EFFECT OF CUTTING PARAMETERS ON SURFACE ROUGHNESS IN DRY DRILLING OF AISI D2 TOOL STEEL BY USING TAGUCHI METHOD

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ABSTRACT: Hard drilling of AISI D2 reportedly produce accelerated wear to the cutting tool that detrimental to the surface finish. This paper presents the effect of drilling tool and drilling parameters by using Taguchi method to produce minimum surface roughness under dry conditions. The experiments were conducted using high speed steel (HSS) based drilling tools, coated with various coating layer (uncoated, TiN and TiCN) on material AISI D2 tool steel. Two cutting parameters, spindle speed and feed rate, each at three levels were considered. An L9 array, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) were employed to analyze the significant and percentage of each parameters for minimum surface roughness. The results revealed that the drilling tools gave main affects the surface roughness based on the highest percentage distribution (95%), followed by the spindle speed (3%) and feed rate (0.4%). Further, the results of ANOVA indicated that the combination of optimum parameter recorded as drilling tools HSS-TiCN with spindle speed of 680 rpm and feed rate of 206.25 mm/min.

KEYWORDS: *Drilling; Taguchi Method; AISI D2; ANOVA*

1.0 INTRODUCTION

Drilling is a process to produce a cylindrical hole on a workpiece with using drilling tools. This process considered traditional material removal process as it applied widely in major industrial productions.

During drilling process, the drill rotated and sheared the material to produce the chips. The chips evacuated according to the drill shear angles and removed from the machining area. Accumulation of chip removal and thrust movement of drill tool produced the holes according to the diameter of the drilling tool [1].

Drilling process is strongly influenced by the drilling tools, type of workpiece and drilling parameters. There are many drilling tools available in industry, varied form High Speed Steels (HSS), carbide and polycrystalline diamond (PCD), depended on the applications. The used of suitable drilling tools affected the performance of drilling process in terms of tool life, surface roughness and diameter accuracy. On the other hand, the used of suitable drilling tool must be accompanied with the right drilling parameters [2]. Among important parameters, cutting speed and feed rate are dominant to control the shearing action during materials engagement as well as to evacuate the chips consistently [3-4]. The proper control of cutting parameters also important to avoid tool breakage tremendously or to avoid the workpiece material deformed due to excessive force from the drilling thrust.

Since the drilling process is important in producing hole inside components, this process considered significant in mould and die industry. In die manufacturing, the drilling process was employed to facilitate the assembly process between die components or to produce the holes for cooling channel inside the die [5]. Among materials that getting attention in die manufacturing is AISI D2. In production of AISI D2, surface roughness is one of the major criteria to represent the accuracy on the machined parts. Surface roughness is controlled by several factors such as such as the properties of cutting tools itself (geometry, materials etc) and cutting conditions (parameters, environments etc).

A small change in any of the above factors can affect the final surface property [6]. There are many previous works focused to study the process parameters on the surface roughness in drilling process [1-6]. However, the study focused on the effect of parameters in drilling AISI D2 tool steel is very limited. This is due to difficulties to machine this material where most of the researchers focused to study the machinability of this material based on the milling or turning process, as an alternatives to grinding [7-10]. This paper presents the preliminary study on the effect of drilling tools, spindle speeds and feed rates during drilling AISI D2 steel. Taguchi method was used to determine the significant factors and optimum conditions that produce minimum surface roughness in drilling hole surface of AISI D2 steel.

2.0 EXPERIMENTAL PROCESSES

2.1 Experiment Setup

The experiments were carried out on 3 axis CNC milling machine in dry condition as shown in Figure 1. AISI D2 tool steel was selected as workpiece which was prepared at 100 mm width × 100 mm length ×10mm thickness size. The programming for drilling process has been done using Catia V5 software. Figure 2 shows the specimen of AISI D2 steel after drilling process. Details experimental procedure can be referred to Osman [11] and Ammar [12].

Figure 1: DMG 365 V Ecoline CNC machine

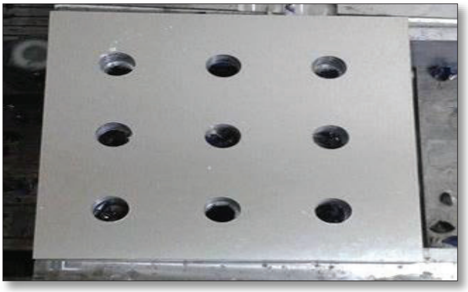


Figure 2: AISI D2 after drilling process

2.2 Design of Experiment

L9 orthogonal array was used as the experimental setup for the machining parameters. The experimental array has three parameters and three levels as shown in Table 1. The parameters selected according to the recommended range from the handbook.

Table 1: The parameter at three levels and three factors

Factor		Unit	Level		
			1	2	3
A	Feed rate	mm/min	136	206.25	291
B	Spindle speed	RPM	680	825	970
C	Drilling tools	ø 10 mm	HSS+ TiN	HSS+ TiCN	HSS uncoated

2.3 Data Analysis

Experimental design was developed based on Taguchi Method. Minitab software has been utilized to analyze the significant parameters that controls the surface roughness. Analysis of variance (ANOVA) was employed to establish the optimum conditions. Table 2 shows the S/N ratios and mean using the smaller is better characteristics.

2.4 Confirmation Test

The purpose of confirmation test is to validate the prediction parameters based on the optimum level, which is recorded at A2B1C2. Based on the respected combinations, simple drilling tests was executed with two drilling holes. The results show that the percentage error for this comparison is around 3%, which is accepted for validation data.

Table 2: Experimental design and the result of experiments

Exp No.	Designation	SNRA1	MEAN1
1	A1B1C1	-3.42282	1.483
2	A1B2C2	-5.2062	1.821
3	A1B3C3	-10.779	3.459
4	A2B1C2	-2.53561	1.339
5	A2B2C3	-10.864	3.493
6	A2B3C1	-4.56801	1.692
7	A3B1C3	-10.769	3.455
8	A3B2C1	-4.91025	1.76
9	A3B3C2	-3.46373	1.49

3.0 RESULTS AND DISCUSSION

Table 3 shows the result of the surface roughness and signal to noise ratio of nine holes that has been drilled according to selected parameters. By referring to the Table 3, the graph plotted shows that the minimum surface roughness recorded at 1.339 μm where the feed rate, spindle speed and drilling tools were Level 2 (206.25 mm/min), Level 1 (680 rpm) and level 2

Table 3: The result of surface roughness

Exp. No.	Feed Rate (mm/min)	Spindle Speed (RPM)	Drilling Tools	Mean Ra	SNRA1
1	136	680	TiN	1.483	-3.4228
2	136	825	TiCN	1.821	-5.2062
3	136	970	Uncoated	3.459	-10.779
4	206.25	680	TiCN	1.339	-2.5356
5	206.25	825	Uncoated	3.493	-10.864
6	206.25	970	TiN	1.692	-4.5680
7	291	680	Uncoated	3.455	-10.769
8	291	825	TiN	1.760	-4.9102
9	291	970	TiCN	1.490	-3.4637

(HSS TiCN coated). For SNRA1, the highest value for feed rate is contributed by level 2 (206.26 mm/min). Spindle speed for level 1 (680 RPM) also shows the highest value plotted. The graph plotted for drilling tools shows the highest value is level 2 (HSS TiCN coated). In other words, the optimum parameter of this experiment is observed by the lowest value is by combination of A2B1C2 (206.25 mm/min, 680 RPM, HSS TiCN coated).

Table 4: The Response Table for Means

Level	Feed Rate (mm/min)	Spindle Speed (RPM)	Drilling Tools
1	2.254	2.092	1.645
2	2.175	2.358	1.550
3	2.235	2.214	3.469
Delta	0.08	0.266	1.919
Rank	3	2	1

Table 4 and 5 show the response table for means and signal to noise ratio. Based on the Table 4 drilling tools shows the number one ranks which mean drilling tools is the critical parameter that contributed the highest effect of surface roughness. This is followed by the spindle speed and feed rate. On the other hand, Table 5 shows the response table for signal to noise ratio. The results consistent with the analysis form Table 5 where the highest rank is drilling tools which have the highest delta (7.069), followed by spindle speed and feed rate.

Table 5: The Response Table for Signal to Noise Ratios (smaller is better)

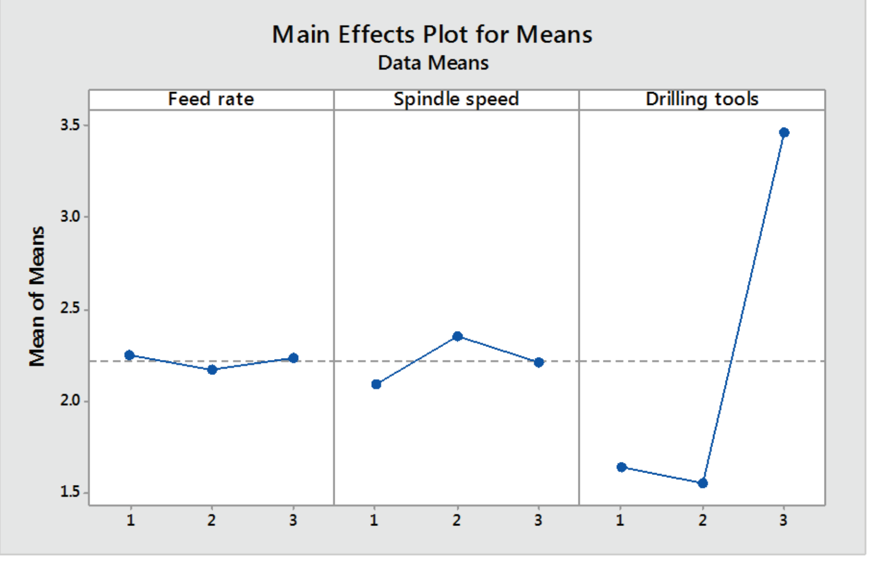
Level	Feed Rate (mm/min)	Spindle Speed (RPM)	Drilling Tools
1	-6.469	-5.576	-4.300
2	-5.989	-6.993	-3.735
3	-6.381	-6.270	-10.804
Delta	0.480	1.418	7.069
Rank	3	2	1

Table 6: ANOVA Results of Analysis

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of Contribution
A	2	0.39	0.39	0.19	0.2	0.79	0.4
B	2	3.01	3.01	1.50	2.0	0.33	3
C	2	92.5	92.5	46.2	62.	0.02	95
Residual error	2	1.48	1.48	0.74			
Total	8						

Table 6 shows the Analysis of variance (ANOVA) of the recorded data, which specifies the percentage contribution significance of each factors. According to Table 6, drilling tools recorded the highest percentage contribution which is 95%. This is followed by spindle speed, recorded at 3%. The lowest percentage of contribution is feed rate which is 0.4%. It should be noted that the contribution from the drilling tool is so much superior which indicate that dominant contribution to the whole drilling performance so much depended on the coating material itself.

Figure 3 shows the variation in surface roughness of the drill holes according to the parameters investigated. The lowest factor to contribute to the minimum surface finish was feed rate. Figure 3(a) shows the change in surface roughness when the feed rate changed. It shows a decrease in the surface roughness when the feed rate increases from 136 mm/min to 206.5 mm/min. However, when feed rate is further increased from 206.5 mm/min to 291 mm/min, the surface roughness slightly increased.



(a) (b) (c)

Figure 3: Main Effects Plot for Means, (a) Feed Rate, (b) Spindle Speed and (c) Drilling Tools

In drilling, the performance of surface roughness closely related with the interaction between spindle speed and feed rate, similar to those in other material removal process [13]. When the drill tool engaged with the workpiece, the rotation of spindle speed generated higher temperature at the contact region, resulting thermal softening of workpiece material. Such conditions enable the thrust forces to decrease, enable the machine to feed the drill with less energy, could resulting better surface finish [2]. However, if the feed rate was too high, the thrust force from the drill tool could deform the workpiece resulting deteriorate surface finish. The second best factor according to the analysis from Table 6 is spindle speed. Effect of change in the cutting speed in Figure 3(b) indicates an increase in the surface roughness when the spindle speed is increased from 680 rpm to 825 rpm. However, when the surface roughness increased from 825 rpm to 970 rpm, to surface roughness decreased.

Cutting speed affected the drilling process when the edge of drilling tool have adequate energy to shear the metal. With further increase in the spindle speed, the temperature generated at the contact region could be higher resulting thermal softening of workpiece material. Such conditions enable the cutting tool to drill the workpiece efficiently, resulting better surface finish especially when using abrasive coated tool such as HSSD-TiCN [2]. However, when using uncoated drill tools, the thermal softening effects could also affected the edge of tools resulting damaged or deformed tool edge. This situation could contribute to the high surface roughness to the drilled surface. However, the significant impact for spindle speed was only 3%. According to the analysis form Table 6, the most dominant factor contributed to the lowest surface roughness is the type of material for drilling tools. Figure 3(c) shows the effect of drilling tools on surface roughness and shows that the coated drilling tool of TiCN gives minimum surface finish as compared to the uncoated and TiN coated tools. The HSS-TICN coated drill tool has superior abrasive performance which helps in shearing finer surface finish as compared to the other counterparts [14]. This proved that the effect of multi-abrasive coating contributed to the significant performance in drilling process. During drilling process, the cutting tool can retain hardness and stability at high impact force and high temperature, hence producing strong drilling action to slide and produce the holes consistently [15]. It should be noted that the use of uncoated drilling tool gave very high surface roughness, contributed to the major change in the percentage distribution. If uncoated carbide tool was eliminated, the percentage distribution could be reduced, resulting better comparison to differentiate the significant effect of the parameters investigated.

4.0 CONCLUSION

This paper has presented the effect of drilling tools and parameters during dry drilling of AISI D2. Taguchi method used to determine the main effects significant factors and optimum machining condition to the performance of drilling hole in D2 steel. Based on the result, some conclusions can be drawn:

i. The drilling tools have mainly affects the surface roughness based on the highest percentage distribution, followed by the spindle speed and feed rate.
ii. The optimum parameter is observed by using HSS-TiCN drilling tools at 680 rpm spindle speed and 206.25 mm/min feed rate.
iii. Uncoated drilling tool gave worst performance, leave highest significant percentage change.
iv. Spindle speed and feed rate control the efficiently of drilling by affecting the temperature generation on workpiece which resulting thermal softening and reduction of thrust force.

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