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Relation between coefficient of friction and surface roughness of workpiece in bulk plastic deformation

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ABSTRACT – Coefficients of friction of mineral oils under bulk plastic deformation were measured to understand lubrication conditions in the metal forming process by using plane strain extrusion apparatus. The apparatus consisted of the container wall, taper die, plane plate tool and billet (workpiece). The detection part of frictional force was placed on the surface of plane plate tool and that part was located in the deformation zone of billet. Relation between coefficient of friction and surface roughness of billet was investigated. The surface roughness parameter *S* is effective parameter to evaluate coefficient of friction from surface condition of partially extruded billet.

1. INTRODUCTION

In metal forming, work load and surface quality of product were affected by friction acted between tool and workpiece. As lubricant has a role to reduce friction in the process, measurement of friction in the metal forming process is important to grasp the information of lubrication characteristics in some work conditions. The methods of measurement of friction in the metal forming process have been reported as previous study [1,2]. Kamitani et al. [3] reported on the measurement of friction under bulk plastic deformation by using plane strain extrusion apparatus with plane plate tool and taper die with force sensors built in the plane plate tool.

In this report, a series of plane strain extrusion tests were carried out by using the above apparatus. The relation between surface condition of billet slid on the plane plate tool surface with bulk plastic deformation and coefficient of friction was investigated.

2. EXPERIMENTAL APPARATUS AND METHOD

2.1 Experimental apparatus

Figure 1 shows the schematic sketch of plane strain extrusion apparatus. Extrusion ratio was two in this apparatus. The apparatus consists of the container wall, taper die, plane plate tool and billet(workpiece). The straight flat surface of plane plate tool is test surface, and works as the tool and container wall too. The taper die has 45 degrees die half angle. The dies and containers were made of the tool alloy steel, SKD11 (JIS), and hardened and tempered. Hardness of dies was 650HV and surface roughness on the test surface was finished in 0.06μm*Ra*.Workpiece material was pure aluminum A1050-JIS. It was annealed and hardness was 25HV. The surface roughness on the test surface was finished in 0.3μm*Ra*. The combination billet with two pieces, 80 mm x 15 mm x 10 mm x 2 pieces, was prepared. Two types of plane plate tools, T+45D and T-45D were prepared to measure the compressive components of frictional force acting on the tool surface toward +45 degrees and -45 degrees with regard to perpendicular direction to the tool surface. The detection parts of the frictional forces were placed on the surfaces of plane plate tools and that parts were located in the deformation zone of billet. Both tools were set in the apparatus together. The compressive components of frictional force, F_A and F_B were measured by the strain gauges in 2-gauge system.

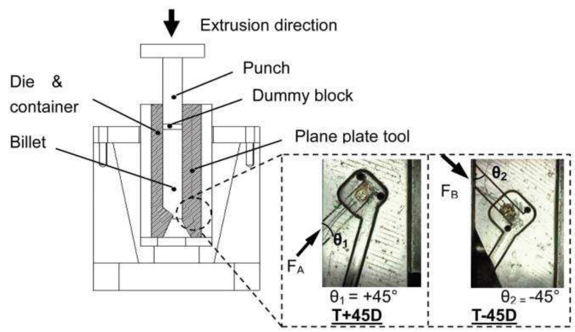

Figure 1 Plane strain extrusion apparatus and detection part of the frictional force.

2.2 Experimental conditions

Initial oil film mass on the test tool surface was set in 15mg at each testing by using the electronic balance. Approximately, equal amount of paraffinic mineral oil VG460 was applied to all other contact surfaces in experiments. Four types of naphthenic mineral oils N; N1(VG10), N2(VG22), N3(VG460), N4(VG1200) and four types of paraffinic mineral oils P; P1(VG7), P2(VG32), P3(VG460), P4(VG1000) were used as test oils in experiments. Experiments were carried out in room temperature.

2.3 Experimental method

The billet in the apparatus was extruded by the oil-hydraulic press, and the extrusion was ceased abruptly at press ram stroke, 24-25mm, in the steady state extrusion condition in which the extrusion speed was held at the constant value. Extrusion load, displacement of press ram and compressive components of frictional force were measured during extrusion process. Surface conditions of partially extruded billets were evaluated by measuring the surface roughness and by microscopic observation after experiments.

2.4 Calculation of coefficient of friction

Coefficient of friction μ is calculated by eq. (1) as previous study [3]. The compressive components F_A and F_B were measured in two types of plane plate tools T+45D and T-45D shown in Figure 1.

$$\mu=(F_B-F_A)/(F_A+F_B) \quad (1)$$

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows coefficient of friction with regard to surface roughness parameter *Ra*. *Ra* is arithmetic average. Adhesion of aluminum did not occur in the all conditions of tested lubricating oils. In the low viscosity conditions, change of coefficient of friction was steep, while coefficient of friction in the high viscosity conditions (*Ra* ≥0.2μm) showed almost constant value. In the low viscosity conditions N1, N2, P1 and P2, surfaces of billets were smoothed because of thin oil film and contact between tool and the billet surface with plastic deformation. In the high viscosity conditions N3, N4, P3 and P4, surfaces of billets were roughened with regard to thick oil film thickness and plastic deformation of billet. It is difficult to judge the difference of coefficient of friction from surface roughness *Ra* of billets in the low viscosity conditions.

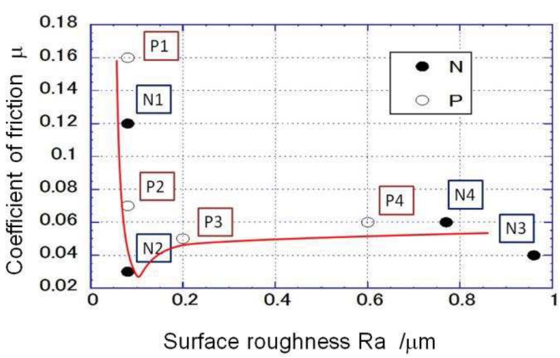

Figure 2 Coefficient of friction with regard to surface roughness parameter *Ra*.

Figure 3 shows relation between coefficient of friction and surface roughness parameter *S*. Where, *S* is mean spacing of local peaks of the profile. Coefficients of friction in low viscosity conditions with thin oil film thickness increased with decreasing of *S* values. While, coefficients of friction in high viscosity conditions with thick oil film changed a little with regard to *S*. It is considered spacing of local peaks of billet surface in low viscosity conditions was narrowed by flattening of billet surface in the thin oil film condition with regard to tool surface constraint. It is found that the surface roughness parameter *S* is effective parameter to evaluate the difference of frictional condition from surface condition of partially extruded billet.

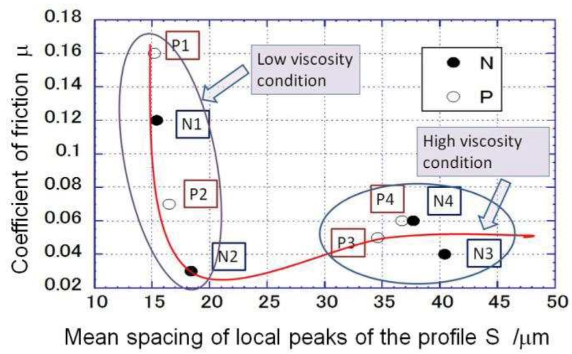

Figure 3 Coefficient of friction with regard to surface roughness parameter *S*.

4. CONCLUSIONS

In the present investigation, coefficients of friction of mineral oils in bulk plastic deformation were measured by plane strain extrusion test. The results were summarized as follows:

(a) In the low viscosity conditions, change of coefficient of friction was steep, while coefficients of friction in the high viscosity conditions (*Ra* ≥0.2μm) showed almost constant value.

(b) Coefficients of friction in low viscosity conditions with thin oil film thickness increased with decreasing of *S* values. While, coefficients of friction in high viscosity conditions with thick oil film changed a little with regard to *S*.

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