OPERATIONAL MODELING FOR OPTIMIZING BURR HEIGHT IN MILD STEEL DRILLING USING TAGUCHI TECHNIQUE

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ABSTRACT

This study presents a Taguchi technique as one of the method for minimizing the burr height and design optimization for quality while drilling Mild steel. The methodology is useful for modeling and analyzing various engineering problems. The aim of this study is to investigate the influence of drilling parameters, such as cutting speed and feed rate, and point angle on burr height formed when drilling Mild steel. An orthogonal array, signal-to-noise ratio, and analysis of variance (ANOVA) were employed to investigate the optimal drilling parameters under study. From the analysis of means and ANOVA, using MINITAB 16 @ software, the optimal combination levels and the significant drilling parameters on burr height were obtained. All tests were run without coolant at various combinations of chosen drilling parameters. A design of experiments, based on L27 Taguchi design method, was also performed to study significant effect such as the interaction among drilling parameters. The optimization results showed that the combination of low cutting speed, low feed rate, and medium point angle is necessary to minimize burr height.

Keywords: *Taguchi method of DOE, ANOVA, Drilling process, Burr formation.*

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1. INTRODUCTION

Drilling is one of the most commonly used machining processes in the shaping of Mild steel. It has considerable economical importance because it is usually among the finishing steps in the fabrication of industrial mechanical parts. The drilling process produces burrs on exit surface of a work piece. (Dornfeld 2004) explained the exit burr is the material extending off the exit surface of the work piece. Their effect on products is important because they may cause some critical problems such as the deterioration of surface quality, thus reducing the product durability and precision. (Kim and Dornfeldd 2002, Ko SL et al. 2003 & Gillespie LK 1994) explained burr formation affects work piece accuracy and quality in several ways: dimensional distortion on part edge, challenges to assembly and handling caused by burrs in sensitive locations on the work piece, and damage done to the work subsurface from the deformation associated with burr formation.

The term steel is used for many different alloys of iron. These alloys vary both in the Way they are made and in the proportions of the materials added to the iron. All steels, however, contain small amounts of carbon and manganese. In other words, it can be said that steel is a crystalline alloy of iron, carbon and several other elements, which hardens above its critical temperature. Like stated above, there do exist several types of steels, which are (among others) plain carbon steel, Mild steel, stainless steel, alloyed steel and tool steel.

The Investigation presents the use of Taguchi method for minimizing the burr height in drilling Mild steel. Mild steel is extensively used as a main engineering material in various industries such as aircraft, aerospace, and automotive industries where weight is probably the most important factor. (ASM 1999) handbook provided that these materials are considered as easy to machining and possess superior machinability.

(Susana Ferreiro et al. 2010) stressed drilling process is one of the most important operations in aeronautic industry. It is performed on the wings of the aero planes and its main problem lies with the burr generation. At present moment, there is a visual inspection and manual burr elimination task subsequent to the drilling and previous to the riveting to ensure the quality of the product. These operations increase the cost and the resources required during the process. They showed the use of data mining techniques to obtain a reliable model to detect the generation of burr during high speed drilling in dry conditions on aluminum Al 7075-T6. (Ghani et al. 2003) outlined the Taguchi optimization methodology, which is applied to optimize cutting parameters in end milling when machining hardened steel AISI H13 with TiN coated P10 carbide insert tool under semi-finishing and finishing conditions of high speed cutting. The milling parameters evaluated is cutting speed, feed rate and depth of cut. (Stein and Dornfeld 1997) presented a study on the burr height, thickness, and geometry observed in the drilling of 0.91-mm diameter through holes in stainless steel 304L. They presented a proposal for using the drilling burr data as part of a process planning methodology for burr control. To minimize the burr formed during drilling, (Ko and Lee 2001) investigated the effect of drill geometry on burr formation. They showed that a larger point angle of drill reduced the burr size. (Sakurai, et al. 2000) have also tried to change the cutting conditions and determined high feed rate drilling of aluminum alloy.

The researchers examined cutting forces, drill wear, heat generated, chip shape, hole finish, etc. (Gillespie and Blotter 1976) studied experimentally the effects of drill geometry, process conditions, and material properties. They have classified the machining burrs into four types: Poisson burr, rollover burr, tear burr, and cut-off burr. (Aurich JC et al. 2009) enlighten valuable review about burr in machining operation provided important information.

Some of the previous works that used the Taguchi method and response surface methodology as tools for the design of experiment in various areas including machining operations are listed in (Zhang JZ, et al. 2007 , Tseng et al. 2003 , Tsao 2008 and Gaitonde VN 2007) . The Taguchi method was used by (Yang and Chen 2001) to find the optimum surface roughness in end milling operations. They introduced a systematic approach to determine the optimal cutting parameters for minimum surface roughness. An application of Taguchi method, optimizing the turning operations with multiple performance characteristics by (C.Y. Nian, et al. 1999). They investigate the influence of cutting speed, feed rate, and depth of cut on the measured surface roughness. The study shows that the Taguchi method is suitable to solve the stated within minimum number of trials as compared with a full factorial design.

The main objective of this study was to demonstrate a systematic procedure of using Taguchi design method in process control of drilling process and to find a combination of drilling parameters to achieve low burr height. Experiments were designed using Taguchi method so that effect of all the parameters could be studied with minimum possible number of experiments. Using Taguchi method, Appropriate Orthogonal Array has been chosen and experiments have been performed as per the set of experiments designed in the orthogonal array. Signal to Noise ratios are also calculated to analyze the effect of parameters more accurately. Results of the experimentation were analyzed analytically as well as graphically using ANOVA.

2. TAGUCHI METHOD

(Rosa JL, et al. 2009) explained the traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only. Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N).

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

(I) SMALLER-THE-BETTER:

$$n = -10 \text{ Log}\left(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{y2}\right)$$

(II) LARGER-THE-BETTER:

$n = -10 \text{ Log}_{10}$ [mean of sum squares of reciprocal of measured data]

(III) NOMINAL-THE-BEST:

$$n = 10 \text{ Log}_{10} \frac{\text{Square of means}}{\text{variance}}$$

Lower is better for minimum burr height so,

Lower is better $= \frac{S}{N} = -10 \text{ Log}\left(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{y2}\right)$

Where n is no of observation, y is observed data.

Regardless of category of the performance characteristics, the lower S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the lowest S/N value. The statistical analysis of the data was performed by analysis of variance (ANOVA) to study the contribution of the factor and interactions and to explore the effects of each process on the observed value.

3. DESIGN OF EXPERIMENT

In this study, three machining parameters were selected as control factors, and each parameter was designed to have three levels, denoted 1, 2, and 3 (Table 1). The experimental design was according to an L27 (3^13) array based on Taguchi method, while using the Taguchi orthogonal array would markedly reduce the number of experiments.

A set of experiments designed using the Taguchi method was conducted to investigate the relation between the process parameters and delamination factor. DESIGN EXPERT @ 16 minitab software was used for regression and graphical analysis of the obtained data.

Table 1 Drilling parameters and Levels

Symbol	Drilling Parameters	Level 1 Level 3	Level 2
A	Cutting speed, v	7	18
B	(m/min)	30	
C	Feed rate, f (rev/min)	0.035	0.070
	Point angle, θ (°)	0.140	
		90	118
		140	

4. EXPERIMENTAL DETAILS

Mild Steel plates of 150×100×15 mm were used for the drilling experiments in the present study. The chemical composition and mechanical and physical properties of Mild Steel can be seen in Tables 2 and 3, respectively. The drilling tests were carried out to determine the bur height and surface roughness under various drilling parameters. HSS drills (10-mm diameter) were used for

experimental investigations. The burr height was measured using a height master and can measure a Value up to 100mm.

5. RESULTS AND DISCUSSION

5.1 Experiment results and Taguchi analysis

In machining operation, minimizing the burr height (H) is an important criterion. The burr

Table 2 Chemical Composition of Mild Steel

Elements	Maximum weight %
C	0.45
S	0.60
Mn	1.00
P	0.40
Si	0.35

Table 3 Mechanical and Physical Properties of Mild Steel

Parameters	Value
Density 10^3 kg m^{-3}	7.85
Thermal conductivity Jm^{-1}K^{-}	48
^{1}S^{-1}	11.3
Thermal expansion 10^{-6} K^{-}	210
young's modulus GNm^{-2}	600
Tensile strength MNm^{-2}	

formation in drilling primarily depends upon the tool geometry, cutting parameters, and workpiece materials. When the material has moderate ductility, the material tends to elongate to some extent during burr formation, resulting in a large burr height and burr volume. However, if the material is quite brittle, catastrophic fracture occurs as the feed rate and cutting speeds increase, resulting in regular burrs having several large chunks, lobes, or petals as explained by (Kim and Dornfeldd 2002).

A series of drilling tests was conducted to assess the influence of drilling parameters on burr height in drilling Mild steel. Experimental results of the burr height for drilling Mild steel. With various drilling parameters are shown in Table 4. Table 4 also gives S/N ratio for burr height.

Table 4 Experimental Result and Corresponding S/N Ratio

S.No.	Levels of factor			Experimental Result	S/N Ratio
	v	f	θ	H (mm)	H
1	7	0.035	90	0.13	-17.72113
2	7	0.035	118	0.15	-16.47817
3	7	0.035	140	0.4	-7.9588
4	7	0.14	90	0.09	-20.91515
5	7	0.14	118	0.29	-10.75204
6	7	0.14	140	0.19	-14.42493
7	7	0.07	90	0.2	-13.9794
8	7	0.07	118	0.24	-12.39578
9	7	0.07	140	0.22	-13.15155
10	18	0.035	90	0.1	-20
11	18	0.035	118	0.2	-13.9794

12	18	0.035	140	0.46	-6.744843
13	18	0.14	90	0.16	-15.9176
14	18	0.14	118	0.23	-12.76544
15	18	0.14	140	0.25	-12.0412
16	18	0.07	90	0.24	-12.39578
17	18	0.07	118	0.19	-14.42493
18	18	0.07	140	0.32	-9.897
19	30	0.035	90	0.29	-10.75204
20	30	0.035	118	0.09	-20.91515
21	30	0.035	140	0.64	-3.876401
22	30	0.14	90	0.34	-9.370422
23	30	0.14	118	0.11	-19.17215
24	30	0.14	140	0.62	-4.152166
25	30	0.07	90	0.37	-8.635966
26	30	0.07	118	0.15	-16.47817
27	30	0.07	140	0.34	-9.370422

Table 5 ANOVA Table for Burr Height

Source	SS	DOF	Variance	F test	F critical	SS´	C%	
Cutting speed(A)	0.065896	2	0.032948	7.165529	4.46	0.058746	10.85279	S
Feed rate(B)	0.002541	2	0.001271	0.276308	4.46			NS
Point angle (C)	0.206941	2	0.103471	22.50276	4.46	0.199791	36.9097	S
A×B	0.010726	4	0.002682	0.583172	3.84			NS
B×C	0.087015	4	0.021754	4.731004	3.84	0.072714	13.43339	S
C×A	0.131393	4	0.032848	7.143836	3.84	0.117092	21.63187	S
error	0.036785	8	0.004598					
Total	0.541296	26	0.020819					
e-pooled	0.050052	14	0.003575					

The S/N ratios for each experiment of L27 (3^13) was calculated. The objective of using the S/N ratio as a performance measurement is to develop products and process insensitive to noise factor. Table 5 shows average effect response table. Thus, by utilizing experiment results and computed values of the S/N ratios (Table 5), average effect response value and average S/N response ratios were calculated for burr height. The S/N ratio response graph for burr height is shown in Fig.1.

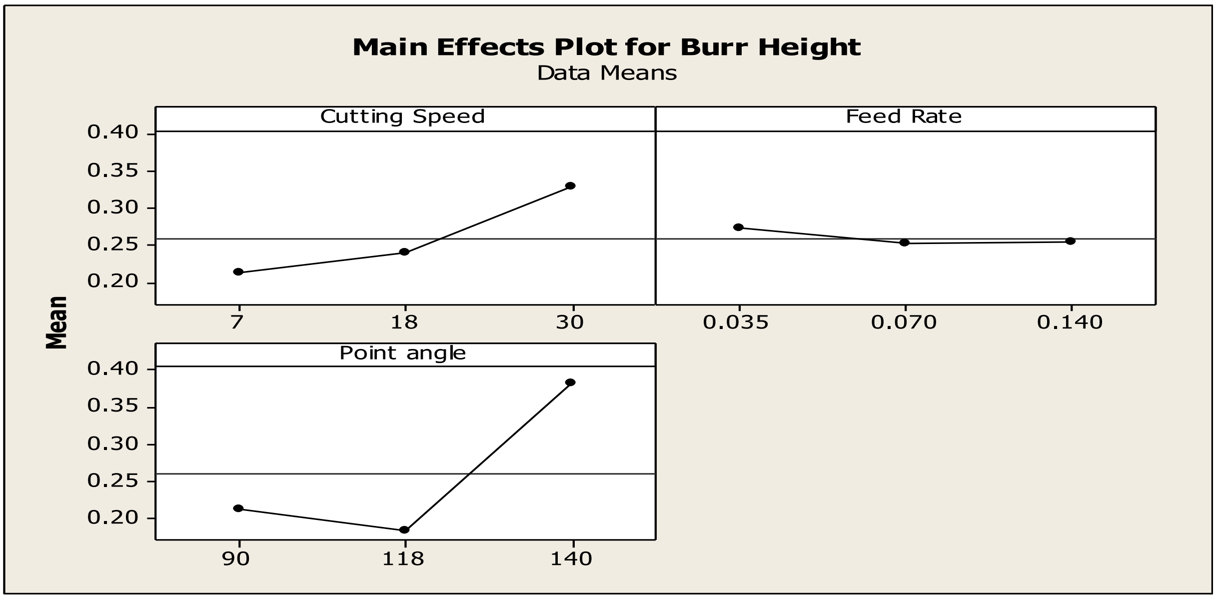

Fig.1. Effect of drilling parameters on Burr Height

Table 6 Mean Values of Process Parameters for Burr Height

Process Parameters	Levels	Mean Burr height (mm)	S/N Ratio
Cutting speed (A)	1	0.212222	-13.4642
	2	0.238889	-12.4361
	3	0.327778	-9.6884
Point angle (A)	1	0.213333	-13.4188
	2	0.162222	-15.7978
	3	0.382222	-8.35369

Table 7 Optimum Levels of Process Parameters

Process Parameters	Parameter Designation	Optimum Level
cutting speed (V)	A_1	7
Point angle (degree)	B_2	118

The effect of parameters i.e. cutting speed, feed rate and point angle and some of their interactions were evaluated using ANOVA analysis with the help of MINITAB 16 @ software. The purpose of the ANOVA was to identify the important parameters in prediction of Burr Height &. Some results consolidated from ANOVA and plots are given below: Point angle is found to be the most significant factor (F-value 22.50276) & its contribution to burr height is 36.9097 % followed by (F-value 22.50276) the factor that significantly affected the burr height which had contribution of 10.85279 % respectively. The interaction between feed rate and point angle (F-value 4.731004) is found to be significant which contributes 13.43339% and the interaction between point angle and cutting speed (F-value 7.143836) is found to be significant which contributes 21.63187 %.For S/N ratio point angle (F value 17.6812), and interaction between point angle & cutting speed (F value 8.1358) were found to be significant to Burr height for reducing the variation. The best results for Burr height (lower is better) would be achieved when mild steel work piece is machined at cutting speed of 7 m/min, point angle of 118^0, feed rate of 0.14 mm/rev. With 99% confidence interval, mean value & optimum value of Burr height was found to be 0.256111 & 0.118333 mm respectively.

6. CONCLUSIONS

The present study was carried out to study the effect of input parameters on the burr height. The following conclusions have been drawn from this work, The Burr height is mainly affected by cutting speed and point angle. With the increase in cutting speed the burr height is increases & as the feed rate increases the burr height is decreases. But it is also observed that with the point angle, Burr height tends to decreases with increase in point angle up to some extent. From ANOVA analysis, parameters making significant effect on burr height point angle, and interaction between point angle & cutting speed were found to be significant to Burr height for reducing the variation. The parameters considered in the experiments are optimized to attain minimum burr height using response graph, fit summary test and analysis of variance (ANOVA) technique. The best setting of input process parameters for defect free drilling (minimum burr height) within the selected range is as follows:

- Low cutting speed i.e. 7m/min.
- High feed rate i.e. 0.14mm/rev.
- Point angle should be 118^0.

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