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ORIGINAL PAPER

# Characterization of Frictional Behavior in Cold Forging

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**Abstract** In the present investigation, tip test was utilized to characterize the effects of surface roughness of the specimen and forming tools, rate of deformation, and type of lubricants on friction in solid and solid contact under high contact pressure at room temperature. For the test, a cylindrical specimen made of aluminum alloy of 6061-O was used and grease, corn oil, VG100, and VG32 were applied as lubricants. Single punch and two counter punch sets with different surface roughness of $R_a = 0.08$ and 0.63 μm were manufactured in order to investigate a frictional behavior during the test. In addition, two different deformation speeds of 0.1 and 5.0 mm/s were used for the test to check their effect on friction as well. Load levels and tip distances obtained from the test were compared to find out any correlation between the two. The change of surface topology of the specimen was monitored by optical measurement technique to better understand a frictional behavior at the punch and counter punch interfaces. Present investigation clearly shows that tip test is easy to apply to experimentally characterize the frictional behavior in cold forging under various processing conditions considered.

**Keywords** Friction test method · Forging · Surface roughness · Optical microscopy · Forging fluids

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## 1 Introduction

Friction is generated between two bodies in contact under a normal load and defined as the resistance to relative motion between the two. Conventionally, friction was described by Coulomb friction ($\tau = \mu p$, $\mu =$ coefficient of friction and $p =$ normal stress) or constant shear model ($\tau = mk_s$, $m =$ shear friction factor and $k_s =$ shear yield stress of the material) known as Tresca friction model [1]. For the high contact pressure, the latter works better under the condition that $m$ is characterized correctly [2]. It is well known that frictional behavior depends on processing variables such as contact area, deformation speed, temperature, surface condition, and environmental factors in general. Thus, it is not easy to characterize $m$ correctly for general purpose.

So far, ring compression test has been widely used for friction measurement because of its simplicity [3]. In this test, calibration curves introduced by analytical or numerical techniques should be employed to determine the $m$ value by measuring dimensional change of the inner diameter. In spite of the extensive literature available on friction studies, an experimental technique for specifically estimating the effects of processing variables such as deformation speed, surface roughness, and the type of lubricants on friction is rather limited [1–4].

Recently, Im et al. [5, 6] proposed a tip test based on a hybrid of simple compression and backward extrusion in which a radial tip was formed on the extruded end of the specimen to evaluate the friction and lubrication more accurately. A cylindrical specimen, whose diameter was larger than the diameter of the punch and smaller than the diameter of the cylindrical die including the counter punch as shown in Fig. 1, formed the tip in the test. Because of large free surface generation during the backward extrusion, this test can be more suitable for friction