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Effect of Hardening Rule for Spring Back Behavior of Forging

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Abstract

Geometrical discrepancy between formed part and designed one is one of the major problems for metal forming processes. Spring back behavior is one of the most important factors on the discrepancy, in not only sheet metal forming but also cold forging process. For cold forging process, it is difficult to observe the change in geometry of forgings before and after release of tools/dies, since the workpiece during forging is covered by tools/dies in most cases. Uncertainty remains for the precision on geometrical prediction after spring back of the cold forged part. In the present research, the diameters of extruded shaft at the bottom dead center and after the release of tools/dies were measured to investigate the spring back behavior in the cold forging process. As a result of experiment, the diameter of extruded shaft was increased at the bottom dead center by spring back and decreased after the release by re-extrusion. For these series of change in diameter, FE analyses using isotropic and kinematic hardening models were performed in order to evaluate influence of spring back on the material hardening models in forging process. For kinematic hardening model, Yoshida-Uemori model modified for large strain region was employed. As a result of calculation, both the isotropic and kinematic hardening models showed the similar tendency on the change in diameter with the experimental one.

Keywords: cold forging; stainless steel; Bauschinger effect; kinematic hardening model; FEM.

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1. Introduction

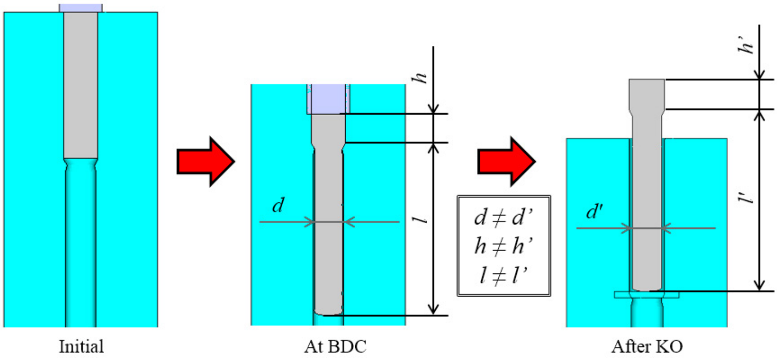
Recently, in metal forming processes typified by forging or sheet metal forming, Finite Element (FE) simulation has been actively used for the design of die/tool and process in production engineering and shop floor. FE software for metal forming process has also been developed as dedicated codes. In particular, the simulation has been recognized to be effective for the prediction of spring back behavior; the difference of formed shape to the designed one. The employment of non-linear kinematic hardening (NLKH) model has been approved to be effective for predicting spring back behavior [1]. By applying them, more accurate prediction of geometry has been performed in sheet metal forming process [2-5].

On the other hand, in case of bulk metal forming such as cold forging, the FE simulation isotropic hardening (IH) model is commonly used, because the accumulated plastic strain $\overline{\varepsilon^{p}}$ often exceeds around 1.0 during the process. In cold forging, however, the required geometric accuracy in simulation has been toward the order of 0.01 mm, which is as the same level as deformation by spring back of forgings. Moreover, in case of multi-stage forging, the control of geometry at each process is quite important. In most cases, however, it is difficult to measure the geometry of forgings before release of tools/dies, since the workpiece during forging is covered by tools/dies except for open die forging process. Therefore, the level in prediction of spring back for forging process by FE simulation has not been as high as for sheet metal forming process.

In the present research, cold forward extrusion as a typical cold forging process is adopted. Figure 1 shows the schematic illustration of typical cold forward extrusion process. If the shaft does not contact to the die surface, the diameter of shaft will be freely increased due to the spring back. Then, the shaft is extruded again when the workpiece is knocked out. As a result, the diameter of shaft decreases closed to the designed value. Therefore, the spring back behavior in cold forging can be evaluated by measuring the change in extruded shaft diameter. In detail, experiment of cold forward extrusion and the FE simulation are carried out. Then the shaft diameter at the bottom dead center (BDC) and after the knockout (KO) is measured and evaluated. In the FE simulation, IH and NLKH model are used as material hardening rules. For NLKH model, YU model modified for taking the work hardening for the large strain [6] is used.

2. Experiment of cold forward extrusion for evaluation of spring back

In order to investigate the spring back in cold forging process, cold forward extrusion and shaft diameter measurement were carried out. The experiments were performed using a Direct Servo Former NS1-1500(D) by Aida Engineering, Ltd. Figure 2 shows the sectional view of the die and the detail dimension. The die can be separated at the position of 10mm below the forming section. The shaft diameter at the BDC can be measured after removing the upper die while the workpiece being in place after forming. Figure 3 shows the state of the shaft diameter measurement at the BDC and evaluation method. The measurement was carried out using Laser probe contour measuring instrument (MLP-2) by Mitaka Kohki, Co., Ltd. The diameter of cross sections were measured from the tip to 20 mm at every 2.0 mm along the axial direction. The diameters in x and y directions of cross sections were measured. The averaged value was used as the shaft diameter of each cross section. SUS304 wire rod subjected to drawing after solution



Initial At BDC After KO

Fig. 1. Schematic illustration of forward extrusion process

treatment was used as the workpiece. Metal working fluid FZ-4101 by Chukyo Kasei Kogyo Co., Ltd. was used as the lubricant. The forming was carried out at two different average punch speed of 11.67 and 350 mm/sec. Figure 4 shows the change in diameter of the extruded shaft when average punch speed at the forming is 350 mm/sec. Figure 4 also shows the calculated results by IH and YU models discussed in the Section 3. The diameter at the BDC is larger than that of the forming section due to the spring back behavior. The diameter at 11.67 mm/sec was larger than that at 350 mm/sec. Regardless of the punch speed, a similar tendency that the diameter at the end tip side of the shaft was larger was observed. The diameter after the KO is smaller than that at the BDC. This is because the re-extrusion occurred again at the forming section when the workpiece was knocked out.

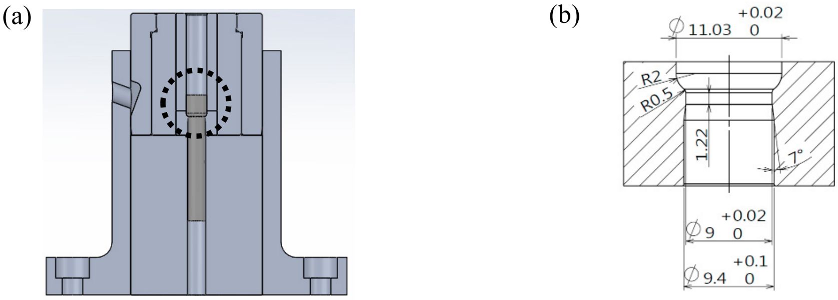


Fig. 2. Forward extrusion die (a) Sectional view of die; (b) Detailed view of die with dimension of forming section

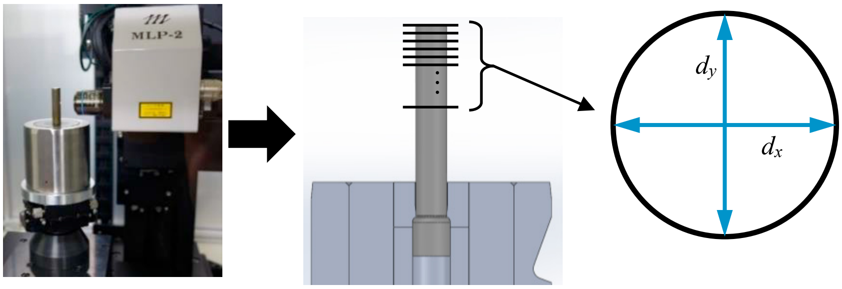


Fig. 3. State of the shaft diameter measurement at BDC and evaluation method

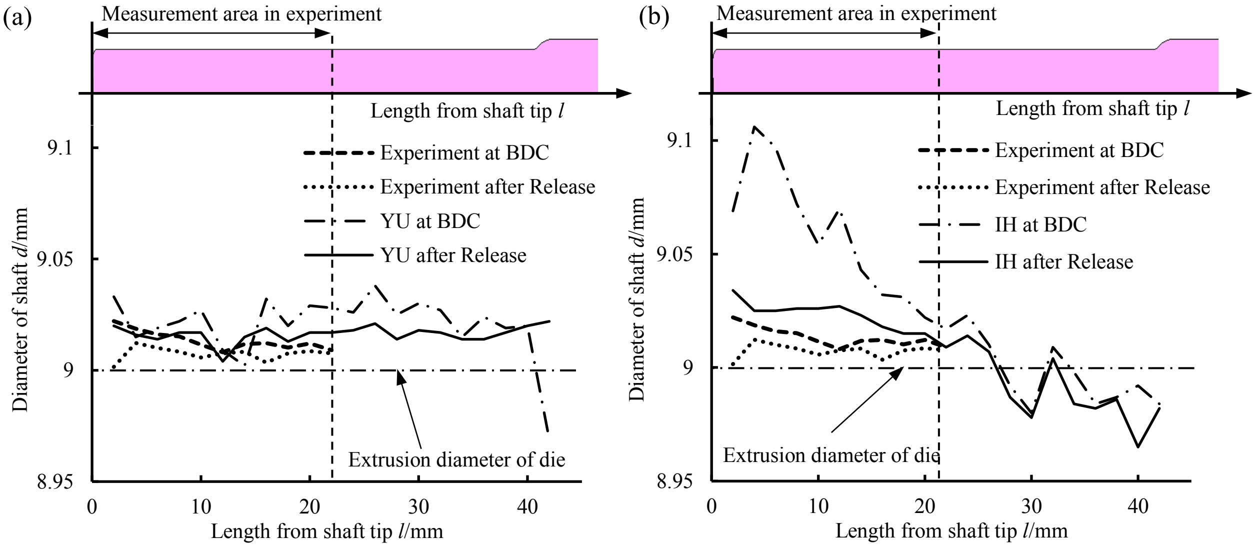


Fig. 4. Change in diameter by measurement (ave. Punch speed 350 mm/sec) and calculation. (a) YU model; (b) IH model

3. FE simulation of cold forward extrusion with isotropic and kinematic hardening models

In the FE simulation of cold forward extrusion, material parameters for IH and YU models were identified using the tensile and cyclic tests. The specimens for the tensile and cyclic tests were taken from the same material as the cold forward extrusion. Figure 5 shows the result of the identification. Moreover, Tables 1 and 2 show the mechanical properties and material parameters for YU model. For IH model, the stress-strain curve shown in Fig. 5(a) was directly used for the calculation. Figure 6 shows the process of FE simulation and geometrical model. The material used in experiment has certain residual stress initially by wire drawing. Therefore, the simulation of wire drawing was performed beforehand. Then, the whole process, as shown in Fig. 1, from the forward extrusion to the KO was performed. The commercial software simufact forming with hexahedral mesh was used for the calculation. The temperature effect by plastic deformation and friction was ignored in the present calculation.

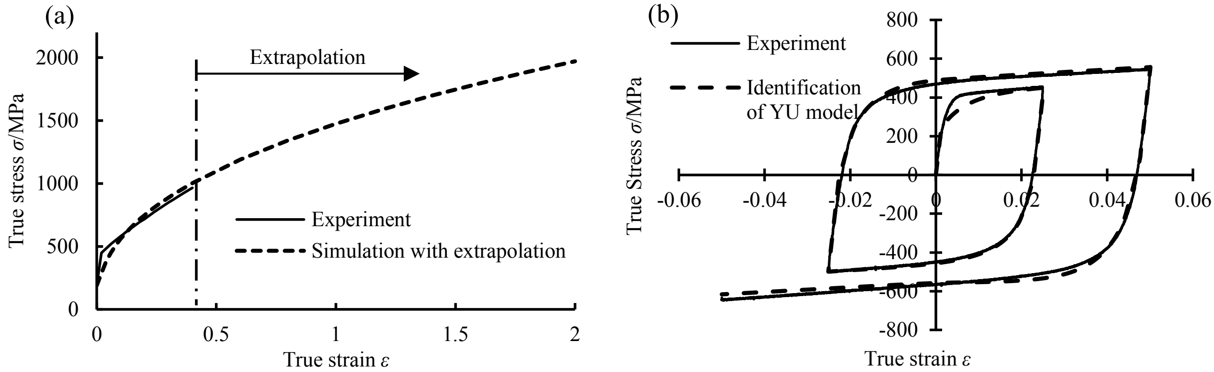


Fig. 5. (a) Comparison of tensile test and simulation for IH model; (b) Comparison of cyclic test and identification for YU model

Table 1. Mechanical properties.

Young modulus E/GPa	196.0
Poisson ratio ν	0.28
Yield stressσ /MPa	190.0
Yield function	Von Mises

Table 2. Material parameter of YU model with isotropic hardening.

A_0 /MPa	194.7
C_l /MPa	289.3
b /MPa	158.9
m	1.0
R_{sat} /MPa	1234.4
h	0.19
Isotropic hardening for boundary surface /MPa	$850\cdot\varepsilon^{0.6}$

The change in diameter by FE simulations are shown in Fig. 4 as mentioned above. Regardless the hardening model, a similar tendency that the increase at the BDC and the decrease by the KO were observed. The distribution of diameter by YU model is more uniform and close to that by the experimental result. In case of IH model, the distribution after the KO becomes uniform as in case of YU model. However, in both results at the BDC and after the KO, the diameter is larger than that of YU model. It follows that YU model can express the spring back behavior more accurately. In both results of IH model and YU model, however, the values are larger than that of the experiment. That is, the spring back is overestimated in FEM simulation.

As one of the reason for the overestimation, a temperature effect can be a conceivable. Temperature dependency on the stress-strain relation of SUS304 as TRIP steel is considerable. It is reported that the proof stress at 100°C decreases by 14% to that at room temperature [7]. The extent of spring back will be decreased if the temperature increases during the process. In order to reveal the temperature effect, the FEM simulation with temperature dependency was performed. Since the stress-strain curve shown by Fig. 5 is not considered temperature effect, the alternative stress-strain curves of SUS304 was used. Figure 7(a) shows the stress-strain curves with temperature dependency used for the simulation. Figure 7(b) shows the calculated temperature distribution of workpiece at the BDC. Temperature exceeding around 100°C was observed in most region of shaft. From the results, it is expected that the extent of spring back is reduced since the deformation resistance decreases as temperature increases.

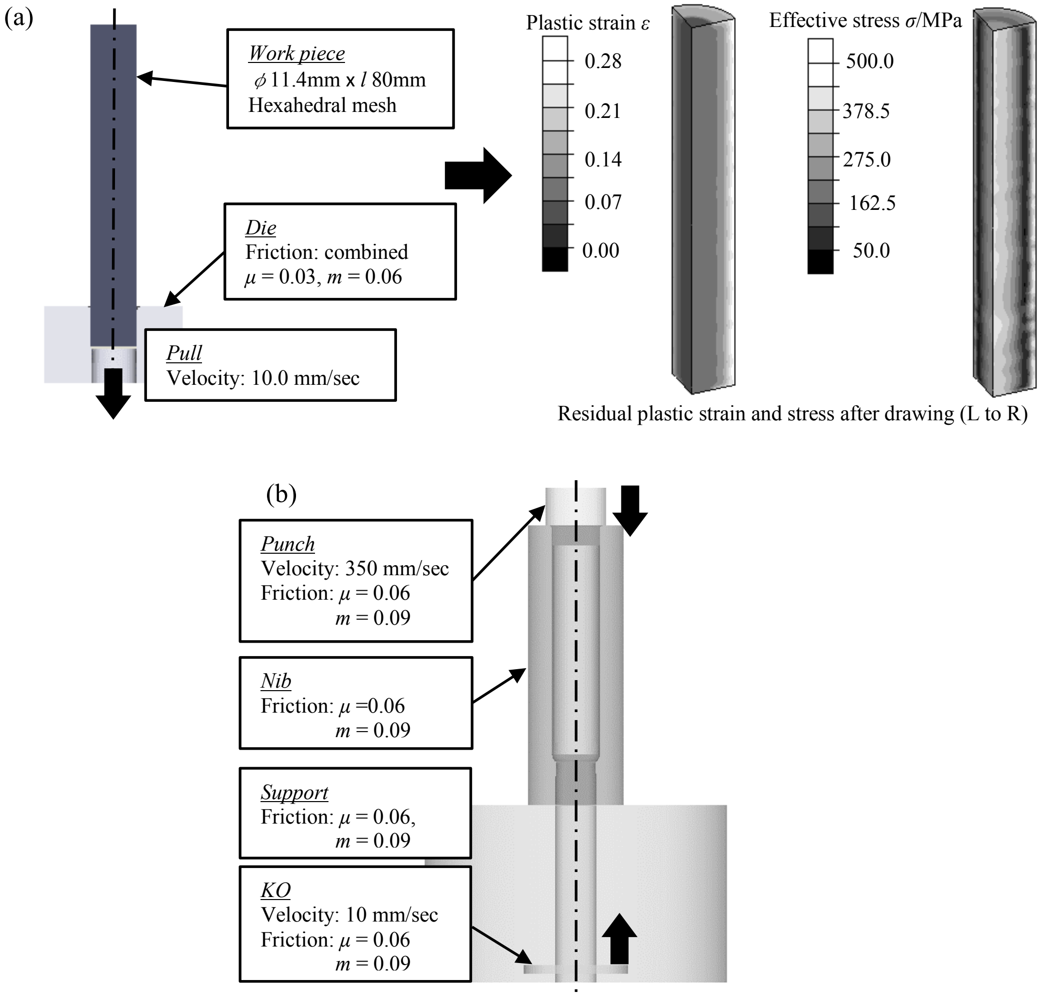


Fig. 6. Process of FEM simulation and model (a) Wire drawing for initial condition; (b) Forward extrusion

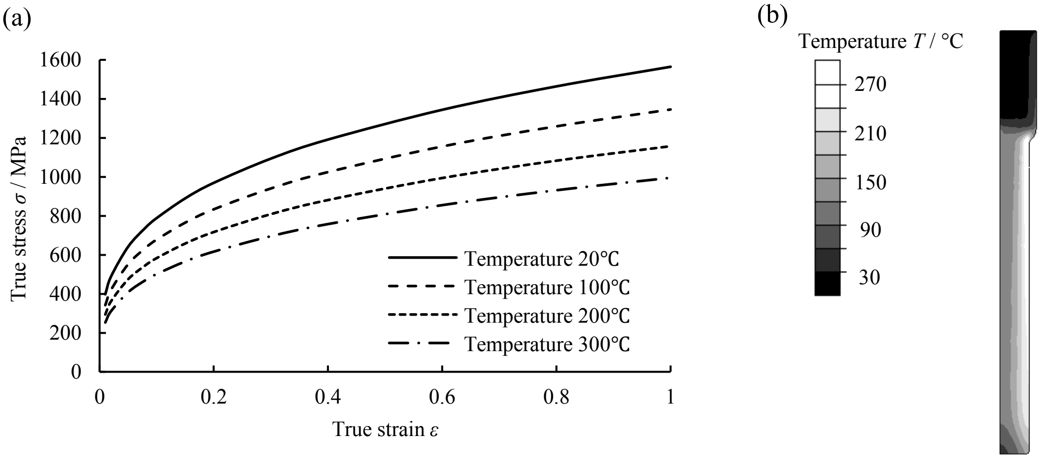


Fig. 7. (a) Temperature dependent flow curve for SUS304 (IH model); (b) Calculated temperature distribution at BDC

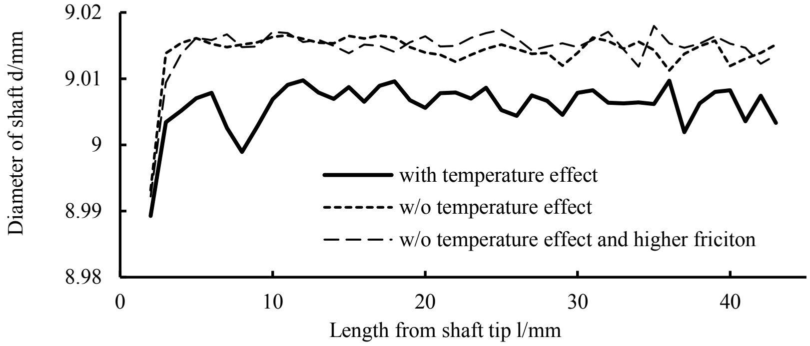


Fig. 8. Change in shaft diameter at BDC for with temperature effect and without temperature effect

Figure 8 shows the change in diameter of shaft with and without temperature effect. In addition, the result without temperature effect and higher friction (μ = 0.12 and m = 0.18) is shown in the figure. The reduction of diameter is larger by considering the temperature dependency. It follows that, even in case of cold forward extrusion, the consideration of the temperature dependency of the stress-strain relation is important for precise description of the cold forgings. As an open issue, YU model with temperature dependency will be needed for more precise simulation for cold forging process considering spring back behavior.

4. Conclusion

The experiment of cold forward extrusion was carried out to grasp the characteristics of spring back behavior in cold forging process. The FE simulations of forward extrusion with isotropic and kinematic hardening models were also performed. As the kinematic hardening model, the modified YU model for large plastic strain was employed. The diameter of the extruded shaft obtained by experiment and calculation was compared and evaluated.

From the experiment, the diameter of the extruded shaft was larger than that at the forming section due to the spring back behavior. Then, the diameter was reduced by the KO, which means that the re-extrusion occurred during the KO. It was revealed that the extruded shaft was formed by a series of extrusion consisting of the forward extrusion and the following KO in one extrusion process.

From FE simulations, the diameter of the shaft was increased at BDC regardless of material hardening model. The increase by FE simulations was overestimated. The diameter was then reduced by the KO. From the result, it follows that a series of calculations from extrusion to KO by FEM simulation is needed in order to acquire more accurate result. The diameter by YU model is more uniform and closer to experimental result. The calculated result by IH model was larger than that by YU model at before and after the KO.

Finally, the impact of temperature on the diameter was discussed for the overestimation by calculation.

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