Fundamental Study of Dry Metal Forming with Coated Tools

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Abstract

Since metal forming induces high friction and heat generation between the tools and the work-piece, lubrication is a very important factor for reducing the forming pressure and avoiding seizure. However, recently, it has become to be considered that many kinds of lubricants are not good for the environment, and non-polluting lubricants, semi-dry metal forming process by spraying slight lubricants and dry metal forming process without lubrication are desired to be developed. If dry metal forming is realized, the influence to the environment and the cost of manufacturing could be reduced. Because dry metal cutting without lubrication has already become possible through the recently developed coating methods for the cutting tools, metal forming processes under semi-dry or dry conditions may be possible. In this study, the frictional characteristics under dry metal forming conditions are studied.

The coefficient of friction was determined with the ring compression test. In the ring compression test, a ring specimen is compressed between flat parallel tools and the friction is measured through the change of the inner diameter of the ring. This test has been frequently used for estimating the friction in forging. To measure the coefficient of friction in the high friction range by the ring compression test, an optimum shape of ring specimen is searched for using the rigid-plastic finite element simulation (RIPLS-Forge).

The ring specimens usually have a ratio of outer diameter (D_0): inner diameter (d_0): height (h_0) = 6: 3: 2. This shape is suitable for measuring the coefficient of friction (μ) lower than about 0.1, because the deformation of ring is sensitive to the friction in this range. But this shape is not suitable for higher coefficients of friction. The sensitivity of the shape change to the coefficients of friction and the limiting reduction (the reduction in height at which the hole of the ring diminishes under extremely high friction $\mu = 1.0$) were evaluated for various ring shapes. A new ring shape was determined to be D_0: d_0: h_0 = 3: 1: 1 for measuring the coefficient of friction higher than 0.1. The sensitivity of this shape is about 2.5 times as great as that of the current shape, but the limiting reduction decreases from 60% to 40%.

By using the above determined specimen shape, the frictional behavior of some working metals sliding over tool surfaces without lubricant is studied. The work-piece materials are pure aluminum, pure copper and carbon steel. As for tool surfaces, the cemented carbide tools (WC) are coated with TiC, TiN, TiCN, TiAlN and DLC (diamond like carbon).

Except for DLC, the coated material does not significantly give influence to the coefficient of friction. It is found that DLC coated tool is effective to reduce the friction with aluminum but it is not good for copper. In the case of compressing aluminum billets at room temperature with DLC coated

tool, the coefficient of friction decreases as the reduction in height increases. On the other hand, when WC tool without coating is used, the friction decreases with the reduction in height, but it increases again at higher reductions. In the case of compression of heated work-pieces at 200°C with the tools kept at room temperature, DLC coated tool gives a low coefficient of friction irrespective of the reduction in height, but WC tool exhibits monotonous increase in friction with the reduction in height.

The coefficient of friction increases linearly with the roughness of tool surface irrespective of the coated material. The roughness of tool surface is an essentially important factor in dry forming and it is needed to polish the tool surface to a mirror surface. It is confirmed through the FEM simulation results that the nominal coefficient of friction in ring compression is significantly changed by the inclination angle of the roughness curve of the tool surface. The roughness of work-pieces after compression without lubrication depends on the roughness of tool and it increases when a lubricant is used.

The oxide layer formed on the carbon steel surface is effective to reduce the friction in hot dry forging. In cold dry forging, however, the existence of oxide layer increases the friction enormously. Therefore it is important to remove the oxide film from the carbon steel billet before forging.

Keywords: dry metal forming, ring compression test, coated tool, coefficient of friction