Development of Drill Geometry for Burr Minimization in Drilling

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Abstract
The researchers carried out drilling tests using drills of various shapes to determine burr minimization. The ultimate objective of this study was to develop a compatible drill shape to minimize burr formation. For the experiment general carbide drills, round drills, chamfer drills and step drills are designed and manufactured. Burrs are generated under various cutting conditions using four different materials. A laser sensor was used to measure the burr dimensions. As a result of the experiments, step drill with specific step angle and step size is suggested for burr minimization.

Keywords:
Burr, Drilling, Burr Minimization

1 INTRODUCTION

A "burr" is a plastically deformed material, generated during cutting or punching. Burrs formed in drilling can be classified into entrance burrs and exit burrs.

The entrance burr is formed around the hole when the drill enters into the material. The exit burr is formed on the other side, when the drill pierces the material and pushes out the uncut material. Exit burrs strongly affect product quality and assembly process, sometimes necessitating an additional deburring process. This additional procedure results in the high cost of the edge finishing of precision parts [1,2].

Gillespie [3] explained the burr formation process using three stages, while Pande and Relekar [4] studied how burr height and thickness can be affected in burr formation when the cutting speed and the feed rate change. Takazawa K. [5] has explored several techniques that can be used for observing the effect of part material on burr formation during drilling. Stein [6] observed the effect of the feed rate, cutting speed, pecking and tool's material on burr height, thickness and shape using micro drill in stainless steel, and the influence of workpiece exit angle on burr formation in drilled intersecting holes.

Burr size depends on several cutting conditions such as cutting velocity and feed rate. Drill shape, point angle, helix angle, length of chisel edge etc. influence on cutting force, hole accuracy and burr formation as well [7,8].

In this paper, the researchers carried out an experiment to observe burr formation in several different materials using a modified drill with chamfer, round edge and step at the corner of the drill edge.

2 MECHANISM OF BURR MINIMIZATION BY MODIFIED DRILL

Sofronas [9] proposed a method to round out the drill cutting edge, increase helix angle and harden the exit surface. Though the burr formed by this is smaller, it is more difficult to remove because of surface hardening. Another approach involves modification of the drilling process by using ultrasonic or low frequency vibratory technique [10,11]. Lee.[12] has also tried to change the cutting condition, and control the thrust force by changing the feed rate during drilling. To minimize burr formation, the researchers designed a step drill to reduce uncut material and prolong cutting activity without bending deformation to the end of exit stage.

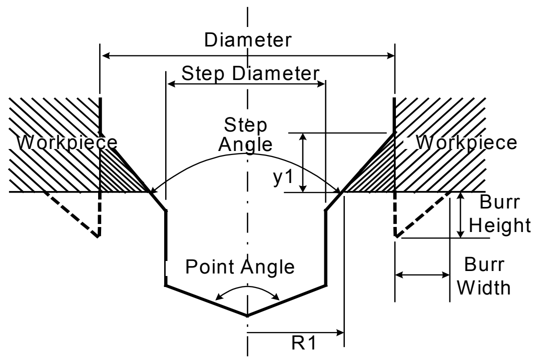


Figure 1 : Process of burr formation in step drilling.

Figure 1 shows the cutting process in step drilling. Unlike a conventional drill, after the front cutting edge drills completely, the second cutting process starts at the step cutting edge. During the second cutting process, cutting can be prolonged until plastic bending deformation occurs in the remaining part. The position at which bending deformation starts is determined by the rigidity of the remaining part, as shown in Figure 1. That's why, y1, R1 in Figure 1 display critical points where 'cutting' is discontinued and 'bending' starts and the 'remains' is turned into the burr. The shape of the remains determines the critical position. If the stiffness of the part bent by thrust force imposed in drill cutting edge is large enough, no bending occurs and cutting is continued. As a result, burr formation is delayed and a small burr is formed.

3 BURR FORMATION EXPERIMENT AND OBSERVATION BY MODIFIED DRILL

3.1 The geometry of the drill

To find out the effect generated by various geometrical factors, the researchers designed and manufactured five kinds of drills. The usual commercially available high speed steel(HSS) drill and carbide drill were used. In addition, the researchers also used a chamfer drill designed to have chamfer at the corner edge, which is specified as chamfer length, L, and chamfer angle, $\theta 2$, as shown in Figure 2. A round drill with radius R, at corner and a step drill with step angle, $\theta 2$, and step diameter, D2, were also used as specifi-

Geom. \ Drill	HSS Drill	Carbide Drill												
			Chamfer		Round		Step							
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14
θ_1 (Pt.Ang.)	**118°**	**140°**	140°	140°	140°	140°	140°	140°	140°	140°	140°	140°	140°	140°
θ_2 (Chamfer/ Step Ang.)	·	·	**60°**	**40°**	·	·	**130°**	**100°**	**75°**	**60°**	**40°**	**75°**	**60°**	**40°**
D_1(mm)	10	10	10	10	10	10	10	10	10	10	10	10	10	10
D_2(mm)	·	·	·	·	·	·	**8**	**8**	**8**	**8**	**8**	**9**	**9**	**9**
R(mm)	·	·	·	·	**1.5**	**2.5**	·	·	·	·	·	·	·	·
L(mm)	·	·	2	2	·	·	2	2	2	2	2	2	2	2

Table 1 : Specifications of drill geometry.

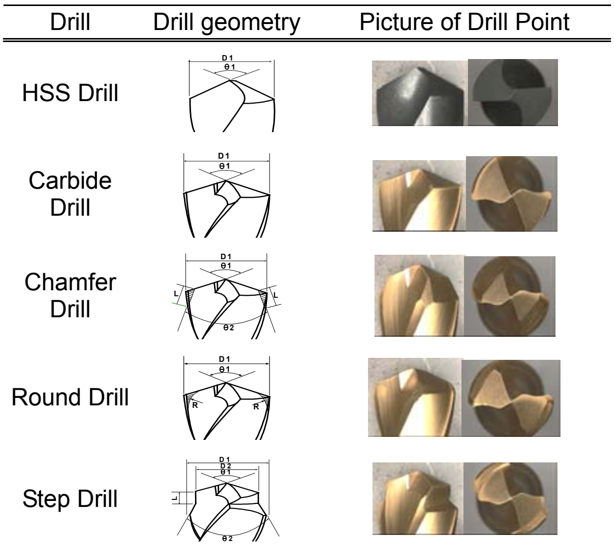


Figure 2 : Configuration of drills.

ed in Table 1.

3.2 Burr formation experiment in SM45C

The drilling is carried out in a CNC machining center using SM45C. Cutting speed is fixed as 35m/min and the feed rate which has an effect on burr formation is changed in five steps as 50,100,150,200 and 250 mm/min. Coolant is not used to observe the generation of cap when the burr is formed. A measurement system was likewise developed to measure burr geometry [13].

3.2.1 Observation of burr formation in chamfer drill

Chamfer drills with 60° and 40° chamfer angle at the corner of the cutting edge are designed for burr formation. In Figure 3(a), the burrs formed by the conventional HSS drill and the carbide drill were measured and compared with the burr produced by the chamfer drill. The burr height from conventional drills is larger than from chamfer drill. The chamfer drill with 60° chamfer angle produces a larger burr than a drill with 40° chamfer angle. Figure 4 shows the drilling process after cutting using the main cutting edge with 140° point angle. The burr is formed when bending deformation occurs as the chamfer edge starts cutting. Considering the same normal stress on the chamfer edge, it can be predicted intuitively that the stiffness of the remaining part shown as a hatched area in Figure 4 is larger in the drill with 40° chamfer angle than in the drill with 60° chamfer angle. The remaining part is cut if this part is stiff enough not to be bent into burrs. This is the key concept for burr minimization in drilling.

3.2.2 Observation of burr formation in round drill

In a round drill, the drills with corner radii R1.5 and R2.5 were used. From Figure 3(b) one can see that larger burrs are formed in drill with R2.5 corner radius, which is larger than R1.5. The uncut volume in R1.5 drill is much smaller than in R2.5 drill as the hatched area in Figure 4 shows. The stiffness of the remaining part in R1.5 drill is much larger than in R2.5 drill. More bending deformation in R2.5 drill produces larger burr. Therefore, it can be inferred that the larger the corner radius at the moment of drill exit, the larger the burr is.

3.2.3 Observation of burr formation in step drill

In step drill, the researchers used drills of varying step angle and step diameter. Five drills with different step angles, 130°, 100°, 75°, 60° and 40°, were manufactured with the same step diameter, 8mm. In Figure 3(c), the burr height in drills with 130° and 100° step angle is almost same as that in

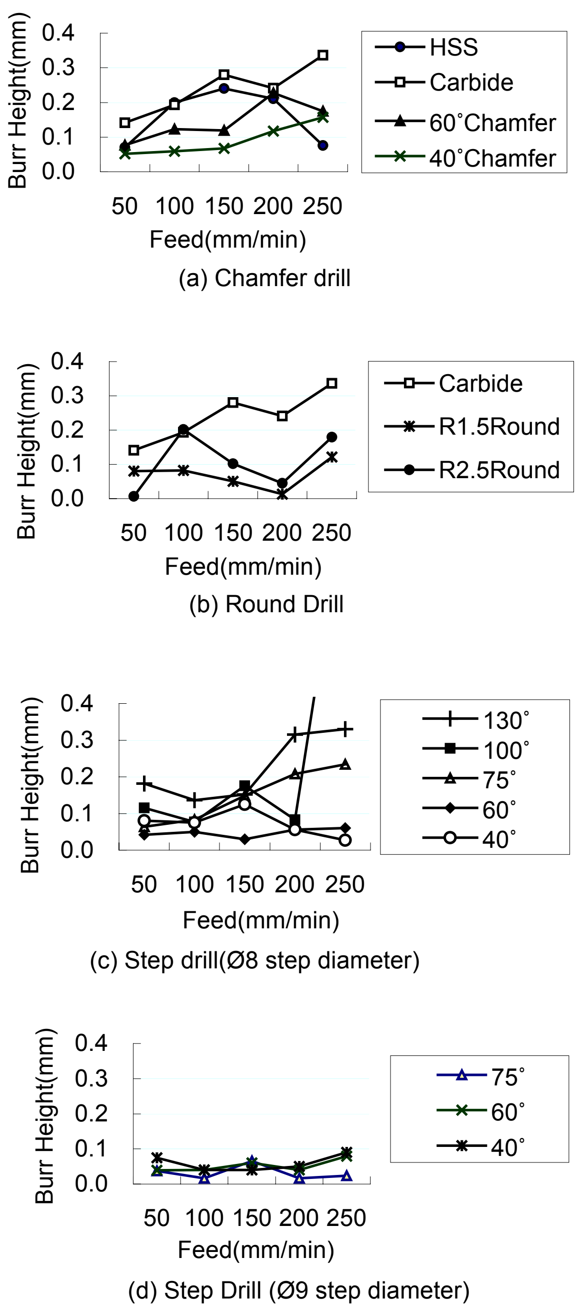


Figure 3 : Burr height using modified drill in SM45C.

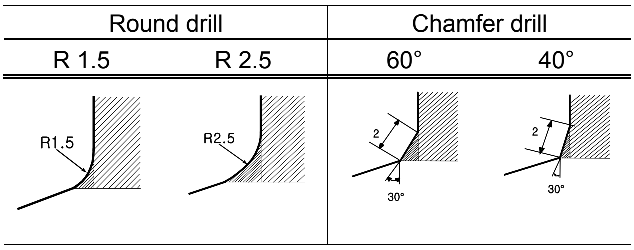


Figure 4 : Schematic illustration of drilling process when drill exits with chamfer drill and round drill

conventional drill as shown in Figure 3(a). When the step angle is reduced to 60° and 40°, burr height is reduced to less than 0.1mm. The mechanism of burr formation in step drill is explained in Figure 5. Just before step edge exits hole the remaining part leaves a very thin burr, with very little resistance to bending deformation. Thus, it can be easily predicted that the thin part will be bent into large burr. During this process, the step edge pushes the remaining part into burr. As illustrated in Figure 5, the cap produced in the first cutting by the front cutting edge with a 140° point angle and attached to the burr by bending deformation is clear evidence of this mechanism. The cap formed at the first cutting is pushed out along with the burr at the second cutting by the step drill with 100° and 130° step angle because stiffness is not enough to support thrust force in the remaining part. The burst type burr is largely formed depending on the difference between drill diameter and step diameter. Burr can be reduced when the step angle is less than 75° . In this case the remaining part has greater resistance or stiffness, resulting in a small burr formation. Figure 3(d) illustrates the effect of step diameter on burr formation. Reducing the step size from 1mm to 0.5mm drastically decreases the burr height to a more stable size compatible with the change of feed rate. For all step drills with 0.5 mm step size and step angle less than 75°, the burr height is less than 0.1mm. However too small step size will also induce a burnishing effect rather than cutting operation in step edges. Therefore it is necessary to determine optimal step size for minimization of burr formation. Measurement results by laser system are illustrated in Figure 6.

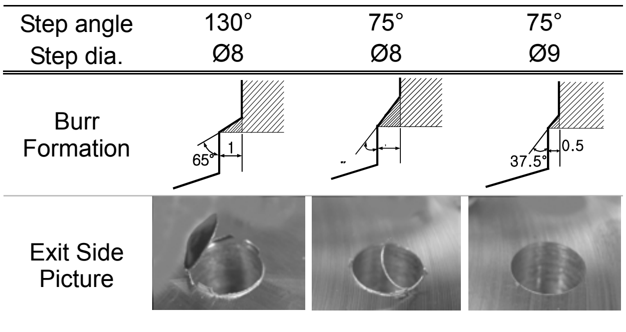


Figure 5 : Schematic illustration of drilling process when drill exits with step drill

3.3 Burr formation according to the change of work material

Drilling tests were carried out on several materials, whose properties are listed in Table 2, to observe the significance of these properties on burr formations. A2024-T4 shows brittleness comparing with other materials. All the drill samples listed in Table 1 were used with the fixed cutting condition as cutting speed, 35m/min and feed rate, 150mm/min. Drill numbers are specified in Table 1 according to the geometry. Figure 7 shows burr heights measured at exit surface obtained in drilling by all drills in 4 different workpieces.

With SM45C, the characteristics according to the change of drill geometry and material properties are well represented in Figure 3 and Figure 7. The burr formed in chamfer and round drill (#3,4,5,6 drill in Table 1) is smaller than that of a conventional drill but larger than that of a step drill with a small step angle (from #9 to #14). The step drill with 130° and 100° step angle produces a larger burr than any other drills. The influence of the step angle is shown clearly in drills #7 through #11. As it increases, a larger burr is formed. The drill with 1mm step size(#9, 10, 11) produces a larger burr than drill with 0.5mm step size(#12, 13, 14). Step drill #14 produces the smallest burr formations among samples.

With SS200, the behavior of burr formation is very similar to that of in SM45C. But burr size increases more noticeably than with SM45C because of the material's ductility, which can be explained by yield strength and elongation. The influence of the step angle is clearly illustrated in drills #7 - #11. Expectedly, the burrs in drills with larger step size are larger than with smaller step size. Drill #14 with 40° step and 0.5mm step size produces a minimum size burr.

With aluminum alloy A6061, which has less elongation and less yield strength than SS200, the burst type burrs are often formed. These burrs are impossible to be measured using the laser measurement system, which cannot be represented in Figure 7. The burst type burrs are formed in the chamfer drill and the step drill with 130° step angle. Changes in step angle and step size have a similar effect as with other material. Even though the difference of the burr height in #2 carbide drill #6 round drill and #14 step drill is not large, #14 step drill still produces the smallest burr.

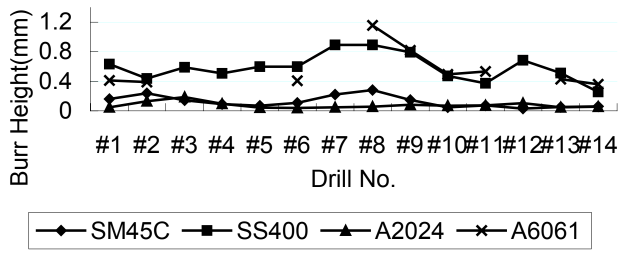


Figure 7 : Burr height using developed drill in each materi al.

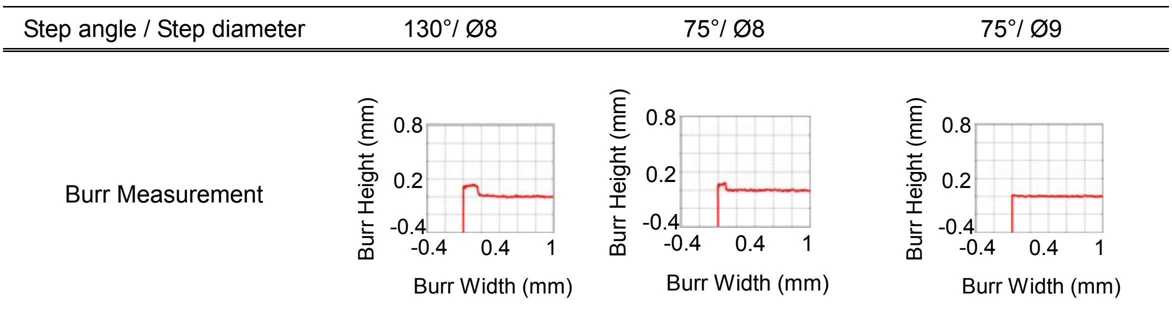


Figure 6 : Burr measurement results in step drills with varied step angle and step diameter.

Workpiece \ Property	Yield Strength (kg/㎟)	Tensile Strength (kg/㎟)	Elongation (%)	Fracture Strain
SM45C	40.1	68.1	23.4	0.62
SS400	31.5	45.6	35.9	1.05
A6061-T6	28.1	25.7	17.6	0.65
A2024-T4	40.2	55	10.3	0.14

Table 2 : Mechanical properties of workpiece

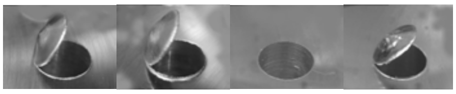
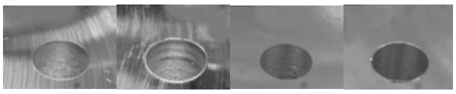
Drill No.	SM45C	SS400	A2024	A6061
#2 Conven -tional Carbide Drill				
#14 40°/ Ø9 Step Drill				

Figure 8 : Burr formation using step drill compared with general carbide drill in each material

With A2024, burrs are formed with less than 0.1mm burr height due to the brittleness of material. In this case, the bending deformation of the material at the exit stage is not allowed. The fracture before bending deformation forms a negative burr, which is classified as A type burr in previous work [7].

From the results presented in Figure 7, it can be observed that the #14 step drill with 40° step angle and 0.5mm step size produces the smallest burr. To compare the burr formations between conventional drill with 140° point angle and step drill #14, burrs formed by each drill are illustrated in Figure 8. Except with A2024, burrs with cap are produced in every work material when drilled with a conventional drill.

4 CONCLUSION

1. Chamfer drill, round drill and step drill form smaller burrs than the non-modified conventional drill. Especially the step drill with 40° step angle and Ø9 step diameter forms minimized burr.

2. The experiment was conducted to determine the characteristic of burr formation in various materials with different properties SM45C, SS200, A6061 and A2024. Generally, burr is minimized in less than 75° step angle in each material. And all modified drills form very small-sized burr in A2024.

5 ACKNOWLEDGEMENT

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6 REFERENCE

[1] Gillespie,L.K., "Deburring Precision Miniature Parts," Precision Engineering, Vol.1, No.4, pp.189-198,1979

[2] Gillespie,L.K., “Deburring Technology for Improved Manufacturing,” SME, Dearborn, MI, 1981.

[3] Gillespie,L.K., “Burr Produced by Drilling,” Bendix Corporation, Unclassified Topical Report BDX-613-1248, December, 1975

[4] Pande. S. S., Relekar, H. P., “Investigations on Reducing Burr Formation in Drilling,” Int. J. Machine Tool Design Research, Vol.26, No.3, pp339-348, 1986

[5] Takazawa.K. "The Challenge of Burr Technology and Its Worldwide Trends," Buu. of Japan Society of Precision Eng., Vol.22/3, Sept., 1988:165-170

[6] Stein, J. M., Dornfeld, D.A., “Burr Formation in Drilling Miniature Holes,” Annals of the CIRP Vol. 46/1/1997, pp63-67

[7] Ko, S. L. and Lee, J. G., "Analysis on Burr Formation in Drilling with a New Concept Drill," J. of Materials Processing Technology, Vol.113, 2001:392-398.

[8] Dornfeld,D.A., Kim, J. S., Dechow, H., Hewson, J. And Chen, L. J., "Drilling Burr Formation in Titanium Alloy, Ti-6Al-4V," Annals of the CIRP, Vol. 48/1/1999, pp 73-76

[9] Sofronas, A., “The Formation and Control of Drilling Burrs,” Ph. D. Dissertation, University of Detroit, 1975

[10] Adachi, K., “A Study on Burr in Low Frequency Vibratory Drilling,” bull. Japan Soc. Of Prec.Eng., Vol.21, No.4, pp.258-264, 1987

[11] Takeyama, K. “Study on Oscillatory Drilling Aiming at Prevention of Burr,” Journal of Japan Soc. Of Prec. Eng.,Vol.59, No.10, pp.1719-1724, 1993

[12] Lee, G.B., “Digital Control for Burr Minimization in Drilling,” Ph. D. Dissertation, University of California at Berkeley, 1989

[13] Ko, S. L., Jun, K. B., and Lee, J. G., "Development of the Burr Measurement System using Laser," 4th Japan-Korea Joint Technical Conference on Surface Finishing Burr Technology, Inchon,1999: 66-76.