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Examination of drilling for small-diameter holes in aluminum alloys

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Abstract. Drilling is used for many automobile parts. In particular, highly precise small-diameter holes are required. Drilling in aluminum alloy is affected by chip-flow and tool run-out. The tool run-out is made a cutting performance worse using small diameter tools. We clarified that modifying the tool setting angle with two-tooth square and ball endmilling reduces the influence of tool run-out on machining accuracy. We examined the cutting characteristics of micro endmills and a method for reducing the influence of tool run-out used in the past. In addition, we considered modifying this method for adapting the drilling of small-diameter holes. We experimentally examined the influence of tool run-out on machining accuracy and cutting conditions with a reamer having a tool diameter of 3 mm. In this paper, we report results of a method for reducing the influence of tool run-out on machining accuracy with two, three and four-tooth reamers by modifying the tool setting angle.

1. Introduction

Drilling is used for many automobile parts. In particular, highly precise small-diameter holes are required. However, it is difficult to achieve high-precision machining in the small diameter reaming of aluminum alloys because of chip-flow and tool run-out. Especially, the tool run-out makes the cutting performance worse when using small diameter tools [1-4]. We clarified that modifying the tool setting angle with two-tooth square and ball endmilling reduces the influence of tool run-out on machining accuracy. We examined the cutting characteristics of micro endmills and a method for reducing the influence of tool run-out in the past [5-10]. In addition, we considered modifying this method for adapting the reaming of small-diameter holes. We experimentally examined the influence of tool run-out on machining accuracy and cutting conditions with a reamer having a tool diameter of 3 mm. In this study, we examine a method for reducing the influence of tool run-out on machining accuracy with two, three and four-tooth reamers by modifying the tool setting angle. The target values for the experiment are a hole diameter≤ ϕ3.0mm ±10μm, roundness ≤ 5μm and surface roughness ≤ 3.2μmRz.

2. Method for Reducing Tool Run-out

When tool run-out occurs during machining, it is possible to calculate the effective tool diameter, d′ using equation (1). In equation (1), d is the tool diameter, δ is the tool run-out, λ is the tool setting angle, NT is the number of tooth in the reamer, and n is the edge number. From this equation, we calculated the tool setting angles λ that reduce the influences of tool run-out to the maximum on two, three and four-tooth reamers. Figure 1 shows the results of the calculations. From figure 1, it can be seen that the tool setting angles λ that reduce the influence of tool run-out to the maximum are λ = 90°, λ = 60°, λ = 45° in two-tooth, three-tooth, and four-tooth reamers, respectively. The tool setting angle is λ = 90° when the cutting edge is set in a direction tangential to the tool, towards the locus of tool run-out, as shown figure 1(a) for a two-tooth reamer. With this configuration, the loci of the cutting edges of the two pieces correspond with each other. Figure 1(b) shows a method for reducing the influence of tool run-out with a three-tooth reamer. When the cutting edge is set to λ = 60°, the loci of the cutting edges of the two pieces correspond with each other in the three pieces. Figure 1(c) shows a method for reducing the influence of tool run-out with a four-tooth reamer. When the cutting edge is set to λ= 45°, the loci of the cutting edges of the two pieces correspond with each other in the four pieces. Figure 2 shows the relationship between the number of tooth and the effective tool diameter. From figure 2, by matching the tool setting angle, it is possible to reduce the influence of tool run-out on effective tool diameter for a two-tooth reamer. Figure 3 shows relationship between tool setting angle and tool run-out when the tool diameter of the two-tooth reamer is ϕ3.0 mm and the tool run-out δ is 30 μm. From figure 3, if the tool setting angle is modified to λ = 90° ± 5°, it is possible to reduce the influence of tool run-out to less than 1/10. Therefore, by matching the tool setting angle, it is possible to significantly reduce the influence of tool run-out on machining accuracy for two, three, and four-tooth reamer. We examined a method for reducing the influence of tool run-out on machining accuracy with two, three, and four-tooth reamer by modifying the tool setting angle.

$$d' = 2\sqrt{\left(\frac{d}{2}\right)^2 + \left(\frac{\delta}{2}\right)^2 + 2\left(\frac{d}{2}\right)\left(\frac{\delta}{2}\right)\cos\left\{\lambda + \frac{2\pi(n-1)}{NT}\right\}} \qquad (1)$$

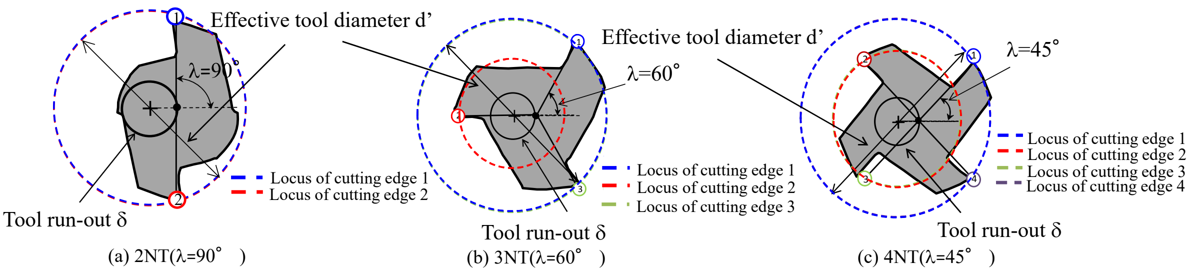


Figure 1. Relationship between tool run-out and locus of cutting edge.

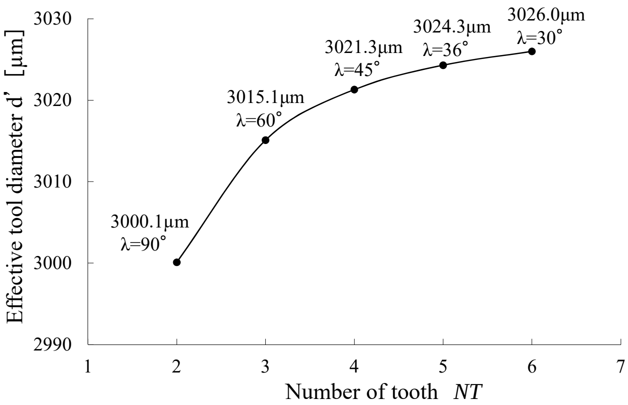


Figure 2. Relationship between number of tooth and effective tool diameter.

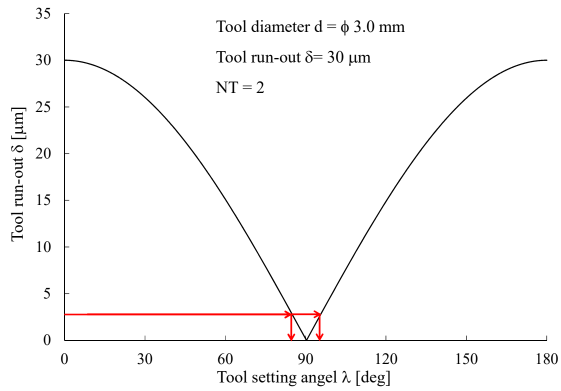


Figure 3. Relationship between tool setting angle and tool run-out.

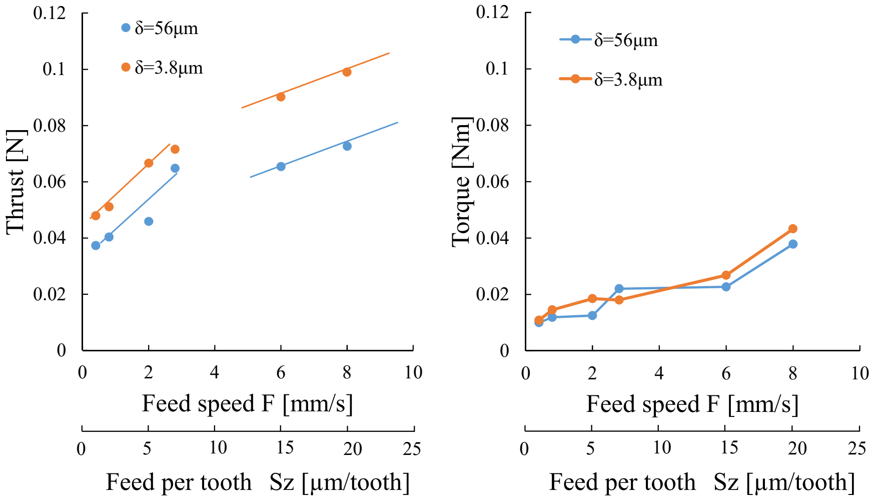
3. Results of Experiment

3.1. *Relationship between feed per tooth and machining accuracy with two-tooth reamer*

We investigated cutting performance to examine about a method for reducing the influence of tool run-out on machining accuracy with a multi-tooth reamer. Table 1 shows the experimental equipment and conditions. The machining method is through hole machining. Reaming with a 3 mm tool diameter is formed after prepared holes are formed with a two-tooth drill with 2.8 mm tool diameter. At this time, the machining radius allowance is 0.1 mm. The cutting conditions are that the feed per tooth Sz is changed from 1-20 μm/tooth and the feed speed F is changed from 0.4-8 mm/s for two-tooth reaming. The tool run-outs are δ=3.8 μm and δ=56 μm which is larger than Sz. Figure 4 shows the relationship between the feed per tooth and cutting force in two tooth reaming. From figure 4(a), the thrust has an increasing trend between Sz=7.0 μm/tooth and 15 μm/tooth. We consider that this change is due to the border of cutting edge R = 8.2 μm. From figure 4(b), when feed per tooth is increased, the value of torque is also increased. Figure 5 shows Relationship between feed per tooth and machining accuracy. The hole diameter and surface roughness Rz improves when feed per tooth is increased. Furthermore, Roundness makes worse above Sz=15 μm/tooth. As a result, we adopt a feed per tooth of Sz=15 μm/tooth which is larger than the cutting edge R = 8.2 μm for reaming.

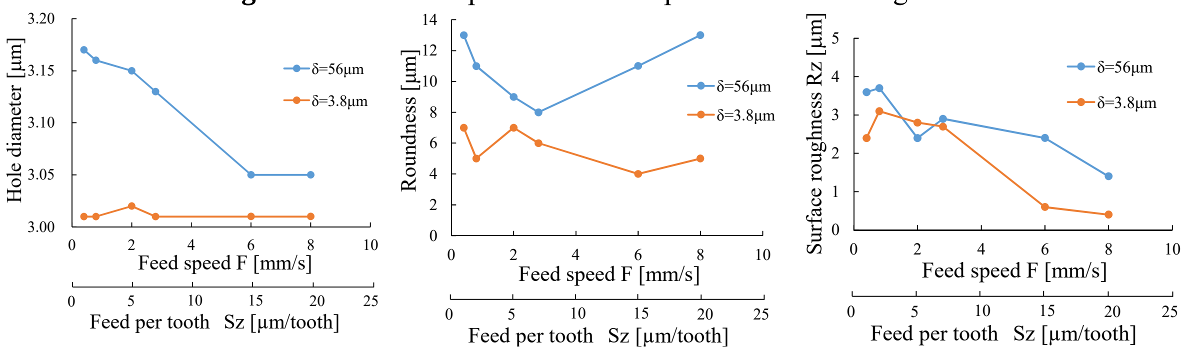
Table 1. Experimental equipment and conditions.

Machine tool	NC milling machine(TG-10A WAIDA)
Cutting tool	Tool material: Cemented carbide ・Drill ϕ2.8 mm 2NT ・Straight reamer ϕ3.0 mm 2NT
Workpiece	A5052 □ 36 × t 3.2 mm
Cutting conditions	・Drilling (Pilot hole) N = 12,000 min^{-1} F = 8 mm/s Sz = 20 μm/tooth Ad = 7 mm δ= 4.0 μm ・Reaming N = 12,000 min^{-1} F = 0.4-8 mm/s Sz = 1-20 μm/tooth Ad = 7 mm δ= 3.8, 56 μm
Lubricating system	MQL equipment: MD-1 Kyoritsu Gokin Corporation (Flow-rate = 24 mL/h, Air Pressure = 0.2 MPa)



(a) Thrust. (b) Torque.

Figure 4. Relationships between feed per tooth and cutting force.



(a) Diameter. (b) Roundness. (c) Surface roughness Rz.

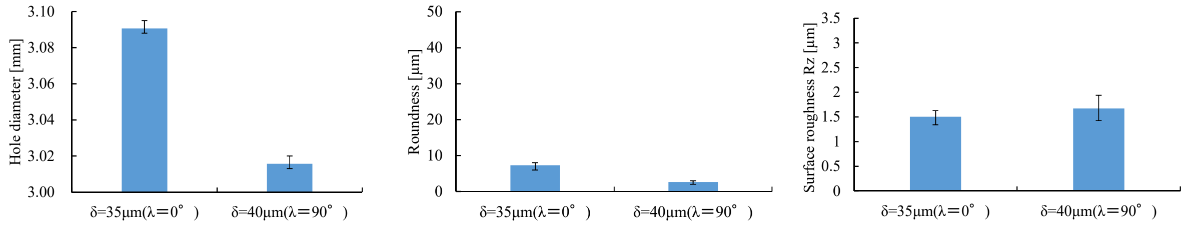
Figure 5. Relationships between feed per tooth and machining accuracy.

3.2. Influence of Tool Run-out on Machining Accuracy with Multi Tooth Reamer

Generally, a helical design for the reamer is used for discharging chip. We examined the influence of tool run-out on machining accuracy and method for reducing tool run-out with a multi-tooth reamer. Table 2 shows the experimental equipment and conditions for a helical multi-tooth reamer. Two, three, four-tooth reamers of ϕ3.0mm are used for right hand cut of straight, right hand helical tooth, and left hand helical tooth reamers. The holes were machined by two, three, and four-tooth reamers with each reamer operating with a constant feed per tooth of Sz = 15 μm/tooth. The tool run-out δ are δ=35μm for λ=0° and δ=40μm for λ=90° for the two-tooth straight reamer, δ=26μm for λ=0° and δ=28μm for λ=90° for the two-tooth right hand helical reamer, and δ=26μm for λ=0° and δ=24μm for λ=90° for the two-tooth left hand helical reamer. Each tool run-out δ are larger than the feed per tooth of Sz = 15 μm/tooth. Figure 6-8 show the machining accuracy with two-tooth reamers. From figure 6, influence of tool run-out can be reduced significantly by modifying the tool setting angle of λ=90° in the hole diameter for two-tooth straight reaming. The roundness result for λ=90° can be reduced by about one-half as compared with that for λ=0°. The surface roughness Rz are mostly the same values. From figure 7, the influence of tool run-out can be reduced significantly by modifying the tool setting angle of λ=90° in the hole diameter and in the roundness of two-tooth right hand helical tooth reamer. There is no notable change in the surface roughness Rz. From figure 8, the influence of tool run-out can be reduced significantly by modifying the tool setting angle of λ=90° in the hole diameter of the two-tooth left hand helical tooth reamer. There are no notable changes in the roundness or in the surface roughness Rz. As a result, it can be said that the influence of tool run-out can be reduced with a two-tooth reamer. Furthermore, we were able to get a favorable result with this consideration. In this case, we considered the direction of chip discharging. The cutting performance is worse due to entanglement of the chip in straight and right hand helical tooth reamers because the chip tends to discharge in a direction opposite to the feed direction. On the other hand, the cutting performance is good in left hand helical tooth reamer because the chip tends to discharge in the feed direction. Figure 9 shows cutting forces of thrust with two-tooth reamers. From figure 9, it can be seen that the thrust of right hand helical reamer is smaller and that of the left hand helical reamer is larger than for straight reamer. In this case, we considered the rake angle of the straight reamer is α=0°, that of right hand helical reamer is α=30°, and that of left hand helical reamer is α=-30° because the helix angle of the reamer corresponds to the rake angle. Therefore, the helix angle affects the cutting performance results. Figure 10 shows the relationship between the number of tooth and machining accuracy. From figure 10, the hole diameter approaches the theoretical value by modifying tool setting angle of λ=90° in a two-tooth reamer. On the other hand, there is no notable change in three and four-tooth reamers. Modifying the tool setting angle has no notable effect on the roundness, regardless of number of tooth. However, the target value of 5 μm of roundness is satisfied by two-tooth reamer. The target surface roughness Rz value of 3.2 μm is satisfied in two, three, and four-tooth reamers and is better using modified tool setting angles of λ=90°, 60°, and 45° than when using a tool setting angle of λ=0°. As a result, it can be said that influence of tool run-out can be reduced by modifying tool setting angle for a multi-tooth reamer. Furthermore, the best machining accuracy is achieved with a modified tool setting angle of λ=90° with a left hand helical tooth reamer.

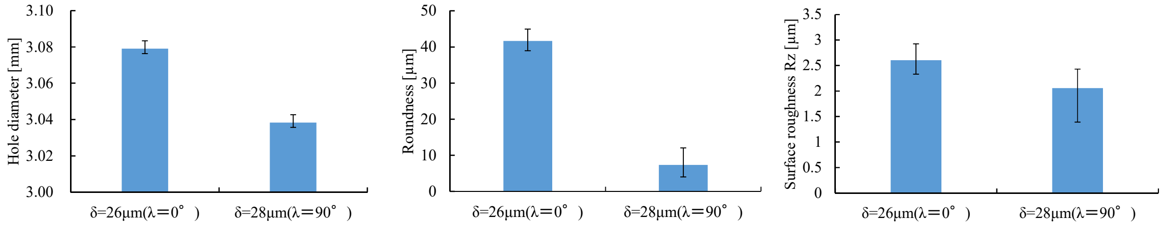
Table 2. Experimental equipment and conditions with helical multi-tooth reamer.

Machine tool	NC milling machine(TG-10A WAIDA)
Cutting tool	Tool material: Cemented carbide ・Drill ϕ2.8 mm 2NT ・Straight reamer, ϕ3.0 mm, 2-4NT ・Right hand helical tooth reamer, ϕ3.0 mm, 2-4NT ・Left hand helical tooth reamer, ϕ3.0 mm, 2-4NT
Workpiece	A5052 □ 36 × t 3.0 mm
Cutting conditions	・Drilling (Pilot hole) N = 12,000 min^{-1} F = 8 mm/s Sz = 20 μm/tooth Ad = 7 mm δ= 0.8-4.0 μm ・Reaming N = 12,000 min^{-1} F = 6, 9, 12 mm/s Sz = 15 μm/tooth Ad = 8 mm δ= 22-40 μm
Lubricating system	MQL equipment: MD-1 Kyoritsu Gokin Corporation (Flow-rate = 24 mL/h, Air Pressure = 0.2 MPa)



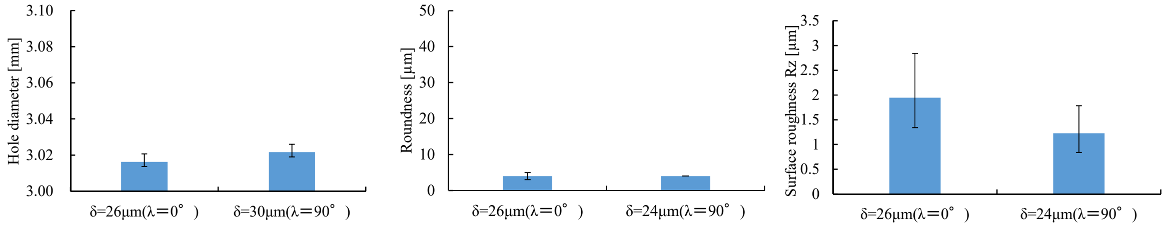
(a) Hole diameter. (b) Roundness. (c) Surface roughness Rz.

Figure 6. Machining accuracy with 2 NT straight reamer.



(a) Hole diameter. (b) Roundness. (c) Surface roughness Rz.

Figure 7. Machining accuracy with 2 NT right hand helical reamer.



(a) Hole diameter. (b) Roundness. (c) Surface roughness Rz.

Figure 8. Machining accuracy with 2 NT left hand helical reamer.

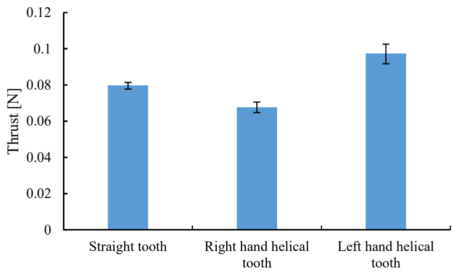
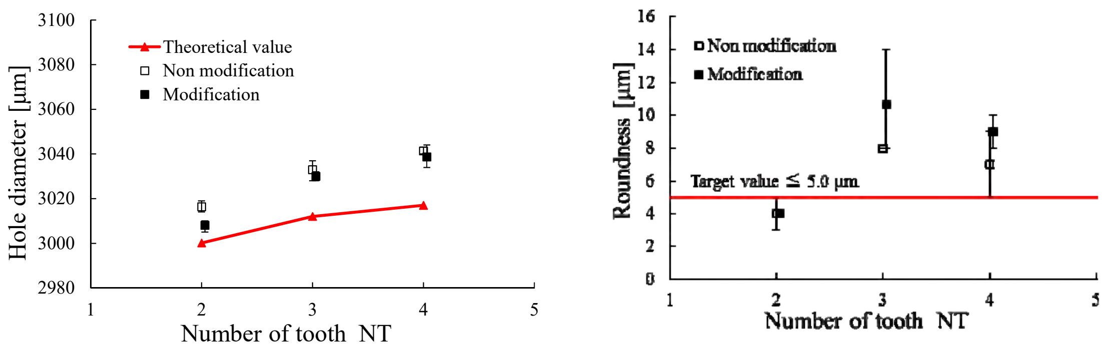
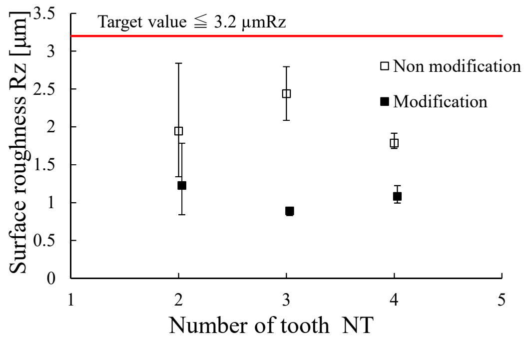


Figure 9. Cutting forces of thrust with 2 NT reamer.



(a) Hole diameter. (b) Roundness.



(c) Surface roughness Rz.

Figure 10. Relationships between number of tooth and machining accuracy.

4. Conclusion

Experiments were conducted to understand examination of the drilling of small-diameter holes in aluminum alloys. The following conclusions were drawn from the results.

(1) Thrust is changed increasing trend due to the border of feed per tooth corresponding to the cutting edge R = 8.2 μm.

(2) The hole diameter approaches the theoretical value by modifying the tool setting angle of λ=90° in a two-tooth left hand helical tooth reamer. Furthermore, the machining accuracy for a two-tooth left hand helical tooth reamer is better than that of three and four-tooth left hand helical tooth reamers.

(3) The surface roughness Rz in two, three, and four tooth reamers are better with modified tool setting angles of λ=90°, 60°, and 45° than with a tool setting angle of λ=0°.

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