Study on ultrasonic vibration assisted drilling of AISI 316
2nd report: Effect of ultrasonic vibration on the cutting temperature

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Abstract. In precision drilling process, burr generation is a serious problem. It is well known that ultrasonic vibration (USV) can decrease cutting force and improve chip discharge performance in turning process. However, the effect of USV on burr generation in drilling process is not well understood. In the previous report, we showed that the height of burrs generated on the drill exit side becomes smaller by applying USV to drills. In this study, we measured the cutting temperature in drilling of AISI 316 stainless steel plate with a thermocouple. As a result, we found that the cutting temperature is decreased by the assist of USV.

1. Introduction

Contamination control is very important in various fields. Especially in the fields of medical equipment and food processing machines, it is necessary to take sufficient care to prevent contamination from mixing into medicine or food because it may cause serious damage to human health [1]. One of the sources of contamination is burrs, which are generated in the machining processes of device components [2]. If a burr falls off from a component part during operation, it becomes a contamination. Therefore, the deburring process is very important after each machining process.

Figure 1 shows a workpiece with intersecting holes. This workpiece is processed by two steps. Firstly, deep blind Hole A is drilled. Secondary, narrow Hole B is drilled so as to intersect to Hole A. In the secondary drilling process, burrs almost always occur on the drill exit side. In this situation, conventional deburring tools are useless to remove the burrs because they are formed in the deep part of a narrow hole. With increase in demand for component parts having intersecting holes, burr-free drilling technique comes to be strongly required. Although special drilling tools have been developed to minimize the burr, we cannot avoid burrs of several ten microns in height yet [3, 4].

AISI 316 stainless steel is widely used in medical equipment and food processing machines because of its excellent corrosion resistance. Our study focuses on the effect of ultra-sonic vibration (USV) in drilling of AISI 316 stainless steel. It is well known that USV is effective in reducing cutting force and enhancing tool life in turning process [5, 6]. However, the effect of USV on the burr generation in drilling process is not well understood.

Our previous report showed the following results: (a) USV, which is applied to the drills, can reduce the burr height on the drill exit side, (b) USV can suppress the growth of built-up edge, (c) USV makes the cutting chips short, and (d) USV makes the thickness of work affected layer small. We considered that the burr height is partially related with the cutting temperature. The burrs on the drill exit side are formed by the pushing out of the part to be cut. If the part to be pushed out is softened by high cutting temperature, the burrs might become large [7]. In order to verify it, we elucidate the effect of USV on the cutting temperature in this report.

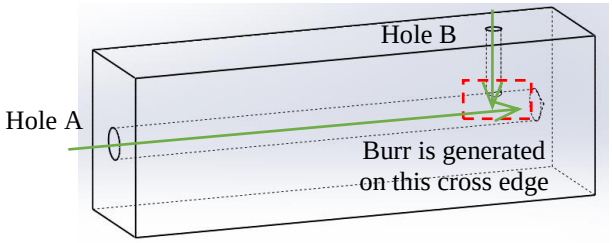


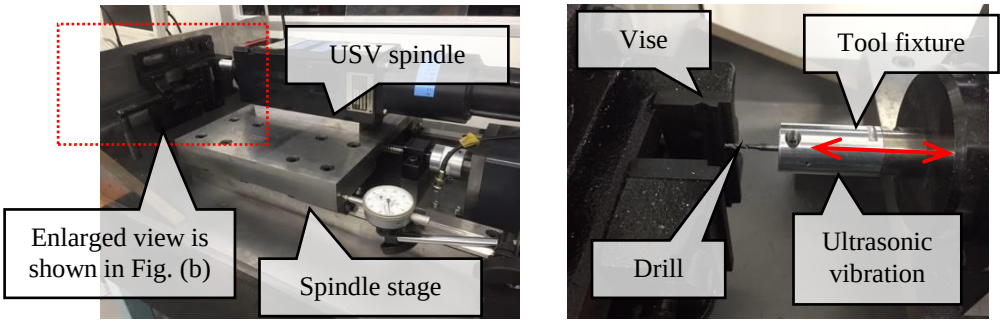
Fig. 1 Workpiece having intersecting holes

2. Experimental equipment

The experiments were conducted using a horizontal drilling machine shown in Fig. 2. This machine is composed of a USV spindle (URT-V04, Takesho Co., Ltd.), a spindle stage driven in the horizontal direction, and a workpiece vise fixed to the machine base.

The maximum revolution speed of the USV spindle is 9000 min^{-1} and the USV frequency is 60±0.5 kHz. The drilling tools are attached to the spindle head via a clamping type tool fixture. The maximum USV amplitude of tool point is about 2 μm.

The spindle stage is guided by linear ball guides and driven by an AC servo motor and a ball screw. The feed speed can be controlled in the range of 3.2 to 160 mm/min by LabVIEW™ based software. The specifications of the experimental drilling machine are summarized in Table 1.



(a) Overview (b) Tool fixture

Fig. 2 Experimental Equipment

Table 1 Specifications of the experimental drilling machine

USV spindle (URT-V04, Takesho Co., Ltd.)		Spindle stage	
Max. rev. speed [min^{-1}]	9000	AC servo motor / Ball screw	
USV frequency [kHz]	60 ±0.5	Feed speed [mm/min]	3.2 ~ 160
Max. USV amplitude [μm]	2	Straightness accuracy [μm]	< 10 / 20mm
Runout accuracy [μm]	< 10	Squareness (vise - drill) [μm]	< 10

In the experiments, the cutting temperature was measured with a thermocouple of type K having a wire diameter of 0.1 mm. We made some drilling experiments of AISI 316 plates having a thickness of 4 mm with tungsten carbide drills (WX-MS-GDS-2, OSG Corporation Co., Ltd.). The drill had a diameter of 2mm and a point angle of 140 degrees. Specifications of the drill, workpiece and thermocouple are shown in Table 2.

Table 2 Specifications of the drill, workpiece and thermocouple used in the experiments

Drill		Thermocouple	
WX-MS-GDS-2 (OSG Corp. Co., Ltd.)		Type	K
Material	Tungsten carbide	Positive metal	Chromel
Diameter [mm]	2	Negative metal	Alumel
Point angle [deg]	140	Compensation	Cold junction comp.
Workpiece			
Material	AISI 316 Austenitic stainless steel	Thickness [mm]	4

3. Measurement of workpiece surface temperature under with and without USV conditions

In order to elucidate the effect of USV on the cutting temperature, in the beginning, we measured the workpiece surface temperature on the drill exit side. We considered that the surface temperature on the drill exit side effects the height of burrs generated on the drill exit side. The measuring method of surface temperature is shown in Fig.3. A thermocouple was fixed on the drill exit side surface by an aluminum tape of a size of 5 mm x 10 mm. The drilling conditions and the measuring conditions are summarized in Table 3 and Table 4 respectively.

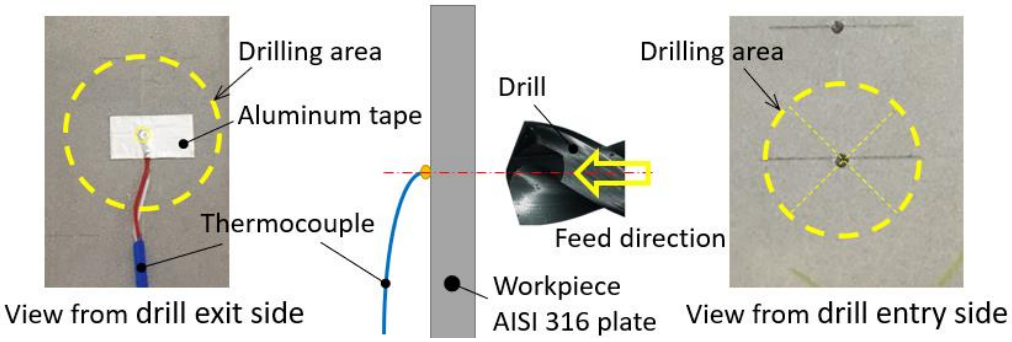


Fig. 3 Measuring method of workpiece surface temperature in drilling

Table 3 Drilling conditions

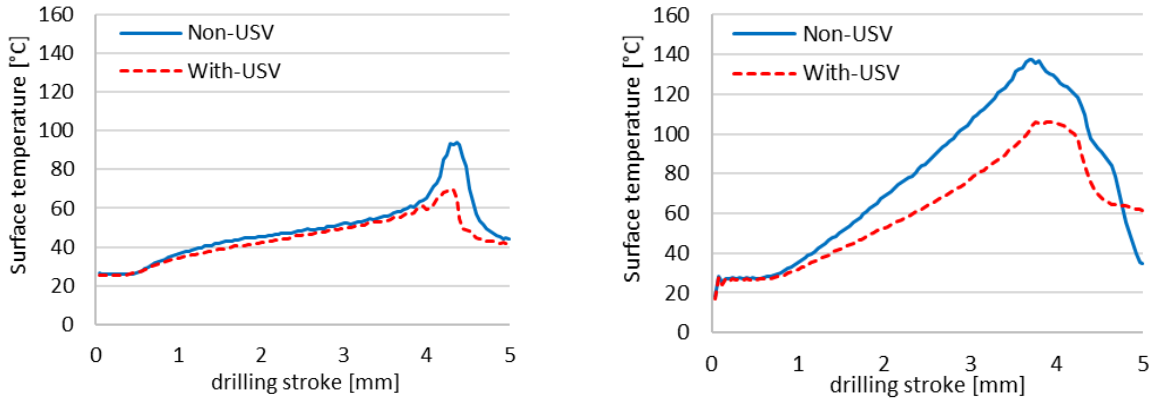
Feed rate [μm/rev]	0.5	1	2	4	6	8
Feed speed [mm/min]	3.2	6	12	24		
Revolution speed [min^{-1}]	6000				4000	3000
USV frequency [kHz]	60 ±0.5					
USV amplitude [μm]	2					
Cutting lubricant	None (Dry)					
Drilling mode	None-step feed					

Table 4 Measuring conditions

Drilling stroke [mm]	5
Room temp. [°C]	20 ±1.0
Sampling freq. [Hz]	1000
Sampling time [s]	12.5 - 100
Filter	4-Hz low pass

The change of surface temperature is shown in Fig.4. When the feed rate was set at 0.5 μm/rev, the maximum surface temperature under Non-USV condition was 94 °C and that with-USV condition was 70 °C as shown in Fig. 4(a). It means that the surface temperature is decreased by the effect of USV. When the feed rate was set at 8.0 μm/rev, the maximum surface temperature was decreased from 137 °C to 106 °C by the effect of USV as shown in Fig. 4(b). The maximum surface temperature under each feed rate is shown in Fig. 5. It is increased with increasing of the feed rate, and decreased by about 20 °C by the effect of USV under every feed rate.

In this experiment, the maximum surface temperature varied from 70 °C to 140 °C. It should be lower than that at the cutting point because it was measured over the burr cap even at the moment the drill broke through the workpiece as shown in Fig. 6. In the next section, we measured the cutting temperature at the position much closer to the cutting point.



(a) Feed rate: 0.5 μm/rev (b) Feed rate: 8.0 μm/rev

Fig. 4 Effect of USV on workpiece surface temperature

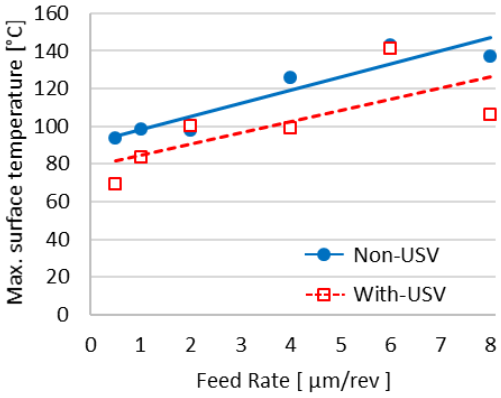


Fig. 5 Change in maximum surface temperature

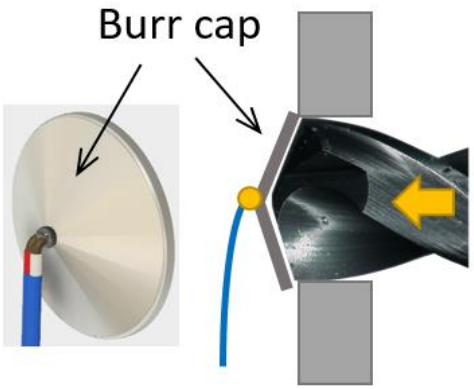


Fig. 6 Image of burr cap

4. Measurement of cutting temperature at the cutting point under with and without USV conditions

The measuring method of cutting temperature at the cutting point is shown in Fig. 7. In this experiment, the workpiece was cut into two pieces, and a twisted thermocouple was put between them and pressed. The twisted length of thermocouple was 4mm, which is as same as the workpiece thickness. The end of the twisted portion was aligned to the bottom surface of the workpiece. The thermocouple was machined together with the work material in drilling. Cutting temperature at the cutting point can be measured when the end of the twisted portion of the thermocouple was cut. The drilling conditions and the measuring conditions were same as in the previous section.

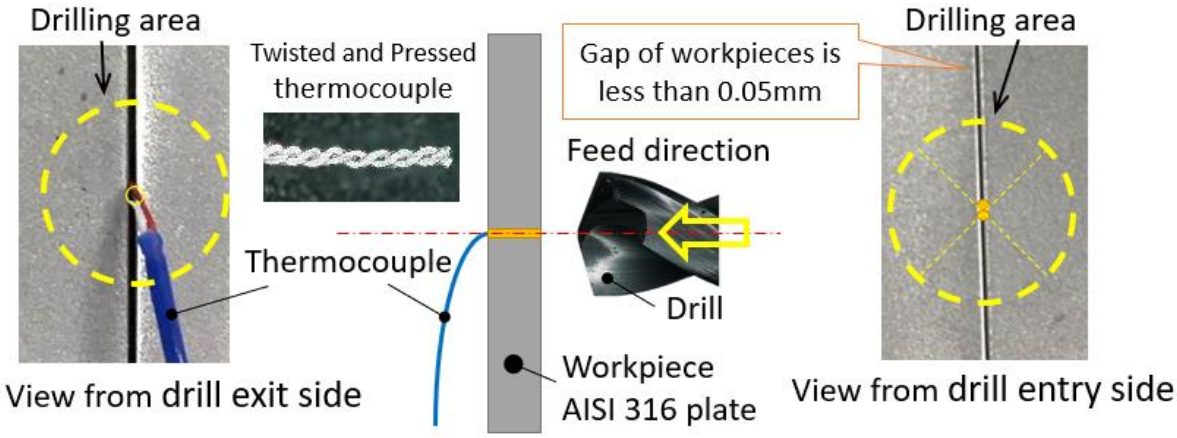
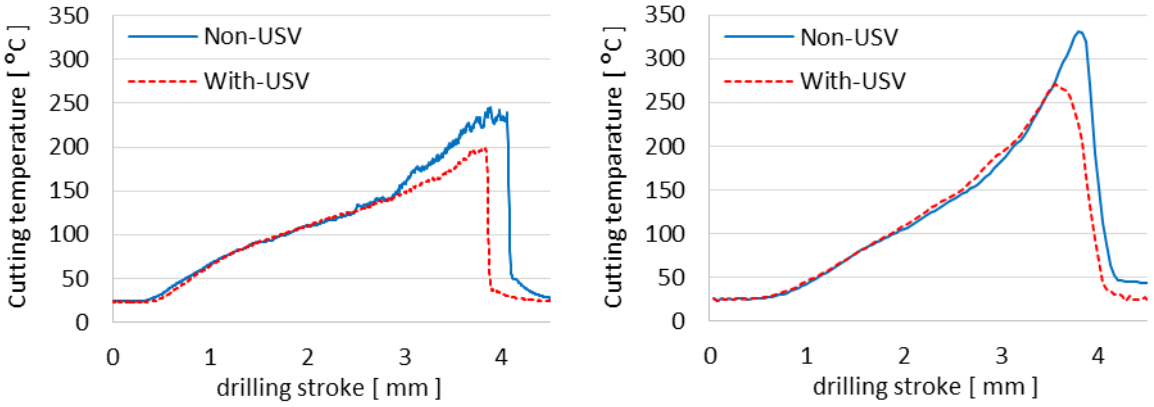


Fig. 7 Measuring method of cutting temperature at the cutting point

The effect of USV on the cutting temperature at the cutting point is shown in Fig. 8. When the feed rate was set at 0.5μm/rev, the maximum surface temperature under Non-USV condition was about 250 °C and it was about 200 °C under With-USV condition as shown in Fig. 8(a). When the feed rate was set at 8.0μm/rev, the maximum cutting temperature was decreased from about 330 °C to 270 °C by the effect of USV as shown in Fig. 8(b). The maximum cutting temperature under each feed rate is shown in Fig. 9. The figure shows that the cutting temperature was decreased by about 50 °C by the effect of USV.



(a) Feed rate: 0.5 μm/rev (b) Feed rate: 8.0 μm/rev

Fig. 8 Effect of USV on cutting temperature

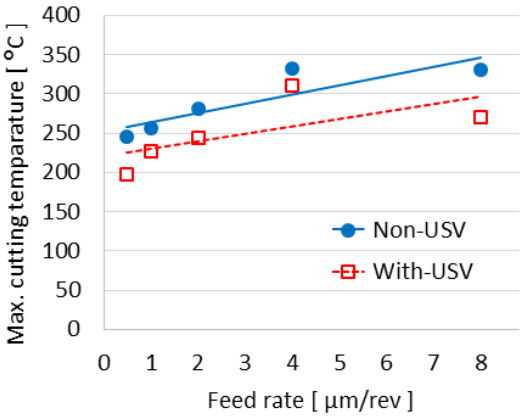


Fig. 9 Maximum cutting temperature

5. Conclusions

In order to elucidate the cause of the burr height reduction effect by USV in drilling process, we measured cutting temperature in drilling of AISI 316 stainless steel plate under Non-USV and With-USV conditions by using thermocouple. The results obtained in this study are summarized as follows;

(1) The maximum temperature of the drill exit side surface of workpiece was increased from 90 °C to 140 °C with an increasing in feed rate from 0.5 µm/rev to 8.0 µm/rev under Non-USV condition.

(2) The maximum temperature of the drill exit side surface of workpiece was decreased by about 20 °C under With-USV condition in any feed rate in the range from 0.5 µm/rev to 8.0 µm/rev.

(3) The cutting temperature was increased from 250 °C to 340 °C with an increasing in feed rate from 0.5 µm/rev to 8.0 µm/rev under Non-USV condition.

(4) The cutting temperature was decreased by about 50 °C under With-USV condition in any range of feed rate from 0.5 µm/rev to 8.0 µm/rev.

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