Burr Minimizing Scheme in Drilling

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Abstract

In conventional drilling, burr formation can be changed by varying the drill's geometry, i.e., the step angle and point angle. To minimize burr formation, it is proposed that a step drill be used. The step drill performs front edge cutting before step edge cutting. The burr formed in first cutting by front cutting edge can be removed in second cutting by step edge. In particular, new burrs are formed through the second cutting. They can be minimized by changing the drill's geometry. A laser sensor is used to measure the burr formed in the drilling.

Key Words : Drilling, Conventional drill, Step drill, Burr minimization, Point angle, Step angle, Laser burr measurement

1. Introduction

Burrs are formed in every machining process as a result of plastic deformation. 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. There are two approaches in burr problem solution. One is by minimizing the burr formation to reduce the cost of deburring and maintain the part precision. This is a direct approach used in most machining processes. To minimize burr formation, its mechanism needs to be analyzed[1,2].

The second approach involves instances when minimizing the burr formation cannot satisfy the requirements of the product. In this cast, deburring is necessary. The cost of deburring is determined by the size of the burr and its location, usually increasing as the size of the burr becomes largher[3,4].

Drilling is the most popular in machinintg. Therefore, the resulting burr problem is generally very serious. Burrs are formed when a drill enters and exits the hole. Serious problems in deburring occur on the exit stage when the burrs formed are much larger. When the exit burr is formed inside a cavity or inside a crossing hole, there are no tools available for deburring [5, 6]. In this case, very special tools must be used; thus increasing the deburring cost. Sometimes, deburring is also not possible. In this situation, drilling must be applied for burr minimization.

The effect of the drill's geometry on burr formation was investigated to minimize the burr formed during drilling [7, 8]. A larger point angle of the drill reduced the burr size [7]. However, it was not satisfactory; thus, more effective methods were necessary to be found. Likewise, the roundness of the drill's corner reduced the burr to a very small size [8]. In this case, the drill must have been examined to see whether it satisfied the requirements or not.

In this paper, a step drill was used to minimize the burr size. Usually, the step drill is used to make holes with different diameters. To minimize the burr size, a step drill is designed to separate the drilling into two steps. First step is drilling process by the front edge that is the usual cutting edge of the drill. The other is the process of enlarging to the final hole size by step cutting using the step edges. In this process, the burr formed after drilling with the front edge is removed and a smaller burr is formed in step cutting with the step edges. Some drills without step are developed to minimize the burr formation with a chamfered edge or round edge [8]. However, two processes of machining in these drills, e.g., drilling by the front edge and enlarging by chamfered or round edge are not separated from each other. These drills are proved to produce a larger burr than the one formed in a step drill, with an optimal step angle and step size that can be used to minimize the burr.

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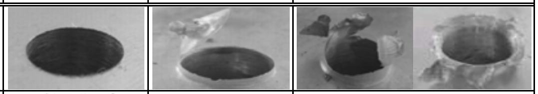
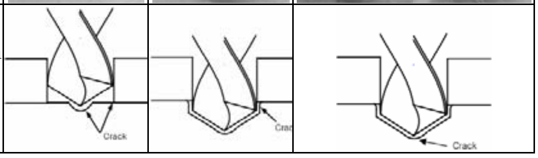
	Type A	Type B	Type C
Burr Types			
Location of Crack			

Fig.1 Classification of Burr Formation in Drilling

Table.1 Specification of Drills for Burr Formation Experiment

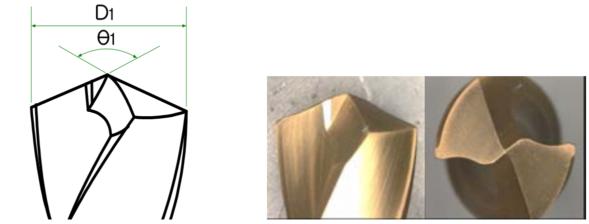
Drill	θ_1 point angle	D_1 diameter	θ_2 step angle	D_2 step diameter	L step length
Conventiol drill	140°	10 mm	0°	0 mm	0 mm
Step drill	140°	10 mm	130°	8 mm	2 mm
	140°	10 mm	75°	8 mm	2 mm
	140°	10 mm	60°	8 mm	2 mm
	140°	10 mm	40°	8 mm	2 mm

2. Burr formation analysis in drilling with a step drill

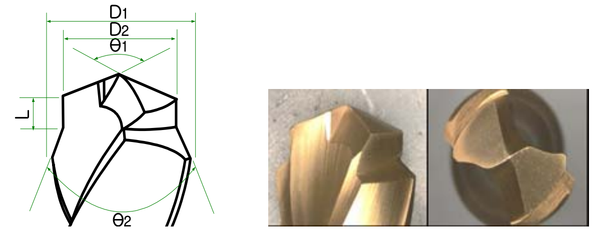
2.1 Experiment and analysis

From the result of the previous analysis, the mechanism of burr formation in drilling was classified into three types according to the location of the crack initiated (Fig.1) [7]. Type A burr was formed with a very small size or a negative shape due to the brittleness of the material. Type B burr was formed as a result of some degree of plastic deformation. The crack during the deformation was initiated along the hole periphery, which produced a uniform burr and cap (type B in Fig.1). However, the cap fractured like a flower and remained as a large burr (type C in Fig.1) when the crack was initiated from the drill point of the cutting edge. These classifications were consistent with the result of Takazawa [9]. To minimize burr formation, the type of burr must be transformed from type C to type B. In a previous work, a drill with a 140° point angle was used instead of a drill with a 118° point angle to reduce the burr size [7]. A drill with a larger point angle always produces a type B burr. In many cases, a drill with a smaller point angle produces a type C burr. As the point angle increases, the plastic deformation is localized along the peripheral part of the hole; thus inducing the crack along this part and producing uniform burrs.

Table1 presents the geometrical specification of the conventional drill with a 140° point angle and the step drills to compare burr formations. Two kinds of drills in Fig.2 with a cutting speed of 35m/min and 5 feed rates at 50, 100, 150, 200, and 250mm/min were used for SM45C alloy steel. Coolant was not used to clearly observe the burr formation process. As shown in Fig.2 (a), a conventional carbide drill with a 140° angle had a similar geometry as the one used in the previous work [7].



(a) Conventional drill



(b) Step drill

Fig.2 Configuration of Drills

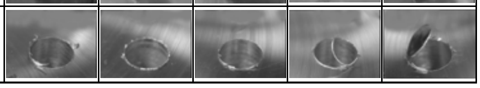
Feed rate (mm/min) / Drill	50	100	150	200	200
Conventional drill					
Step Drill (Θ_2 =75°)					

Fig.3 Burr Formation in Each Drilling Operation for SM45C

In Fig.2 (b), a step drill was designed to contain two different cutting edges. Each cutting edge had a specific angle and diameters of Θ_1 and Θ_2 and D_1 and D_2, respectively and a step distance between edges was L. The front cutting edge with 8.0 mm diameter and 140° angle performed the drilling. The step cutting edge with a 75°step angle and 10.0 mm diameter removed the remaining part that resulted in a 10.0 mm hole. The chip formation was divided into two ways: through front cutting edge and through step edge. These processes produced the long chips.

In Fig.3, the burrs were formed using two kinds of drill. As a result of the previous work, the burr formed by the conventional drill had uniform shape (type B burr in Fig.1). The type B burr was formed using a step drill that first cut through the front edge, which was similar to conventional drilling. The second drilling that cut through the step edges removed the burr formed during the first cutting and produced very small burrs (Fig.3). The cap remained with a 250mm/min feed rate. This cap produced during the first drilling was attached to the burr formed in the second drilling.

In step drilling, only very tiny burrs that can be easily removed were formed. A laser sensor was used to measure burr geometry. The averaged burr heights were represented and compared in Fig.4. The burr height in conventional drills started at 0.14-0.31 mm and increased with the feed rate, which was larger than those ranging from 0.07 to 0.21mm in step drills. From this experiment,

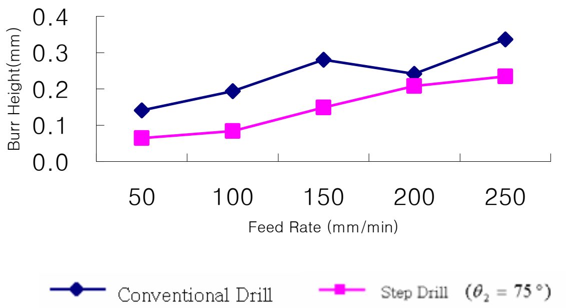
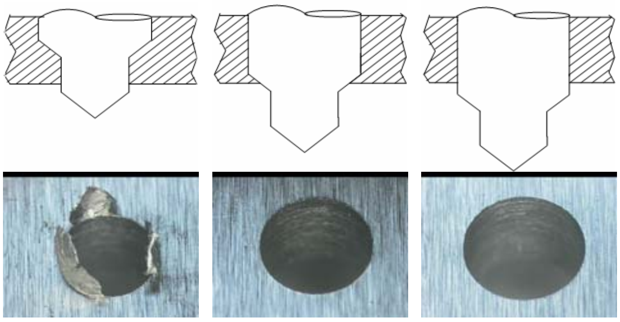


Fig.4 Burr Height in Each Drilling Operations for SM45C



(a) (b) (c)

Fig.5 Burr formation in Each Step Drilling Operation

it was observed that it was possible to effectively use the step drill in minimizing burr formation.

2.2 Burr formation mechanism in drilling with a step drill

In Fig.5, the process of step drilling was represented schematically at each step. Burr formation was also observed during the exit stage of the process. As mentioned earlier, burr formation in step drilling can be done in two stages.

The first stage included cutting by the front edge with a point angle similar to a conventional drill. This first drilling produced type C burrs caused by a front edge with a small point angle of about 118° (Fig.5 (a)). If the drill had a larger point angle, the uniform type B burr would be formed during the first stage. In the second stage, the hole was expanded to its final size through step edge drilling. The burrs formed by step edges are shown in Fig.5 (b) and the final burrs in Fig.5 (c).

Drilling by the front edge is a process similar to the conventional drilling. The burrs formed during the first stage were classified into three types, based on the drill's geometry and the properties of the materials. The burr formation in the second drilling was determined by the angle of edges, Θ_2, and step size, $(D_1 - D_2)/2$ (Fig.2 (b)). The step length L may also affect burr formation. In using conventional drills, a larger point angle is ideal for a uniform burr formation. However, a drill with a larger step angle of 130° (Fig.6) produced a larger burr than the one with a 75° step angle during drilling with step edges. This cannot be easily removed due to its flexibility; thus, it will remain even when the step edges exited the hole.

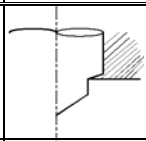
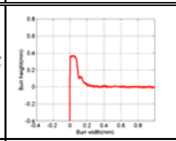
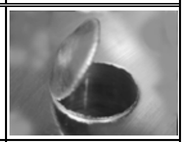
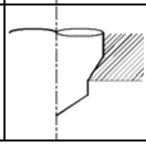
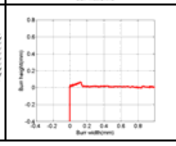
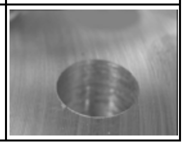
Step Angle Step Diameter	Situation	Laser measurement	Burr formation
Θ_2 = 130° D_2 = 8			
Θ_2 = 75° D_2 = 8			

Fig.6 Detail Observation of Cutting in Step Drilling and Measurement of Burr Geometry

In Fig.6, the burrs were formed by drilling a 10mm hole in a SM45C steel sample using a step drill with 130° and 75° step angles and a 8-mm step diameter. During drilling with a 130° step angle, a thin part was produced when the step edge exited the hole. This was deformed into a large and thin burr as shown by the laser measurement system. The figure showed the burr with a cap and revealed important information on burr formation at a step angle larger than 130°. The cap attached to the burr was formed during the first drilling by cutting the front edge with the 8-mm diameter, as observed in the previous study [7]. The thin part observed in Fig.6 remained, which was bent into burrs. The cap attached to the burr formed during the first drilling also remained after the step drilling. This observation clarified that additional burrs were formed at a step angle larger than a certain critical value. To minimize burr formation, designing a step drill requires finding an optimal step angle.

The rest of the workpiece remained stiff at a step angle as small as 75° compared to step angle of 130° (Fig.6); thus, a small degree of deformation occurred as a result of the step cutting. The larger stiffness of the remained part allowed machining until the drill exited, with only a small part deformed by bending. A burr smaller than the burr formed by a larger step angle would be formed. The size of the step also influenced the size of the burr, since a large step size indicates a large depth of cut during the second drilling. A large degree of deformation is known to result in a large burr when the tool exits the workpiece. However, the effect of the step size on the burr size is more critical when the step angle is large. An excessive step size in a small step angle will cause rapid wear in the step edges even if there are no problems in the burr size. On the contrary, a too small step size would trigger a rubbing effect that would cause deterioration of the surface roughness and the tool's durability and performance. Therefore, designing a step drill requires determining an optimal step to minimize the burr.

2.3 Burr formation according to variation of the step drill's geometry

Burrs were formed experimentally with step drills (Table 1) to observe the changes in burr formations with varying step drill's geometry. Only the step angles as a

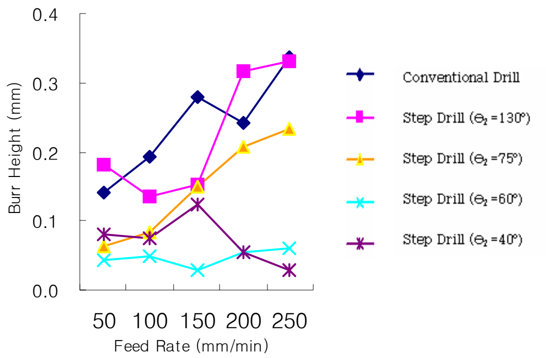


Fig.7 Height of the Burr Formed in Drilling with Different Geometry.

main factor in burr formation were changed. To drill the SM45C steel, a 35m/min cutting speed and 50~150mm/min feed rates were used again.

Fig. 7 illustrates the burr formations based on the changes in the feed rate from all the step drills. The burrs were measured by a laser system [10]. The burr height varied according to the changes in the step angle. Smaller burrs were formed as the step angle decreased. This was explained by the same process described in Fig.6. Drilling with a smaller step angle resulted in stronger stiffness for the remaining part. The burr's height increased as the feed rate increased at a height larger than 0.1mm. The effect of the feed rate was negligible in a smaller burr height.

As mentioned earlier, the undeformed part becomes very thin and deforms into burrs when the drill exits during step drilling at a step angle as large as $\Theta_2 \geq 130°$. In this case, the burrs are very thin and high as shown by the laser measurement in Fig.6. The inclination angle of the burr was almost 90°. It was formed as a result of deformation in the feed direction without machining. Usually, the burr formed in the feed direction has the same size as the depth of the cut in milling process [1]. When drilled with a 130° step angle, the burr height was almost the same as that one produced by conventional drill (Fig.7). In contrary to the case when the step angle was as small as $\Theta_2 \leq 75°$, the undeformed part in machining with step edges maintained sufficient stiffness. Machining can then be performed up to the end stage of drilling (Fig.5). This small deformation allowed only a small burr formation. Since the part with large stiffness can sustain strong cutting resistance, only a small degree of deformation is possible. The shape of the burr was also taken from the data of the laser measurement system in Fig.6. When the step angle decreased from 75° to 40°, the burr thickness increased and its height decreased.

The burr size did not significantly change due to the large stiffness when step angle was small. This indicates that the step size does not have any severe effect on burr formation even at a step angle smaller than the critical angle. However, as explained earlier, the burr size will increase according to the increase of the step size at a step angle larger than the critical value. A smaller step size will reduce the burr height when drilling with a larger step angle.

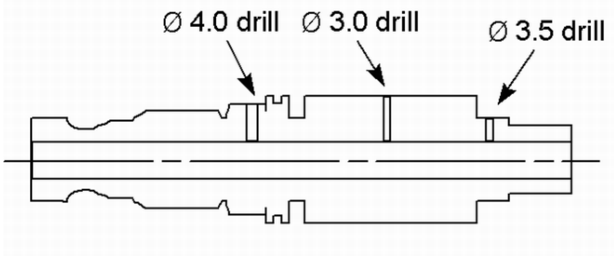


Fig.8 Configuration of Input Shaft

Table.2 Specification of Drills for Input Shaft

Drill #	Θ_1	D_1(mm)	Θ_2	D_2(mm)	L(mm)
1	150°	4.5	0°	0	
2	139°	4.5	0°	0	
3	120°	4.5	63°	3.156	0.763
4	114°	4.5	64°	3.214	1.478
5	129°	3.5	59°	2.563	1.309
6	125°	3.5	74°	2.544	1.163
7	118°	3.5	59°	2.076	1.401
8	115°	3.5	77°	2.0	1.40

3. Application of a step drill to minimize burr formation

An input shaft was drilled to minimize burr formation. As shown in Fig. 8, an input shaft is one of the parts of an automobile's steering system that contains many small holes in a radial direction from the inner hole. If the formed burrs are separated during operation, the function of the sealing parts may deteriorate and result in steering failure. The burrs formed inside the inner hole usually caused these problems.

The input shaft was drilled for oil pass holes with diameters of 3.0mm, 3.5mm, and 4.0mm. The parts with the inner hole were produced by forging a S35C steel and subsequently tempering it to remove residual stress. This piece was very tough, which resulted in a very large burr formation. The hardness of the surface of the inner hole ranged from HV202 to HV246 at a 2mm depth from the surface. Two kinds of drills were used to observe the burr formations, e.g., a conventional drill and a step drill with a 3.5mm and 4.5mm diameter, respectively. Drills listed in Table 2 were used. 33m/min cutting speed and 0.06mm/rev feed rate were used as cutting conditions.

The piece was cut in an axial direction and the burrs measured by a dial gauge. Due to pressure, the spring force in the gauge reduced the burr height to a negligible level because the burrs were very large and rigid. The small burr that was deformed while being measured and removed by pressurized air was neglected in this experiment. In measuring the burr geometry, the laser system was used after removing the rolled burr as shown in Fig.9 [10].

Fig.9 depicted burr formations from a conventional drill and a step drill. Using a conventional drill with a point angle larger than 130° produced a burr with cap, i.e., a type B burr (Fig.9). It was a result of a uniform deformation along the periphery of the edge and crack initiation [7].

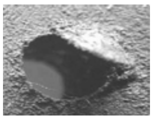
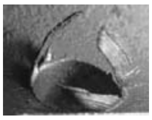
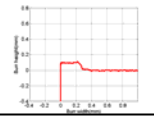
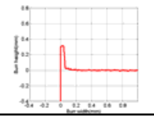
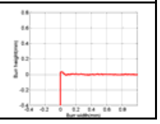
Drill	Conventional drill(a)	Conventional drill(b)	Step drill
Burr shape			
Laser measurement			

Fig.9 Examples of Burr Formation in Drilling Input Shaft

The burr formed by a conventional drill (b) was classified as type C burr, wherein the cap was fractured and the deformation could not be uniformly developed. When the drilled holes crossed each other with an exit angle other than 90°, a type C burr was formed by the conventional drill (a). To induce burr formation in type B, it was helpful to drill crossing holes with a 90° exit angle [6]. Likewise, the uneven surface inside the inner hole formed during the forging process caused a non-uniform burr formation.

A step drill with a step angle less than 75° produced a very small burr regardless of the drilling position and the exit angle (Fig.9). This result proved that a step drill could be used to successfully minimize the burr formation, barring any problem in the tool's durability and performance. More research on this application should follow.

From the experiment, 30 holes were drilled using a conventional drill. Among these, 12 holes were type B burrs without a cap, nine holes were burrs with a cap, and the remaining nine holes were fractured burrs. Among the 18 holes drilled with a step drill, all were type A burrs. Very small non-uniform burrs were also observed in five holes. Fig.10 shows the burr height and thickness as measured by the laser system. Most burrs formed by the step drill showed a height and thickness less than 0.2mm and 0.03mm, respectively. In the case of those formed by the conventional drill, their height ranged from 0.05mm to 0.7mm and their thickness from 0.05mm to 0.15mm. These wide ranges in burr measurements indicated that they were formed as result of non-uniform deformations.

4. Conclusions

1. It was observed that burrs formed by a step drill with step edges were smaller in size comparing with those produced by a conventional drill with a point angle that was larger than 130°.

2. The burrs formed by a step drill were observed and analyzed. They first underwent front edge cutting. The resulting burrs were removed by step edge cutting. From this, the geometry of the final burrs was determined by the step angle and the step size.

3. The effect of the change in the step drill's geometry on burr formation was analyzed. A step angle of less than 75° was verified to minimize burr formation and compared with a step angle that was larger than 130°

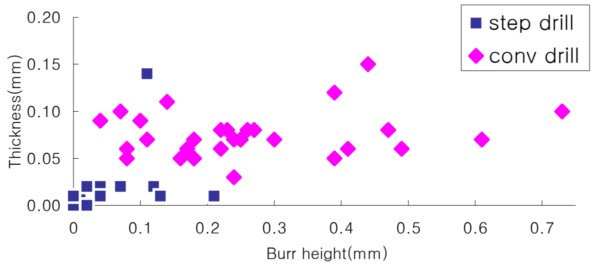


Fig.10 Comparison of Burr Height and Thickness in Conventional and Step Drill

The step size did not have any effect on burr formation when the step angle was less than the critical value.

4. The step drill designed to minimize burr formation was applied to the input shaft that is a part of an automobile's steering system. The step drill produced very small burrs without a cap and effectively minimized burr formation.

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