Effect of Cutting Fluid on Surface Processing with Non-Rotational Cutting Tool using Damping Alloy

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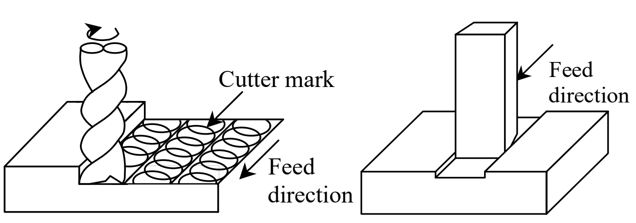
This study aims to achieve a superior sealing surface quality through a cutting process utilizing a non-rotational cutting tool. Previous research has explored the suppression of chatter vibration using indexable non-rotational cutting tools fabricated from damping alloys. The current experiments employed a commercial cemented carbide tool alongside a custom indexable tool composed of a damping material (M2052), with cemented carbide serving as the insert material. The investigation into chatter vibration involved altering cutting forces via a dynamometer and examining the machined surfaces with a digital microscope. Findings from prior research indicated that non-rotating cutting tools incorporating damping alloys exhibit enhanced suppression of chatter vibrations compared to traditional non-rotating tools. This study extends the inquiry to assess the influence of cutting fluid on the stability of cutting operations using non-rotational cutting tools with damping alloys. Results demonstrate that spray-type cutting fluids significantly enhance cutting stability in operations involving non-rotational cutting tools and damping alloys.

1. Introduction

The sealing surface plays a crucial role in preventing internal fluid leakage and the intrusion of external contaminants. However, achieving a high-vacuum environment is challenging due to arc-shaped cutting marks left by end milling, which compromise the integrity of the sealing surface. Consequently, manual polishing post-milling is required, a method that is both time-intensive and costly [(1)].

As depicted in Fig. 1, the use of non-rotational cutting tools is deemed effective for processing sealing surfaces. The aim of this study is to enhance process efficiency by achieving high-quality sealing surfaces through the use of non-rotational cutting tools. However, it is well-documented that non-rotational cutting tools can induce chatter vibration. Previous research has explored the suppression of chatter vibration through the application of indexable non-rotational cutting tools equipped with a damping material tool (M2052) [(2)]. This study further investigates the impact of cutting fluids on surface processing when using indexable non-rotational cutting tools with a damping material tool.



(a) End milling (b) Cutting using non-rotational cutting tool

Fig. 1 Cutting using non-rotational cutting tool

2. Experimental Procedure

Cutting tests were conducted on a vertical machining centre, adapting the setup to prevent motor failure often associated with non-rotating tools. As depicted in Fig. 2, the workpiece was affixed to a spindle and engaged by a nonrotational cutting tool mounted on a turntable through a jig. Cutting forces (Fx, Fy, and Fz) were measured using a Kistler dynamometer (Type 9257), securely attached to the spindle head and linked to a personal computer via an A/D converter for data analysis, as shown in Fig. 3. Post-cutting, the residual stress levels were assessed using an X-ray residual stress analyzer (μX360, Pulstec Industrial Co., Ltd.), and the arithmetic mean roughness of the machined surface was quantified with a 3D optical profiler (NewView 5032; Zygo Corporation), providing a comprehensive evaluation of the

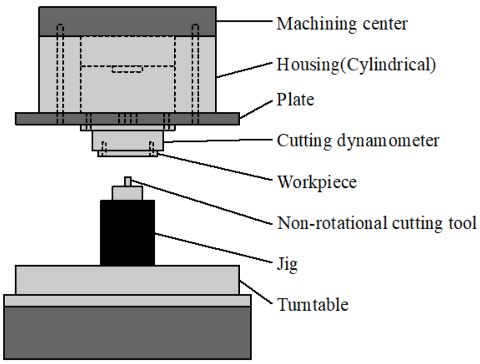


Fig. 2 Experimental setup

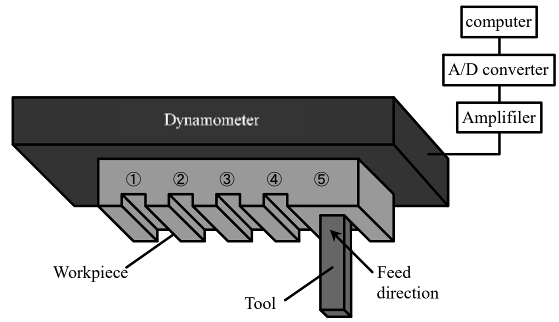


Fig. 3 Experimental method

Fig. 4 Indexable damping material tool (M2052)

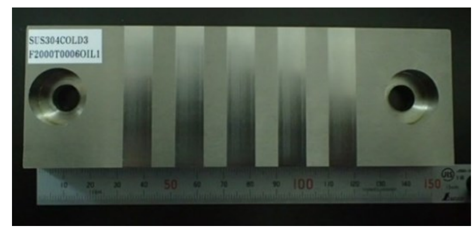


Fig. 5 Machined surface

cutting process's impact on surface integrity.

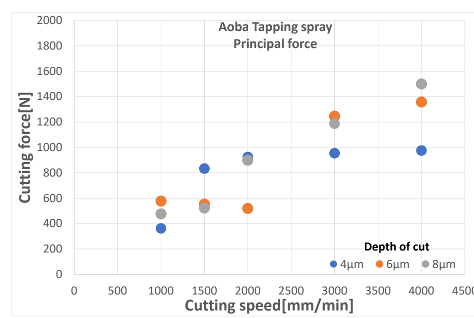
A custom indexable damping material tool (M2052) was utilized in the experiments, with cemented carbide inserts. Figure 4 displays the custom indexable damping material tool, and Fig. 5 presents a photograph of the surface post-cutting. The cutting conditions are summarized in Table 1. Three types of cutting fluids were examined: a tapping spray (Aoba Chemical Industry Co., Ltd.) and oils with kinematic viscosities of 2751 mm^2/s (Castrol Ltd.) and 712 mm^2/s (TAIYU Co., Ltd.), respectively.

Table 1 Cutting conditions

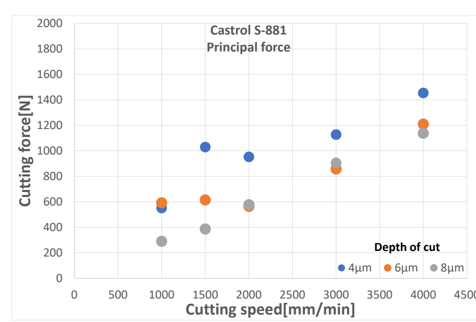
Tool	Insert	Rake angle [deg]	30
		Clearance angle[deg]	10
		Width [mm]	10
		Cutting edge shape	Straight
		Material	Cemented carbide
	Holder	Length [mm]	60
		Diameter	20
		Material	M2052
Workpiece			SUS304
Depth of cut [μm]			4, 6, 8
Cutting speed [mm/min]			1000, 1500, 2000, 3000, 4000
Cutting fluid			Aoba Tapping spray Castrol S-881 TAIYU S-cut No.200KY

3. Experimental Results

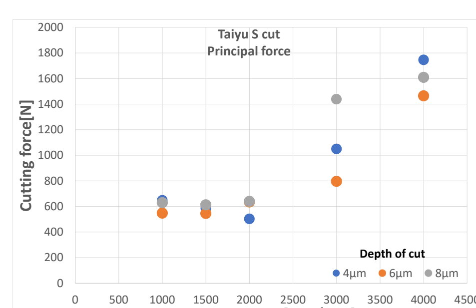
Figure 6 shows the effect of cutting fluid on the average cutting force. The data indicate that the average forces encountered with the two oils are greater than those with the tapping spray. This stability when using the tapping spray can be attributed to the continuous presence of fluid at the cutting interface. Conversely, the use of highly viscous oils resulted in instability, likely due to inconsistent fluid coverage. Additionally, an increase in the average cutting force is



(a)Aoba tapping spray



(b) Castrol S-881



(c) Taiyu S-cut

Fig. 6 Cutting force (Principal force)

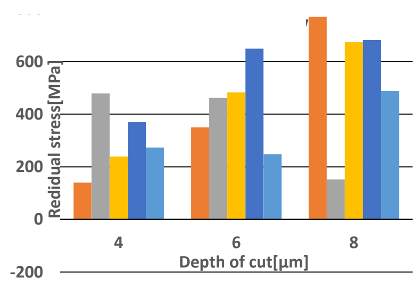
observed at a depth of cut of 8 μm with all cutting fluids as cutting speed increases. However, at depths of 4 and 6 μm, the average cutting forces demonstrate variability at lower speeds with all fluids, suggesting that burnishing effects may occur at these lower speeds and depths.

Figure 7 shows the residual stress patterns observed on the machined surface following the cutting experiments. Notably, compressive residual stress measurements were absent when tapping spray was employed, suggesting minimal impact on the surface integrity in this context. In contrast, the application of the two oils at cutting depths of 4 and 6 μm resulted in detectable compressive residual stresses, indicative of burnishing effects.

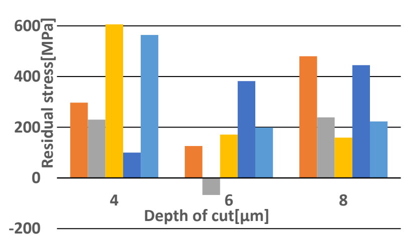
The presence of compressive residual stress is generally associated with the mechanical smoothing effect of burnishing, which enhances surface finish by plastically deforming the material surface under compression.

Figure 8 compares the arithmetic-mean roughness values along the cutting direction post-experiment. The data reveal minimal variation in surface roughness attributable to cutting conditions when tapping spray was utilized, underscoring the stability and effectiveness of this cutting fluid in maintaining consistent surface quality.

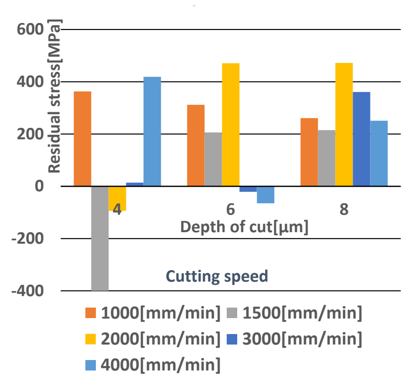
Conversely, a significant disparity in roughness was observed under the conditions facilitated by the two oils. This variation is attributed to the instability of the cutting process when using oils with high viscosities, as the intermittent fluid delivery to the cutting interface likely contributed to irregularities in surface finish.



(a)Aoba-tapping spray



(b) Castrol S-881



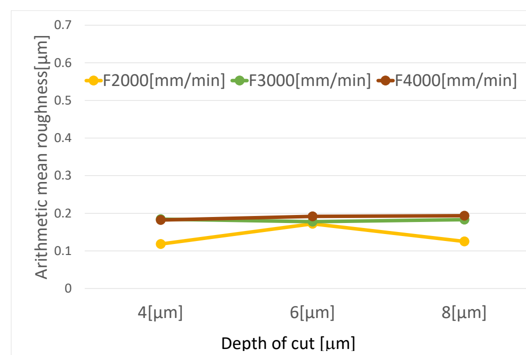
(c) Taiyu S-cut

Fig. 7 Residual stress

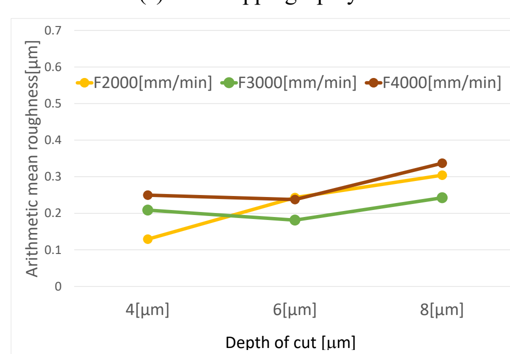
4. Conclusions

The findings of the study lead to two key conclusions regarding the optimization of cutting processes with non-rotational cutting tools using damping alloys:

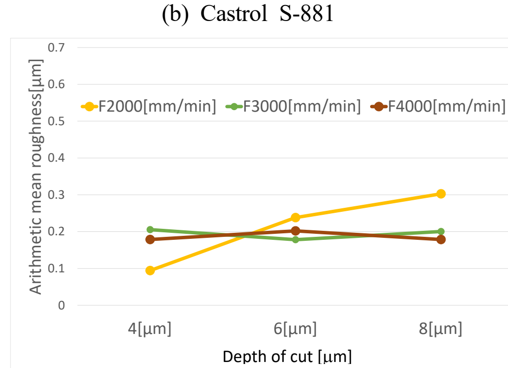
1) The application of spray-type cutting fluids has been identified as significantly enhancing stability during cutting operations. This superiority is attributed to the fluid's ability to consistently lubricate and cool the cutting interface, thereby facilitating a more stable cutting environment when utilizing damping alloys.
2) The phenomenon of burnishing is primarily observed when the cutting interface is inadequately lubricated by highly viscous oils, leading to unstable cutting conditions. Conversely, tapping spray, enriched with extreme-pressure additives, ensures uniform



(a)Aoba tapping spray



(b) Castrol S-881



(c) Taiyu S-cut

Fig. 8 Arithmetic mean roughness

distribution across the cutting surface. This uniformity promotes a stable cutting process by effectively reducing friction and heat generation, thereby mitigating the likelihood of burnishing and ensuring a smoother surface finish.

These conclusions underscore the critical importance of selecting appropriate cutting fluids to enhance the efficiency and quality of machining operations, particularly when employing non-rotational cutting tools equipped with damping materials.

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