Optimization of Drilling Process Parameters Using Taguchi Method Coupled With Desirability Function Analysis (DFA)

A Project report submitted in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

Submitted by

R.PRAVEEN KUMAR	**(314126520137)**
P.ANIL KUMAR	**(314126520116)**
M.NAGA LAKSHMI TEJASWI	**(314126520099)**
R.VIVEK	**(314126520135)**
P.HEMANTH KUMAR VARMA	**(314126520121)**

Under the guidance of

Mrs.V. BINDU NEEHARIKA

Assistant professor

DEPARTMENT OF MECHANICAL ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (Permanently Affiliated to Andhra University, Approved by AICTE, Accredited by NBA & NAAC with ‘A’ grade)

Sangivalasa - 531162, Bheemunipatnam (Mandal), Visakhapatnam (Dist.), Andhra Pradesh, India.

2018

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
(Permanently Affiliated to Andhra University, Approved by AICTE, Accredited by NBA & NAAC with 'A' grade)
Sangivalasa, Bheemunipatnam, Visakhapatnam, A.P.

PRAGNANAM BRAHMA
ANITS

CERTIFICATE

This is to certify that this project report entitled **"Optimization of Drilling Process Parameters Using Taguchi Method Coupled With Desirability Function Analysis (DFA)"** has been carried out by **R.Praveen Kumar (314126520137), P.Anil Kumar (314126520116), M.Naga Lakshmi Tejaswi (314126520099), R.Vivek (314126520135) and P.Hemanth Kumar Varma (314126520121)** under the esteemed guidance of **Mrs.V.BINDU NEEHARIKA,** in partial fulfillment of the requirements for the award of "**Bachelor of Engineering**" in **Mechanical Engineering** of **Andhra University**, Visakhapatnam.

APPROVED BY:
Dr. B.NAGARAJU
Head of the Department
Department of Mechanical Engineering
ANITS
Sangivalasa
Visakhapatnam.

PROJECT GUIDE:
Mrs.V. BINDU NEEHARIKA
Assistant Professor
Department of Mechanical Engineering
ANITS
Sangivalasa
Visakhapatnam.

24.4.18
Signature of HOD

Neeharika 24/4/18
Signature of Internal Guide

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist A.P.

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMINER:

Dr. B. Naga Raju
M.Tech,M.E.,Ph.d
Professor & HOD
Dept of Mechanical Engineering
ANITS, Sangivalasa,
Visakhapatnam-531 162.

EXTERNAL EXAMINER:

ACKNOWLEDGEMENT

We express immensely our deep sense of gratitude to **Mrs.V. BINDU NEEHARIKA**, Assistant Professor, Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences for his valuable guidance and encouragement at every stage of work for the successful fulfilment of students.

We were very thankful to **Prof.T.V.HanumanthaRao**, Principal and Prof. **B.Nagaraju,** Head of the Department, Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences for their valuable support and facilities.

We express our sincere thanks to **Mr.Ch.Maheswara Rao**, Assistant Professor, Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences for his valuable suggestions throughout the project.

We express our sincere thanks to the non-teaching staff of Mechanical Engineering for their kind co-operation and support to carry on work.

Last but not the least, we like to convey our thanks to all who have contributed directly or indirectly for the completion of this project work.

R.PRAVEEN KUMAR	**(314126520137)**
P.ANIL KUMAR	**(314126520116)**
M.NAGA LAKSHMI TEJASWI	**(314126520099)**
R.VIVEK	**(314126520135)**
P.HEMANTH KUMAR VARMA	**(314126520121)**

LIST OF CONTENTS

ABSTRACT

In present days the manufacturers are facing the challenges in attaining the high productivity, quality and overall economy in the field of manufacturing by machining. Among all the machining processes available drilling is a major and common hole making process and it uses the drill bits to cut or enlarge the holes in solid materials such as wood or metal. The present work is to investigate the effect of the drilling process parameters on the multiple responses of Volume of material removal rate (VMRR) and surface roughness (R_a). A series of experiments were carried out on AA6082 material using carbide twisted drills on CNC machine. Speed, feed, depth of cut and drill sizes are considered as the process parameters and Taguchi’s standard L16 orthogonal array (OA) has been followed for conducting the experiments. The optimal setting of process parameters was done by employing taguchi method coupled with the desirability function analysis (DFA) and analysis of variance (ANOVA) methods. From the results, it is concluded that speed is the most influencing factor for the combined desirability index value. The optimal combination of process parameters for multi-response value is obtained at speed of 2000 rpm, feed of 400 mm/min, depth of cut of 12 mm and drill size of 13mm.

Keywords: Volume of Material Removal Rate (VMRR), Surface Roughness (R_a), Taguchi method, Desirability Function Analysis and ANOVA.

LIST OF FIGURES Page No.

LIST OF TABLES **Page No.**

NOMENCLATURE

v	Cutting speed, m/min
f	Feed, mm/rev
d	Depth of cut, mm
VMRR	Volume of Material Removal Rate, cm^3/min
R_a	Arithmetic Surface Roughness Average, µm
CNC	Computerized Numerical Control
DOE	Design of Experiments
OA	Orthogonal Array
S/N	Signal to Noise Ratio
ANOVA	Analysis of Variance
DF	Degree of Freedom
SS	Sum of Squares
MS	Mean Square
F	Variance ratio
P	Probability of significance
S	Variance
R^2	Coefficient of determination
R^2 (Adj)	Adjusted R^2
DFA	Desirability Function Analysis
d_i	Individual Desirability
D_g	Composite Desirability

CHAPTER 1
INTRODUCTION

Drilling is a major and common hole making process, it uses the drill bits to cut or enlarge the holes in solid materials, such as wood or metal. Drilled holes are characterized by their sharp edge on the entrance side and the presence of burrs on the exit side (unless they have been removed). Also, the inside of the hole usually has helical feed marks. Drilling may affect the mechanical properties of the work piece by creating low residual stresses around the hole opening and a very thin layer of highly stressed and disturbed material on the newly formed surface. This causes the work piece to become more susceptible to corrosion and crack propagation at the stressed surface. A finish operation may be done to avoid these detrimental conditions. But in case of fluted drill bits, any chips are removed via the flutes. Chips may form long spirals or small flakes, depending on the material, and process parameters. The type of chips formed can be an indicator of the machinability of the material, with long chips suggesting good material machinability. Whenever possible the drilled holes should be located perpendicular to the work piece surface. This minimizes the drill bit's tendency to "walk", that is, to be deflected from the intended center-line of the bore, causing the hole to be misplaced. The tendency to walk is also preempted in various other ways, which include:

- Establishing a centering mark before drilling
- Center punching
- Spot drilling (i.e., center drilling)
- Spot facing, which is machining a certain area on a casting or forging to establish an accurately located face on an otherwise rough surface?
- Constraining the position of the drill bit using a drill jig with drill bushings

Cutting fluid is commonly used to cool the drill bit, increase tool life, increase speeds and feeds, increase the surface finish, and aid in ejecting chips. Application of these fluids is usually done by flooding the work piece with coolant and lubricant or by applying a spray mist. Drilling is a preliminary step for many operations, such as reaming, tapping and boring. In the present era of globalization manufacturers are facing the challenges of higher productivity, quality and overall economy in the field of manufacturing by machining. To meet these challenges in a global environment, there is an increasing demand for high material removal rate (MRR) and also longer life and stability of the cutting tools. But high production machining with high cutting speed, feed and generates large amount of heat and temperature at the chip-tool interface which ultimately reduces dimensional accuracy, tool life and surface integrity of the machined component. This temperature needs to be controlled at an optimum level to achieve better surface finish and ensure overall machining economy.

Basically, the traditional experimental design procedures are too complicated and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Using Taguchi technique optimum controllable parameter combinations are identified for each response. In view of the fact, that traditional Taguchi method cannot solve a multi-objective optimization problem; to overcome this limitation Desirability Function Analysis has been coupled with Taguchi method in the present work. Desirability function analysis (DFA) had been most widely used in industries to optimize the multi response process characteristics into single response characteristics. The advantage of the DFA method is that many factors can be analyzed using less data. It does not involve complicated mathematical theory or computations like traditional approaches and thus can be employed by engineers without strong statistical background.

CHAPTER 2
LITERATURE REVIEW

Turgay Kıvak et al. (2012)[1] investigated the effect of cutting parameters of cutting tool, cutting speed and feed rate on drilling of AISI 316 stainless steel. Experiments were done on CNC vertical machine using Taguchi L16 orthogonal array. Coated and uncoated M35 HSS twist drill bit were used under dry condition for this purpose. Analysis of variance was done to draw the effects of the control factors. It was found that cutting tool was the most significant factor on surface roughness and feed rate was the most significant factor on thrust force.

Adem Çiçek et al. (2012)[2] investigated the effect of deep cryogenic and cutting parameters on surface roughness as well as roundness error in drilling of AISI 316 austenitic stainless. Cutting tools, cutting speeds and feed rate was taken as control factors. M35 twist drill bit were used for doing the experiment. L8 orthogonal array was used and multiple regression analysis was performed to find out predictive equation of surface roughness. A confirmation experiment has showed Taguchi method precisely optimized the drilling parameters in drilling AISI 316 steel.

A. Navanth et.al. (2013)[3] focused on optimization of drilling parameter for minimum surface roughness and hole diameter by using Taguchi methodology. Al 2014 material and HSS twist drill bit has been taken for performing experiment. L18 orthogonal array has been used and the results obtained were analyzed in MINITAB 16 .Analysis of variance (ANOVA) was used to find out the optimal factors from cutting tool, spindle speed and feed rate. Optimal values are spindle speed 300 rpm, point angle and helix angle 1300/200 and feed rate 15mm/rev for minimum roughness.

J.Pradeep Kumar et.al. (2012)[4] investigated the effect of cutting parameters such as cutting speed, drill tool diameter feed and feed on surface finish of OHNS material using HSS spiral drill. L18 orthogonal array, S/N ratio, ANOVA and Regression analysis has been employed to study the effect of drilling parameters on surface roughness value. Experimental data was analyzed using MINITAB 15 and it was found that speed and feed plays most dominating factors on surface roughness, tool wear, material removal rate.

Reddy Sreenivasulu et.al. (2014)[5] focused on optimization of surface roughness in drilling of Al 6061 using Taguchi design method and artificial neural network method. Cutting speed, feed rate, drill diameter, clearance angle and point angle were taken as cutting parameters and HSS twist drill bit as a tool. L27 orthogonal array, ANOVA, S/N ratio was employed to study the effects of the control factors. ANOVA analysis showed cutting speed, feed rate, drill diameter, clearance angle and point angle all were significant on surface roughness. The optimal settings for roughness are found at speed 800 rpm, feed rate .3 mm/rev, drill diameter 10 mm, point angle 1180, clearance angle 40 respectively.

YogendraTyagi, VedanshChaturvedi, et al. (2012)[6] investigated the effect of cutting parameters spindle speed, feed rate and depth of cut for maximizing material removal rate and minimizing surface roughness in drilling of mild steel. Taguchi L9 orthogonal array is used. Results are analyzed using Taguchi DOE software. They concluded that spindle speed is significant for surface roughness and feed rate is for Material removal rate.

M Sundeep et al. (2014)[7] have done an experimental investigation on drilling of Austenitic stainless Steel (AISI 316) using Taguchi L9 array. Spindle speed, feed rate and drill diameter was taken as process parameter. It was found that spindle speed plays the most dominating role in surface finish as well as Material removal rate in drilling.

Kadam Shirish, M. G. Rathi (2013)[8] focused on optimization of drilling parameters using the Taguchi technique. L9 orthogonal array has been used to drill on EN-24 steel blocks. Uncoated M32 HSS twist drill was used under dry condition. Cutting speed, feed rate and depth of hole were taken as process parameter. S/N ratio was employed to get optimal control factors and they found that cutting speed was the main significant factors on surface roughness and the tool life.

B.Shivapragash, K. et al.(2013)[9] studied the optimization of the process parameters spindle speed, feed rate, depth of cut to investigate their influence in drilling composite Al-TiBr2. Taguchi method with grey relational analysis was used to optimize the factors. L9 orthogonal array has been used and optimal settings found for better surface finish at spindle speed (1000 rpm), feed rate (1.5 mm/rev), depth of cut 6 mm.

Nalawade P.S. et.al. (2015)[10] optimized the cutting parameters speed, depth of cut, feed and type of tool to get better Surface finish and Hole accuracy in dry Drilling of EN-31 material. Taguchi L9 orthogonal array, S/N ratio, ANOVA, Regression analysis was done to find out the optimal settings. Optimal settings for surface roughness were Cutting speed (30 m /min), feed (0.2 mm/min) and type of tool (HSS uncoated).

Arshad Noor Siddiquee et al. (2014)[11] focused on optimizing drilling parameters such as cutting fluid, speed, feed and hole depth in drilling AISI312 material. Experiments were done in CNC lathe machine using solid carbide cutting tool. Taguchi L18 orthogonal array has been used for the experiment. Signal to noise ratio(S/N), analysis of variance (ANOVA) were used to find out the effects of cutting parameters on surface roughness. It has been found that in presence of cutting fluid, speed 500 rpm, feed .04 mm/sec, hole depth 25 mm were the optimum value for surface roughness. Anova analysis showed that speed was the most significant factor followed by cutting fluid, feed and hole depth for surface roughness value.

Vishwajeet. N et al. (2015)[12] focused in optimizing drilling parameters such as cutting speed, feed and point angle for sharpened HSS twist drill bit on hardened boron steel using Taguchi method. L16 orthogonal array has been used to perform the experiment in a double spindle drilling machine. Analysis of variance (ANOVA) was employed to find out effects of control factors on surface roughness. It was found that point angle was the main significant factor for tool wear and feed rate for surface roughness.

Sathish Rao. U et.al. (2014)[13] have made an attempt to study the effect of spindle speed, feed rate, drill diameter, fiber orientation on tool wear during drilling GFRP components in dry condition. HSS drill bit was used for the experiment. Taguchi L9 orthogonal array has been used. S/N ratio, ANOVA, regression analysis was used to find out the optimal settings. It has been found that speed, feed rate, drill diameter has significant effect on tool wear.

Nisha Tamta et.al. (2015)[14] analyzed the effect of spindle speed, feed rate, drilling depth on drilling Aluminium alloy 6082 with the help of CNC machine. Taguchi L9 orthogonal array was used to perform the experiment. Signal to noise ratio (S/N), analysis of variance (ANOVA) were used to analyze the effects drilling parameters on surface roughness. It has been found that spindle speed 3000 rpm, feed rate 15 mm/min and drilling depth 9 mm were the optimum combination values. It is also found that the drilling depth was the most significant factor for surface roughness followed by spindle speed.

Srinivasa Reddy et al. (2014)[15] investigated the impact of cutting parameters such as cutting speed, point angle and feed rate on surface roughness in drilling of AL 6463 material.

HSS drill bit was used and the experiment was done in CNC drilling machine using Taguchi L9 orthogonal array. Signal to noise ratio (S/N), analysis of variance (ANOVA) has been employed to find out the optimal drilling parameter. It was found that Cutting speed, feed rate and point angle plays significant role on surface roughness during drilling operation of AL 6463 material.

N. Keerthi et.al.[16] studied the impact process parameters- Spindle speed, feed rates, type of drill tool, cutting environment on performance parameters- material removal rate, surface roughness, Torque, cutting force, & power during the drilling of En 8 steel. They employed Taguchi method combined with ANOVA for effective data representation in wide range with low experimental cost, to predict responses in drilling of En 8. From ANOVA it was observed that torque and surface roughness are mostly affected by feed and cutting force, material removal rate & power is mostly affected by spindle speed.

ErolKilickap. et.al.[17] Studied the influence of machining parameters- cutting speed, feed rate and cutting environment on the surface roughness obtained in drilling of AISI 1045. It was found that minimum surface roughness is obtained at lower cutting speeds, while it deteriorates as the feed rate increases. Surface roughness was much better for the MQL condition than for the compressed air and dry drilling.

Kapil Kumar Goyal. et.al.[18] have conducted the experiments to optimize the cutting parameters - Spindle speed, Feed rate, and Slurry concentration in order to improve the surface finish of stainless steel SS304 in the abrasive assisted drilling process. RSM has been adopted for planning of experiments and ANOVA has been used to find the contribution of process parameters and the interaction among them. It was observed that the surface roughness of drilled surface significantly improves through the use of abrasive particles. The speed and feed significantly affects the surface roughness of SS304 in comparison to the slurry concentration and an overall improvement of 10.81% was observed in surface finish by using the abrasive slurry instead of only coolant.

R.Pradeep Kumar. et.al.[19] employed Taguchi method to investigate the effects of drilling parameters- cutting speed, feed rate and drill diameter on surface roughness, tool wear by weight, material removal rate and hole diameter error in drilling of OHNS material using HSS spiral drill. It was found that, Feed rate and Spindle speed are important process parameters to control surface roughness, tool wear, material removal rate and hole diameter error. Suitable combination of cutting speed and feed rate should be used so as to reduce the variations that can affect the quality of the holes that are drilled on OHNS material.

Sumesh A. S. et. al.[20] has conducted an experiment using Taguchi technique to obtain minimum surface roughness (R_a). The experiments were performed on cast iron using HSS twist drills. A number of drilling experiments were conducted as per the L9 orthogonal array on a radial drilling machine, it is observed that the variation in drilling parameters are optimized with respect to multiple performances in order to achieve a good quality of holes in drilling. Finally it was identified that a spindle speed of 80 rpm, drill diameter of 4mm and a feed rate of 0.1 mm/rev is the optimal combination of drilling parameters that produced a high value of S/N ratios of hole roughness.

Nisha Tamta et.al.[21] has conducted an experiment to optimize the drilling machining process for Surface roughness (R_a). Spindle speed, Feed rate and Drilling Depth are taken as the process parameters. L9 orthogonal array was used to conduct the experiments. Signal to noise (S/N) ratio and analysis of variance (ANOVA) are used to analyze the effect of the drilling parameters on material. From the results, it is conclude that optimum parameter combination for the minimum Surface roughness (R_a) are, Spindle speed 3000 rpm, Feed rate 15 mm/min, and Drilling Depth 9 mm. The ANOVA and S/N ratio results showed that Drilling Depth is obtained as the most significant factor for R_a followed by Spindle speed.

A.Navanth et.al. [**22**] have conducted experiments to optimize the drilling parameters using Taguchi technique in order to obtain the minimum surface roughness (R_a) and hole diameter on conventional drilling machine. The numbers of drilling experiments were conducted using the L18 orthogonal array. The material AI 2014 alloy block was drilled using HSS twist drills under dry cutting conditions and the measured results were analyzed with the help of MINITAB16 and Analysis of variance (ANOVA). It concludes that a spindle speed of 300 rpm, point angle & Helix angle of 1300/200 and a feed rate of 0.15 mm/rev is the optimal combination of drilling parameters that produced a high value of s/n ratios of hole roughness. And it is also found that a spindle speed of 200 rpm, point angle & Helix angle of 900/150 and a feed rate of 0.36 mm/rev is the optimal combination of drilling parameters that produced a high value of s/n ratios of Hole diameter.

Indumathi V. et.al.[23] Presents the optimization of machining parameters- Spindle speed, Feed rate & Cone radius ratio for drilling of Aluminum sheet (AA1100) with tungsten carbide tool using desirability function analysis (DFA). The spindle speed (Percentage contribution of 27.59%) is found to be more significant machining parameter for affecting the multiple performance characteristics form drilling process. The optimum machining conditions are obtained at high values of spindle speed, feed rate and cone ratio respectively.

R. Ramanujam et.al.[24] (2014) have conducted milling experiments on INCONEL 718 super alloy by taking speed, feed and depth of cut as cutting parameters. The experiments were carried out based on L9 orthogonal array. The optimal cutting conditions were obtained using Taguchi method and desirability function analysis. The optimal combination of cutting parameters was found at 75 m/min of cutting velocity, 0.06 mm/tooth of feed rate and 0.4 mm of depth of cut respectively.

The objective of the present work is to setting of drilling cutting parameters which will maximize the volume of material removal rate (VMRR) and minimize the surface roughness simultaneously. In the above literature discussed many authors have contributed their work in optimization of cutting parameters while machining but they have discussed the optimal combination which corresponds to a single response only. For solving a multi objective optimization problems there are many methods available but in the present work for analyzing the multiple performance characteristics, Taguchi method coupled with Desirability Function Analysis (DFA) has been employed. This method transforms the multiple responses into a single objective in terms of composite desirability index (D_g) and the higher composite desirability value implies the better product quality

CHAPTER 3
METHODOLOGY

There are a number of techniques for optimization of output characteristics and to obtain optimum value but from all the optimization techniques, Taguchi's method for experimental design is straight forward and east to apply to many engineering problems. It can be used to quickly narrow down the scope of a research project or to identify problems in a manufacturing process from the data already in existence. Also, the taguchi method allows the analysis of many different parameters without a prohibitively high amount of experimentation. It also allows for the identification of key parameters that have the most effect on the performance characteristic value so that further experimentation on these parameters can be performed and the parameters that have little effect can be ignored.

3.1. Taguchi Method

A systematic statistical approach to product and process improvement has developed by Dr. Genichi Taguchi. The technique emphasizes moving the quality issue upstream to the design stage and focusing on prevention of defects by process improvement. Taguchi has placed great emphasis on the importance of minimizing variation as the primary means of improving quality. Taguchi defines the quality level of a product to be the total loss incurred by society due to the failure of the product to deliver the expected performance and due to harmful side effect of the product, including the operating cost. In the concept some loss is unavoidable from the time a product is served to the customer and smaller loss provides desirable products. It is very important to quantify this loss for comparing various products designs and manufacturing processes. This is done with a quadratic loss function. In the usual practice of manufacturing quality control the producer specifies a target value of the performance characteristic and a tolerance interval around that value. Any value of the performance characteristics value which is within the tolerance range about 3σ is defined to be desirable product. With the loss function as a definition of quality the emphasis is on achieving the target value of the performance characteristic and deviation from that value are penalized. The greater deviation from the target value results with a greater quality loss.

3.1.1. Signal-to-Noise (S/N) ratio In the taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard deviation). The S/N ratio measures the sensitivity of the quality characteristic being investigated in a controlled manner to those external influencing factors (noise factors) not under control. So, taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are mainly two S/N ratios available depending on the type of characteristic; Lower-the-Better and Higher-the-Better.

Smaller-the-Better:

The smaller is better quality characteristic can be given as

$$\frac{S}{N} = -10\ log_{10}[y^2]$$

Higher-the-Better:

The higher is better quality characteristic can be given as

$$\frac{S}{N} = -10\ log_{10}\left[\frac{1}{y^2}\right]$$

Where, y is the response value.

3.2. Desirability Function Analysis (DFA)

Taguchi method can be applied to analyze the process parameters for single performance characteristics only, to overcome this difficulty a multi objective optimization method called Desirability function analysis (DFA) is employed in the present work. DFA can be effectively used for analyzing the multi performance characteristics at a time. This method was introduced by Derringer and Suich (1980). The method makes use of an objective function, D(X), called the desirability function and transforms an estimated response into a scale free value d_i called desirability. The desirable ranges are from zero to one (least to most desirable, respectively). The factor settings with maximum total desirability are considered to be the optimal parameter conditions.

3.2.1. Procedure of Desirability Function Analysis (DFA)

STEP 1: Calculate the individual desirability (d_i) for the corresponding responses using the formula proposed by Derringer and Suich. There are three forms of the desirability functions according to the response characteristics.

Nominal-the-best:

The value of ŷ is required to achieve a particular target T. when the ŷ equals to T, the desirability value equals to 1; if the departure of ŷ exceeds a particular range from the target, the desirability value equals to 0, and such situation represents the worst case.

$$d_i = \begin{cases} \left(\dfrac{\hat{y} - y_{min}}{T - y_{min}}\right)^s, & y_{min} \leq y \leq T, s \geq 0 \\ \left(\dfrac{\hat{y} - y_{min}}{T - y_{min}}\right)^t, & T \leq y \leq y_{min,} T \geq 0 \\ 0 & \end{cases}$$

Where the y_{max} and y_{min} represent the upper and lower tolerance limits of ŷ and s and t represent the indices.

Larger-the-better:

The value of ŷ is expected to be the larger the better. When the ŷ exceeds a particular criteria value, which can be viewed as the requirement, the desirability value equals to 1; if the ŷ is less than a particular criteria value, which is unacceptable, the desirability equals to 0.

$$d_i = \begin{cases} 0, & \hat{y} \leq y_{min} \\ \left(\dfrac{\hat{y} - y_{min}}{y_{max} - y_{min}}\right)^r, & y_{min} \leq \hat{y} \leq y_{max,} r \geq 0 \\ 1, & \hat{y} \geq y_{max} \end{cases}$$

Where the y_{min} represents the lower tolerance limit of ŷ, the y_{max} represents the upper tolerance limit of ŷ and r represents index.

Smaller-the-better:

The value of ŷ is expected to be the smaller the better. When the ŷ is less than a particular criteria value, the desirability value equals to 1; if the ŷ exceeds a particular criteria value, the desirability value equals to 0.

$$d_i = \begin{cases} 1, & \hat{y} \leq y_{min} \\ \left(\dfrac{\hat{y} - y_{max}}{y_{min} - y_{max}}\right)^r, & y_{min} \leq \hat{y} \leq y_{max,} r \geq 0 \\ 0, & \hat{y} \geq y_{min} \end{cases}$$

Where the y_{min} represents the lower tolerance limit of ŷ, the y_{max} represents the upper tolerance limit of ŷ and r represents the weight.

The s, t and r in above Equations indicate the weights and are defined according to the requirement of the user. If the corresponding response is expected to be closer to the target, the weight can be set to the larger value; otherwise, the weight can be set to the smaller value.

STEP 2: The individual desirability values have been accumulated to calculate the overall desirability, using the following equation (k).

Here D_g is the composite desirability value, d_i is the individual desirability value of i^{th} quality characteristic and n is the total number of responses.

$$D_g = (d_1 * d_2 * d_3 \ldots \ldots \ldots \ldots d_n)^{\frac{1}{n}}$$

Here, D_g = Composite Desirability

STEP 3: Determine the optimal parameter and its level combination. The higher composite desirability value implies better product quality.

STEP 4: Performing Analysis of variance (ANOVA) for the most significant parameter. ANOVA establishes relative significance of parameters.

STEP 5: The final step is to predict and verify the quality characteristics using the optimal level of the design parameters.

CHAPTER 4

EXPERIMENTAL DETAILS

This chapter presents the details of work piece (chemical and mechanical properties), drill bits, CNC drilling machine specifications, cutting process parameters and their levels, orthogonal array (L16) design and the setup conditions in measurement of surface roughness values for the machined components etc.

4.1. Work Material and Drills

In the present work the drills are made on a plate of aluminium alloy 6082-T6 having 25 mm thickness shown in the figure 4.1 using carbide twisted drills (11mm and 13mm size with 4 flutes) shown in the figure 4.2. Aluminium alloy 6082 is a medium strength alloy with excellent corrosion resistance. The addition of a large amount of manganese controls the grain structure which in turn results in a stronger alloy. AA 6082 is typically used for

- Highly stressed applications
- Trusses
- Bridges
- Cranes
- Transport applications
- Ore skips
- Beer barrels
- Milk churns

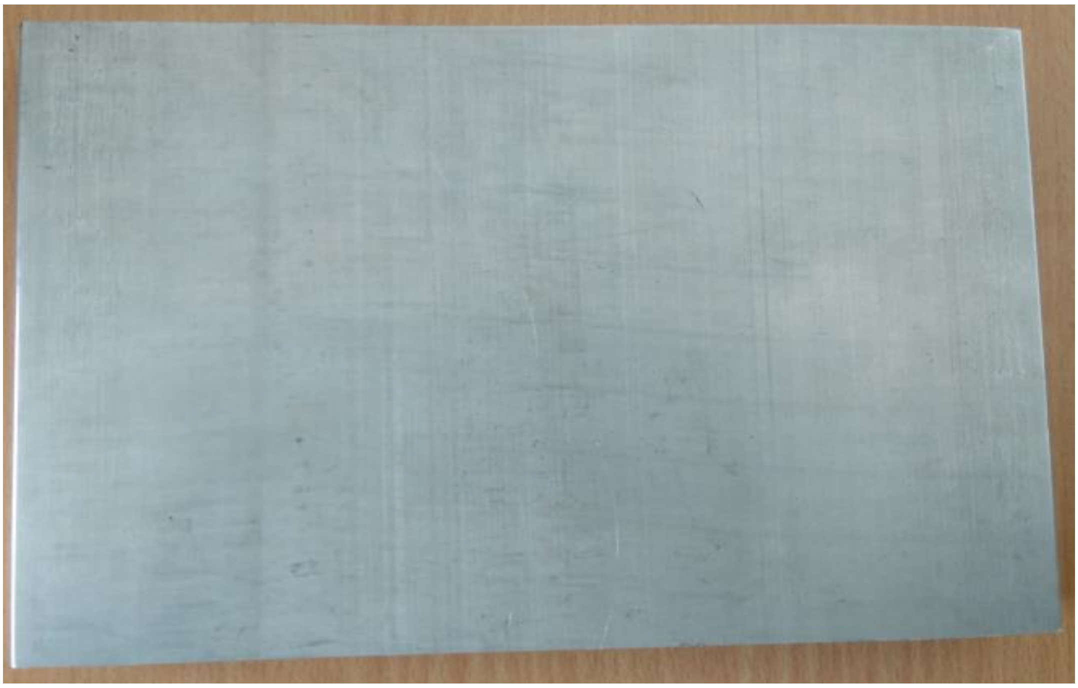

Figure 4.1. AA6082 Plate

Figure 4.2. Drill Tools

4.2 Chemical Composition and Mechanical Properties of AA6082

6082 aluminium alloy is an alloy in the wrought aluminium-magnesium-silicon family. It has the highest strength of the 6000 series alloys. The chemical composition and some of the mechanical properties of AA6082 are given in the tables 4.1 and 4.2.

Table 4.1. Chemical Composition of AA6082

Aluminium (Al)	95.2 to 98.3%
Chromium (Cr)	0.25% max
Copper (Cu)	0.1% max
Iron (Fe)	0.5% max
Magnesium (Mg)	0.6 to 1.2%
Manganese (Mn)	0.4 to 1%
Silicon (Si)	0.7 to 1.3%
Titanium (Ti)	0.1% max
Zinc (Zn)	0.2% max
Residuals	0.15% max

Table 4.2. Mechanical Properties of AA6082

Density	2.71 gm/cm3
Ultimate Tensile Strength	295 N/mm2
Yield Strength	240 N/mm2
Hardness	89 BHN
Elongation	8%
Youngs modulus	71 GPa
Thermal expansion	23.1 µm/m-K

4.3 CNC Machine Specifications used for Drilling

In the present work the experiments were conducted on CNC drilling machine and the specifications of the machine were tabulated in table 4.3.

Table 4.3 CNC Machine Specification

PARAMETERS	DETAILS
Clamping area	450mm x 900 mm
No/Width/CD of T-slots	5/18mm/80mm
Maximum Safe load on Table	600kg
Distance from table to Spindle face	100-600(300-800)
Traverse	
X-axis	600mm
Y-axis	450mm
Z-axis	500mm
Axis Drive	
Feed rates	1-10000mm/min
Rapid Traverse X/Y/Z	36m/min
Spindle	
Power	5.5/7.5kw
Speed	6000rpm
Taper	BT45
Auto Tool Changer	
No of tools	20
Maximum Tool diameter with Adj pocket	75/140

full/empty	
Maximum Tool length	250mm
Maximum Tool weight	8kg
Tool change time(tool to tool)	2.5sec
Accuracy	
Positioning	±0.005mm
Repeatability	±0.003mm

4.4 Selection of Process Parameters and Their Levels

The methodology of taguchi for four factors with mixed levels is used for the implementation of the experiments. The degree of freedom required for the study is 10 and taguchi’s L16 OA is used to define the sixteen experiments. The experiments were conducted on a CNC drilling machine (maximum spindle speed of 6000 rpm and 5.5/7.5 Kw drive motor) as shown in the figure 4.3. The selected process parameters with their levels and L16 OA are given in the tables 4.4 and 4.5.

Figure 4.3. CNC Machine used for Machining

Table 4.4. Process Parameters with Their Levels

Parameter	Level1	Level2	Level3	Level4
Speed, rpm	1000	1500	2000	2500
Feed, mm/min	100	200	300	400
Doc, mm	08	12	16	20
Drill size, mm	11	13	-	-

Table 4.5. L16 Orthogonal Array

S.No.	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Drill size (mm)
1	1000	100	8	11
2	1000	200	12	11
3	1000	300	16	13
4	1000	400	20	13
5	1500	100	12	13
6	1500	200	8	13
7	1500	300	20	11
8	1500	400	16	11
9	2000	100	16	11
10	2000	200	20	11
11	2000	300	8	13
12	2000	400	12	13
13	2500	100	20	13
14	2500	200	16	13
15	2500	300	12	11
16	2500	400	8	11

4.5 Measurement of Surface Roughness after Machining

After conducting the experiments the machined surface was measured at three different positions using roughness measuring instrument SJ-210 as shown in the figure 4.4 and the average surface roughness (R_a) values is recorded in microns.

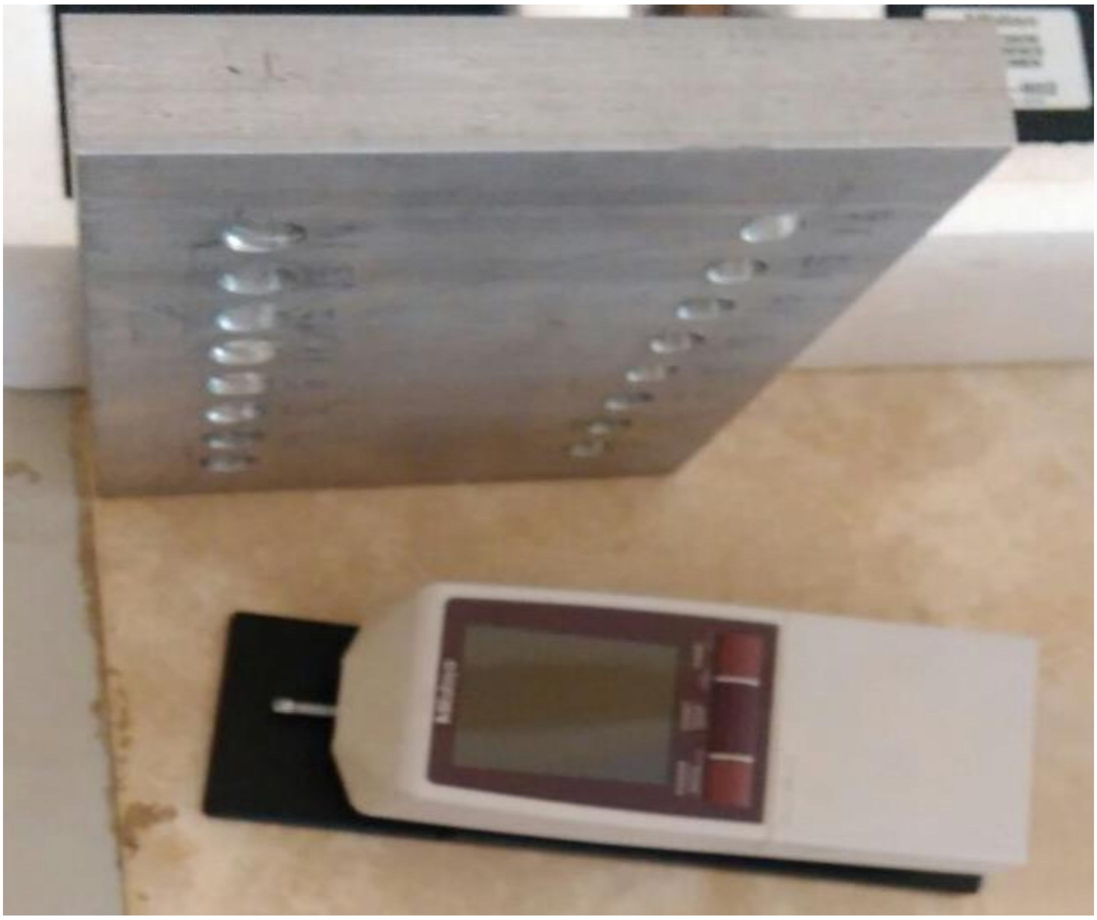

Figure 4.4. SJ-210 Surface Tester

CHAPTER 5

RESULTS & DISCUSSIONS

In The present work a series of experiments were carried out on AA6082 material using carbide twisted drills on CNC machine. Speed, feed, depth of cut and drill sizes are considered as the process parameters and Volume of material removal rate (VMRR) and surface roughness (R_a) are considered as the output characteristics. In this chapter the experimental results and their analysis using desirability function analysis (DFA) and analysis of variance (ANOVA) methods has been discussed.

5.1. Experimental Results of the Responses

The Volume of material removal rate (VMRR) and Surface Roughness (R_a) are considered as the quantity and quality responses in the present work. The measured values of VMRR in cm^3/min and surface roughness in μm were given in the table 5.1.

Table 5.1. Experimental Results of Responses

S.No.	VMRR (cm^3/min)	R_a (μm)
1	5.7034	0.3283
2	9.7748	0.6626
3	15.9278	2.6196
4	22.7540	2.9446
5	8.6879	0.828
6	12.7422	0.5083
7	14.2549	2.1546
8	18.2463	1.7306
9	7.6026	2.133
10	12.6710	1.4153
11	15.9278	0.756
12	19.1134	0.2726
13	11.3770	1.1623
14	18.2032	2.285
15	13.6847	1.0096
16	11.4039	0.3020

5.2. Results of Desirability Function Analysis (DFA)

The multiple performance characteristics of the experimental results were analyzed using the desirability function analysis (DFA). In this analysis, the larger-the-better characteristic is applied to determine the individual desirability values for volume of material removal rate (VMRR) and smaller-the-better characteristic is applied to determine the individual desirability values of surface roughness (R_a). After evaluating the individual desirability of the experimental values then the composite desirability is evaluated as explained in the methodology. The values of individual (d_i) and the composite desirability (D_g) for the output characteristics were tabulated in table 5.2.

Table 5.2. Individual and the Composite Desirability Values of the Responses

S.No.	d_i of VMRR	d_i of R_a	D_g
1	0.0001	0.9791	0.0001
2	0.2387	0.8540	0.4514
3	0.5996	0.1216	0.2700
4	1.0000	0.0001	0.0001
5	0.1750	0.7921	0.3723
6	0.4128	0.9117	0.6134
7	0.5015	0.2956	0.3850
8	0.7356	0.4543	0.5780
9	0.1113	0.3037	0.1838
10	0.4086	0.5723	0.4835
11	0.5996	0.8866	0.7291
12	0.7864	1.0000	0.8867
13	0.3327	0.6670	0.4710
14	0.7331	0.2468	0.4253
15	0.4680	0.7241	0.5821
16	0.3343	0.9889	0.5749

5.3. Taguchi Analysis

The complicated multi objective problem is now converted into a single objective problem in terms of composite desirability (D_g). It is well known that larger the composite desirability, the better is the multiple performance characteristics. Hence, taguchi’s higher-the-better characteristic has been used for knowing the effect of cutting parameters on the multiple responses and to identify the optimal combination of process parameters. The mean values of the D_g are given in the table 5.3.

Table 5.3. Response Table for Means of D_g

Level	s	f	D	Drill size
1	0.1804	0.2568	0.4794	0.4049
2	0.4872	0.4934	0.5731	0.4710
3	0.5708	0.4916	0.3643	
4	0.5133	0.5099	0.3349	
Delta	0.3904	0.2531	0.2382	0.0661
Rank	1	2	3	4

For the mean values of composite desirability (D_g) main effect plot is drawn and shown in the figure 5.1. From the figure it is observed that on the composite desirability values the speed has high effect and drill size has least effect.

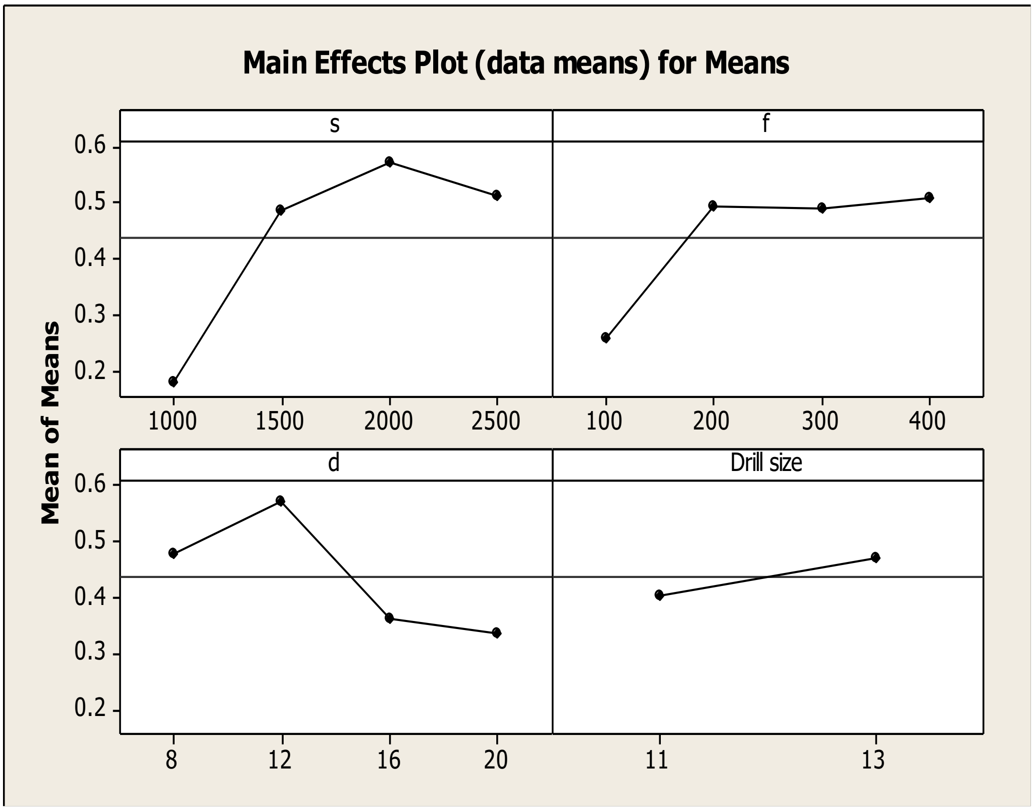

Figure 5.1. Main Effect Plot for Means of D_g

The optimal combination of process parameters for the multi objective function from the main effect plot is obtained at speed of 2000 rpm, feed of 400 mm/min, depth of cut of 12 mm and drill size of 13 mm respectively.

5.4. ANOVA Results

Analysis of variance (ANOVA) is a method of apportioning variability of an output response to various inputs. The purpose of statistical ANOVA is to investigate which design parameter significantly affects the performance characteristics. This is accomplished by separating the total variability of the composite desirability value, which is measured by sum of the squared deviations from the total mean of the composite desirability value into contributions by each machining parameter and the error. From the results shown in the table 5.4, the contributions of the process parameters are speed of 42.68, feed of 20.36, depth of cut of 16.70 and drill size of 0.020 respectively. Hence, it is clear that the speed is the high influencing factor on the multi response value called composite desirability index and followed by feed, depth of cut and drill size respectively.

Table 5.4. ANOVA Results of D_g

Source	DF	Seq SS	Adj SS	Adj MS	F	Contribution
S	3	0.36832	0.36832	0.12277	3.91	42.68
F	3	0.17577	0.17577	0.05859	1.86	20.36
D	3	0.14414	0.14414	0.04805	1.3	16.70
Drill size	1	0.01750	0.01750	0.01750	0.56	0.020
Error	5	0.15719	0.15719	0.03144		
Total	15	0.86292				

The residual plots for the composite desirability index (D_g) are drawn and shown in the figure 5.2. It is clearly observed that all the residuals are lying near to the straight line (mean line) hence following the normality and from the versus fits and order plots it is observed that they are not representing or following any regular patterns i.e. following the constant variance.

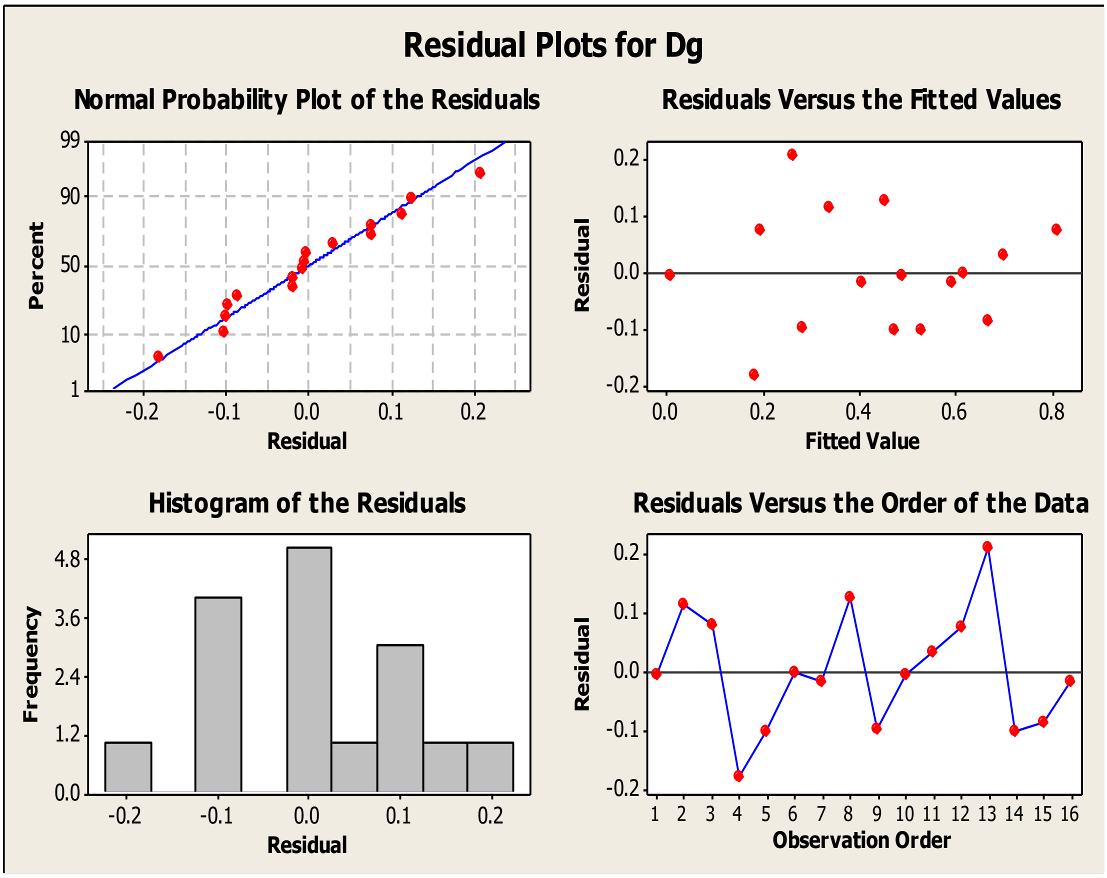

Figure 5.2. Residual Plots for D_g

CHAPTER 6

CONCLUSIONS

From the experimental, Desirability Function Analysis (DFA) and ANOVA the following conclusions can be drawn

- The optimal combination of process parameters for the multi objective function is obtained at speed of 2000 rpm, feed of 400 mm/min, depth of cut of 12 mm and drill size of 13 mm.
- ANOVA results of composite desirability concluded that the Speed is the high influencing factor and followed by feed, depth of cut and drill size respectively.
- The normal probability and the constant variance assumptions of ANOVA are verified from the residual plots of composite desirability (D_g).
- This Desirability function analysis (DFA) method is very simple in calculations and can be apply for any industrial multi-objective problems effectively.

REFERENCES

[1] Yogendra Tyagi, Vedansh Chaturvedi, Jyoti Vimal, “Parametric Optimization of Drilling Machining Process using Taguchi Design and ANOVA Approach”, International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 7, pp 339 to 347, 2012.

[2] Nisha Tamta and R S Jadoun, “Parametric Optimization of Drilling Machining Process for Surface Roughness on Aluminum Alloy 6082 Using Taguchi Method”, SSRG International Journal of Mechanical Engineering (SSRG-IJME), volume 2 Issue 7, pp.49-55, 2015.

[3] Kunal Sharma and Abhishek Jatav, “Optimization of Machining Parameters in Drilling of Stainless Steel”, International Journal of Scientific Research Engineering & Technology, Volume 4, Issue 8, pp. 902-908, 2015.

[4] S.V. Alagarsamy, S. Arockia Vincent Sagayaraj and P. Raveendran, “Optimization of Drilling Process Parameters on Surface Roughness & Material Removal Rate by Using Taguchi Method”, International Journal of Engineering Research and General Science Volume 4, Issue 2, pp. 290-298, 2016.

[5] Arshad Noor Siddiquee Zahid A. Khan, Pankul Goel, Mukesh Kumar, GauravAgarwal and Noor Zaman Khan, “Optimization of Deep Drilling Process Parameters of AISI 321 Steel using Taguchi Method”, 3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), Procedia Materials Science 6, pp.1217 – 1225.

[6] Yogendra Tyagi, Vedansh Chaturvedi and Jyoti Vimal, “Parametric Optimization of CNC Drilling Machine for Mild Steel Using Taguchi Design And Single-to-Noise Ratio Analysis”, International Journal of Engineering Science and Technology (IJEST), Vol.4, No.8, PP 3758- 3766, 2012.

[7] Navanth,T. Karthikeya Sharma, “A Study of Taguchi Method Based Optimization of Drilling Parameter in Dry Drilling of AL2014 Alloy at Low Speeds”, International Journal of Engineering Sciences & Emerging Technologies, Vol. 6, Issue 1, pp: 65-75, 2013.

[8] M.A. Amran S. Salmaha, N.I.S. Husseina, R. Izamshahb, M. Hadzleyb, Sivaraosb, M.S. Kasimb and M.A. Sulaimanb, “Effects of Machine Parameters On Surface Roughness Using Response Surface Method In Drilling Process”, The Malaysian International Tribology Conference 2013, MITC2013, Procedia Engineering 68, pp.24 – 29.

[9] Arya Yashvardhan, Sharma Gyanendu, “Optimization of Process parameters of “CNC Drill Machine for Mild Steel Using Taguchi Design and Single to Noise Ratio Analysis”,

International Research Journal of Engineering and Technology (IRJET),Vol.03, Issue.05, 2016.

[10] S.M.Darwish, "The Impact Of Tool Material And Cutting Parameters On Surface Roughness Of Inconel 718 Nickel Super Alloy", Journal of Materials Processing Technology, Vol. 97: 10, 2000.

[11] Yung-Kuang Yang, Ming-Tsan Chuang and ShowShyan Lin., "Optimization of Dry Machining Parameters for High-Purity Graphite In End Milling Process Via Design Of Experiments Methods", Journal of Materials Processing Technology, 209: 4395, 2009.

[12] Jeyapaul R, P. Shahabudeen and K. Krishnaiah, "Quality Management Research By Considering Multi response Problems In The Taguchi Method – A Review", International Journal Advanced Manufacturing Technology, 26: 1331, 2005.

[13] N. Muthukrishnana, T.S. Mahesh Babu and R. Ramanujam, "Fabrication and Turning Of Al/Sic/B4C Hybrid Metal Matrix Composites Optimization Using Desirability Analysis", Journal of Chin. Inst. Ind. Eng. 29(8): 515, 2012.

[14] Radhakrishnan Ramanujam, Nambi Muthukrishnan, and Ramasamy Raju, "Optimization of Cutting Parameters for Turning Al-SiC (10p) MMC Using ANOVA and Grey Relational Analysis", International Journal of Precision Engineering Manufacturing, Vol.12 (44): 651, 2011.

[15] Bala Murgan Gopalsamy, Biswanath Mondal and Sukumal Ghosh, "Taguchi Method and ANOVA: An Approach For Process Parameter Optimization Of Hard Machining While Machining Hardened Steel", J. sci. Ind. Res., 68: 686, 2009.

[16] G. Derringer, R. Suich, "Simultaneous Optimization of Several Response Variables", Journal of Quality Technology, Vol. 12,n. 4, pp. 214 – 219, 1980.

[17] Antony, J., Anand, R.B., Kumar, M., and Tiwari, M. K., "Multiple Response Optimization Using Taguchi Methodology and Neuro-Fuzzy Based Model", Journal of Manufacturing Technology Management, 17(7), 908–925, 2006.

[18]Harrington, E., The desirability function. Industrial Quality Control, 21(10), 494 – 498.

[19] Hung-Chang, Liao., "A Data Envelopment Analysis Method for Optimizing Multi-Response Problems With Censored Data In The Taguchi Method", Computers and Industrial Engineering, 46(4), 817-835, 2004.

[20] Sumesh A S and Melvin Eldho Shibu, "Optimization Of Drilling Parameters For Minimum Surface Roughness Using Taguchi Method", International Conference on Emerging Trends in Engineering & Management (ICETEM-2016), pp.12-20.

[21] A. Navanth and T. Karthikeya Sharma, “A Study of Taguchi Method based Optimization of Drilling Parameter in Dry Drilling of Al 2014 Alloy at Low Speeds”, International Journal of Engineering Sciences & Emerging Technologies, vol. 6 (1), pp.65-75, 2013.

[22] K. Ramesh, “Optimization of Cutting Parameters for Minimizing Cycle Time in Machining of SS 310 using Taguchi Methodology and ANOVA”, IOSR Journal of Mechanical and Civil Engineering, 12 (1), pp.31-39, 2015.

[23] Arshad Noor Siddiquee, Zahid A. Khan, Pankul Goel, Mukesh Kumar, Gaurav Agarwal and Noor Zaman Khan, “Optimization of Deep Drilling Process Parameters of AISI 321 Steel using Taguchi Method”, 3rd International Conference on Materials Processing and Characterization (ICMPC 2014), 6, pp.1217 – 1225.

[24] Sunil Hansdaa and Simul Banerjeeb, “Optimizing Multi Characteristics in Drilling of GFRP Composite using Utility Concept with Taguchi’s Approach”, 3rd International Conference on Materials Processing and Characterization, 6, pp.1476 – 1488, 2014.

[25] K.Palani kumar, “Experimental investigation and optimization in drilling of GFRP composites”, Measurement 44, pp.2138–2148, 2011.

[26] Tom sunny, J.Babu and Jose Philip, “Experimental Studies on Effect of Process Parameters on Delamination in Drilling GFRP Composites using Taguchi Method”, 3rd International Conference on Materials Processing and Characterization, 6, pp.1131 – 1142, 2014.

[27] Mr. Nalawade P.S. and Shinde S.S., “Cutting Parameter Optimization for Surface Finish and Hole Accuracy in Drilling Of EN-31”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 12, Issue 1, pp. 20-27, 2015.

[28] N. Satheesh Kumar, Ajay Shetty, Ashay Shetty, Ananth and Harsha Shetty, “Effect of Spindle Speed and Feed Rate on Surface Roughness of Carbon Steels In CNC Turning”, International Conference on Modeling, Optimization and Computing (ICMOC 2012), Procedia Engineering, 38, 691 – 697.

[29] Y.D.Chetan, H.V.Ravindra, Y.T.Krishne Gowda and G.D.Mohan Kumar, “Parametric Optimization in drilling EN-8 Tool Steel and Drill Wear Monitoring using Machine Vision Applied With Taguchi Method”, International Conference on Advances in Manufacturing and Materials Engineering, 5, pp.1442-1449, 2014.

[30] H Prakash, “An Investigation to Study the Effect of Drilling Process Parameters on Surface Finish Using Taguchi Method”, International Journal of Mechanical Engineering and Robotics Research, 3 (2), pp.54-62, 2014.

[31] Ali Riza Motorcu, “The Optimization of Machining Parameters Using the Taguchi Method for Surface Roughness of AISI 8660 Hardened Alloy Steel”, Journal of Mechanical Engineering, 56 (6), pp.391- 401, 2010.

[32] Gurpreet Singh, Sehijpal Singh, Manjot Singh and Ajay Kumar, “Experimental Investigations of Vegetable & Mineral Oil Performance Machining Of EN-31 Steel With Minimum Quantity Lubrication”, IJRET, Volume 2, Issue 06, 2013.

[33] Adikesavulu, Sreenivasulu. Bathina and Sreenivasulu. Bezavada, “Optimization of Process Parameters in Drilling of EN31 Steel Using Taguchi Method”, IJIERT, Volume 1, Issue 1, 2014.

[34] Pantawane.P.D and Ahuja.B.B., “Experimental Investigations and Multi-Objective Optimization of Friction Drilling On AISI 1015”, International Journal of Applied Engineering Research, Dindigul, vol.2, no.2, 2011.

[35] Naveen Sait, S. Aravindan and A. NoorulHaq, “Optimisation of Machining Parameters of Glass-Fibre-Reinforced Plastic (GFRP) Pipes by Desirability Function Analysis using TaguchiTechnique”, International Journal of Advanced Manufacturing Technology, Vol. 43, pp. 581–589, 2009.

[36] Yogendra Tyagi, Vedansh Chaturvedi and Jyoti Vimal, “Parametric Optimization of Drilling Machining Process Using Taguchi Design and ANOVA Approach”, International Journal of Emerging Technology and Advanced Engineering , Volume 2, Issue 7, 2012.

[37] Upinder Kumar Yadav, Deepak Narang and Pankaj Sharma Attri, “Experimental Investigation and Optimization of Machining Parameters for Surface Roughness In CNC Turning by Taguchi Method”, International Journal of Engineering Research and Applications, Vol. 2, Issue4, 2012.