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Experimental study of miniaturized tip test

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Abstract

A tip test was developed and used successfully for friction measurement between the billet and dies or punches for the cold forging process. In the present investigation, the test was downsized and experimentally investigated to find the size effect on test results. For the test, aluminum alloys of 2024-O and 6061-O were used and the specimen was made into a cylinder of diameter and height of 10.0mm and 5.0mm, respectively. For lubrications, VG32, VG100, grease, and corn oil were used in experiments and tests were also carried out with two different humidity conditions. A micro-hardness test was made to compare the hardness distribution with the strain distribution obtained from the finite element simulation. The load levels and tip distances were measured for Al6061-O specimen with various lubrication conditions and compared to each other to find any correlation between the two. The shear friction factors were determined for various lubrications by using the finite element simulation under the present condition.

Keywords: Tip test; Friction measurement; Finite element simulation; Size effect

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1. Introduction

In metal working processes, friction is generated at the interface between the billet and dies or punch. Because of frictional forces in the process, deformation loads are increased, internal structure and surface characteristics (surface finish and surface defects) of the product are affected, wear is produced on the tooling material, thus reducing its life, and dimensional variations are introduced in the billet. Therefore, friction is considered to be a major variable in metal working processes and must be adequately controlled to optimize the processing condition for economically producing material with the desired geometry and surface characteristics.

To measure friction, the ring test had been the most widely used due to simplicity, but did not work properly when the deformation level was higher as shown in Fig. 1. In addition, it required a non-linear calibration curve to determine the shear friction factor. To overcome such a problem, several tests [1-3] based on backward extrusion or forward and backward extrusion, have been developed. These tests were better suited for predicting the friction levels in the cold forging process involved with the large surface expansion and higher pressure distribution along the punch compared to the interface between the billet and dies. However, these methods required the non-linear calibration curve to determine the shear

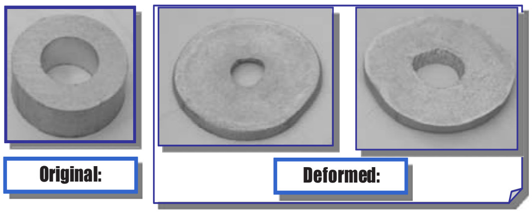

Fig. 1. The compressed specimens at higher deformation level in the ring test of aluminum alloy.

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friction factor as well.

Recently, Im, et al. [4-6] proposed the tip test to solve this problem. It is based on backward extrusion in which a radial tip is formed on the extruded end of the billet to separately measure the frictions at the punch and die interfaces with the billet. In the tip test using a cylindrical specimen with the diameter of 30 mm and height of 15mm, experimental work revealed that the radial tip distance and maximum forming load increased depending on the various lubricants at the billet and punch or dies interfaces. Moreover, the relationship between the maximum forming load and radial tip distance was linear for each lubricant. This suggested that simple geometrical measurement of this radial tip distance in experiments can be used effectively as an indicator of the friction condition**.** Then, finite element analyses with CAMP*form*-2D [7] were used to determine the value of shear friction factor m_f in the constant shear friction model [8].

In the previous studies [5, 6], it was also found out that the friction conditions at the punch and lower die interfaces with the billet were different. The friction condition on the punch (m_{fp}) was higher than that on the lower die (m_{fd}). The ratio between the two ($x = m_{fp} / m_{fd}$) has been quantitatively determined with the help of numerical simulations, depending on the material used for investigations.

Based on such investigations, Kang, et al. [9] have determined the following non-dimensional equations for the materials investigated to find the shear friction factor with different lubricants as $m_{fp} = 4.35 \times d/t - 0.95$, where d is the tip distance, t the thickness of the extruded part, and m_{fp} the shear friction factor at the punch and billet interface. Once the tip distance is measured, the friction conditions at both punch and die interfaces with the billet can easily be determined from this equation and the ratio between m_{fp} and m_{fd}.

In the present study, the tip test was downsized and applied to a smaller specimen to investigate whether the earlier findings on friction measurements will be recovered. For tests, aluminum alloys of 2024-O and 6061-O were used and a smaller tip test apparatus was designed and manufactured. In order to consider the environmental friendliness of the lubricant, corn oil was selected and the humidity varied in experiments.

2. Experimental

The tip test experiments were performed with the experimental set-up illustrated in Fig. 2. The upper punch was moving downward while the counter punch and lower die (container) were stationary. To apply the load, an MTS press with a maximum load of 100kN and variable ram speeds was used. The punch velocity was fixed as 5mm/s in the present experiment. Two different aluminum alloys were used for experiments, Al2024-O and Al6061-O.

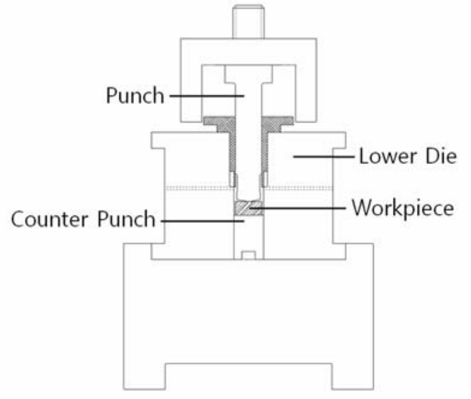
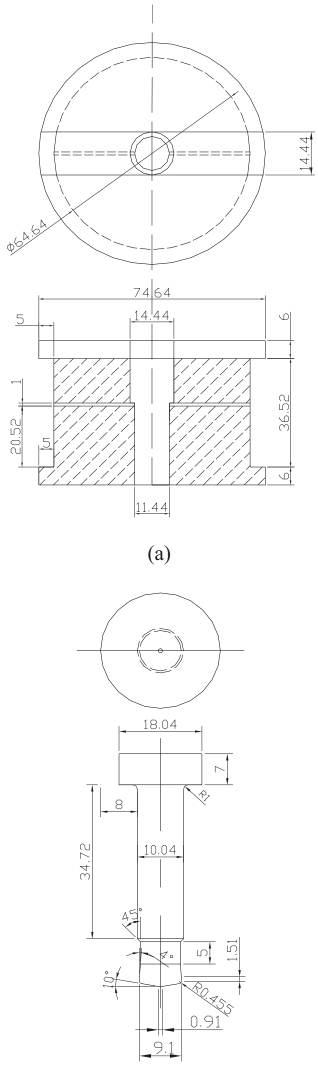


Fig. 2. Experimental set-up for the downsized tip test.

Before experiments were performed, full annealing was applied to the billet sample. To anneal experimental specimens, the aluminum alloy specimens were heated from room temperature to 415°C and kept at this temperature for three hours. Then, the specimens were cooled at a heat extracting rate of 30°C/h to 265°C and finally exposed to air-cooling until reaching room temperature.

The punch and container for the tip test used were made of tool steel alloy AISI D2 and were chromium coated and polished. The dimensions of the punch and lower dies used for the downsized tip test can be seen in Fig. 3. The cylindrical billet was made of a cylinder with a diameter of 10.0 ± 0.035mm and height of 5.0 ± 0.030mm. Billet samples were polished to 0.8μm in terms of arithmetic mean value of R_a in the upper and bottom sides and 0.5μm in terms of R_a in the circumferential side.

Two kinds of mineral oil with different kinematic viscosity (VG 32 Viscosity: 32 Centistokes and VG 100 Viscosity: 100 Centistokes), grease and cooking corn oil (Viscosity: 72 Centistokes), were used as lubricants in tip tests. For lubrication, the dies were cleaned with acetone and then the lubricants were brushed manually. Three experiments were carried out for each lubricant. The stroke was limited up to 3.8mm in each experiment because of the capacity of



(a)

(b)

Fig. 3. Dimension of (a) lower die (container) and (b) punch used in the downsized test in mm.

the MTS.

In order to obtain the material property, a compression test was carried out with the same cylindrical specimen used for the tip test. In Fig. 4, the stress-strain curves obtained from the present and earlier compression tests using the larger specimens are compared for both materials under lubrication with grease. This figure shows that the change of material response was negligible for the current specimen sizes considered. In simulations, the stress and strain relations obtained for the smaller specimens were used.

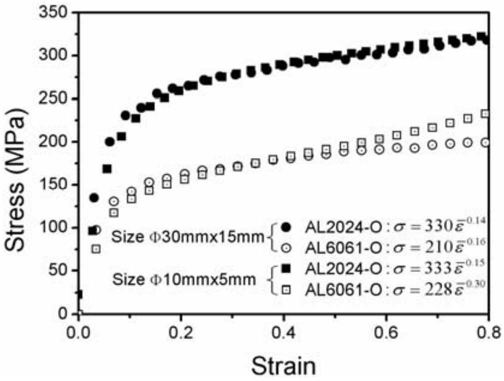
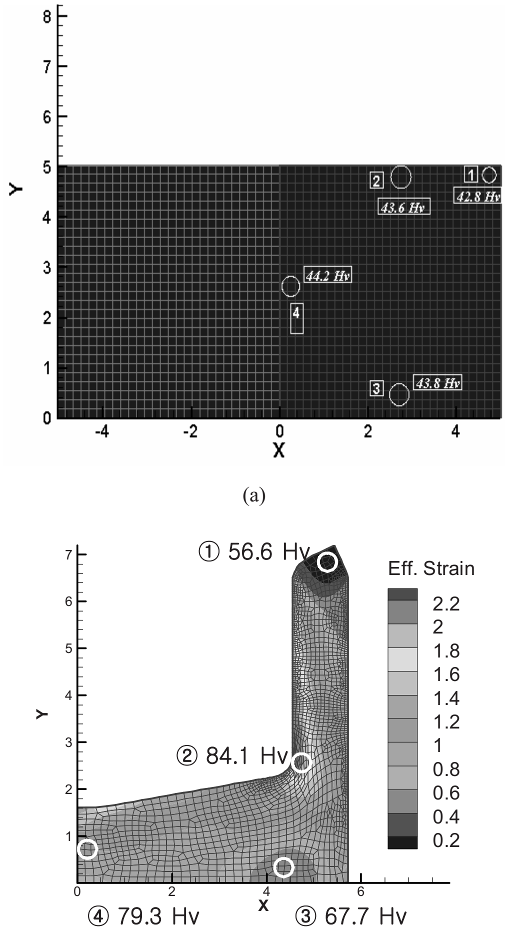


Fig. 4. Comparison of the stress-strain curves for both materials obtained from the present and conventional tip tests using smaller and larger specimens, respectively.



(a)

(b)

Fig. 5. Comparison between hardness and strain distributions between (a) non-deformed and (b) extruded samples using Al 6061-O with lubricant of VG32.

To confirm the validity of numerical simulations, the hardness distribution was obtained by a micro-hardness test in a Vickers Scale (Hv) that was applied on the sample of Al6061-O before and after extrusion under the lubrication of VG 32. The load applied was 0.0005N and the speed of the pick was 10μs during 30s. The hardness test was carried out for 4 points on the half of the sample due to axi-symmetry. The locations are indicated by circles in Fig. 5, including the number of positions and values of the hardness measured.

3. Numerical

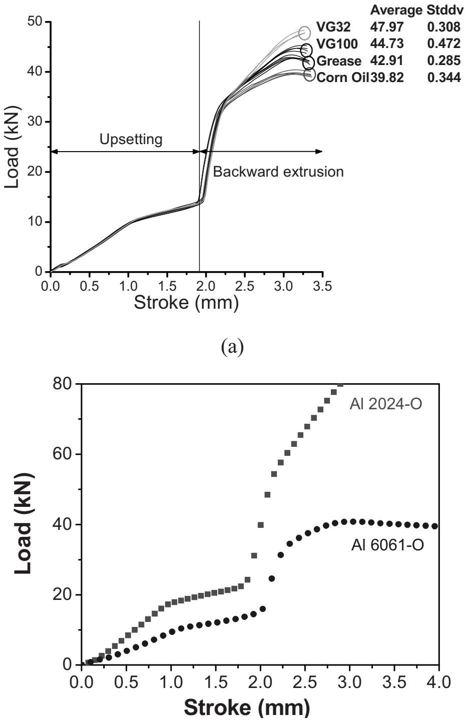
An in-house finite element program for bulk metal forming analyses, CAMP*form*-2D [7], was used for numerical simulations and calibrations. This program was developed based on the rigid-thermoviscoplastic approach proposed by Kobayashi, et al. [8]. Since the detailed finite element formulations are available in the same reference, they are omitted here.

To confirm the validity of applying CAMP*form*-2D for the present simulations, the strain evolution in the billet with m_{fd} of 0.1 was compared with the result of the hardness distribution obtained from the micro-hardness tests in Fig. 5(b). In this figure, the hardness test on a backward extruded sample confirms the similar tendency of the strain evolution obtained from the finite element simulation with CAMP*form*-2D. The levels of the measured hardness were dependent on the strain levels obtained from simulations. Consequently, CAMP*form*-2D was indirectly believed to be reliable for simulations of the tip test.

4. Results and discussion

The load-stroke curves measured in experiments are shown in Fig. 6. In this figure two modes of deformation are clearly observed. At first, upsetting of the billet occurs at earlier deformation stage and then the backward extrusion follows later as expected. This behavior is typical in the tip test. The same kind of load-stroke curves were obtained with the earlier tip-test reported in references [4-6] with the larger specimens of the diameter of 30mm.

It was also found out in this figure that the corn oil represented better lubricity for the present experimental condition than classical lubricants used for the same process requiring the lowest load level. The lubricity is known to be dependent on the viscosity and oiliness. Since the oiliness of the corn oil might be better than VG100 and grease, the load level for corn oil was lower than those for VG100 and grease. Thus, if the material cost is acceptable, the corn oil can be an alternative environment friendly lubricant in cold forging.



(a)

(b)

Fig. 6. Load-stroke curves obtained from the tip test of (a) Al 6061-O and (b) comparison of load values between the two aluminum alloys.

For Al6061-O, the maximum load was saturated to a plateau at the stroke of 3.0mm as in the conventional tip test shown in Fig. 6(b). With Al2024-O, however, a more powerful press was required to obtain such behavior as shown in the same figure. Because of limitation of capacity of the MTS used, the experiment with Al2024-O was not continued.

By comparing the experimental results with the original tip test results, the maximum load values were varied depending on the lubricant. So the tip test is a good and simple test to differentiate the lubrication conditions for smaller specimens as well. However, it was found that the difference in average tip distances of the downsized tip test by applying various lubricants was not as large as the original tip test.

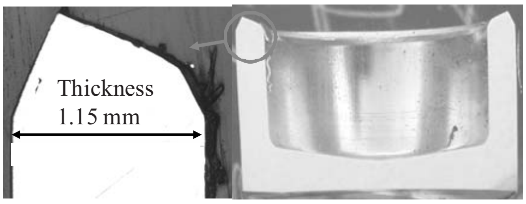


Fig. 7. Deformed billet and extruded tip formed using Al 6061-O specimen.

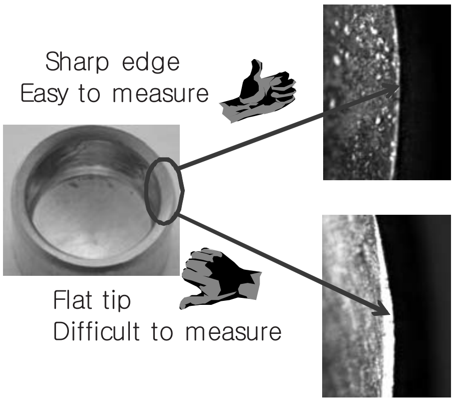


Fig. 8. Difficulty in measuring the tip distance due to the shape of the tip.

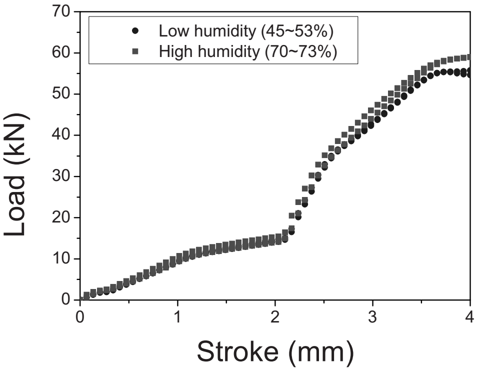


Fig. 9. Environmental factor during the downsized tip test using Al 6061-O specimen.

In the downsized tip test, the accuracy of the measurement device appeared to be critical for determining the tip distance because of the relatively small size of the dimension as shown in Fig. 7. Thus, a microscope equipped with a micrometer (0.1μm in precision) and monitor was used in measuring the tip distance accurately. In addition, great care must be given during preparation of the specimen and measurement.

When the billet sample, including cutting, lathing and polishing, etc., is not carefully prepared, the edge might be damaged. In this case, the tip was not sharp enough to get precise measurement as shown in Fig. 8.

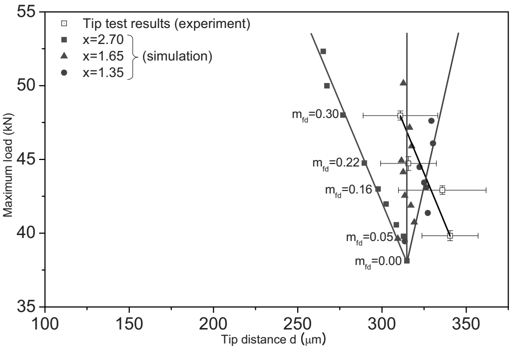


Fig. 10. Maximum load vs. tip distance determined in downsized tip test of Al 6061-O.

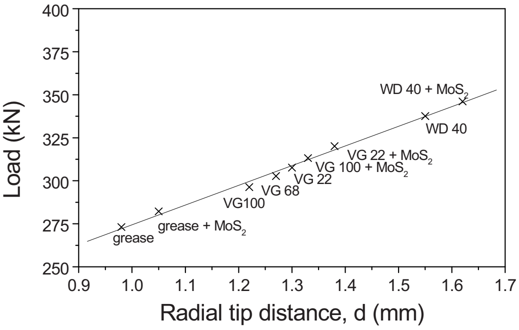


Fig. 11. Position of radial tip from the inner wall of the lower die with the conventional tip test from reference (Im et al. [4]).

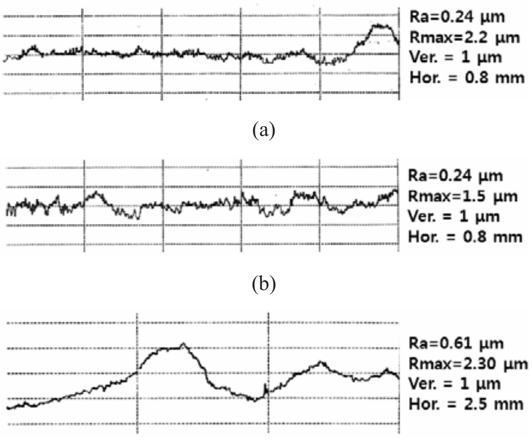
To check the effect of humidity on friction measurements the tests were carried out for higher (70~73%) and lower humidity (45~53%) conditions as shown in Fig. 9. Under the circumstance with higher humidity, a higher load was observed in this figure at the larger stroke compared to the one of the lower humidity. According to this interesting result, the downsized tip test results were dependent on the humidity levels. In general, humidity creates a thin oxidized layer on the billet surface which interferes with lubrication at the billet surface. This might contribute to the load variations although the detailed investigation is necessary.

The tip-distances were measured at four different locations for each sample and arithmetically averaged. The average of maximum load was plotted as a function of the average of tip distances in Fig. 10. In this figure, the tip distance decreased with increasing the friction, contrary to the conventional tip test results with a larger specimen of the radius of 30mm as recaptured in Fig. 11. In a conventional tip test the slope was positive as shown in this figure and the friction condition at the punch interface was determined to be higher than the one at the lower die interface. So the tip tended to move toward the punch until its final position was reached.

Contrary to this, the opposite tendency occurred in the present investigation as shown in Fig. 10. According to this result, it was construed that the friction condition at the surface of the counter punch and inner wall of the lower die might be higher than that on the punch. The surface roughness test and finite element simulation confirmed this deduction.

A surface roughness test for the punch and dies was made by using a Mitutoyo SURFTEST 301. As shown in Fig. 12, the surface roughness was measured to be 0.24μm for the flat surface of the punch, 0.24μm for the circumferential lower die and 0.61μm for the counter punch in terms of R_a. Since the surface of the counter punch was polished manually, it was wavy as shown in Fig. 12(c). Because of this waviness, the friction condition at the lower die interface seemed to be higher in the present investigation.

To calibrate the shear friction factor for the present case, numerical simulations were made with CAMP*form*-2D by applying a ratio of $x = m_{fd}/m_{fp}$ = 1.35, 1.65, and 2.70 between the shear friction factor at the lower die interface (m_{fd}) and the one at the punch interface (m_{fp}). According to the simulation results in Fig. 10, a negative slope between the forming load and tip distance was recovered for the case of x = 2.70. In this figure it is clearly shown that the slope is dependent on the ratio between the friction conditions at the lower die and punch (x). According to the experimental results, the tip distance and maximum load can be assumed to be linear in Fig. 10.



(c)

Fig. 12. Surface profiles of (a) the punch, (b) circumferential lower die, and (c) counter punch.

By comparing the slope between experiment and simulation in Fig. 10, the x value of 2.70 was selected. Considering the variations of the measurement data involved with experiments due to the size effect of the specimen, the difference of the values between simulations and experiments is acceptable. Under the present condition, the shear friction factors at the lower die interface (m_{fd}) for VG32, VG100, grease, and corn oil were determined to be 0.30, 0.22, 0.16, and 0.05 in that order. These values are reasonable compared to the data obtained in the conventional tip test.

5. Conclusions

This study shows the feasibility and reliability of the downsized tip test to determine the shear friction factors in cold forging with smaller specimens. The experiments recovered the linear relationship between the measured tip distance and load requirements for Al6061-O specimen under various lubrication conditions. Depending on the surface qualities of the upper punch and lower dies including the counter punch, the slope between the measured tip distance and load requirements was varied. Consequently, the tip test was found to be effective in determining the level of friction condition depending on the surface roughness of the tools. In addition, the downsized tip test can be used for differentiating the effect of humidity on the level of forging load requirements as well. According to the present investigation, corn oil was found to be an environment-friendly lubricant for cold forging. Further experimental studies are needed to verify the effect of surface roughness of the punch and dies to the relationship between the maximum load and tip distance.

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