a quadratic model for responses.

HE Zhen, Zhang Xu-tao, XIE Gui – quing [9] presented a case study on improving the quality performance of the terminal earphone in an electronic company. For this they employed sequential number of experiments and a mathematical model is built using response surface method considering curvature in linear model. They considered factors such as cylinder pressure, decent speed, block height and slot width. So, they coducted20 experiments while considering full factorial and a model is constructed and validated using ANOVA. The first stage of experiment result in lower pressure a higher height may yield lower coplanarity. Since there is a possible curvature, central composite face centered design is used for second stage of experiment. By considering 4 factorial points, 5 center points and 4 axial points, 13 experiments are conducted and as two order terms are not significant, table is reduced and found the mathematical model and validated at 5% level of significance.

Pawan kumar , Anish kumar and Balinder singh [10] studied the effect of abrasive tools on En24 steel surface by using surface grinding parameters such as grinding wheel speed, table speed and depth of cut. They used half fractional factorial design with five center points and conducted total 15 trials. They found that wheel speed and table speed has most significant effect on material removal rate.

Singaram Lakshmanan and Mahesh kumar [11] presented a study on optimizing of material removal rate of EDM by constructing second order response surface model for E31 steel work piece. This model is built considering pulse on time, pulse off time, current and applied voltage as process variables. The response variable is MRR and RSM model is built. As 4 variables are considered, 31 experiments have been carried out. The results obtained are validated with analysis of variance. The calculated error between experimental and model predicted value is observed to be small. Finally, optimum MRR within the experimental range and the levels of the process parameters are Pulse on 500 µs, Pulse off 1500 µs, Current 20 A and Voltage 60 V obtained.

M.Manohar, Jomy Joseph, T.Selvaraj and D.Sivakumar [12] studied the effect of turning Inconel 718 alloy input parameters such as cutting speed, feed and depth of cut on the material removal rate. Here, Box Behnken Design is used to plan number of experiments as15. A polynomial model was developed to relate the relation between input and output parameters. Then further, ANOVA is carried on.

Pratik A. patil and C.A Waghmare [13] presented a study on the effect of electric discharge machining parameters such as wire tension, pulse on time and peak current on material removal rate (MRR). Machining was performed on AISI D2 cold work piece. The experiments were designed based on response surface methodology central composite design. They conducted 20 experiments. They found from the analysis that peak current had a great affect on material removal rate.

Gaurav Chaudhary, Manojkumar, Santhosh Verma and Anupam Srivastav [14] studied the effect of drilling input parameters such as speed, feed and point angle on the material removal rate and surface roughness of Aluminium matrix composite(AMC) and Hybrid aluminium matrix composite(HAMC). They used face centered central composite design based response surface methodology for both composites to conduct experiments. They found great influencing factor as feed rate. They analyzed both HAMC's and AMC's and found that AMC's have good machinability when compared to HAMC's.

Paresh D.Patel, Absar Lakadwala and Rajesh N.Patel [15] studied the effect of compression ratio (CR), injection pressure(IP), injection timing(IT) on brake thermal efficiency of compression ignition engine. They used Box Behnken Design as it runs 15 experiments. A mathematical model was developed. They revealed that an optimum combination of engine parameters i.e. CR D 18, IP D 220 bar and IT D 200 before top dead centre.

Sunil kumar , Amit kumar Bansal, Suman Anand, Chandan kumar and Bhaskar Srivastava [16] presented a study on the effect of EDM parameters on surface roughness using response surface methodology based on the two level full factorial design including 4 center points. They considered input parameters as voltage, current, pulse on time and pulse off time. They conducted 20 experiments. They analyzed and formed the relation between input parameters and response. They found that pulse on time is most significant factor. They also found that surface roughness decreases as pulse off increases, voltage increases, current decreases and pulse on decreases.

Dr.Funda kahraman [17] studied the effect of burnishing parameters such as burnishing force, number of passes, feed rate and burnishing speed on surface hardness of AA7075 aluminium alloy. Burnishing is performed using ball burnishing apparatus to produce a smooth and work-hardened surface. He used rotatable central composite design based response surface methodology and conducted 30 experiments. He came to know that burnishing force and number of passes are the significant factors on surface hardness.

Mr. Somanath M.kale and Mr. D.S khedekar [18] studied the effect of Electric discharge machining (EDM) input parameters such as current, voltage and pulse on time on material removal rate(MRR) and tool wear rate(TWR) of Inconel718. They used Central Composite Design of response surface methodology to conduct number of experiments. They had chosen a design 2^3 with 8 cube point, 6 center point in cube, 6 axial points and conducted 20 experiments. They found that current is most affecting parameters for both MRR & TWR. They also found that MRR and TWR increases as the current and pulse on time increases. While MRR and TWR decreases as the voltage increases.

Christopher Olkechukwu Izelu, Samuel Chikezie Eze and Festus Ifeanyi Ashiedu [19] used response surface methodology to study the effect of turning parameters such as feed rate, cutting speed, tool nose radius on the surface roughness of 41Cr4 alloy steel. They had chosen central composite design based response surface methodology to conduct experiments. The three factors has a great effect on surface roughness is found.

S.Marichamy, M.Sravanan, M.Ravichandran and B.Stalin [20] studied the effect of process parameters on material removal rate of Duplex brass alloy which is fabricated using stir casting technique during EDM process. The process parameters such as current, voltage, pulse on time and flushing pressure were considered to study their effect on surface roughness. For this they formulated a second order model using response surface method. To design the experiment they considered Box-Behnken design from RSM. The values are validated using ANOVA.

M.SaiRam and B.Srinivas [21] presented Box-Behnken based response surface methodology to study the effect of Electric Discharge Machining parameters on certain Cast Irons. They considered the input parameters as hardness of various cast irons, spark gap and current. They found that with respect to surface roughness, short pulse duration combined with a high peak value can generate better surface finish.

Sushanth Kumar Behera, Himanshu Meena, Sudipto Chakraborty and B.C.Meikap [22] studied the effect of three independent variables such as concentration, temperature, time for ash reduction from low grade coal. They proposed a quadratic model to correlate the independent variables for maximum ash reduction at optimum process condition by using Central Composite Design. By this they revealed that hydrofluoric acid concentration was the most effective parameter than other parameters. Leaching process optimization was carried out and the experimental values obtained for the ash reduction were found closer to the values obtained as predicted by the models.

M. V. Satish Kumar and M. Pradeep Kumar [23] Optimized CNC turning parameters in machining EN 19 alloy steel for MRR and surface roughness. Face centered central composite RSM was used for design of experiments and ANOVA is used find out the signifying factor on the response. Further, regression analysis and desirability approach was carried out using Minitab 17 software.

S. no	NAME OF PAPER	Number of factors	Number of levels	Number of experiments	Design of experiments	software used
1	Modelling of machining parameters for MRR in EDM using response surface methodology [4].	3	3	2^3+6+6=20; 8 cube points,4 center points cube,6axialpoints and 2 center points in axial.	CENTRAL COMPOSITE DESIGN	Not mentioned
2	Application of Response Surface Methodology (RSM) to Evaluate the Influence of Deposition Parameters on the Electrolytic Cu-Zn Alloy Powder [5].	4	5	2^4+8+3=27	CENTRAL COMPOSITE DESIGN	STATISTIC A 8.0
3	Analysis and Optimization of Machining Process Parameters Using Design of Experiments [6].	4	3 in 3level and one in two levels	24	FACTORIAL EXPERIMENT	DESIGN EXPERT 8
4	Product quality improvement through response surface methodology: a case study [9].	Stage i: 4; Stageii:2	Stagei:3 ; Stageii: 3	Stagei:2^4+4=20; 16 factorial points, 4 center points; Stageii:2^2+4+5=13; 4 factorial points,4axial	Stage i: FULL FACTORIAL Stage ii: FACE CENTERED COMPOSITE	Minitab

				points,5center points	DESIGN	
5	Optimization of EDM parameters using Response Surface Methodology for EN31 Tool Steel Machining [11].	4	3	2^4+8+7=31; 16 cube points,7center points in cube,8axial points	ROTATABLE CENTRAL COMPOSITE DESIGN	Minitab
6	Application of Box Behnken design to optimize the parameters for turning Inconel 718 using coated carbide tools [12].	3	3	2*3(3-1)+3=15 runs	BOX-BEHNKEN	DESIGN EXPERT
7	Optimization of process parameters in WIRE-EDM Using Response Surface Methodology [13].	3	3	2^3+6+6=20; 8 cube points,6center points in cube,6axial points	FACE CENTERED COMPOSITE DESIGN	Not mentioned
8	Box–Behnken response surface methodology for optimization of operational parameters of compression ignition engine fuelled with a blend of diesel, biodiesel and diethyl ether [15].	3	3	2*3(3-1)+3=13 runs	BOX-BEHNKEN	DESIGN EXPERT
9	Optimization of EDM Parameters for Minimum Surface Roughness During Electric Discharge Machining using Two Level Full Factorial Design [16].	5 but type of dielectric is one level. So, 4 factors are considered	2(max, min)	2^4+4=20; 4centerpoints	TWO LEVEL FULL FACTORIAL	DESIGN EXPERT 8.0.4.7
10	Optimization of Process parameters in EDM for Machining of Inconel 718 using Response Surface Methodology [18].	3	3	2^3+6+6=20; 8 cube points,6center points in cube,6axial points	CENTRAL COMPOSITE DESIGN	Not mentioned
11	Optimization of Surface Roughness for Duplex Brass Alloy in EDM Using Response Surface Methodology [20].	4	3	2*4(4-1)+5=29 runs	BOX-BEHNKEN	Not mentioned
12	Investigation of Characteristics in Electrical Discharge Machining Of Certain Cast Irons Using Response Surface Methodology [21].	3	3	2*3(3-1)+5=17 runs	BOX-BEHNKEN	DESIGN EXPERT 10.0.6.0
13	Application of response surface methodology (RSM) for optimization of leaching parameters for ash reduction from low-grade coal [22].	3	5	2^3+6+6=20; 8 factorial points,6center points in cube,6axial points	CENTRAL COMPOSITE DESIGN	DESIGN EXPERT 8.0.7.1
14	Comparison between Taguchi Method and Response Surface Methodology (RSM) in	5	3	2^(5-1)+(2*5)+6=32; 10axialpoints, 6center points	CENTRAL COMPOSITE DESIGN	Not mentioned

	Modelling CO2 Laser Machining [24].					
15	Application of Central Composite Design Based Response Surface Methodology in Parameter Optimization of Watermelon Fruit Weight Using Organic Manure [25].	3	5	2^3+6+6=20; 8 cube points,6center points in cube,6axial points	CENTRAL COMPOSITE DESIGN	Not mentioned
16	Optimization of Surface Roughness using Response Surface Methodology for EN31 Tool Steel EDM Machining [26].	4	3	2^4+8+7=31; 16 cube points,7center points in cube,8axial points	ROTATABLE CENTRAL COMPOSITE DESIGN	Minitab
17	Teaching Design of Experiment and Response Surface Methodology Using Paper Helicopter Experiment [27].	5	2	2^(5-1)*3=48; 3 replicates	ONE- HALF FRACTIONAL FACTORIAL	Minitab
18	Overview on the Response Surface Methodology (RSM) in Extraction Processes [28].	4	3	Stagei:2^4+(2*4)+7=31; 16 factorial points,7 center points,8 axial points; Stageii:2*4(4-1)+5=29,24 factorial points,5center points	Stage i: CENTRAL COMPOSITE DESIGN Stage ii: BOX-BEHNKEN	Not mentioned
19	Optimization of turning parameters for surface roughness using RSM and GA [29].	3	5	2^3+6+6=20; 8 factorial points,6center points,6axial points	ROTATABLE CENTRAL COMPOSITE DESIGN	DESIGN EXPERT
20	Analysis of EDM Process Parameters Using Response Surface Methodology And Grey Relational Analysis [30].	4	3	2^4+8+6=30; 16 factorial points,6center points,8axial points	FACE CENTERED COMPOSITE DESIGN	Not mentioned
21	Optimization of CNC Turning Parameters in Machining EN19 using Face Centered Central Composite Design Based RSM [23]	3	3	2^3+(2*3)+6=20	Face Centered Central Composite Design	Minitab

Table 1: Briefing the choice of experimental runs

IV. CONCLUSION

This paper clearly concludes that RSM is the appropriate optimization tool which can be used in any process or product design. RSM is more helpful for researchers whose area is concerned with the optimization. The major advantages of RSM can be stated as follows

- No. of experimental run can be reduced
- Response can be predicted prior to the experimentation phase.
- It can able to detect the parameter interaction effect on response.

CCD and Box-Behnken are two effective designs used in RSM. The central composite design (CCD) is a well known design for setting a quadratic model. Based on the number of levels and parameters CCD can be classified into CCC, CCI and CCF as described earlier. Box-Behnken method is used for solving the multi objective optimization problem.

REFERENCES

[1] M. Pradeep Kumar, Dr. N.V.S. Raju, Dr. M.V. Satish Kumar, Quality of Quality Definitions –An Analysis, International Journal of Scientific Engineering and Technology, ISSN:2277-1581, Volume No.5 Issue No.3, pp: 142-148 01 March.2016
[2] M. Sunil Kumar, K. Amarnath, M. Pradeep Kumar, Optimization of Process Parameters in Drilling of Short Fiber (KENAF) Composite, International Journal of Engineering Research, ISSN:2319-6890 (online),2347-5013 (print), Volume No.5, Issue No.2, pp : 153- 161 1 Feb. 2016
[3] Sudhir Kumar, Pradeep Kumar, and H. S. Shan. Effect of Process Parameters on the Solidification Time of Al-

7%Si Alloy Castings Produced by VAEPC Process, Materials and Manufacturing Processes 2007; 22:879-886.
[4] Mohan Kumar Pradhan and Chandan Kumar Biswas, Modelling of machining parameters for MRR in EDM using response surface methodology, Proceedings of NCMSTA’08 Conference National Conference on Mechanism Science and Technology: from Theory to Application 2008; National Institute of Technology, Hamirpur.535-542.
[5] Gökhan Orhan, Gökçe Hapçı, Özgül Keleş, Application of Response Surface Methodology (RSM) to Evaluate the Influence of Deposition Parameters on the Electrolytic Cu-Zn Alloy Powder, International Journal of Electrochemical Science 2011; 6:3966 – 3981
[6] Dr. M. Naga Phani Sastry, K. Devaki Devi, Dr, K. Madhava Reddy. Analysis and Optimization of Machining Process Parameters Using Design of Experiments, Industrial Engineering Letters 2012; 2(9):23-32.
[7] Ashvin J. Makadia, J.I. Nanavati, Optimisation of machining parameters for turning operations based on response surface methodology. Measurement 2012; 46:1521–1529.
[8] Norasiah Muhammad and Yupiter HP Manurung, Design Parameters Selection and Optimization of Weld Zone Development in Resistance Spot Welding. International Journal of Industrial and Manufacturing Engineering 2012; 6(11):2464-2469.
[9] HE Zhen, Zhang Xu-tao and XIE Gui – quing, Product quality improvement through response surface methodology: a case study. Proceedings of international conference on technology innovation and industrial management: Thailand; 2013; 120-130.
[10] Pawan Kumar, Anish Kumar and Balinder Singh, Optimization of Process Parameters in Surface Grinding Using Response Surface Methodology, International Journal of Research in Mechanical Engineering & Technology 2013; 3(2):245-252.
[11] Singaram Lakshmanan and Mahesh Kumar. Optimization of EDM parameters using Response Surface Methodology for EN31 Tool Steel Machining, International Journal of Engineering Science and Innovative Technology (IJESIT) 2013; 2 (5): 64-71.
[12] M.Manohar, Jomy Joseph, T.Selvaraj and D.Sivakumar, Application of Box Behnken design to optimize the parameters for turning Inconel 718 using coated carbide tools, International Journal of Scientific & Engineering Research 2013; 4(4): 620-642.
[13] Pratik A. Patil and C.A. Waghmare. Optimization of process parameters in wire-edm using response surface methodology, International Journal of Mechanical and Production Engineering 2014; 2(8):15-20.
[14] Gaurav chaudhary, Manoj kumar, Santosh verma and Anupam srivastav. Optimization of drilling parameters of hybrid metal matrix composites using response surface methodology, Procedia Materials Science 2014; 6:229 – 237.
[15] Paresh D.Patel, Absar Lakadwala and Rajesh N.Patel. Box–Behnken response surface methodology for optimization of operational parameters of compression ignition engine fuelled with a blend of diesel, biodiesel and diethyl ether. Taylor & Francis 2015; 1-14.
[16] Sunil kumar , Amit kumar Bansal, Suman Anand, Chandan kumar and Bhaskar Srivastav. Optimization of EDM Parameters for Minimum Surface Roughness during Electric Discharge Machining using Two Level Full Factorial Design. IJSTE - International Journal of Science Technology & Engineering 2015; 1(11):431-438.
[17] Dr.Funda kahraman. Application of the response surface methodology in the ball burnishing process for the prediction and analysis of surface hardness of the aluminum alloy AA 7075. Materials Testing 2015; 57(4):311-315.
[18] Mr. Somanath M.kale and Mr. D.S khedekar. Optimization of Process parameters in EDM for Machining of Inconel 718 using Response Surface Methodology, International Journal of Innovations in Engineering and Technology 2016; 7(3):188-193.
[19] Christopher Olkechukwu Izelu, Samuel Chikezie Eze and Festus Ifeanyi Ashiedu. Modeling and Optimization of Hard Turning Operation on 41Cr4 Alloy Steel Modeling and Optimization of Hard Turning Operation on 41Cr4 Alloy Steel Using Response Surface Methodology. International Journal of Mechanical Engineering and Applications 2016; 4(2):88-102.
[20] S.Marichamy, M.Sravanan, M.Ravichandran and B.Stalin. Optimization of Surface Roughness for Duplex Brass Alloy in EDM Using Response Surface Methodology, Mechanics and Mechanical Engineering 2017; 21(1):57-66.
[21] M.SaiRam and B.Srinivas. Investigation of Characteristics in Electrical Discharge Machining Of Certain Cast Irons Using Response Surface Methodology, International Journal of Applied Engineering Research 2017; 12(17):7011-7018.
[22] Sushanth Kumar Behera, Himanshu Meena, Sudipto Chakraborty and B.C.Meikap. Application of response surface methodology (RSM) for optimization of leaching parameters for ash reduction from low-grade coal, International Journal of Mining Science and Technology 2018; 28:621–629.
[23] M. V. Satish Kumar, M. Pradeep Kumar, S. Vamshi Krishna, K. Vikram Kumar, Optimization of CNC Turning Parameters in Machining EN19 using Face Centered Central Composite Design Based RSM, International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume-9 Issue-2, July 2020.
[24] Sivaraos , K.R.Milkey, A.R.Samsudin, A.K.Dubey and P.Kidd,. Comparison between Taguchi Method and Response Surface Methodology (RSM) in Modelling CO2 Laser Machining. Jordan Journal of Mechanical and Industrial Engineering 2014; 8(1):35-42.
[25] Dennis K. Muriithi, J. K. Arap Koske, Geofrey K. Gathungu. Application of Central Composite Design Based Response Surface Methodology in Parameter Optimization of Watermelon Fruit Weight Using Organic Manure. American Journal of Theoretical and Applied Statistics 2017; 6(2): 108-116.

[26] Singaram Lakshmanan, Prakash Chinnakutti, Mahesh Kumar Namballa. Optimization of Surface Roughness using Response Surface Methodology for EN31 Tool Steel EDM Machining. International Journal of Recent Development in Engineering and Technology 2013; 1(3):33-37.
[27] Seyed Mojib Zahraee, Ghasem Rezai,Ashkan Memari and Jafar Afshar. Teaching the Design of Experiment and Response Surface Methodology Using Paper Helicopter Experiment. Conference paper 2013.
[28] Khairul Anwar Mohamad Said and Mohamed Afizal Mohamed Amin. Overview on the Response Surface Methodology (RSM) in Extraction Processes. Journal of Applied Science & Process Engineering 2015; 2(1):8-17.
[29] Sahoo, P. Optimization of turning parameters for surface roughness using RSM and GA. Advances in Production Engineering & Management 2011; 6(3):197-208.
[30] Vishwajeet Kumar and Prof. Rakesh. Analysis of EDM Process Parameters Using Response Surface Methodology and Grey Relational Analysis. International Journal of Science Research and Education 2016; 4(9):5907-5921.