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RESEARCH ARTICLE

Effect of Rake Angle on Dimensional Accuracy of Copper Micro-drilling

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Abstract

Drilling is a metal removal process and is important for the final fabrication stage prior to application. In this study, we have utilized Taguchi method to investigate the effects of micro-drilling parameters such as micro-drill diameter, spindle speed and feed rate on dimensional accuracy. We found out that with the increase in value of rake angle (120°), there is more variation in value of drilled hole diameter. At lower rake angle, 116°, there is less variation in the value of drilled hole diameter. Also the amount of hole oversize increased with increase in spindle speed and feed rate.

Keywords: Drilling, Taguchi method, micro-drill diameter, spindle speed, dimensional accuracy.

Introduction

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole of circular cross-section in solid materials. The drilling operation is evaluated and carried out based upon the performance characteristics such as variation in drilled hole diameter, surface roughness, material removal rate, tool wear, tool life and are also related with the cutting parameters such as cutting speed and feed rate (Chryssolouris and Guillot, 1990). Among traditional machining processes, drilling is one of the most important metal cutting operations, comprising 33% of all metal cutting operations (Chen and Tsao, 1999). Taguchi design is proved to be an efficient tool to produce high quality products at very low cost. The objective of Taguchi robust design is to determine the optimal parameter settings and making the process performance insensitive to various sources of variations. The approach can economically satisfy the needs of the problem solving and design optimization.

Taguchi technique allows the process optimization with minimum number of experiments without need for process model development (Paulo davim, 2003). Drilling is a metal removal process and is important for the final fabrication stage prior to application (Basavarajappa *et al.,* 2008). Also an experiment was done in the optimization of cutting parameters for surface roughness in dry drilling process using Taguchi method. It was evident from literature survey that there exists a need to study on the effects of various parameters on drilling of OHNS since lot of works are reported pertaining to drilling of composite materials, aluminum alloys and very rarely on drilling of tool steels (Mustafa *et al.,* 2009). Also Pradeep Kumar and packiaraj (2012) discussed the effects of drilling parameters on surface roughness, hole diameter and tool wear. The results were collected and analyzed using Minitab 13. The predicted values were compared with experimental data and were found to be in good agreement. In the aerospace industry, hole drilling is one of the most important and well-known machining processes. However, machining research on Inconel 718 alloy up to now has mostly involved turning and milling operations and as a result the literature concerning drilling operations is very limited (Rahman *et al.,* 1997). From the viewpoint of cost and productivity, modeling and optimization of drilling processes are extremely important for the manufacturing industry because largest amount of money spent on any one class of cutting tools is spent on drills (Jalali and Kolarik, 1991). The drill bit is a rotary cutting tool, often multipoint. The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work-piece, cutting off chips from what will become the hole being drilled. A drilling machine comes in many shapes and sizes, from small hand-held power drills to bench mounted and finally floor-mounted models. They can perform operations other than drilling, such as countersinking, counterboring, reaming and tapping large or small holes. Because the drilling machines can perform all of these operations, this will also cover the types of drill bits, took and shop formulas for setting up each operation. Against these backdrops, in this study, we have utilized Taguchi method to investigate the effects of micro-drilling parameters such as micro-drill diameter, spindle speed and feed rate on dimensional accuracy.

Materials and methods

Drilling machines: Drilling machines are generally or mainly used to originate through or blind straight cylindrical holes in solid rigid bodies and/or enlarge (co-axially) existing (premachined) holes.

Fig. 1. Vertical Machining Centre.

Table 1. Dimensional properties of the drilling tool.

Tool material	HSS
Tool diameter	2.3 to 2.6 mm
Flute	2 flute
Flute length	27 mm
Overall length	53 mm
Shank type	Cylindrical
Rake angle	116°,120°
Spindle speed (rpm)	1000, 1500, 2000
Feed rate (mm/rev)	0.01, 0.015, 0.02

Table 2. Mechanical properties of copper.

Name	Copper
Symbol	Cu
Number	23
Element category	Transition metal
Group	11
Period	4
Block	D
Electrons per shell	2,8,18,1

Table 3. Physical properties of copper.

Phase	Solid
Density	8.94 gcm^{-3}
Melting point	1084.62°C
Boiling point	2562°C
Miscellaneous	
Crystal structure	Face centred cubic
Young's modulus	110-128 Gpa
Shear modulus	48 Gpa
Bulk modulus	140 Gpa
Poisson ratio	0.34
Brinell hardness	874 Mpa

Experimental design: The drilling experiments were conducted without the use of lubrication. The machine used for experimentation was Vertimach V-400 vertical machining centre (VMC). Figure 1 shows the VMC machine. The software for programming was Delcam-6.0 on which the drawing and programming was done.

The dimensional and mechanical properties of the drilling tool are displayed in Table 1. HSS drilling tool is used in this project with starting diameter 2.3 mm to 2.6 mm.

Work material: Copper is used as work material in this experiment. The material selected is chosen based on their characteristic such as ductile soft and malleable. The block size of copper is 100 mm × 35 mm × 6 mm for length, width and thickness. Three blocks of same size are used. Table 2 and 3 provides detailed information on the mechanical and physical properties of copper material.

Table 4. Data collection for copper material at rake angle 120^0.

Tool diameter (mm)	Spindle speed, S (rpm)	Feed rate (mm/rev)	Hole diameter (mm)
2.6	1000	0.010	2.621
		0.015	2.632
		0.020	2.643
	1500	0.01	2.651
		0.015	2.663
		0.020	2.67
	2000	0.010	2.673
		0.015	2.682
		0.020	2.714
2.5	1000	0.010	2.515
		0.015	2.525
		0.020	2.535
	1500	0.010	2.551
		0.015	2.562
		0.020	2.578
	2000	0.01	2.611
		0.015	2.618
		0.020	2.625
2.4	1000	0.010	2.408
		0.015	2.417
		0.020	2.421
	1500	0.010	2.441
		0.015	2.456
		0.020	2.466
	2000	0.010	2.481
		0.015	2.498
		0.020	2.518
2.3	1000	0.01	2.315
		0.015	2.33
		0.020	2.342
	1500	0.010	2.356
		0.015	2.371
		0.020	2.381
	2000	0.010	2.385
		0.015	2.391
		0.020	2.398

Taguchi method: A set of experiments were designed using Taguchi method to investigate the relation between the process parameters. The design expert 10.5 software was used.

Table 5. Data collection for copper material at rake angle 116°.

Tool diameter (mm)	Spindle speed, S (rpm)	Feed rate (mm/rev)	Hole diameter (mm)
2.6	1000	0.010	2.61
		0.015	2.612
		0.020	2.622
	1500	0.01	2.632
		0.015	2.641
		0.020	2.646
	2000	0.010	2.652
		0.015	2.661
		0.020	2.667
2.5	1000	0.010	2.502
		0.015	2.512
		0.020	2.523
	1500	0.010	2.531
		0.015	2.542
		0.020	2.561
	2000	0.01	2.549
		0.015	2.565
		0.020	2.623
2.4	1000	0.010	2.402
		0.015	2.407
		0.020	2.414
	1500	0.010	2.421
		0.015	2.432
		0.020	2.445
	2000	0.010	2.45
		0.015	2.459
		0.020	2.467
2.3	1000	0.01	2.308
		0.015	2.312
		0.020	TB
	1500	0.010	2.332
		0.015	2.341
		0.020	2.353
	2000	0.010	2.361
		0.015	2.368
		0.020	2.375

There are two rake angles and three machining parameters such as drilling tool size, spindle speed and feed rate that had been put into consideration (Table 4 and 5, Figs. 2 and 3). These parameters have large influences on the investigation in previous research reports. The performances of drilled holes are measured in terms of surface roughness, MRR and dimensional accuracy.

Results and discussion

Figure 4 and 5 shows the variation in the diameter values for drilled holes. The accuracy of hole is important in micro-drilling operation. One area of growing interest is spindle/collet run out and it affect on hole accuracy and other is vibration. A frequent cause of drill vibration is loose or poorly designed tool holder that imparts wobble to the drill.

Fig. 2. Drilling with rake angle 120°.

Fig. 3. Drilling with rake angle 116°.

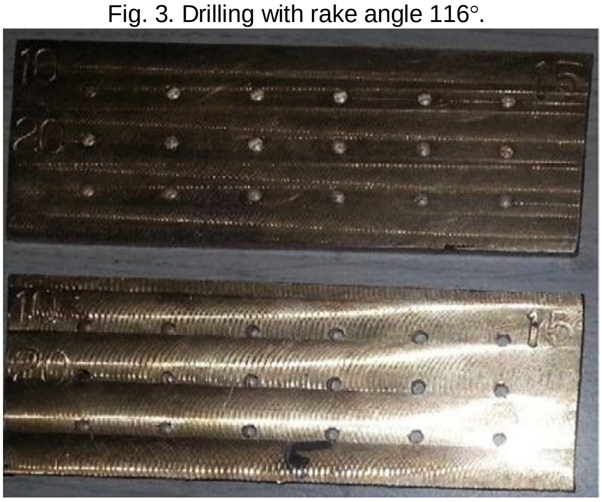


Fig. 4. Variation of drilled holes with rake angle 120°.

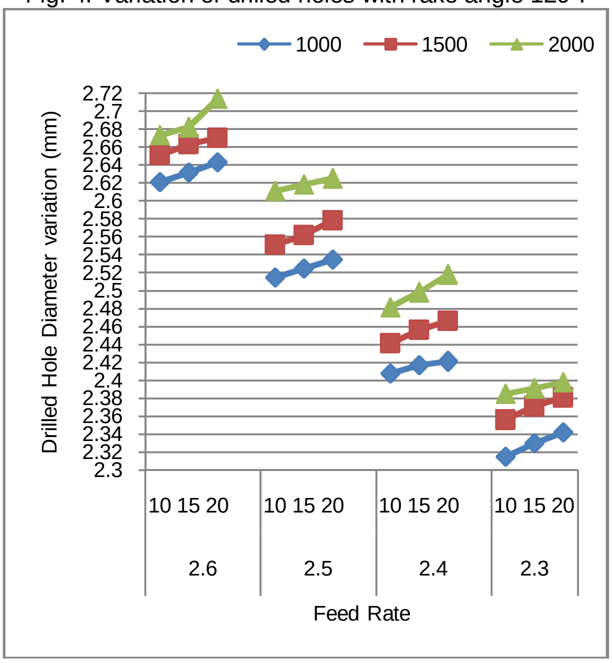
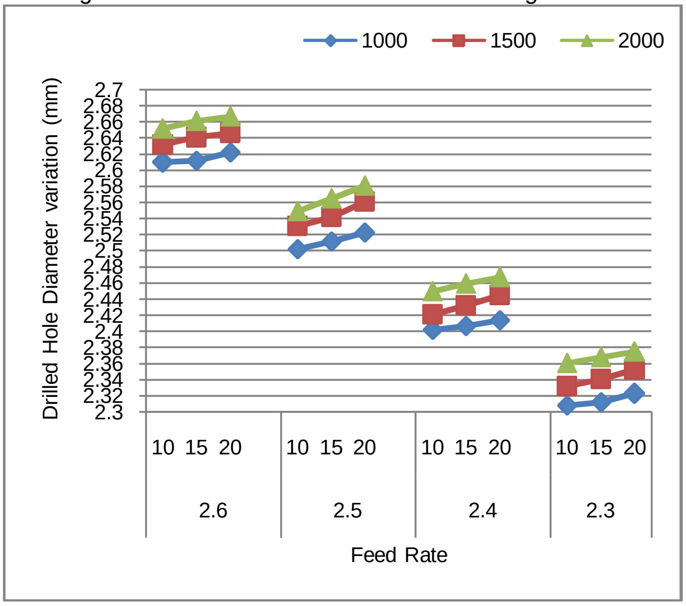


Fig. 5. Variation of drilled holes with rake angle 116^0.



Generally to reduce vibration, the drill should be fully tight and clamped with same drilling length and work-piece thickness because longer drill increases vibration. Other factor is work-piece clamping as it can produce side forces and inaccurate hole size or it can break a drill also. It was observed that spindle speed and feed rate have mostly affected the variation in drill size diameter. Also at larger rake angle 120°, there is more variation in diameter of the drilled holes especially at tool diameter 2.5 mm and tool diameter 2.4 mm. So at lower rake angle, there is less amount of variation in the tool diameter.

Conclusion

After performing all the experiments of micro-drilling operations at rake angles 116^0, 120^0 on Copper material, following conclusions are derived:

1. Feed and spindle speed have the most profound effect on micro-drilling performance.
2. The amount of hole oversize increased with increase feed rate and spindle speed.
3. There is more variation in hole diameter at higher rake angle 120^0.

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