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Surface Quality of Extruded Sidewall in Cold Backward Cup Extrusion with Low-Frequency Torsional Oscillation

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Abstract

The effect of torsional oscillation on surface quality of an extruded sidewall of a workpiece was investigated in backward cup extrusion with an extrusion ratio of 2.0 at room temperature. In this extrusion process, a cylindrical aluminum workpiece lubricated with mineral oil was extruded in the axial direction and simultaneously twisted in the circumferential direction between extrusion and knockout punches. The two punches were controlled with an axial speed of 0.1 mm/s, an alternating amplitude of 5 °, and a maximum angular speed of 0.5 rpm. The torsional oscillation tilted the traction direction at the container–workpiece from the radial direction to the circumferential direction with approximately 25% lower contact pressure on the container. As the results, the surface of the extruded sidewall was uniformly smoothed.

Keywords

Forging, Extrusion, Torsion, Friction, Surface

1. Introduction

To reduce axial load in forging process, the authors developed forging process with torsional oscillation. In this process, torsional oscillation around the forging axis was superposed with axial deformation. According to the theory of plasticity, plastic deformation of metals can be promoted by the combination of normal and shear stresses [1]. In our previous studies, maximum reduction in axial load was attained with larger than 20% under torsion/axial speeds higher than 60 °/mm in cold forging and cold backward cup extrusion [2, 3].

On the other hand, the authors aim not only to reduce the axial load but also to improve the properties of the forged products such as surface qualities, shape accuracy and microstructure in forging process with torsional oscillation. This is because the superposition of torsional moment during axial deformation is a well known method to change the stress and strain distributions in the workpiece. For example, crystallographic grain refinement of workpiece by applying large shear strain was reported in KOBO Type Forming with torsional moment in die forging [4]. The superposition of torsional moment

during axial deformation was also applied to friction test [5, 6] because the contact and sliding conditions between die and workpiece can be controlled. In forging process, the application of torsional moment is expected to change friction, lubrication and surface qualities of the forged product.

In this study, the effect of torsional oscillation on surface quality of extruded workpiece was investigated in cold backward cup extrusion. The relationship between the torsional oscillation conditions and the surface qualities is investigated through extrusion experiment on an originally designed equipment. The change in contact state between the die and the workpiece is discussed using the results of finite element simulation.

2. Extrusion process with torsional oscillation and procedures of experiment

Figure 1 shows the schematic illustration of the die layout, the punch shape and the surface groove of the punches for backward cup extrusion with torsional oscillation. A cylindrical workpiece inserted in the container was extruded by the extrusion punch in the z direction (the axial direction or height direction) and simultaneously twisted by the knockout punch in the θ direction (the circumferential direction) around the z -axis. The extrusion punch was moved to downward in the z direction, while the knockout punch was rotated or rotationally oscillated in the θ direction (not moved in the z direction). The diameter of the workpiece, the inner diameter of the container and the diameter of the extrusion punch were $\phi 13.9$ mm, $\phi 14$ mm and $\phi 10$ mm, respectively. The extrusion ratio was 2.0.

Backward cup extrusion with torsional oscillation was performed on using an originally designed equipment. Due to the capacities of the maximum load and torque of the apparatus, JIS A1070 aluminum cylinder was selected as the workpiece. The initial surface roughness of the outer surface of the workpiece was $Ra = 0.30\text{--}0.50$ μm . The mineral oil with a kinematic viscosity of 32 mm^2/s (at 313 K) was applied with a thickness of approximately 90 μm to the outer surface of the workpiece. The dies were made of JIS SKH51 high-speed tool steel (63 HRC). In the experiment, when the axial extrusion stroke reached 0.5 mm, the knockout punch started to rotate circumferentially around the extrusion axis. To grip and twist the workpiece by the two punches, knurled grooves with a depth of 0.4 mm and a vertical angle of 60° were prepared with a crossing angle of 120° and a pitch of 0.8 mm on the end surfaces of the punches, as shown in **Fig. 1(c)**. From our previous report of upsetting with torsional oscillation [2], the axial extrusion speed was set to $v = 0\text{--}0.1$ mm/s, while the rotation speed and amplitude were set to $\omega = 0\text{--}0.5$ rpm ($0\text{--}0.05$ rad) and 5° ($\pi/36$ rad), respectively. The maximum frequency of the torsional oscillation was 0.15 Hz.

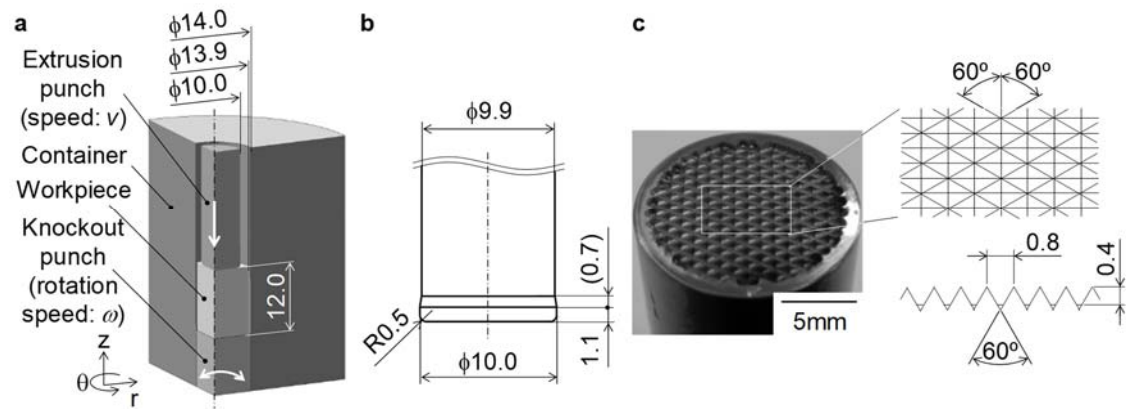


Fig. 1 **a** Layout of dies and workpiece, **b** Detail of end shape of extrusion punch, **c** Groove on end surface of punches

3. Experimental results

3.1 Appearance and surface roughness of outer surface of extruded workpiece

Figure 2 shows the appearance of the outer surface of the extruded workpiece. The surface defects of the extruded workpiece were caused by turning marks in the initial workpiece because the adhesion of the workpiece was not observed at the surface of the container. The surface defects were stretched in the extrusion (z) direction of the workpiece in extrusion without torsional oscillation. On the other hand, the length of the surface defects was shortened in the circumferential direction and was tilted from the radial direction to the diagonal direction in extrusion with torsional oscillation. It means that the surface defects are elongated and shallowed by the torsional oscillation.

The surface profile of the outer surface of the extruded workpiece in the extrusion direction is shown in **Fig. 3**. The surface profile was measured by a 2D stylus type profilometer along the extrusion direction. The surface was roughened due to the stretching of the surface defects as above described in extrusion without torsional oscillation, while the surface was smoothed as the rotation speed increased in extrusion with torsional oscillation.

Figure 4 shows the relationship between the surface roughness on the outer surface of the extruded workpiece and the accumulative rotation angle of the knockout punch (accumulative twisted angle of the workpiece, θ_{acc}). The surface roughness was measured at 16 locations of which four places every 4.0 mm in the extrusion direction of the extruded workpiece and four places every 90° in the circumferential direction. The average and standard deviation of the surface roughness decreased with increasing accumulative rotation angle in the range of $0^\circ < \theta_{acc} < 360^\circ$. The average and standard deviation of the surface roughness were lower than the initial in the range of $200^\circ < \theta_{acc} < 360^\circ$. It was confirmed that the outer surface of the workpiece was flattened and the unevenness of the surface roughness was reduced by applying torsional oscillation during extrusion. This implies that torsional oscillation was effective for reducing the unevenness of the lubrication state because the lubricant was squeezed not only in the extrusion

direction but also in the circumferential direction between the container and the workpiece. However, excessive torsion deteriorated the surface qualities of the extruded workpiece because the average and standard deviation of the surface roughness increased with increasing accumulative rotation angle in the range of $\theta_{acc} > 360^\circ$.

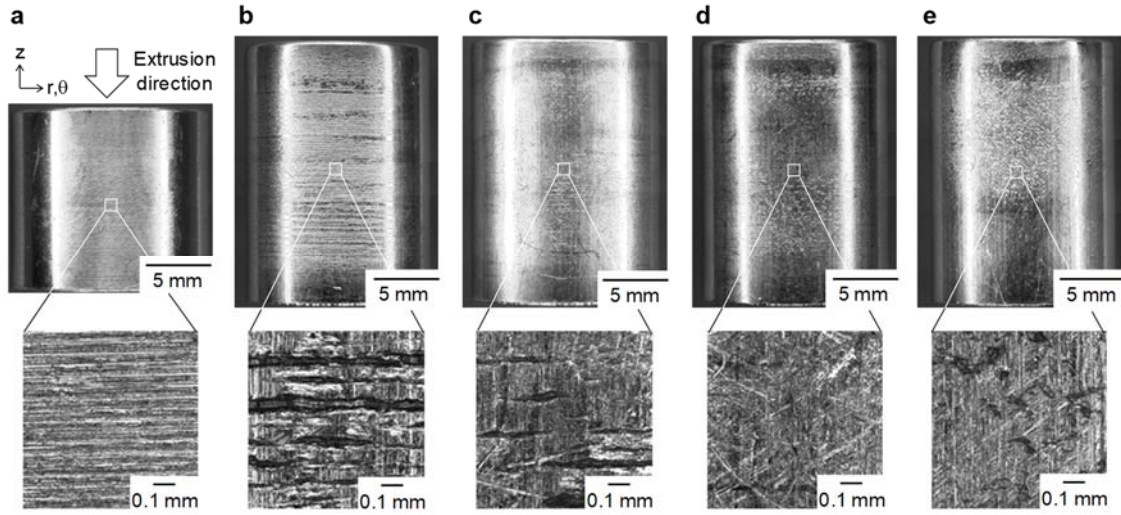
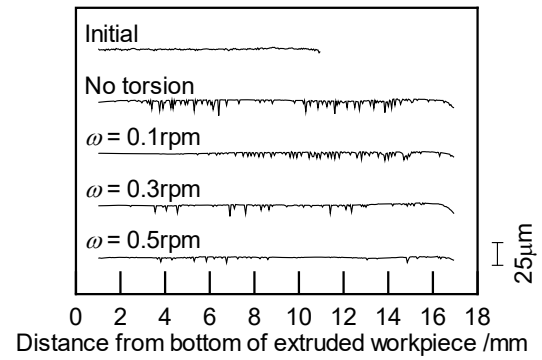


Fig. 2 Photographs of outer surface of extruded workpiece in backward extrusion with torsional oscillation ($v = 0.1$ mm/s, axial stroke: 6.0 mm), **a** Initial workpiece, **b** $\omega = 0$ rpm, **c** $\omega = 0.3$ rpm ($\theta_{acc} = 83^\circ$), **d** $\omega = 0.5$ rpm ($\theta_{acc} = 165^\circ$), **e** $\omega = 0.5$ rpm ($\theta_{acc} = 165^\circ$, one-way) (θ_{acc} : accumulative rotation angle of knockout punch)

Fig. 3 Surface profile of outer surface of extruded workpiece in backward extrusion with torsional oscillation ($v = 0.1$ mm/s, axial stroke: 6.0 mm)



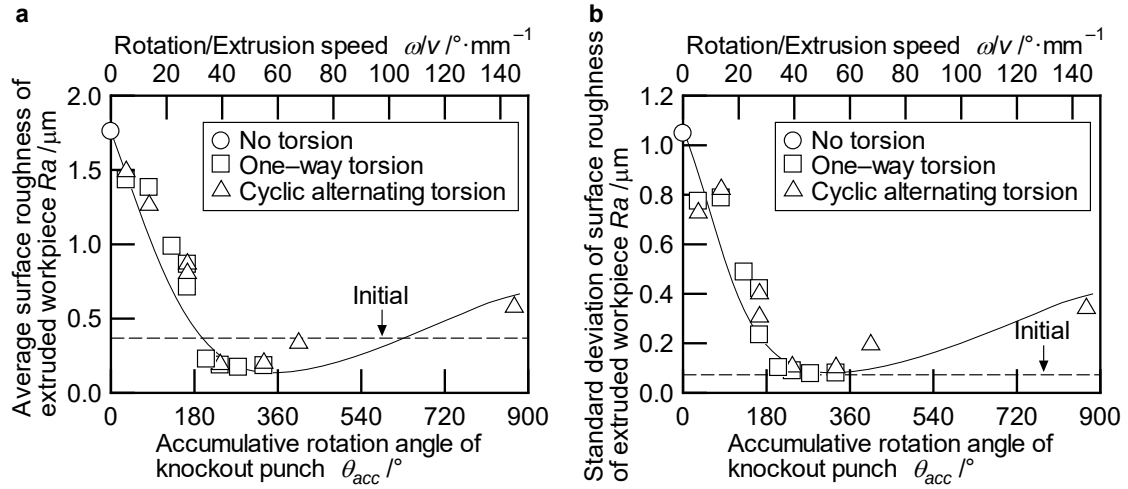


Fig. 4 Relationship between surface roughness at outer surface of extruded workpiece and rotation angle of knockout punch in backward extrusion with torsional moment ($v = 0\text{--}0.1 \text{ mm/s}$, $\omega = 0.5 \text{ rpm}$, axial stroke: 6.0 mm), **a** Average surface roughness, **b** Standard deviation of surface roughness

3.2 Deformation behavior of indentation of outer surface of workpiece during extrusion

To investigate the sliding behavior of the workpiece at the container–workpiece interface, four hemispherical indentations were prepared at a height of 6.0 mm from the bottom and 90° intervals in the circumferential direction in the outer surface of the initial workpiece using a Rockwell hardness tester. The diameter and depth of the indentation were approximately 0.56 mm and maximum 0.13 mm , respectively.

Figure 5 shows the photograph of the indentation of the extruded workpiece. The indentation was deformed to ellipse slightly stretched in the extrusion direction in extrusion with/without torsional oscillation (**Fig. 5b** and **c**). The indentation was deformed to ellipse with a high aspect ratio tilted toward the torsional direction in extrusion with one-way torsional moment (**Fig. 5d**). The relationship between the indentation shape of the extruded workpiece and the accumulative rotation angle of the knockout punch is shown in **Fig. 6**. Here the indentation shape was measured by a laser microscope with image processing function. The accumulative rotation angle of the knockout punch was equal to the accumulative twisted angle of the workpiece because the workpiece was twisted by the knurled grooves of the punches without slipping. The cross-sectional area of the indentation became large in extrusion with torsional oscillation, while the depth of the indentation became shallow with increasing accumulative rotation angle. As the results, the volume of the indentation decreased with increasing accumulative rotation angle. It was confirmed that the outer surface of the workpiece was smoothed by applying torsional oscillation during extrusion.

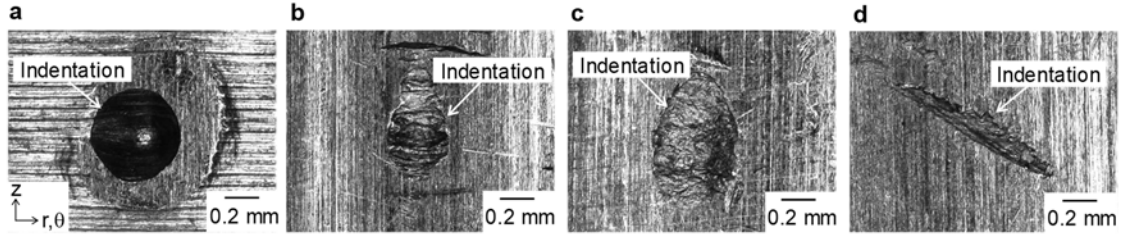


Fig. 5 Photographs of hemispherical indentation at outer surface of extruded workpiece in backward extrusion with torsional oscillation ($v = 0.1$ mm/s, axial stroke: 6.0 mm), **a** Initial workpiece, **b** $\omega = 0$ rpm, **c** $\omega = 0.5$ rpm ($\theta_{acc} = 165^\circ$), **d** $\omega = 0.5$ rpm ($\theta_{acc} = 165^\circ$, one-way)

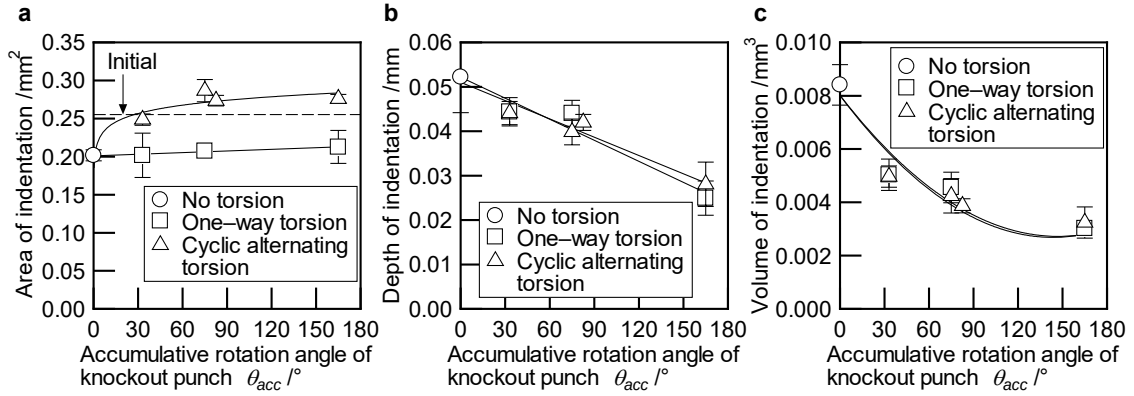


Fig. 6 Relationship between hemispherical indentation shape at outer surface of extruded workpiece and accumulative rotation angle of knockout punch in backward extrusion with torsional moment ($v = 0.1$ mm/s, axial stroke: 6.0 mm), **a** Cross-sectional area, **b** Maximum depth, **c** Volume

4. Discussions by finite element analysis

4.1 Finite element analysis conditions

The elastic-plastic deformation and temperature change of the workpiece in extrusion were analysed by a commercial three-dimensional finite element code, Simufact Forming ver. 15.0 (MSC Software Company). In the analysis, the material properties of the aluminum workpiece were employed from the built-in database of material properties in Simufact Forming ver. 15.0. The model of the flow stress was isotropic hardening model. The temperature dependences of the flow stress, the Young's modulus, the thermal conductivity, and the specific heat were taken into account in the analysis, and the strain rate sensitivity of the flow stress was also taken into account.

The dies were treated as rigid bodies under isothermal state, and the end surfaces of the punches were assumed to be flat (no knurled grooves). To grip the workpiece for circumferential twisting, the frictional condition at the end surface of the punch–workpiece interface was assumed to be sticking (no sliding), while the frictional condition at other part of the container–workpiece interface was shear friction

factor $m = 0.2$. The heat transfer coefficients on the die–workpiece interface and the free surfaces of the workpiece were assumed to be $5000 \text{ W}/(\text{m}^2 \cdot \text{K})$ and $50 \text{ W}/(\text{m}^2 \cdot \text{K})$, respectively.

4.2 Rotation speed and contact pressure between container and workpiece

Figure 7 shows the calculated circumferential rotation speed of the outer surface of the workpiece in backward extrusion with one-way torsional moment. The rotation speed of the workpiece gradually decreased from the bottom of the workpiece to the height position of the end surface of the punch, while the rotation speed of the extruded sidewall of the workpiece (the distance from the bottom of the workpiece: longer than 8 mm) was constant at 20–40% of the rotation speed of the knockout punch. It is found that the part of the workpiece sandwiched between the extrusion and knockout punches was circumferentially twisted during extrusion, while the sidewall part of the extruded workpiece was not twisted during extrusion.

The calculated contact pressure between the container and the workpiece in backward extrusion with torsional moment was shown in **Fig. 8**. The contact pressure in extrusion with torsional moment was reduced by approximately 25%. This is due to the traction direction at the container–workpiece is tilted from the radial direction to the circumferential direction by torsional moment during extrusion.

The above circumferential sliding of the workpiece and the reduction in contact pressure at the container–workpiece are suggested to influence the surface quality of the outer surface of the extruded workpiece. It was also reported that surface roughness of JIS A1050 aluminum was smoothed to approximately 10% in sliding with longer than 0.25 mm under contact pressure with higher than 150 MPa [7]. Therefore, the changes of the indentation shape in Section 3.1 and the surface roughness in Section 3.2 are reasonable.

Fig. 7 Circumferential rotation speed of outer surface of workpiece in backward extrusion with one-way torsional moment (axial stroke: 4.0 mm, FEM)

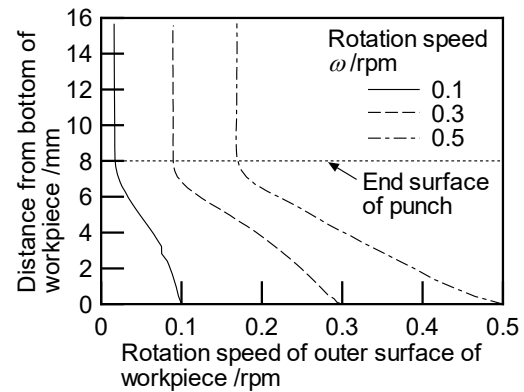
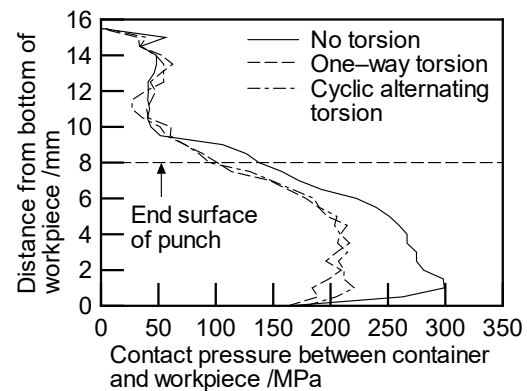


Fig. 8 Contact pressure between container and workpiece in backward extrusion with torsional moment (axial stroke: 4.0 mm, $\omega = 0.5$ rpm, FEM)



5. Conclusions

In this study, the effect of torsional oscillation on surface quality of extruded workpiece was investigated in cold backward cup extrusion. Torsional oscillation with a maximum frequency of 0.15 Hz around the extrusion axis was applied on axial extrusion. The relationship between the torsional oscillation conditions and the surface properties was investigated by experiment and the finite element simulation. The following remarks were obtained.

- 1) The torsional oscillation tilts the traction direction at the container–workpiece from the radial direction to the circumferential direction. The contact pressure between the container and the workpiece is reduced by approximately 25%.
- 2) The average and standard deviation of the surface roughness of the outer surface of the extruded workpiece are lower than the initial by applying the torsional oscillation with accumulative torsion angle of 200 °–360 °.

Acknowledgements

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References

- [1] Bridgman PW (1964) Studies in large plastic flow and fracture. Harvard University Press. 247-278. doi:10.4159/harvard.9780674731349
- [2] Matsumoto R, Kou J, Utsunomiya H (2017) Reduction in axial forging load by low-frequency torsional oscillation in cold upsetting. Int. J. Adv. Manuf. Technol. 93:933-943. doi:10.1007/s00170-017-0553-1
- [3] Matsumoto R, Takatsuka S, Utsunomiya H (2019) Reduction in axial extrusion load by low-frequency torsional oscillation in cold backward cup extrusion. Proc. 52nd Int. Cold Forging Group Plenary Meeting (ICFG 2019) 143-148.

- [4] Korbel A, Bochniak W (2004) Refinement and control of the metal structure elements by plastic deformation. *Scr. Mater.* 51:755-759. doi:10.1016/j.scriptamat.2004.06.020
- [5] Hansen B G, Bay N (1986) Two new methods for testing lubricants for cold forging. *J. Mech. Work. Technol.* 13:189-204. doi:10.1016/0378-3804(86)90065-3
- [6] Sawamura M, Yogo Y, Kamiyama M, Iwata N (2014) Measurement of friction coefficient by backward extrusion with rotating tool under severe forming conditions. *Procedia Eng.* 81:1866-1871. doi:10.1016/j.proeng.2014.10.247
- [7] Nakamura T, Kondo K, Nishigaya T (1990) Smoothing conditions of workmetal surface in metalworking processes (effects of contact pressure and relative slip displacement). *Trans. Jpn Soc. Mech. Eng. Ser. C* 56:2794-2801. (in Japanese) doi:10.1299/kikaic.56.2794