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Frictional sensitivity and effect of surface roughness in boss and rib test

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ABSTRACT

Based on boss and rib test to quantitatively evaluate the friction, we investigated the variations of frictional sensitivity and linearity of frictional calibration curve according to tool design. From these, the appropriate tool design was determined to obtain the maximum frictional sensitivity and the highest linearity of the calibration curve. Effect of surface roughness and size of the specimen on friction were also discussed. The quantitative evaluation of friction was made according to the lubricants applied and surface roughness. It was found that the friction level on fine surface of the workpiece becomes high and micro-MoS2 particles blended in oil show the lower friction regardless of surface roughness.

1. Introduction

Friction is inevitable nature phenomena between contact interfaces in metal forming process. Friction condition, which means lubrication characteristic, has an extensive effect on metal forming process such as forming load, metal flow, tool life, workpiece integrity and surface quality. Hence, the appropriate selection of lubricant with quantitative evaluation of friction condition is essential for successful production. However, despite of unceasing academic contribution of understanding friction mechanism, it is still complicate to express universal phenomena of friction in one numerical friction model and to evaluate frictional condition in any process with simple frictional testing method due to the nonlinear inter-relation of various parameters involving friction mechanism. For instance, it was well known that Amonton-Coulomb friction model $\tau=\mu p$(τ: frictional stress, μ: friction coefficient, p: normal pressure) overestimates frictional stress in forging process owing to highly developed interface pressure between tools and workpiece which exceeds several times the yield stress [1]. Also it is hard to emulate frictional phenomena involving large surface expansion of workpiece in conventional friction testing method. The limited application of Amonton-Coulomb friction model accelerates use of shear friction model $\tau=mk$ or general friction model $\tau=f\alpha k$ (m: shear friction factor, k: shear strength of workpiece material, f: friction factor, α: real contact area) in bulk metal forming with highly generated new surface and high normal pressure [2,3].

There are various friction testing methods for the quantitative evaluation of interfacial friction condition between the tool and workpiece in bulk metal forming: ring compression test, spike test, injection upsetting test, forward-backward extrusion test, double cup extrusion test, tip test and BnR test. Ring compression test is easy to carry out with ring workpiece and flatten dies [4,5]. This method is prevalent among the researchers due to its simplicity. Measurement of only inner diameter is required at different reductions of height to determine the friction condition. However, since the amount of newly generated surface expansion is quite small due to restriction of ring shape, quantitative estimation of friction condition through this method may not be suitable in bulk metal forming with complicate material flow, large surface expansion and high normal pressure. Isogawa et al. [6] experimentally verified the frictional sensitivity of the height in spike test combining forward extrusion and upsetting. Hereafter, Xu et al. [7] investigated tool design to obtain a higher frictional sensitivity through FE simulation of spike test. Similar method named injection upsetting method was also suggested by Nishimura et al. [8,9]. The main advantage of this testing method is not to require the flow stress of workpiece and forging load. However, these two methods limit the amount of newly generated surface during forming due to their tool shapes. Forward-backward extrusion test was also well known method to measure interfacial friction condition [10]. Even though the large amount of new surface can be achieved in this method, the frictional sensitivity is degraded at the higher level of friction. Im et al. [2,11] suggested tip test based on the backward extrusion, in which sharp tip on the end of extruded workpiece is formed. In the tip test, friction condition according to the applied lubricant is quantitatively determined based on the linear relationship between tip distance and forming load. However, accurate positioning of the workpiece in the die is very difficult because of the smaller diameter of the workpiece than that of die. This method also provides the lower surface expansion induced from restriction of workpiece shape. In recent, Kang et al. [12]

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Nomenclature

α	real contact area
β	relief angle (fixed as 4°)
ε	plastic strain
μ	friction coefficient
σ	flow stress (MPa)
τ	frictional stress (MPa)
C	clearance between punch land and die face (thickness of rib, mm)
f	friction factor
F_s	frictional sensitivity
H_b	height of boss (mm)
H_l	length of punch land (fixed as 0.45 mm)
H_r	height of rib (mm)
H_s	height of specimen (fixed as 4.5 mm)
k	shear strength of workpiece material (MPa)
K	strength coefficient (MPa)
m	shear friction factor
n	strain-hardening exponent
R_a	arithmetical mean roughness value (μm)
R_z	mean roughness depth (μm)
R_b	radius of punch hole (radius of boss, mm)
R_c	corner radius of punch (fixed as 0.45 mm)
R_d	radius of die and counter punch (radius of specimen, fixed as 4.5 mm)
p	normal pressure (MPa)
S_p	punch stroke (mm)
S_{pf}	final punch stroke (mm, 3.6 mm)

suggested the new friction testing method named “boss and rib test(BnR test)” based on the backward extrusion. This test provides the higher amount of newly generated surface, the linear calibration curve only dependent on deformed shape of workpiece and thus simple measurement of friction condition. The key in this method is to use the punch with hole so that the boss and rib along the punch hole and on outer surface of the punch are formed. Plotting of experimentally measured heights of boss and rib into calibration curve gives the quantitative value of friction condition according to the lubricant applied.

In this work, we investigated the frictional sensitivity and linearity of calibration curve according to punch and die designs using the downsized BnR test. From these, the appropriate tool design was determined to obtain the highest frictional sensitivity and the highest linearity of the calibration curve. Effect of surface roughness and size of the specimens on friction condition was also discussed. In addition, the quantitative evaluation of friction condition was made according to the applied lubricants and surface roughness. Finally, it was also shown in downsized BnR test that shear friction factor in small specimen size is higher than that in large specimen of the previous work [12].

2. BnR test

BnR test consists of four parts: Cylindrical billet, die, counter punch and punch with a hole. The concept of BnR test and deformed shape according to shear friction factor(defined as m) are shown in Fig. 1 [12]. In BnR test, plastic flow of billet leads to formation of boss and rib due to backward extrusion, heights of which are dependent on the friction condition as shown in Fig. 1(b). At the higher friction level, the boss height increases in respect to rib height. This phenomenon occurs due to the difference of relative velocity on the punch and die interfaces. Due to stationary motion of die, the relative velocity on the punch interface is much higher than that on the die interface. Therefore, the plastic flow towards rib is more restricted and height of boss is more sensitive to the friction condition. The BnR test has some potential advantages as follows:

- High normal pressure on the tool interface and large surface expansion of the workpiece emulate frictional phenomena in practical forging condition.
- Calibration curve in terms of boss and rib height shows linear relation and is very sensitive to friction condition.
- Interfacial friction condition can be easily estimated by simple measurement of heights of boss and rib.

3. Experimental preparation

3.1. Material

Two common nonferrous materials Al6061 and Copper were chosen as frictional testing specimen. In order to prevent possibility of earing and crack defects occurrence during BnR test, grain orientation and formability of the initial testing specimen have to be controlled. Extruded bars with the diameter of 17 mm of which grain

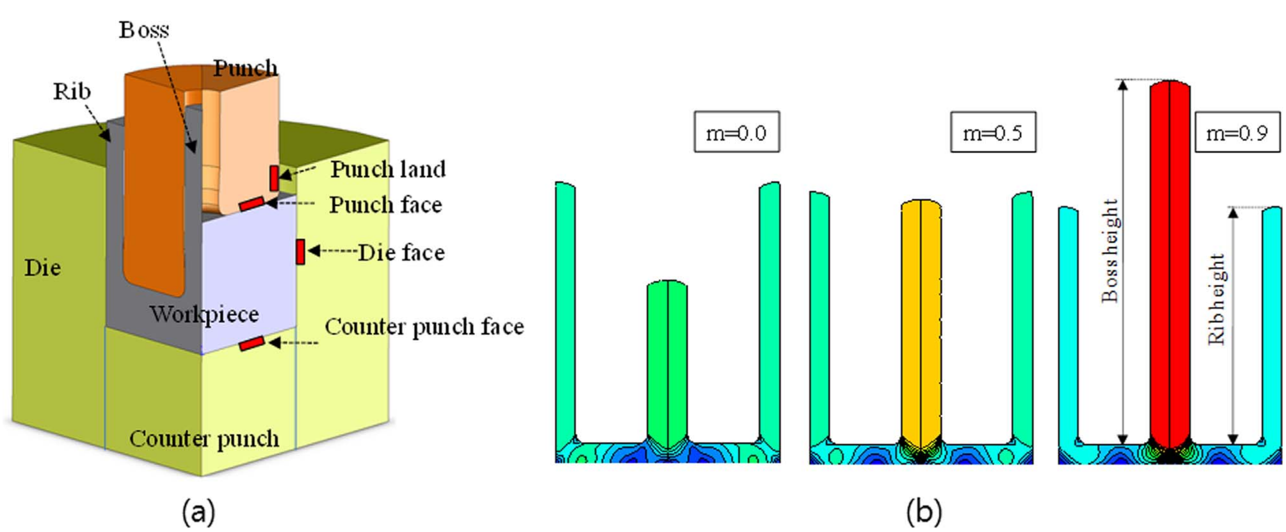

Fig. 1. (a) Concept of BnR test and (b) variation of boss and rib heights according to shear friction factor [12].