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Effect of Tool Edge Geometry on Sheared Surface Formation in Blanking of Oxygen-Free Copper

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Abstract. An oxygen-free copper has been utilized as a terminal material in the power transistors and their related electric system in the electric mobiles because of its high electric conductivity and excellent engineering durability in high current usage. The high ductility and its low mechanical strength cause large shear droop and increase of fractured surface. In this report, the shearing of oxygen-free copper was carried out using a punch with a mirror-finished surface roughness. Using the punch tip deflection as a parameter, a comparison of shearing characteristics was made between a punch with a nitrided tool surface and an untreated punch. The influence on the formation of the sheared surface was considered from an investigation of the shearing characteristics. When shearing oxygen-free copper with a thickness of 500 μm, it was shown that by providing a punch tip deflection of approximately one-tenth of the thickness in the punch stroke direction, the shear droop could be kept to 10 % or less of the plate thickness and a burnished surface ratio was approximately kept 90 %.

Introduction

The copper alloys continue to develop as conductive materials. Among these, oxygen-free copper has a copper purity of 99.95% or higher, which suppresses electron scattering due to impurities and allows for stable maintenance of high conductivity. It is free from hydrogen embrittlement and has few oxide boundaries that cause distortion in electrical signals. Due to its advantages in signal transmission, it is increasingly being adopted as material that supports the information society. With the electrification of automobiles, power semiconductors that control large currents are becoming more common, and oxygen-free copper electrodes are sometimes used to transmit this current. A method of shearing sheet material is used to form electrodes. However, due to its soft and easily stretched mechanical properties, as well as its high activity and tendency to adhere, a detailed understanding of the shearing processing characteristics is essential to obtain the properties required for terminals.

The high ductility and its low mechanical strength cause large shear droop and increase of fractured surface [1]. Various investigations have been conducted into the shearing properties of copper alloys, not just oxygen-free copper [2]-[6]. The studies have examined the effect of copper alloy composition differences on tool wear [2] and attempted to predict punch wear rates [3]. The influence of work hardening as a factor in shear surface formation has been investigated [4], and the effects of clearance and processing speed have been studied [5]. Simulations of polycrystalline materials with differing grain sizes have been conducted [6]. After the previous studies, the mirror-finish punches improved the burnished surface ratio and reduced the surface roughness [7]. However, how to suppress the shear droop formation on the sheared surface was left as a challenging issue.

In this experiment, a ϕ 5 mm diameter punch is used to shear oxygen-free copper sheets with a thickness of 500 μm. Three punch-tip finishing conditions are prepared, all based on mirror finished. Under the polishing condition, the punch tip has a rounded edge of approximately 50 μm. In addition, a surface condition modified from conventional alloy tool steel by nitriding is also examined. Using these tools, the study investigates the effectiveness of punch-tip rounding and nitriding treatment for punches with smooth surfaces. This study aims to clarify the effect of the punch tip geometry of a mirror-finished punch on the amount of shear droop and formation of burnished surface.

Experimental Method

The oxygen-free-copper sheet with a thickness of 500 μm C1020 P 1/2H (Mitsubishi Materials Co, Ltd.; Tokyo, Japan) was used as workpiece. **Fig. 1** shows the small-scaled screw servo-stamping system and special piercing die for experiment. The loading capacity of servo-stamping system was set at 30 kN (DT-J311 system, Microfabrication Laboratory, LLC.; Tokyo, Japan). The piercing experiment was performed without lubrication. The piercing speed was set at 5.0 mm/s. The piercing load was measured by the load cell (LMBT-A-2KN, Kyowa Electric Co., Ltd.; Tokyo, Japan) which was embedded into the lower die set. The die stroke was measured by the laser displacement meter (LK-G30, KEYENCE Co., Ltd.; Tokyo, Japan). The whole measured data were transferred to PC through the interface (NR-600, KEYENCE Co., Ltd.; Tokyo, Japan).

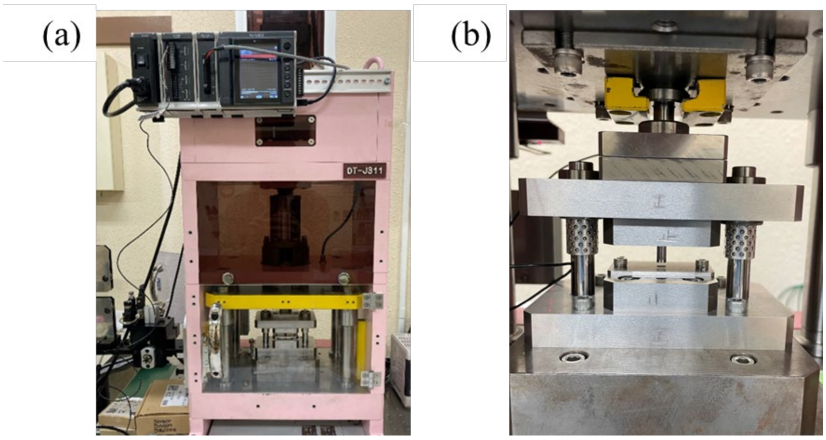

Fig. 1. A small-scaled screw servo-stamping system and shearing die. (a) outlook of small-scaled screw servo-stamping system (b) special die for piercing φ5 mm hole.

Three punch–die pairs were prepared for tooling as listed in **Table 1.** The punch uses AISI D2 steel (equivalent to JIS SKD11) and the die material is made from carbide tool. The punch diameter used in the experiment was unified at 5.000 mm and basically clearance between punch and die was set at 0.015 mm. The condition called "Polishing" is a punch that has been polished with diamond paste after conventional ground finishing. The "Lapping" condition refers to a punch that has undergone wet-blast lapping process (AERO LAP; Yamashita Works Co., Ltd.; Hyougo, Japan) after conventional ground finishing. The conditions indicated as “Lapping after nitriding” involve applying plasma nitriding [8] after conventional ground process to achieve a hardness exceeding 1200 HV. Following this, wet-blast lapping is performed to improve surface roughness. The outer surface roughness of the three types of punches was measured using a laser microscope (VX-3000; Keyence Co., Ltd.; Tokyo, Japan) with a cutoff value of 0.008 μm. **Fig. 2** shows an SEM image of the punch tip and a schematic diagram of the amount of deflection in the punch stroke direction and the punch radial direction measured by a laser microscope.

The piercing speed was set at 5.0 mm/s. After piercing, the punched-out samples were cut in half, and the shear droop amount was measured using a scanning electron microscope (SEM). Using an optical microscope, the sheared surface was photographed using an optical microscope, and the burnished surface ratio was calculated from this image. The punch used in the experiment was observed using EPMA (JXA-8230; JEOL Co., Ltd.; Tokyo, Japan) to check the adhesion state of copper.

Table 1. Punch and die conditions in experiment.

No.	Condition	Punch			Die		Clearance [mm]
		Finishing	Outer dia. [mm]	Outer side roughness [µm]	Finishing	Inner dia. [mm]	
A	Polishing	Polishing	5.000	0.039	Ground	5.030	0.0150
B	Lapping	Wet-blast	5.000	0.081	Ground	5.030	0.0150
C	Lapping after nitriding	Wet-blast after nitriding	4.997	0.009	Ground	5.030	0.0165

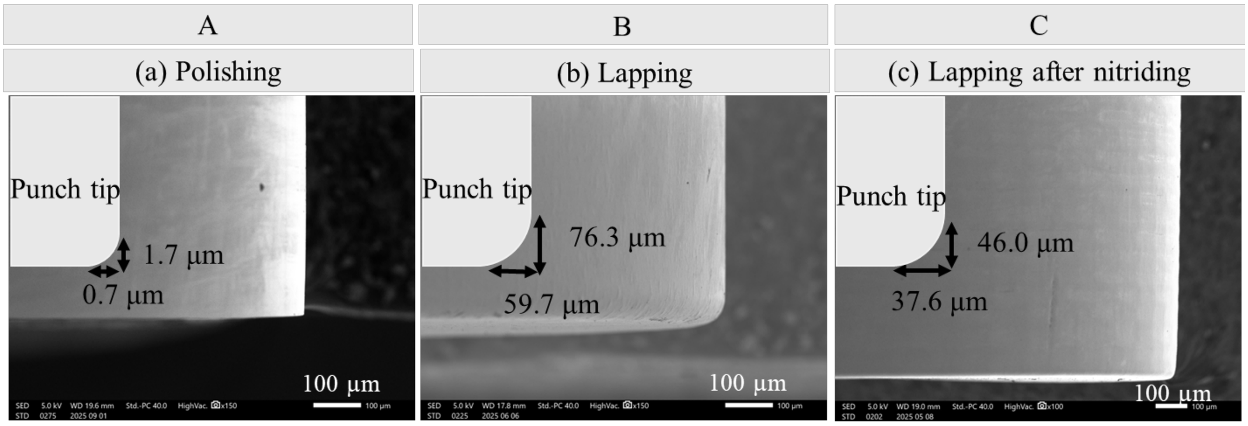

Fig. 2. Results SEM image of the punch tip and a schematic diagram showing the results of measuring the amount of sagging measured using a laser microscope. (a) Polishing finish punch. (b) Lapping finish punch. (c) Lapping after nitriding punch.

Experimental Results

Fig. 3 shows Load – stroke diagram. When using Lapping punch, the load increased rapidly in the early stage of shearing, and the maximum shear load was 1710N. The condition under which the load increased the slowest in the early stage of shearing was the Lapping condition. The maximum shear load under the Lapping condition was 1660N. The load increase in the initial stage of forming under the lapping after nitriding condition showed intermediate behavior with the three punches, and the maximum shear load was the smallest at 1630 N. The breakage strokes were found to fall within the range of 0.52 mm to 0.55 mm.

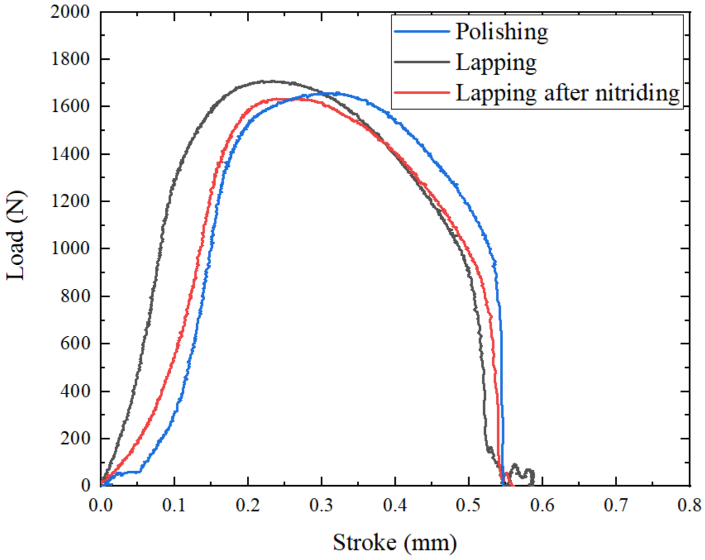

Fig. 3. Load – stroke diagram from three punch conditions.

Fig. 4 shows the observation results of sheared surface. The front of the die was defined as the Front, and four locations were defined as the Front, Back, Left, and Right, and the punched samples were observed. The observation results under the A: Polishing condition show that smooth burnished surface and the fracture surfaces are formed at each of the four measurement points. Under the B: Lapping condition, the burnished surface is smooth, but vertical lines parallel to the punch stroke direction can be seen, and fractures are almost nonexistent. Under C: Lapping after nitriding conditions, the burnished surface is smooth, indicating that fracture has occurred.

Fig. 5 shows the calculation results for the ratio of shear surfaces obtained from punched hole under three types of punch conditions. The ratio of sheared surface was calculated from the center of the front, back, left, and right images shown in Fig. 4, and the average values of the four measurements are shown as a bar graph. The ratio of burnished surface was the smallest at 82.4 % under the Lapping condition, while the remaining two conditions result were approximately 91 %.

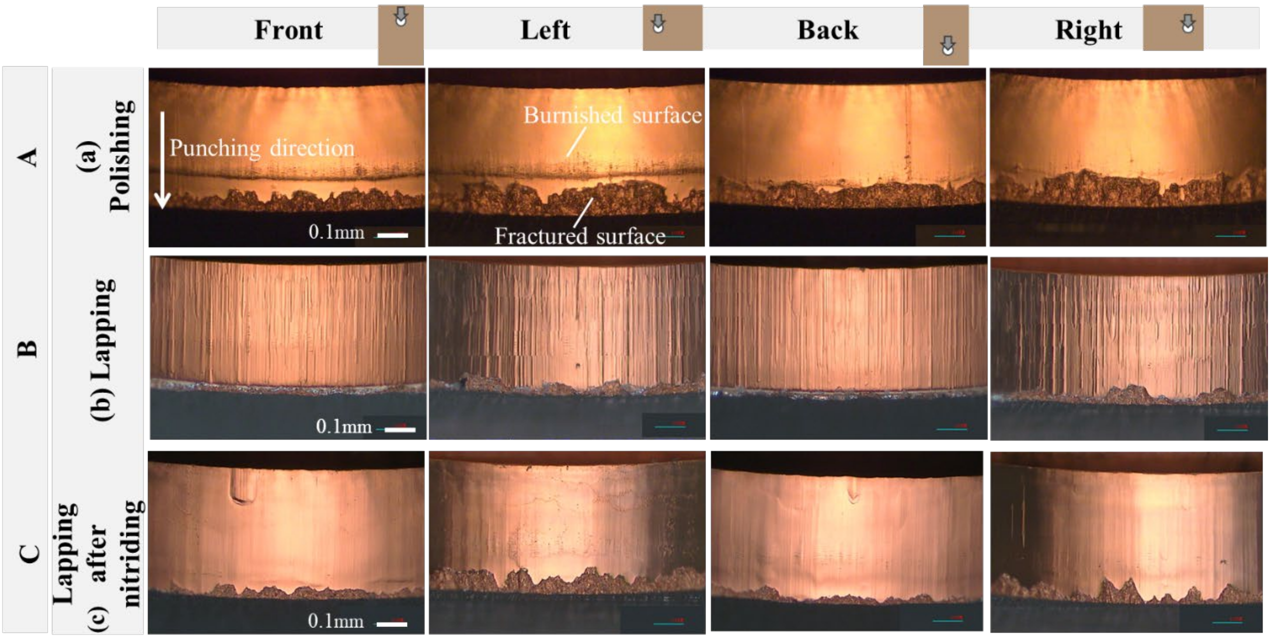

Fig. 4. Results of observing the sheared surface of a punched hole from four directions. (a) Polishing punch punched sample. (b) Lapping punch punched hole. (c) Lapping after nitriding punch punched hole.

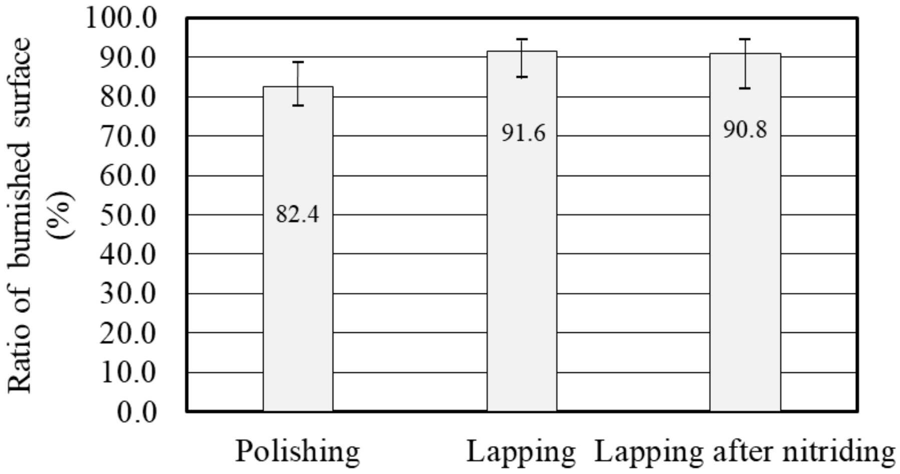

Fig. 5. Calculation results for the ratio of shear surfaces obtained from punched hole under three types of punch conditions.

Fig. 6 shows the SEM image of punched hole cross-section and measurement results of the amount of shear droop length in the punch stroke direction and hole radius direction. The shear droop of the punch stroke direction reached a maximum value of 56.8 μm under Lapping conditions. Similarly, the shear droop in the hole radius direction reached a maximum of 190.3 μm under Lapping conditions. The minimum punch stroke direction value was 20.3 μm under Polishing conditions. The minimum hole radius direction value was 103.6 μm under the lapping after nitriding condition.

Fig. 7 shows the results of measuring the copper around the punch periphery after the shear experiment using EPMA. The copper reaction in the three punches is weak, meaning that almost no adhesion occurs. Under the lapping condition, a weak copper reaction is observed in the area indicated by the white arrow in the figure.

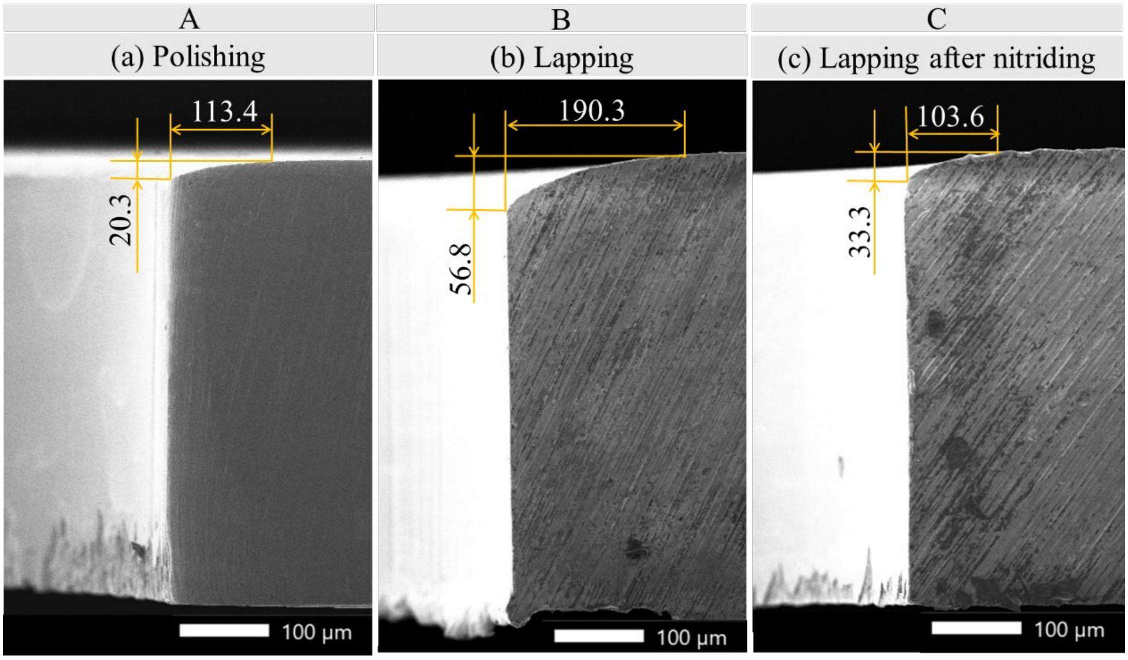

Fig. 6. SEM image of the punched hole cross-section and measurement results of the amount of shear droop length in the punch stroke direction and hole radius direction. (a) Polishing punch punched sample. (b) Lapping punch punched hole. (c) Lapping after nitriding punch punched hole.

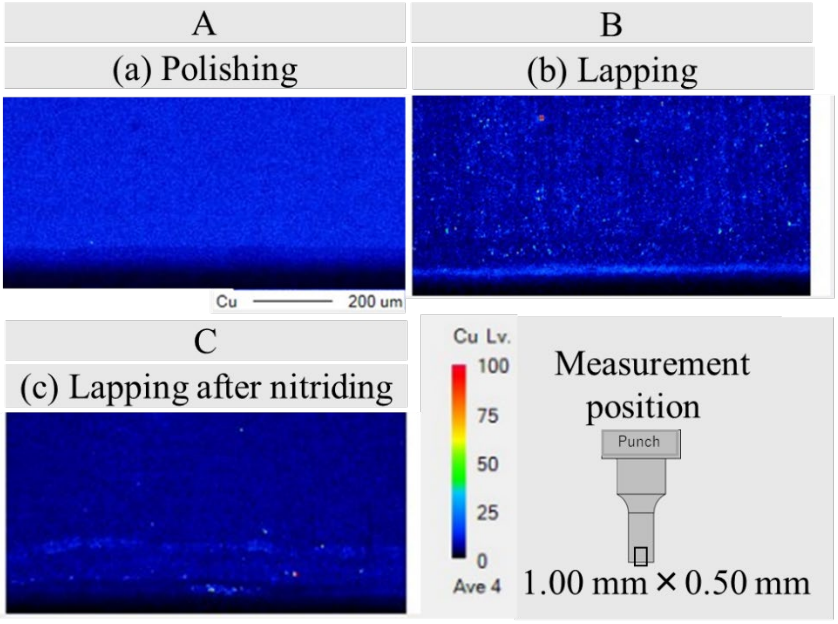

Fig. 7. EPMA measuring results of the copper reaction around the punch circumference after the shear experiment. (a) Polishing punch. (b) Lapping punch. (c) Lapping after nitriding punch.

Discussion

As a result of shearing oxygen-free copper using three types of mirror-finished punches, changes were observed in the amount of the shear droop length and the ratio of burnished surface. **Fig. 8** shows the relationship between punch deflection of punch stroke direction and shear droop length that figure calculated from Fig. 2 and Fig. 6. The symbols in the figure represent the following conditions: A: Polishing, B: Lapping, and C: Lapping after nitriding. These results imply that minimizing punch deflection is effective for reducing the rollover amount in the punch stroke direction of a pierced hole. This finding is consistent with previous knowledge.

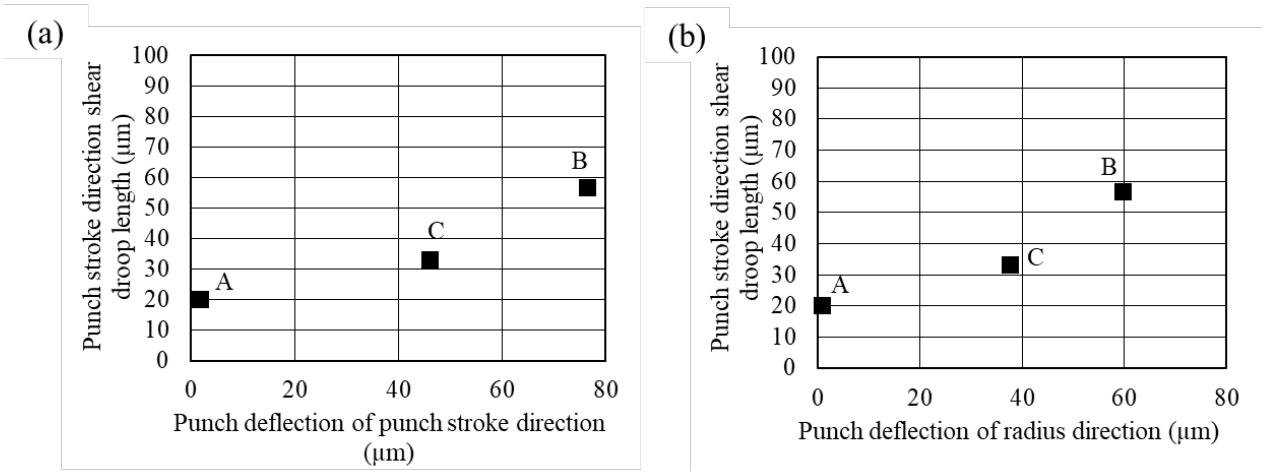

Fig. 8. Relationship between droop length and punch deflection. (a) Punch stroke direction shear droop length and punch deflection of punch stroke direction. (b) Punch stroke direction shear droop length and punch deflection of punch radius direction.

Next, **Fig. 9** shows the relationship between punch deflection of punch stroke direction and shear droop length that figure calculated from Fig. 2 and Fig. 6. The radius direction shear droop length is minimized for condition C: Lapping after nitriding. This implies that the result does not correspond to the amount of punch tip deflection. This implies that even with a sharp edge, such as in condition A: Lapping, the radius direction shear droop length punching with oxygen-free copper cannot be minimized.

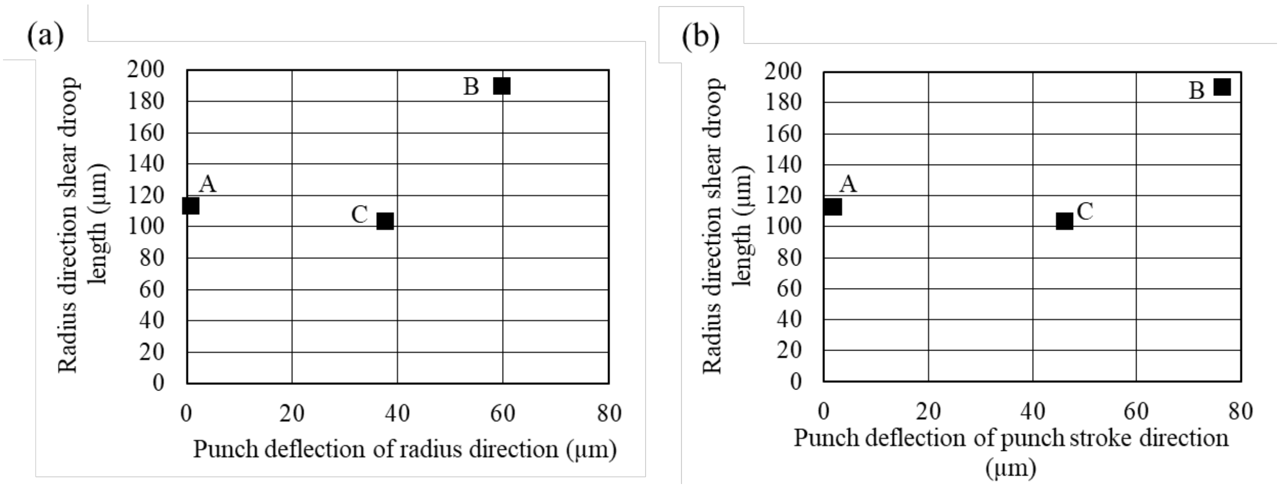

Fig. 9. Relationship between radius direction shear droop length and punch deflection. (a) radius direction shear droop length and punch deflection of punch stroke direction. (b) radius direction shear droop length and punch deflection of radius direction.

The reason why the radius shear droop length is minimized under condition C (lapping after nitriding) is discussed below. The punch used under condition C is hardened to 1200 HV by nitriding [8]. As shown in Table 1, this punch exhibited the smallest surface roughness. It is considered that the high hardness achieved through nitriding contributed to minimizing the surface roughness, which may have suppressed the activation of the oxygen-free copper surface during the shearing process. During the initial stage of rollover formation in punching, the punch tip meets the workpiece. This activated material tends to cause adhesion to the punch. However, as shown in Fig. 7, no adhesion of copper occurs at the punch tip in condition C, despite the presence of punch deflection. This implies that the process proceeds without the oxygen-free copper adhering to the punch surface. It is considered that this anti-adhesion performance provided by nitriding prevents the workpiece from being drawn into the die side and rolling over, thereby minimizing the radius shear droop length of the pierced hole.

Consider the relationship between the shear surface length and the amount of punch deflection. **Fig. 10** shows the relationship between the shear surface ratio and the deflection of the punch in the punch stroke direction. This figure shows that under the condition C, a punch deflection of 46 µm in the punch stroke direction ensures a shear surface ratio of 91 %. Generally, as punch deflection increases, shear droop length increases, leading to reduced fracture length and increased burrs height. Fig. 6 shows that no clear burrs were observed under condition C. Setting a narrow clearance of 15 µm, corresponding to a 3% plate thickness ratio, likely reduced the fracture length and created a shear state that suppressed burr formation.

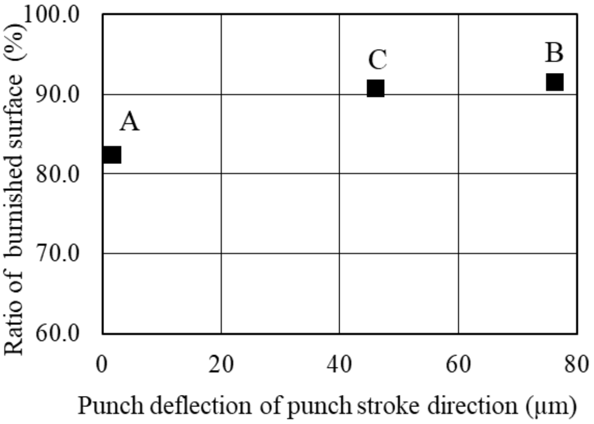

Fig. 10. Comparison of ratio of burnished surface and punch deflection in the punch stroke direction.

Based on the analysis thus far, it has been demonstrated that setting a punch deflection to approximately 50 µm - corresponding to a thickness ratio of about 10% - during shear processing of oxygen-free copper, followed by nitriding and then lapping, can optimize the shear characteristics of the punched holes.

In this experiment, the influence of punch deflection and punch geometry is supported only to a limited extent. It will be necessary to continue conducting experiments that separate their effects on the burnished-surface ratio, punch stroke, and radial shear droop length in future studies.

Conclusion

The following conclusions were obtained by punching oxygen-free-copper sheets.

1) The punch which undergoes nitriding followed by lapping enables activated oxygen-free copper to deform without adhesion, thereby minimizing the radius direction shear droop length of the punched holes.
2) To shearing oxygen-free copper with a thickness of 500 µm at a burnished surface ratio of 90%, it is effective to set the clearance to 0.015 mm (3% of the plate thickness ratio), set the deflection of the AISI D2 punch to approximately 50 µm (10% of the plate thickness), perform nitriding treatment, and then proceed with lapping.

References

[1] T. Iihara, K. Morikawa, K. Fukuoka, Y. Ito, K. Suehiro, S. Funaki, K. Maki, Development of MOFC-HR: high strength, high heat-resistance oxygen-free copper with superior shearing quality, Materia Jpn. 62.2(2023) 125-127.

[2] T. Ishiguro, K. Nakamura, N. Hayakawa, Y. Yoshida, N. Yukawa, T. Ishikawa, M. Murase, S. Murase, S. Nakano, K. Yoshida, Influence of product material property on tool wear in shearing process, Tetsuto-Hagane, 97-3(2011)99-107.

[3] E. Falconnet, J. Chambert, H. Makich, G. Monteila, Prediction of abrasive punch wear in copper alloy thin sheet blanking, Wear, 338-339(2015)144-154.

[4] F. Grebana, G. Monteilb, X. Roizard, Influence of the structure of blanked materials upon the blanking quality of copper alloys, J. Mater. Process. Techol., 186(2007)27-32.

[5] D. Z. Lubis1 I. Ristiawan, Blanking clearance and punch velocity effects on the sheared edge characteristic in micro-blanking of commercially pure copper Sheet, J. Mech. Sci. Technol., 1-2(2017)53-60.

[6] X. Li, X. Li, R.D.K. Misra, Z. Chen, Grain size effect on shearing performance of copper foil: A polycrystal plasticity investigation, Mech. Mater., 166(2022)104212.

[7] T. Shiratori, Y. Shiratori, T. Aizawa, Effect of tool surface condition on sheared surface in piercing of oxygen-free copper, Proc. 2024 Jpn. Spring Conf. Technol. Plast., (2024)139-140.

[8] T. Aizawa, K. Wasa, Low temperature plasma nitriding of inner surfaces in stainless steel mini-/micro-pipes and nozzles, micromachines, 8(2017)157.