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Optimization of Drilling Process Parameters for AISI 316L by Using Taguchi Method

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ABSTRACT

Drilling operation is one of the fundamental processes in the manufacturing industry to drill holes especially in sheet metal parts. It is observed that the produced parts under the drilling process have high rejection because of surface roughness in drilled hole. The main objective of this work is to reduce surface roughness in drilling operation. As drilling is the operation which is carried at the end process for final machining of components requires smooth surfaces and precise tolerances. It is a widely used in industry aerospace, aircraft, automotive industries and many more. The paper discusses following input processes parameters namely spindle speed, drilled hole depth and feed rate. In this work, experimental investigation is done to predict drilling behavior and to achieve optimal operating processes parameters. A software package is utilized which integrates these various models to simulate what happens during drilling operation processes. Predictions from this simulation are analyzed by calibration with actual data. It involves many variables such as spindle speed, feed rate, chemical composition of work piece, etc. A number of drilling experiments is conducted using the L9 orthogonal array on VMC drilling machine. The experiments is performed on AISI 316L block using HSS twist drills. The measured results is collected and analyzed with the help of the commercial software package MINITAB16. The main objective in this is to optimize drilling parameters. In order to do so, Taguchi method, Analysis of variance and linear regression analysis is employed to determine the most significant control factors affecting the surface roughness, and material removal rate which can be obtained from Taguchi S/N ratios analysis.
Keywords: Drilling Process, Taguchi Method, MINITAB16, Analysis of Variance, Spindle Speed, Feed Rate

I. INTRODUCTION

Alloy AISI 316L is a chromium-nickel-molybdenum austenitic stainless steel is developed to provide improved corrosion resistance in moderately corrosive environments. Tensile properties can vary but are usually between 550-650 N/mm². The low carbon combination of 316L combined with an addition of nitrogen gives 316L to meet the mechanical properties of 316. Alloy 316L resists atmospheric corrosion, moderately oxidizing. It can be easily welded and processed by standard shop fabrication practices. The Taguchi method is statistical tool, used experimentally to investigate the effect of surface roughness by cutting parameters such as spindle speed, feed and depth of hole. The Taguchi process helps to determine the optimum cutting conditions for drilling process. The variation in the material hardness, alloyed elements present in the work piece material and other than the machine tool the workpiece set-up, and the use of cutting fluids, etc. In a drilling operation, it is an important task to select cutting variables for achieving high cutting performance.

Usually, the desired cutting variables are determined based on experience, however, this does not ensure that the selected cutting parameters have optimum or near optimum cutting performance for a particular machine or environment. To select cutting parameters properly it requires a more methodical approach by using experimental methods and mathematical and statistical models. Not only does this requires considerable knowledge and experience to design experiments and analyse data, but traditional design of experiments (DOE) techniques require a large number of samples to be produced. Therefore, a more efficient method is needed to effectively optimize cutting parameters for surface roughness in drilling operations.

The Taguchi method has been widely used in engineering analysis and is a powerful tool to design a high quality system. Significance of the effects was tested through analysis of variance (ANOVA), and selection of optimum levels for the factors was based on the level means. In studies that provides a most economical way of experimentation was used to study the effects of process parameters on surface roughness while machining AISI 316L. The main objectives of this work are:

1. Selection of material for workpiece.
2. Selection of methodology for drilling process optimization.
3. To study the effects of process parameters namely spindle speed, feed, and depth of hole on surface roughness and material removal rate.

Literature Review

H Prakash states that the major operation carried out in the machining industry is drilling process. It is observed that the produced parts under the drilling process have high rejection because of surface roughness in drilled hole. We identified five factors with three levels and one factor with two levels and experiment is carried out using L18 orthogonal array. The data obtained is analyzed using manual method and solver (Minitab). Feed rate and Type of coolant are the factors which affect the surface finish severely. In this study, a confirmation experiment was conducted by utilizing the optimal levels of the process parameters (A1 B1 C1 D2 E2 F3) resulted in response values of 3.210, 3.203, 3.208 μm. Each Ra measurement was repeated at least three times. Therefore the optimum surface finish (Ra = 3.207 μm) can be obtained under the above mentioned cutting condition. This methodology can be used for process improvement of similar kind.

M Sundeep, M Sudhahar, and T T M Kannan pointing towards Metal removal Techniques is a mature technology involving several disciplines of sciences. This paper aims to make an experimental investigation on drilling behavior of Austenitic stainless Steel (AISI 316) and attempt made to optimize the process parameters using L9 Orthogonal array design of experiment of Taguchi methodology. The process parameters of spindle speed, feed rate and drill diameter are influenced by surface roughness and Metal removal rate during Drilling operations. The main objectives of this research paper to identify lowest thrust force and more metal removal rate (MRR) of drilling process through experimental analysis and theoretical calculations using Analysis of Variance (ANOVA). The result of the experiments indicates cutting speed play abominating role in surface roughness and Metal removal rate in drilling process parameters.

Ali Riza Motorcu used surface roughness in the turning of AISI 8660 hardened alloy steels by ceramic based cutting tools was investigated in terms of main cutting parameters such as cutting speed, feed rate, depth of cut in addition to tool’s nose radius, using a statistical approach. Machining tests were carried out with PVD coated ceramic cutting tools under different conditions. An orthogonal design, signal-to-noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness.
However, the cutting speed showed an insignificant effect. The interaction of feed rate/depth of cut was found to be significant on the surface finish due to surface hardening of steel. Optimal testing parameters for surface roughness could be calculated.

Dayal Saran P and BalaRaju J investigated that the productivity and the quality of the machined parts are the main challenges of metal cutting industry during drilling processes. Therefore cutting parameters must be chosen and their effect is studied in such a way that the required surface quality can be controlled. This paper presents an Experimental Analysis of process parameters (drill bit diameter, speed, feed) effecting the surface finish in radial drilling process to achieve better surface finish. The experimental layout was designed based on the Response surface Methodology (RSM) technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the surface finish. The model is tested for its adequacy by using Fisher’s test at 95 % confidence level. The main and interaction plots are drawn using MINITAB 14 and the effect of various process parameters on surface finish was studied.

Yogendra Tyagi, Vedansh Chaturvedi, and Jyoti Vimal states that the drilling of mild steel with the help of CNC drilling machine operation with Tool use high speed steel by applying Taguchi methodology has been reported. The Taguchi method is applied to formulate the experimental layout to ascertain the Element of impact each optimum process parameters for CNC drilling machining with drilling operation of mild steel. A L9 array, taguchi method and analysis of variance (ANOVA) are used to formulate the procedure tried on the change of parameter layout. The available material study in focuses optimization of CNC Drilling machine process parameters to provide good surface finish as well as high material removal rate (MRR). The selection of optimal machining parameters i.e., spindle speed, depth of cut and feed rate) for drilling machine operations was investigated in order to minimize the surface roughness and to maximize the material removal rate.

Amarnath R. Mundhekar, Subhash R. Jadhav reviewed that the various literatures on the optimization of drilling process by studying the influence of various drilling parameters (spindle speed, feed rate, drill diameter, drill point angle, etc.) on the performance parameters (surface roughness, material removal rate, thrust force, etc) during drilling process.

II. METHODS AND MATERIAL

A. Taguchi method

Taguchi method is a effective tool for the design of high quality systems. It provides simple, effective and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient tool for designing process that operates consistently and optimally over a variety of conditions. To determine the optimum design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to analyse and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. The desired cutting variables are determined based on experience or by hand book. Cutting parameters are reflected.

B. Experiment & Material

In this investigation, for the work piece material, alloy was used. This material was chosen based on its applications in industry. Alloy 316L has superior corrosion resistance. It is highly oxidizing acids such as nitric acid, performs well in sulphur containing service such as that encountered in the pulp and paper industry, good resistance to pitting in phosphoric and acetic acid, utilized to handle hot organic and fatty acids with high levels of chlorides.

The material work pieces of 90mm length, 80mm width and thickness 25 mm is considered for conducting experiments. These were cantered and cleaned by removing a 2mm depth from the outside surface prior to the actual machine process. Surface finish of the work piece material measured by SURFCOM 130A with 0.25mm cut-off value, surface roughness parameter used to evaluate roughness, in this study, is the roughness average R. Ra is recognized universally a the most common international parameter of roughness. The surface roughness was measured at three equally spaced locations around the circumference of the work pieces to obtain the statistical significant data for each test.

We selected AISI 316L work material as: The composition of this material is Manganese 2 % max , Carbon 0.030%, Silicon 0.75%, Phosphorous 0.045%, Sulphur 0.03%.

Figure 1. VMC Drilling Machine

Table 1. Chemical Composition

Type	C	Cr	Mn	Mo	Ni	P	Si	S
316 L	0.030 Max	16.0 to 18.0	2 Max	Min:2 Max:3	Min:10.0 Max:14.0	0.045 Max	0.75 Max	0.03 Max

This enriches the material in properties of:

1. High strength
2. Good toughness
3. Good ductility
4. High hardenability

Table 2. Mechanical Properties

AISI 316L Mechanical properties	
Max Stress	450 MPa
Yield Stress	170 MPa
Elongation	40% Min
Hardness	217 Brinell

The property of the material is:

1. High strength
2. Rigidity
3. Impact resistant
4. Heat and oxidation resistance
5. Resistance to corrosion and wear.

C. Experimental Design

The most direct method to predict surface quality is by the creation of ANOVA models based on experimental investigation. The advantage of such models is that they are able to take into account multiple factors influencing surface roughness that would not have been able; to be accounted for in analytical models and for cases where an analytical formulation is not feasible. The purpose of the experiments was to analyse the influence of process parameters and evaluate the performance on the surface roughness in hard turning process. In this study, the three parameters namely spindle speed, feed, and depth of cut were selected for the experimentation. The range of each variable was set at three different levels namely low, medium and high based on industrial practice. Different settings of control factor is used in the experimentation are summarized in Table III.

Table 3. Level of Control Factors

Factor Symbol	Factor	Level 1 (Low)	Level 2 (Medium)	Level 3 (High)
S	Spindle Speed	1000	1500	2000
F	Feed Rate (mm/min)	30	40	50
D	Depth of Hole (mm)	10	15	20

Table 4. Machine Readings of Roughness

(S) (RPM)	F (mm/min)	H (mm)	Ra (µm)	(MRR) (g/min)
1000	50	20	0.497	9.0
1000	40	15	0.566	6.9
1000	30	10	0.489	4.7
1500	50	10	0.412	5.3
1500	40	20	0.621	8.4
1500	30	15	0.602	6.3
2000	50	15	0.529	7.3
2000	40	10	0.621	5.0
2000	30	20	0.705	7.6

Design of experimental techniques was used for the Execution of the plan of experiments. Each experiment is carried out and a total of 9 experiments were needed to analyse the influence of various factors on the surface roughness. The experimental layout along with the response (surface roughness) and material removal rate obtained is shown in table IV. Experiments were conducted as shown in the table IV.

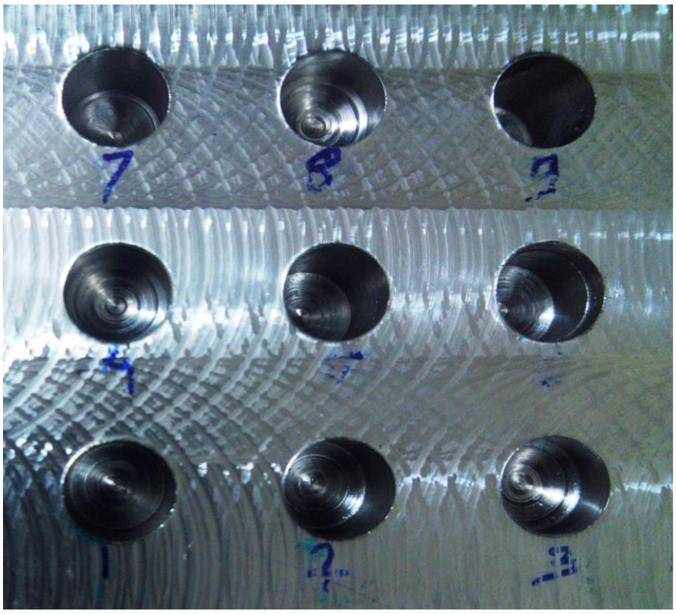

Figure 2. Workpiece after Experimentation

III. RESULTS AND DISCUSSION

DATA ANALYSIS AND DISCUSSION OF RESULTS

The plan of tests was developed aiming at determining the relation between the influence of cutting parameters and the surface roughness.

A. Surface Roughness

Applying Linear Model Analysis, which highlight the significant factors one at a time, option of Minitab software is used to develop the models. The parameter, surface roughness results and analysis of variance for the model are given in table of ANOVA.

It can be observed that the cutting speed and feed are affecting on surface roughness. The presence of square terms of cutting speed and depth of cut indicates the nonlinear behaviour on surface roughness. Further, interaction term of cutting speed and feed is also available into the model.

B. Effect of Process Parameters on Surface Roughness

The effects of cutting parameters according to the experiments conducted can be summarized as follows: As seen from model equation and Figure no. 3, the feed rate has the greatest effect on surface roughness followed by spindle speed. It can be observed that a increase in spindle speed decreases surface roughness from its lower level to middle level and then slightly increases from middle level to higher level. But the better surface roughness is noticed at higher level of feed rate irrespective of spindle speed and depth of hole.

From the figure 3, it can be observed that at higher level of feed value the minimum value of surface roughness occurs at a feed rate of 50 mm/min. At higher level of speed, the increases the value of surface roughness which occurs at medium and/or higher levels of feed. When the depth of drill hole is at its lower and higher level there is no change in surface roughness value.

C. Taguchi Analysis: surface roughness vs speed, feed, depth of drill hole

Table 5. Response for Signal to Noise Ratios Smaller is better

Level	Speed	Feed	Hole Depth
1	5.743	4.553	6.018
2	5.416	4.407	4.961
3	4.235	6.435	4.416
Delta	1.508	2.029	1.602
Rank	3	1	2

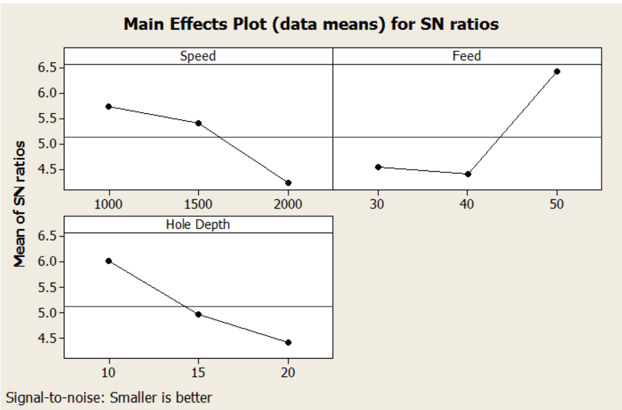

Figure 3. Main Effects Plot For S/N Ratios

Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

D. Analysis of variance (ANOVA)

Analysis of data variance with surface roughness with the objective of analysing the influence of spindle speed (s), feed rate (f) and Depth of drill hole (d) on the total variance of the results.

Table 6. Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Effect %
Speed	2	3.7771	3.7771	1.8886	12.29	0.075	23.99
Feed rate	2	7.6806	7.6806	3.8403	24.98	0.038	48.77
Hole depth	2	3.9819	3.9819	1.991	12.95	0.072	25.29
Error	2	0.3075	0.3075	0.1537			1.95
Total	8	15.7471					100

From the above ANOVA table it can be observed that the feed rate has great influence on surface roughness followed by spindle speed.

E. Effect of Process Parameters on Material Removal Rate

The effects of cutting parameters according to the experiments conducted can be summarized as follows: As seen from model equation and Figure no. 4, the feed rate has the greatest effect on material removal rate. It can be observed that a decrease in spindle speed decreases material removal rate from its lower level to middle level and then slightly increases from middle level to higher level. But the better material removal rate is noticed at higher level of feed rate irrespective of spindle speed and depth of hole.

From the figure 4, it can be observed that at higher level of feed value the maximum value of material removal rate occurs at a feed rate of 50 mm/min. At higher level of speed, the minimum value of material removal rate occurs at medium and/or lower levels of feed.

Table 7. Response for Signal to Noise Ratios Larger is better

Level	Speed	Feed	Hole Depth
1	15.68	13.97	16.43
2	16.41	16.68	16.32
3	16.95	18.4	16.29
Delta	1.26	4.43	0.15
Rank	2	1	3

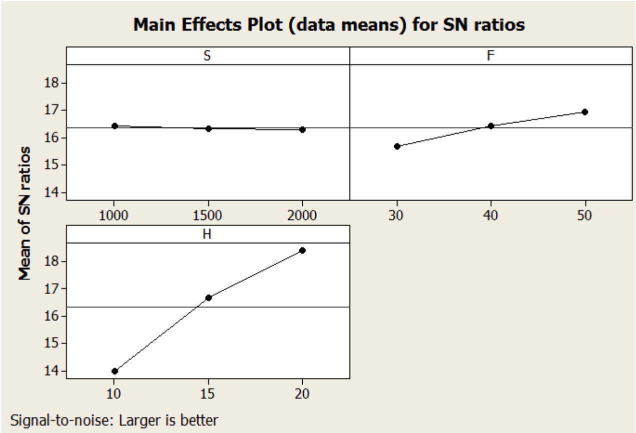

Figure 4. MAIN EFFECTS PLOT FOR S/N RATIOS

Signal-to-Noise ratio of common interest for optimization for material removal rate is larger is better.

F. Analysis of variance (ANOVA)

Analysis of data variance with material removal rate with the objective of analysing the influence of spindle speed (s), feed rate (f) and Depth of drill hole (d) on the total variance of the results.

Table 8. Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Effect %
Speed	2	2.4164	2.4164	1.208	145.48	0.007	7.47
Feed rate	2	29.8814	29.8814	14.94	1799.06	0.001	92.37
Hole depth	2	0.036	0.036	0.018	2.17	0.316	0.11
Error	2	0.0166	0.0166	0.008			0.05
Total	8	32.3504					100

From the above ANOVA table it can be observed that the feed rate has great influence on surface roughness followed by spindle speed.

IV. CONCLUSION

The feed rate is observed to be most dominant factor followed by spindle speed on surface roughness within the ranges considered. Analysis shows that large contribution is due to feed rate whereas small contribution is due to hole depth and spindle speed. The higher level of feed, medium level of spindle speed and low level of hole depth are identified as optimum levels for achieving the better surface finish. In an experimental investigation is carried out to predict the surface roughness AISI 316L steel in drilling operation. The output responses considered for evaluating the results which are influenced by input parameters such as spindle speed, depth of drill hole and feed rate is obtained from the experiments and this is optimized using linear regression analysis method results were predicted. In this, an application and adaptation of the Taguchi optimization and quality-control method is established for the optimization of the surface roughness in a drilling process. An austenitic stainless steel can produces better surface finish during drilling process in drilling process parameters which will eliminate the reaming and honing operation which will reduce cycle time of product manufacture, in turn saving time and labour cost of an organization.

Material removal rate is also influenced by feed rate and spindle speed. To get maximum MRR feed rate must be maximum and minimum spindle speed. The MRR obtained by experimentation is higher for feed rate 50 mm/min and speed as 1000 rpm.

Thus taguchi approach is successively applied to get the optimum results for drilling operation on Alloy 316L to get minimum surface roughness and material removal rate with feed rate as the most influencing factor followed by spindle speed.

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