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Friction control using ultrasonic vibration and application to sheet metal forming

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1. Introduction

In manufacturing, friction occurs not only in mechanical processing but also in various places such as object movement and insertion processes. If this frictional resistance can be controlled, it will greatly contribute to improving manufacturing processability. Examples of research on reducing frictional resistance include the development of lubricants, modification of sliding surfaces, coatings such as DLC (Diamond Like Carbon), and nano- and micro-level texture formation[1,2].

On the other hand, a method of applying ultrasonic vibration between two interfering surfaces has been proposed as a method to reduce frictional force. The authors have previously conducted research on methods of controlling friction in real time using ultrasonic vibration[3-5]. To date, we have examined frictional behavior under high normal force and frictional behavior against small objects, and have clarified the degree of change in friction force and friction coefficient, as well as the mechanism of frictional force reduction by ultrasonic vibration.

For example, sheet metal forming of micro connector parts has complex aspects. Depending on the shape, there are portions and processes that are prone to breakage during processing. If it is possible to control the friction coefficient to suit such portions and processes, the benefit of greatly increasing design freedom can be obtained.

In this study, we investigated a method of reducing friction using ultrasonic vibration, and verified its effectiveness through basic experiments. We also investigated how to apply this method to sheet metal forming processes.

2. Friction reduction method using ultrasonic vibration

Fig. 1 shows the friction reduction method using ultrasonic vibration. Three directions, *x*, *y* and *z* are generally considered for applying ultrasonic vibration to the sliding surface. In the *x* direction, the vibration direction is the same as the sliding direction, and in this case, the friction force direction and the vibration direction are the same. It is important to note that the vibration direction is the same as the direction used for ultrasonic metal welding. In other words, when a strong surface pressure is applied to the object, it is considered that friction reduction will transition to ultrasonic welding. The *y* direction is the direction in which the sliding direction and the vibration direction are perpendicular within the friction surface. This direction also coincides with the ultrasonic welding direction. The *z* direction is perpendicular to the friction surface and is the same direction as the normal force. In other words, the vibration force acts in a direction that cancels the normal force *N*.

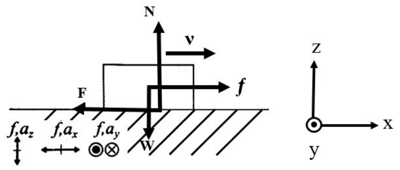

Fig. 1 Ultrasonic vibration direction.

3. Experimental equipment and method for measuring the friction coefficient

The experimental equipment is shown in **Fig. 2**. A 1/2 wavelength horn with a square cross section was prepared as the sliding surface. The sliding surface had a square flat area of 20 x 20 mm on the end and side of the horn. Therefore, depending on the installation direction of the horn, three vibration directions from *x* to *z* can be obtained. The vertical load was applied by a weight. The friction force was measured by pushing the test piece parallel to the sliding surface using a load meter, and the load when the test piece started to move was measured as the static friction force.

The experimental conditions are listed in **Table 1**. The test piece was made of brass, and the sliding surface was made of hardened steel. The frequency *f* of the ultrasonic vibration was set to 38 kHz.

Table 1: Friction experimental conditions.

Test of material	Brass (C3604B)
Sliding surface material	Pre-hardened steel: HPM1
shape of workpiece	Ø 5 mm
Surface area of friction	19.635 mm^2
Frequency *f*	38 kHz
Amplitude *a*(0-P)	0 ~ 2.4 μm
Vertical load *N*	29.4 ~ 49 N
Vibration direction	- Vertical vibration - Parallel vibration - Orthogonal vibration
Sliding speed *v*	70 mm/min

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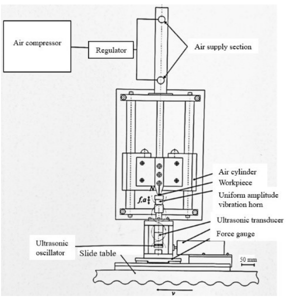
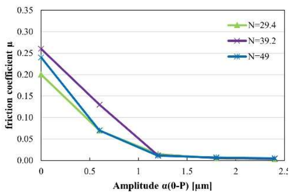


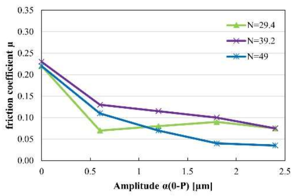
Fig. 2 Ultrasonic vibration friction experimental equipment.

3. Experimental results and considerations

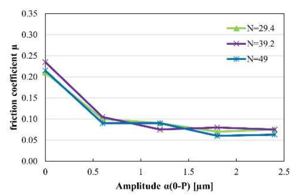
Fig. 3 shows the relationship between the amplitude of ultrasonic vibration and the friction coefficient for each vertical load. In the case of *z*-direction vibration in Fig. (a), the normal friction coefficient without ultrasonic vibration was μ = 0.20-0.25 regardless of the load W. In contrast, when ultrasonic vibration was applied, the friction coefficient was μ = 0.05 or less at an amplitude a = 0.5 μm. In other words, the friction coefficient was significantly reduced by the action of ultrasonic vibration. In the case of *x*-direction vibration in Fig. (b), when ultrasonic vibration was applied, the friction coefficient was close to μ = 0.10 at an amplitude a = 0.5 μm or more. In addition, in the case of *y*-direction vibration in Fig. (c), when ultrasonic vibration was applied, the friction coefficient was μ = 0.05 to 0.10 at an amplitude a = 0.5 μm or more. In summary, the friction coefficient reduction effect was highest when the ultrasonic vibration direction was the *z* direction, followed by the *y* direction, and the effect was the least in the *x* direction.



(a) Vertical vibration (z direction).



(b) Parallel vibration (x direction).



(c) Orthogonal vibration (y direction).

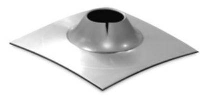
Fig. 3 Relationship between ultrasonic vibration amplitude and friction coefficient

4. Application of friction reduction method using ultrasonic vibration to sheet metal forming

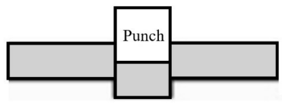
Sheet metal forming includes bending, deep drawing, hole expansion, punching, and sheet metal forging. In these sheet metal forming processes, the friction coefficient between the die and the sheet metal has a large effect on the processing accuracy and processing limit. We will consider a method of reducing the friction coefficient by introducing ultrasonic vibration to the die surface in areas where the sliding with the sheet metal is severe.

Fig. 4 (a) shows the application method to deep drawing and bending, and in this process, it is thought that the formability will improve by reducing the friction coefficient of the die shoulder. Fig. (b) shows the case of hole expansion, and in this process, it is possible to prevent the fracture at the edge of the hole by applying ultrasonic vibration to the hole expansion punch. Fig. (c) shows half punching, and in this case, by reducing the friction coefficient at the cutting edges of the punch and die, it is believed that the occurrence of fracture at the cut surface can be suppressed, which will result in improved processing accuracy and improved tool life.

(a) Deep drawing and bending



(b) Hole expansion



(c) Half punching

Fig. 4 Examination of application method to sheet metal forming.

5. Summary

In this study, we considered that the friction coefficient can be controlled by controlling the amplitude of ultrasonic vibration, and verified it through basic friction experiments. We considered that this friction control method could be applied to sheet metal forming, and investigated how to apply it to various sheet metal forming processes. We plan to verify its effectiveness through experiments in the future.

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References

1) S. Tsuda, S. Yoshihara, Y. Tsuji, and Y. Iriyama, J. Jpn. Inst. Light Met. **60**, 9(2010), pp. 438–443.
2) T T. Kakegawa, T. Shimizu, Y. Sagisaka, and M. Yang, J. Jpn. Inst. Light Met. **56**, 657(2015), pp. 891-896.
3) M. Jin, Proc. of 2018 Spring Conf. for Tech. of Plasticity, (2018), pp. 185-186
4) M. Jin, Proc. of 69th Japanese Joint Conf. for Tech. of Plasticity, (2018), pp. 47-48.
5) M. Jin, R. Jankree, and S. Thipprakas, Proc. of 2024 Spring Conf. for Tech. of Plasticity, 428(2024).