Fundamental Study of Dry and Semi-Dry Metal Forming

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Abstract

Since metal forming induces high friction and heat generation between the tools and the work-piece, lubrication is a critically important factor for reducing the forming pressure and avoiding seizure in many forming processes. Recently, however, it has become to be considered that many kinds of lubricants are not good for the environment, and dry metal forming process without lubrication, semi-dry metal forming process by spraying slight lubricants and non-polluting lubricants are desired to be developed. Dry metal cutting without lubrication has already become possible through the recent development of coating methods for cutting tools, for example, CVD (Chemical Vapor Deposition) and PVD (Physical Vapor Deposition) processes. If dry metal forming is realized, the influence to the environment and the cost of manufacturing could be reduced dramatically. For attaining dry metal forming, it is essentially important to choose appropriate combinations of coating material of tool surface, work-piece material and working condition.

In this study, the coefficient of friction was determined with the ring compression test, in which 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 without large expansion of billet surface. In chapter 2, in order to measure the coefficient of friction accurately in the high friction range by the ring compression test, an optimum shape of ring specimen is searched for by using the rigid-plastic finite element simulation (RIPLS-Forge). The ring specimens having a ratio of outer diameter (D_0): inner diameter (d_0): height (h_0) = 6: 3: 2 are usually used. 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 as dry metal forming. 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%.

In chapter 3, by using the determined specimen shape for the high friction range, the frictional behaviour of some working metals sliding over the tool surfaces without lubricant is studied. The work-piece materials are pure aluminum (A1050), pure copper (C1020) and carbon steel (S45C). As for tool surfaces, the cemented tungsten carbide (WC) tools are coated with TiC, TiN, TiCN, TiAlN and DLC (Diamond Like Carbon) by CVD or PVD process.

Except for DLC, the coated material does not give influence to the coefficient of friction significantly. It is found that DLC coated tool is effective to reduce the friction with aluminum billet, but it is not good for copper billet. 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 roughness of the tool surface irrespective of the coated material. The roughness of the tool surface is an essentially important factor in dry metal forming and it is necessary 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. It is shown that the roughness of the work-pieces after compression without lubrication depends on the roughness of tool and it increases when a liquid lubricant is used.

Frictional behaviour under semi-dry condition is measured with the ring compression test in chapter 4. A small quantity of mist lubricant (less than 3.0g/m^2) is sprayed onto WC tool surfaces by mist spraying system for metal cutting, and the aluminum billets are compressed at room temperature and 200°C. It is found that spraying a small quantity of lubricant (0.50g/m^2) is effective in reducing the friction in comparison with that for compression without lubrication. The coefficient of friction with the aluminum billet –

WC tool under semi-dry condition (0.25 – 0.50g/m^2 mist lubricant) is as low as the aluminum billet – DLC coated tool under dry condition. On the other hand, the roughness of the work-pieces after compression increases as the quantity of the trapped lubricant increases and becomes R_a = 0.20 – 1.0μm which is of the same order as the lubricant film thickness. Furthermore, surface profiles of the aluminum billet after upsetting is measured, and the behaviour of the trapped mist lubricant during upsetting is discussed.

Since magnesium alloys have smaller impact to the environment, magnesium alloys are increasingly used for lightweight structural and functional parts in automotive and electronic industries. The magnesium alloys have an advantage of the lowest density among the practically used metals and have high specific strength and electromagnetic interference shielding capability. Die casting and thixoforming are commonly used methods for mass production of magnesium alloy parts. Since liquid magnesium alloys are flammable, it is desirable to produce magnesium alloy parts by forging. The strength and toughness of the forged products are higher than those of the cast ones.

Magnesium alloys are brittle at room temperature and cannot be forged at room temperature, but are possible to be forged at the temperatures higher than 200°C, and heavy oxidation of billet takes place at the temperatures higher than 400°C. The forgeability and frictional property of magnesium alloy has not been examined yet. Since the magnesium alloys do not adhere to the tool surfaces during several forgings without lubrication, warm forging of magnesium alloy may be possible without lubrication or with only simple lubrication.

In order to realize precision forging of magnesium alloys, the frictional behaviour of wrought magnesium alloy ZK60 (Mg–6%Zn–0.5%Zr) is studied in chapter 5. At room temperature, the friction test of ZK60 sliding over the surfaces of WC tool and coated with TiC+TiCN+TiN and DLC is carried out. It is found that the DLC coated film is effective to keep the coefficient of friction as low as 0.10, and results a low rate of adhesion with magnesium alloy. For warm forging, ring compression tests are carried out at temperatures from 200°C to 300°C under dry and thin film lubricating conditions. When WC tools are used without lubrication, the coefficient of friction for ZK60 is between 0.25 and 0.35. In ring compression test, DLC coating on tool surface causes a low friction with ZK60 under dry condition.

It is also examined the lubrication in warm forging of magnesium alloy, and several liquid lubricants are applied onto the tool surfaces by controlling the film thickness. When the lubricant film is 0.50μm thickness, the coefficient of friction for ZK60 decreases from 0.35 to 0.10. It is considered that although the friction of magnesium alloy in warm forging is high under dry condition, appropriate tool coating and low amount of lubricant will reduce the friction effectively.

In chapter 6, a new warm forging method of magnesium alloy is proposed by taking its material properties into consideration. Since the ductility of magnesium alloy is low at room temperature, the forming operation is conducted at elevated temperatures. When a magnesium billet is heated, it is important to avoid its temperature drop before forging, because magnesium alloy has a high thermal conductivity and a low thermal capacity. To solve this problem, the magnesium billet is sandwiched between high temperature tools and is heated up to the tool temperature by heat transfer from the high temperature tools. Since the flow stress of the magnesium alloy exhibits significant work softening, a high peak of load tends to appear at the beginning of the forging process. In order to reduce the peak forming load, the billet shape is so chosen that initial straining is caused without restraining the flow in the early stage of the process and then die filling is attained with a low flow stress. In this study, the proposed warm forging method is confirmed to be valid by the finite element simulation and the experiment using a servo controlled press.

Finally, the concluding remarks for the present study are given in chapter 7.