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Research Article

Optimization of Drilling Process Parameters for Aluminum ALLOY AA8011

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Abstract

In industry, the drilling process is the most interesting among all the other machining process which has to maintain quality of holes required for producing riveted and bolted joints in the many more operation of workpiece. The major tasks which arise from the drilling on any materials are characterized by the poor hole quality that possibly initiate cracks within its frame structure and reduces their reliability. Predicting the optimal parameter has become increasingly important given the rise in expenses involved in drilling a well. Several models and methods have been published for predicting, and therefore potentially optimizing. However, these models and methods have limitations, too many variables are included, their input parameters are often not readily available, and their relationships are complex and not easily modelled. Therefore, the optimization technique of grey relation analysis is suggested in this work. Another methodology has been developed to predict the parameter of responses by ANOVA method. The system uses a knowledge base of various drilling parameters, to produce a "correlation" description of the responses. These responses are predicted by ANOVA method.

Keywords: Drilling, Aliminium alloy, Optimization, Process parameters.

1. Introduction

The most important characteristics of drilled-hole quality are hole diameter and the deviation of the hole size (HS) from its nominal diameter this is because component constantly operate under vibration/shock conditions where thousands of fastener holes in the fuselage skins are prone to fatigue. Fatigue cracks normally initiate and propagate after the fastened holes create regions of concentrated stress; therefore, the reliability of component structures depends on their fatigue life, which is directly related to hole quality [1]. Machining parameters play a significant role in any drilling operation where optimal process parameters help in achieving high-quality holes [2]. Drilling is a cutting or material removal process that uses a drill bit to cut a hole of circular cross section in solid material. This process has wide applications like for making hole for riveted joints, in heat exchangers, in fuel injector bodies etc. This process is very to setup, easy to monitor, has high flexibility, requires low maintenance cost etc. Conventional mechanical drilling has to face increasing physical limitation when hole diameter is decreased. Below some decisive dimension, friction exceeds the mechanical strength of the tool and machining is possible only by diamond, carbide coated tools which are having high modulus values. So, optimization of process parameters is essential for drilling of 10mm hole in aluminum strip taking HSS as drill material. The lubrication with water mixture, feed and the spindle rpm are used as process parameters to determine the optimum drilling conditions [7].

Hole quality in drilling is evaluated in terms of hole diameter and cylindrical shape, it is generally used for parts requiring the great reliability and resistance of wear, and therefore high hole quality must be maintained. Two critical criteria (hole diameter and cylindricity) are usually applied to determine the hole quality in terms of size and shape. The average hole diameter has to be within the size tolerance which is described as two concentric circles. Cylindricity is the extension of roundness into the entire length of the hole. In drilling operation good quality of hole is desirable. If the quality of hole so obtain is poor due to the presence of concentrated stress zone fatigue will generate leading to the wear of product and thus reducing its reliability. For good quality of hole, hole diameter error must be low with good material removal rate [21].

2. Literature Review

Aamir et al. [1] worked on multi-spindle drilling using a poly-drill head as an industrial hole-making approach that allows drilling several holes simultaneously. This work focuses on the optimization of drilling parameters using the Taguchi method, analysis of variance and regression analysis. Bharti & Moulick [4] optimized multi response factors for micro-drilling operation. Drilling operation is influenced by spindle speed, feed rate, tool point angle, presence of coolant & lubricating agent, vibration, tool material, clearance and chip length. In this case study, the Machining parameters spindle speed, feed rate and tool point are analyzed for their effect on the hole diameter produced and the material removal rate Taguchi based method along with ANOVA (Analysis of Variance) and DOE (Design of Experiments). Hanif et al. [11] recommended high speed and feed rate to reduce the burr height in aluminium. Smaller feed rate was recommended for dimensional accuracy of holes. More burrs were formed when an increase in both the spindle speed and feed rate was noted.

Heisel. et.al. [13] investigated the influence of the point angle of a drill tool and increased cutting speeds on machining forces and drill hole quality. With increase in drill point angle there is increase in feed forces and increase in cutting speeds result did not affect drill hole quality. Kumar. et.al. [21] utilized 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. Orthogonal arrays of Taguchi, the Signal–to- Noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis are employed to analyze the effect of drilling parameters on the quality of drilled holes. Ramesh Kumar et al [31] optimized drilling parameters in hybrid Al-6061/SiC/B4C/talc composites and studied using grey relational analysis. Grey relational analysis equations were utilized for finding the optimum machining condition. The most important parameter, namely the cutting speed, was found to have influenced the thrust force and circularity. Uddin et al. [42] reported that adhesions, BUE (Build up Edge), and diffusion on the tool are the most common problems in the drilling aluminium alloys. Therefore, the dominant wear mechanism in aluminium alloys requires better understanding to reduce tool wear which helps in increasing productivity. The significant factors affecting tool wear include drilling parameters

1.2 **Background of Work**

Optimization of drilling process with various workpiece materials by studying the references by scholars correlating the relationship between the input process parameters[6] and the output responses in order to optimize the process parameters so that the desired values of performance parameters are obtained and hence making the drilling process cost effective along with the assurance of the quality specifications within the experimental limit through optimization as it supports continuous improvement of output quality of products and process through modeling and determination of optimal cutting conditions [9]. The proposed work shows that we are supposed to determine the region of critical process control factors such as drill diameter, material thickness and the drill point angle leading to desired output or responses with acceptable variations that will ensure a low cost of manufacturing through optimization. Thus, it contributes to manufacturers to face the challenge of higher productivity and quality of the product.

1.3 Objective of the work

Machining tests were carried out under different conditions with high-speed steel drilling tool. To calculate constants and coefficients of these models, the software Minitab characterized by analysis of variance (ANOVA) and Taguchi's Analysis [41]. This objective requires better management of the machining system. This literature includes information on soft materials, used in drilling operations and responses of the machined work piece. Accuracy of drilling is an inherent occurrence in any machining process. Hence, improvements have to be made in order to increase operation quality in drilling. MRR is also an important aspect of a machined product.

i. To study the influence/effect of drilling parameters viz. feed, cutting speed and coolant mixture on drilling.

ii. To develop an empirical model for the hole diameter error and MRR for the chosen combination within the specified domain of parameters.

iii. To determine optimum machining parameter settings for the chosen combination so as to maximize the hole accuracy and MRR using Grey Analysis Method.

iv. The influence of drilling parameters (feed, cutting speed and coolant mixture) on hole diameter error, MRR has been analyzed. Under the both responses conditions ANOVA analysis is applied to obtain the significant parameter.

2. Methodology

Aluminium alloys have a superior machinability index and are extensively used in various industries such as the aircraft, aerospace, marine, and automotive industries [23]. Therefore, an Aluminium AA8011 plate with a thickness of 10 mm and a size of 50 mm × 50 mm was used in this work. The tool material used was 4 mm uncoated high-speed steel (HSS) twist drills with a point angle of 118o and a helix angle of 30o for both one-shot drilling shown in Fig 1.

2.1 **Process Parameter**

During the experiment, three factors and three levels are considering for performing the experiment. The three feeds were selected as 0.04, 0.08, 0.12 mm/rev, spindle speeds used in the experiment were 1000, 1200, 1400 rpm and the type of coolant has taken with water mixture of their percentage, for this experiment the coolant lubricant mixture is prepared with 100 ml of water with their different level of coolant have been added is 15%, 20% & 25% respectively. The machining parameters with their levels as input parameter are shown in Table 1. Mathematical models were deduced by software design Expert in order to express the influence degree of the main cutting variables such as feed, cutting speed, and mixture of coolant and water experiments with combination of different cutting parameters were randomly repeated.

Table 1. Factors and Level

Sl. No.	Feed mm/rev	Cutting Speed (rpm)	Coolant Mixture (%)
1	0.04	1000	15
2	0.08	1200	20
3	0.12	1400	25

The 9 experiments of settings were done to analyse the response that is the hole dia error and Material removal rate. For experiments the range of each parameter is set at three different levels, as shown in Table 2.

Table 2. DOE L9 Orthogonal array

Sl. No.	F	S	M
1	0.1	1000	15
2	0.1	1200	20
3	0.1	1400	25
4	0.3	1000	20
5	0.3	1200	25
6	0.3	1400	15
7	0.5	1000	25
8	0.5	1200	15
9	0.5	1400	20

2.2 **Grey Relation Analysis**

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters [40].

This process is known as grey relational generation. For lower-the-better criterion follow eq1 and for higher the better criteria follow eq6, the normalized data can be expressed by equation (1)

$$X_i = \frac{max(y)_i - (y)_i}{\max(y)_i - \min(y)_i} \quad \dots..(1)$$

$$X_i = \frac{(y)_i - min(y)_i}{\max(y)_i - \min(y)_i} \quad \dots..(2)$$

$$where\ i = 1,2 \dots..n$$

Based on normalized responses data, grey relational coefficient is calculated to signify the correlation between the desired and actual experimental data.

The optimal parametric combination is then evaluated by maximizing the overall grey relational grade.

The calculation of the grey relational coefficient and the weight of each quality characteristic is determined by equation (3):

$$G_i = \frac{L_{min} + \varepsilon L_{max}}{L_i(k) + \varepsilon L_{max}} \quad \dots\dots..(3)$$

Where, L_{min} is the global minimum, L_{max} is the global maximum and ε is distinguish coefficient which is taken in between 0 to 1 in this case 0.5 weight is taken. Grey relation grade can be calculated by equation (4)

$$Grg_i = \frac{1}{n}\sum_{j=1}^{n} G_i(j) \quad \dots\dots\dots\dots\dots(4)$$

Where n is the number of process responses. The lower value of the grey relational grade represents the reference sequence Grg_i. As mentioned before, the reference sequence Grg_i

is the best process response in the experimental layout is taken whose grey relation grade is maximum [41].

2.3 **Experimental Process**

The drilling speed experiments are performed for three different speeds of 1000, 1200 and 1400 RPM, while the feed rate is kept at 0.04, 0.08 and 0.12 mm/rev, with three different level of water and coolant mixture, hole is being drilled for 10 mm in depth and drill diameter is 4 mm. Experimental setup and specimen after drilled are shown in Fig 2 and Fig 3.

Fig. 2 Experimental Setup

Fig. 3 Specimen of Drilling

Table 3. Responses of parameter

Sl. No.	F	S	M	Hole Diameter Error (e) (mm)	MRR mm^3/min
1	0.04	1000	15	0.11	475.1479
2	0.04	1200	20	0.05	618.0462
3	0.04	1400	25	0.13	749.8213
4	0.08	1000	20	0.01	999.7823
5	0.08	1200	25	0.02	1193.733
6	0.08	1400	15	0.03	1427.9
7	0.12	1000	25	0.02	1522.31
8	0.12	1200	15	0.06	1863.306
9	0.12	1400	20	0.04	2152.493

3. Results and Discussion

On the base of DOE (Design of Experiment) parameter, the drilling on aluminium plate is applied as per the sequence of experiment with their input parameter control operation. Drilling hole are made by CNC machine to maintain the accuracy of parameters. Drilled hole error are measured by Rehinshaw graph [25] and MRR [18] is evaluated by mathematically. The response of hole diameter error and MRR as shown in Table 3. Feed is represented by (F) rotation speed of tool id (S) and coolant with water mixture is coolant mixture which depict as(M).

ANOVA table 4. shows that the lowest P value is 0.038 of Feed, so it means that the feed is the significant parameter against the responses of hole diameter Error.

ANOVA Table 5. shows that the lowest P value is 0.005 of Feed, so it also proves that the feed is the significant parameter against the responses of MRR.

Table 4. Analysis of Variance for Hole Diameter Error

Source	DF	Seq SS	Adj SS	Adj MS	f	P
F	2	0.009489	0.009489	0.004745	5.41	0.038
S	2	0.000956	0.000956	0.000478	0.54	0.061
M	2	0.001756	0.001756	0.000878	1.00	0.072
Residual Error	2	0.001756	0.001756	0.000878		
Total	8	0.013956				

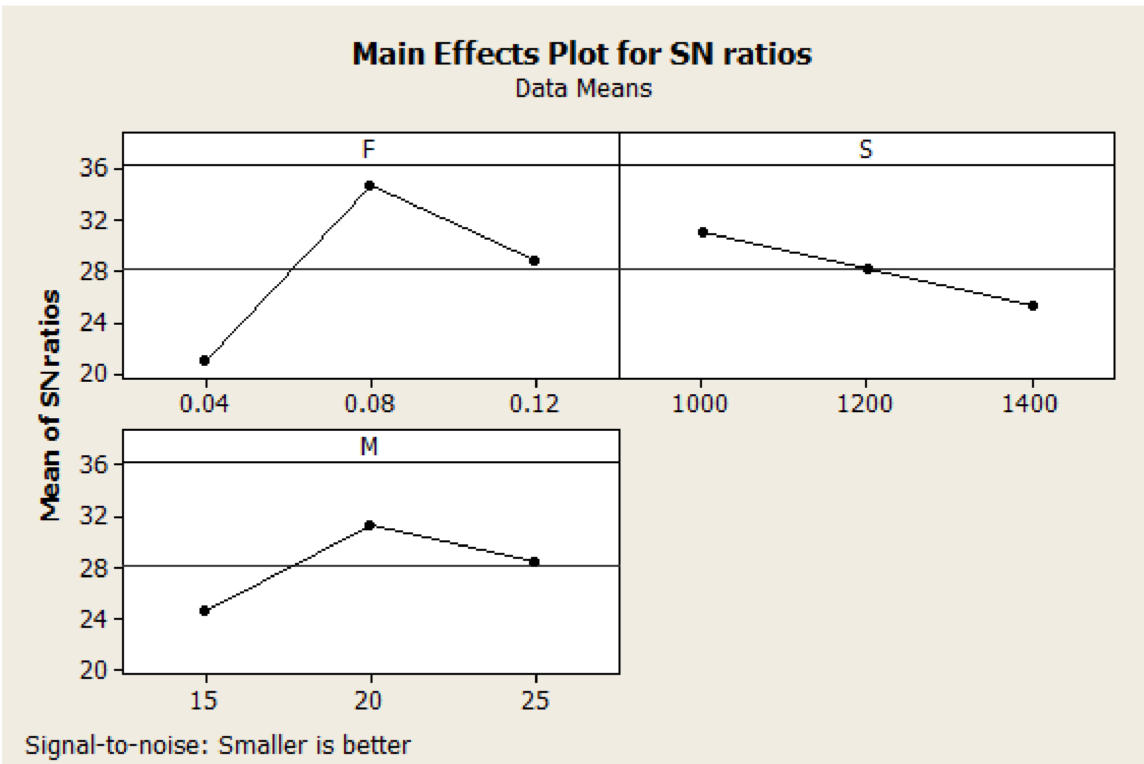

Fig 4. S/N ratio graph of Hole Dia Error

Table 5. Analysis of Variance for MRR

Source	DF	Seq SS	Adj SS	Adj MS	f	P
F	2	2276682	2276682	1138341	187.09	0.005
S	2	296165	296165	148082.5	24.34	0.039
M	2	20334	20334	10167	1.67	0.374
Residual Error	2	12169	12169	6084.5	-	-
Total	8	2605350	-	-	-	-

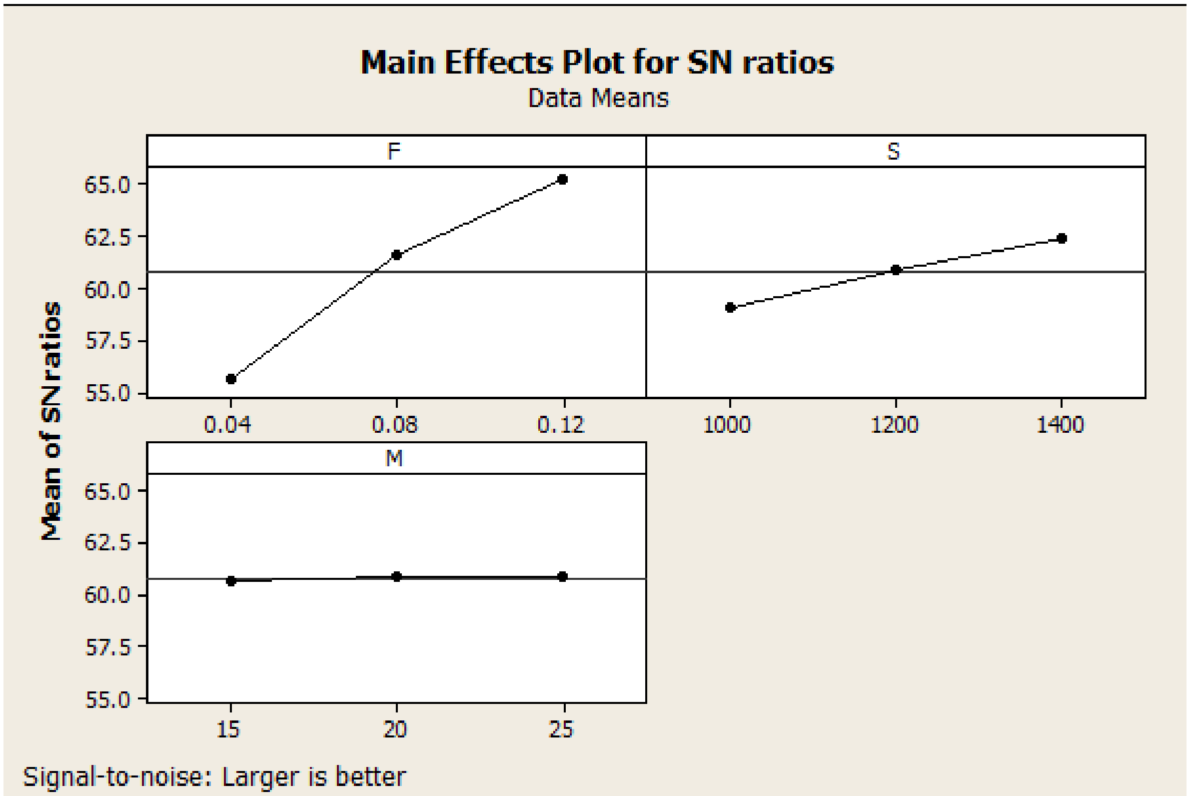

Fig 5. S/N ratio graph of MRR

3.2 Optimization Calculation

Grey relation analysis calculation is shown in Table 6 which shows that the higher value of Grg_i is ninth experiment which gives the best possible parameter and ANOVA table 7 again shows the lowered P value is feed so it is clear that feed is the significant parameter in drilling operation corresponding to the responses taken in this work. The final optimize parameter are feed is 0.12 mm/sec cutting speed is 1400 rpm and the percentage of lubrication on water mixed is 20 has been optimize.

Table 6. Optimization of Grey relation Analysis

e(x_i)	MRR (x_i)	e(L)	MRR(L)	e(Gi)	MRR(Gi)	Grg_i
0.166667	0	0.833333	1	0.375	0.333333	0.354167
0.666667	0.085218	0.333333	0.914782	0.6	0.353411	0.476706
0	0.163803	1	0.836197	0.333333	0.374196	0.353765
1	0.312869	0	0.687131	1	0.421183	0.710592
0.916667	0.428532	0.083333	0.571468	0.857143	0.46665	0.661896
0.833333	0.568179	0.166667	0.431821	0.75	0.536584	0.643292
0.916667	0.624481	0.083333	0.375519	0.857143	0.57109	0.714116
0.583333	0.827836	0.416667	0.172164	0.545455	0.743866	0.64466
0.75	1.000294	0.25	-0.00029	0.666667	1.000588	0.833628

As per the Signal to noise ratio graph the best possible parameter of these responses are feed is 0.12 mm/sec cutting speed is 1200 rpm and the percentage of lubrication on water mixed is 20 has been optimize as shown in Fig 6.

For ANOVA [38] test the optimize data are tabulated in table 7 shows that the lowest P value is 0.020 of Feed, so it also proves that the feed is the significant parameter against the responses of hole quality and MRR [21].

Table 7. Analysis of Variance for GRG

Source	DF	Seq SS	Adj SS	Adj MS	f	P
F	2	0.193065	0.193065	0.096533	48.70	0.020
S	2	0.000550	0.000550	0.000275	0.14	0.878
M	2	0.26216	0.26216	0.13108	6.61	0.131
Residual Error	2	0.003965	0.003965	0.001983		
Total	8	0.223796				

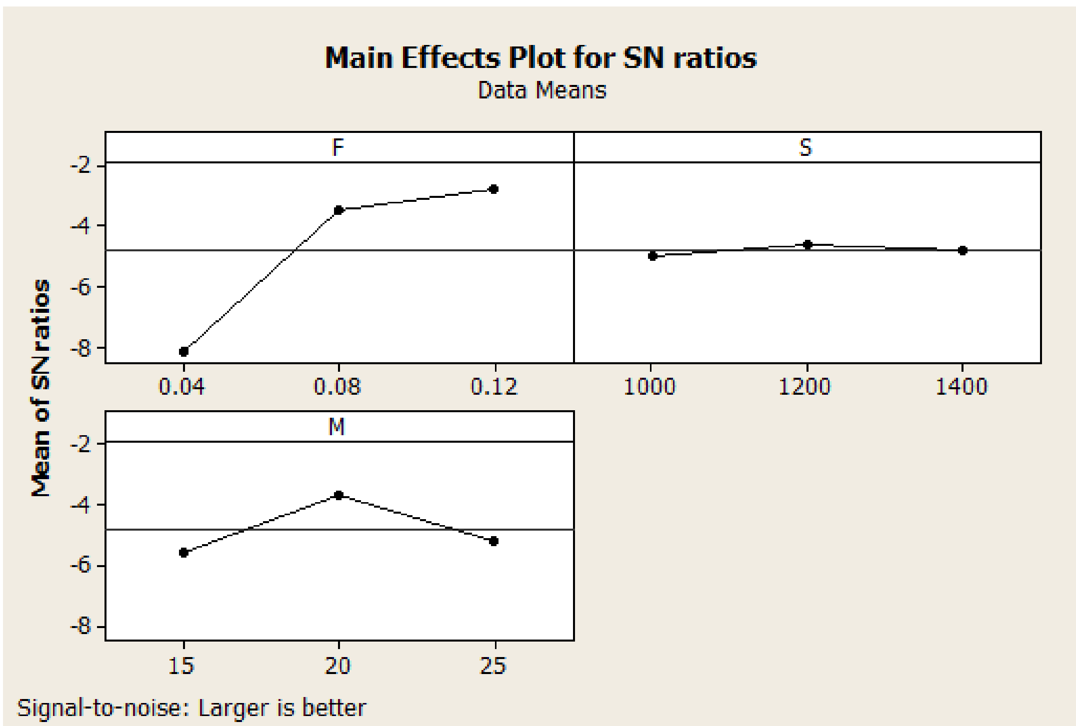

Fig 6. Graph of Optimization

ANOVA Analysis was successfully applied in predicting the process parameter of drilling based on the responses hole diameter error and Material removal rate for the selected domain of the input drilling parameters as shown in Table 8.

Table 8. Optimize Input Parameter

Method	Feed F (mm/rev)	Speed S (rpm)	Coolant mixture M (%)
Optimization	0.12	1400	20
S/N Graph	0.12	1200	20

Conclusions

Based on the experimental results presented and discussed, the following conclusions can be drawn on the effect of feed, cutting speed and mixture of water and lubricant for cooling the operation on the performance of aluminum alloy.

- ❖ The important factor affecting the hole diameter error and Material Removal Rate is feed. The optimum condition for lower the hole diameter error and Material Removal Rate is F=0.12 mm/sec, S=1400 rpm and M= 20 %.
- ❖ The ANOVA gives the better response for its individual category feed is 0.04mm/sec, Speed is 1400rpm and coolant mixture is 15% for hole error whereas similar speed also predicts for MRR but variation in feed and coolant mixture.
- ❖ Finally, the speed of tool responses is predicted for Aluminium alloy and rest of the parameters are scope of research in future.

Conflict of interest

The author declares no conflict of interest.

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