Determination of friction factor by ring compression test for Al-5Zn-1Mg using graphite and MoS_2 lubricants

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Abstract

*There are two types of friction viz, sliding friction and sticking friction. Both of them can be quantified by either friction coefficient (**μ**) or friction factor (**m**), but, friction factor is advantageous. Friction coefficient, **μ**, decreases inversely with interface pressure and can lead to misinterpretation of frictional forces. On the other hand, friction factor, **m**, is independent of normal stress at the interface. Moreover, it can easily be measured and also leads to a mathematical simplification of analysis of forces for metal working processes. In the present study an attempt has been made to study the friction factor, **m**, of Al-5Zn-1Mg alloy by Ring compression test in a 40 T Universal testing machine with graphite and MoS_2 as lubricants. The test was carried out at temperatures from 303-673K. The reduction in height and change in internal diameter were measured and using a calibration chart, the friction factor was estimated.*

*It was noticed that friction factor, **m** was considerably low for graphite lubricant between temperatures 303 and 673K. It can be concluded that graphite is a better lubricant compared to MoS_2 for Al-5Zn-1Mg between temperatures 303 and 673K from the aspect of lower frictional force. Lower frictional forces implies less wear and tear of tooling, hence, increased tool life.*

Keywords: Friction factor, sticking,sliding, aluminium, zinc, magnesium

1. Introduction

Friction is unavoidable in many metal-forming processes. Whenever a die is in contact with the metal to be formed, a relative motion, and resistance (friction) to this motion arises. Friction, in spite of being an independent parameter, is not measured directly, whereas independent parameters such as reduction and die angle can be measured directly. Still, in many metal-forming processes, the effect of friction is given equal importance to measurable independent parameters [1]. Friction has significant effects on both the workpiece and process variables such as deformation load, metal flow and surface quality, and internal structure of the product in metal forming processes. Therefore, the interface friction has to be optimized [2]. For effective friction control, effects of lubrication must be investigated. There are several methods developed for quantitative evaluation of friction at the die/workpiece interface in metal forming processes. The most accepted one is to define either a coefficient of friction, **μ**, the coloumb law of friction, or the friction factor, **m**, a value varies from zero for frictionless interface to one for sticking friction.

$$\mu = (\tau/\sigma).... \quad (1)$$

Where τ is shear stress at the interface and σ is normal stress at the interface. This is valid when there is sliding.

When there is sticking, $$\mu = (\tau_y/\sigma_y)...... \quad (2)$$

Where τ_y and σ_y are yield stresses in shear and normal case. When there is perfect sliding μ=0. When there is perfect sticking it is equal to 0.5 if Tresca criteria are adopted and 0.577 when von Mises' criteria are used. To avoid such inconvenience, instead of friction coefficient, friction factor '**m**' is used.

$$m = (\tau/\tau_y) ...... \quad (3)$$

Where τ is interfacial shear strength and τ_y is yield stress in shear. When there is perfect sliding m=0 and when there is perfect sticking m=1 in both Tresca and von Mises criteria. **m** is independent of normal stress at the interface while μ depends on it. **μ** is inversely related to normal stress at the interface which is contrary to reality. Moreover, m is easy to measure by a simple ring compression test and also easy to handle in mathematical equations [3].

Solid lubricants are thin films composed of a single solid or a combination of solids introduced between two rubbing surfaces for the purpose of reducing friction and wear. Applications or operations involving severe temperatures, pressures, and environments, which preclude the use of organic fluids, have promoted the development of solid lubricants. Many common solid lubricants, such as graphite and molybdenum disulfide are layered lattice compounds that shear easily along preferred planes of their structure. Molybdenum disulfide shows relatively low coefficient of friction because of the weak van der Waals forces between sulfur bonds. It also oxidizes at approximately 672 K in air, and the oxides can be abrasive. The low friction associated with graphite depends on intercalation with gases, liquids, or other substances. For example, the presence of absorbed water in graphite imparts good lubricating qualities. Thus, pure graphite has deficiencies as a lubricant except when used in an environment containing contaminants such as gases and water vapour. With proper additives, graphite can be effective up to 922 K [4].

Graphite and MoS_2 exhibit low friction because of their layered structures. The former consisting of carbon atom arranged in hexagonal lattice while in the latter each sulfur centre is pyramidal to three Mo centers.

Each layer contains strong bonds that make it resistant to breakup and thereby enable it to carry substantial load. Because of the weak van der waals interactions between the layers, they slide readily over one another [5]. Direct microscopic observations of the dynamics of solid lubrication show that sliding is accompanied by severe ductile shear of the solid lubricant film [6]. Thus a solid lubricant must have low shear strength for a low friction factor.

2. Materials and methods

Aluminium rods were melted and alloyed with zinc and magnesium to get an alloy of Al-5Zn-1Mg. Rings of (6:3:2) outer diameter, 24 mm, inner diameter, 12 mm and height, 8 mm were machined from

Al-5Zn-1Mg alloy and annealed in a furnace at 623 K for 1 hr. These rings were compressed and tested in a 40 T hydraulic press with graphite and MoS_2 as lubricants. The schematic setup is shown in Fig. 1 and the ring specimens before and after compression are shown in Fig. 2a-c [7]. The test was carried out at temperatures 303, 373, 473, 573, and 673 K for Al-5Zn-1Mg alloy. The reduction in height and decrease in internal diameter were measured, and using the calibration chart [8] shown in Fig. 3, the friction factor was estimated. The deformation of a ring is shown in Fig. 4 for zero friction, low friction, high friction, and sticking friction [3, 4, 9, 10, 11 and 12].

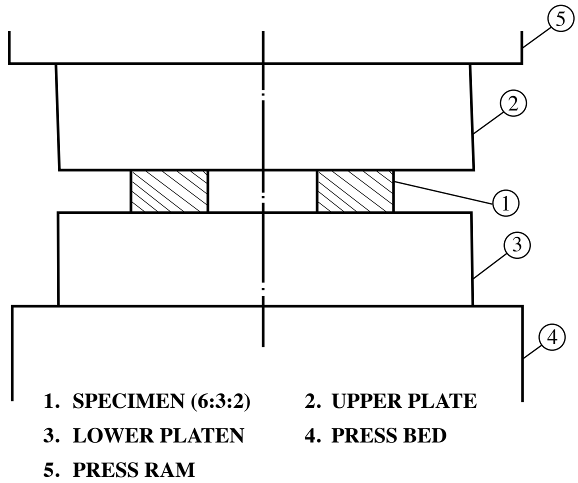

Fig. 1. Schematic set up of ring compression test [13].

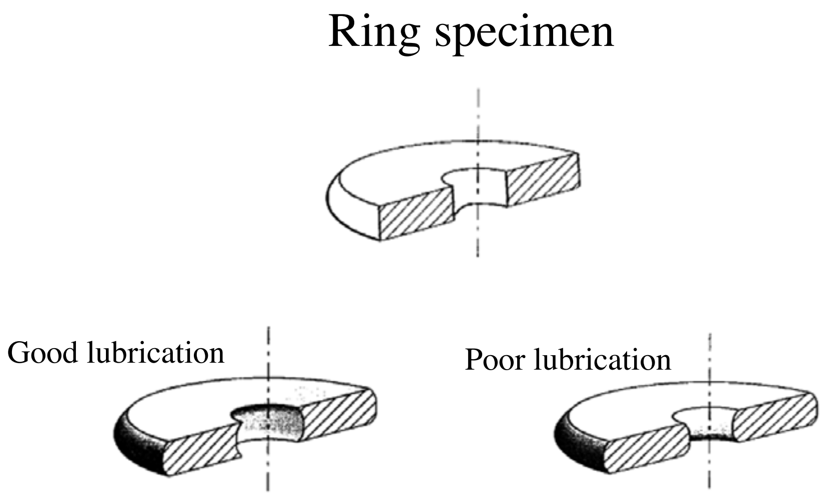

Fig. 2. Ring compression: (a) before compression, (b) after compression with low friction and (c) after compression with high friction.[7].

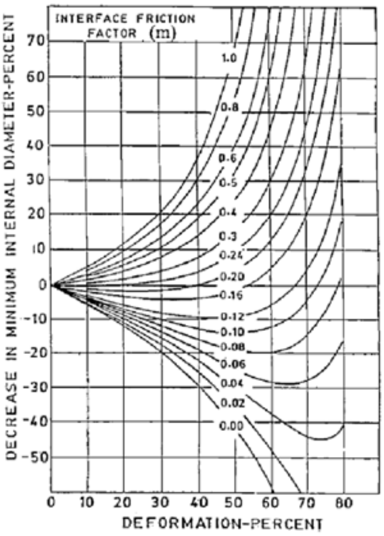

Fig. 3. Calibration chart to determine friction factor (m) [8].

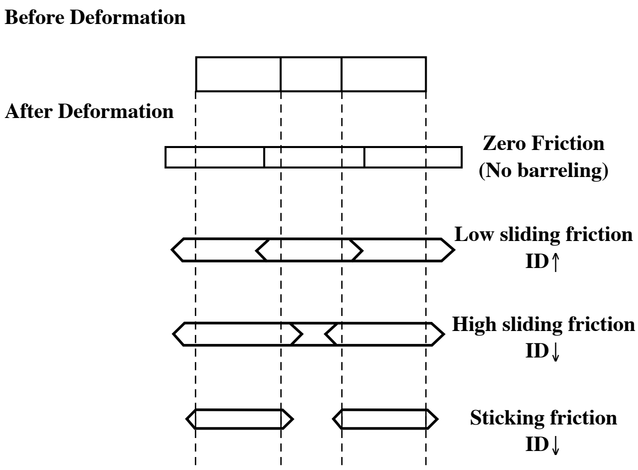

Fig. 4. Types of ring deformations after compression [9, 10]

3. Results and Discussion

The friction factor, m, of Al-5Zn-1Mg alloy with graphite lubricant at various temperatures are given in Table 1 and friction factor, m, of Al-5Zn-1Mg alloy with MoS2 lubricant at various temperatures are given in Table 2 [14] .

Table 1 Friction factor (m) of Al-5Zn-1Mg alloy with graphite lubricant at various temperatures.

Temp. (K)	Friction factor (m)
303	0.31
373	0.36
473	0.37
573	0.34
673	0.37

Table 2 Friction factor (m) of Al-5Zn-1Mg alloy with MoS2 lubricant at various temperatures.

Temp. (K)	Friction factor (m)
303	0.42
373	0.44
473	0.62
573	0.75
673	0.9

The friction factor, m, was low (0.31-0.37) while using graphite lubricant, compared to MoS_2 lubricant (0.42-0.9). Fig. 5 & 6 show the plot of friction factor for alloys with temperature using graphite and MoS_2 respectively.

It can be seen that friction factor increases as temperature increases in case of MoS_2 lubricant, whereas in the case of graphite lubricant, friction factor increase until 473K, decreases to 573K and further increases to 673K.

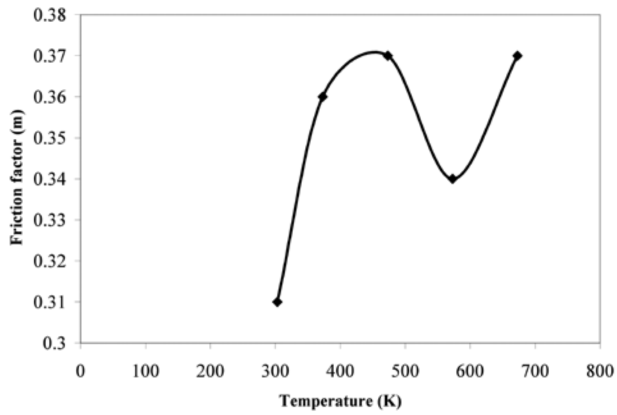

Fig. 5. The plot of friction factor for Al-5Zn-1Mg alloy with temperature using graphite lubricant.

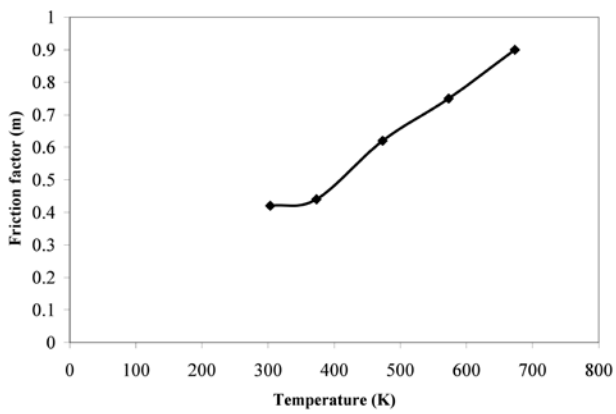

Fig. 6. The plot of friction factor for Al-5Zn-1Mg alloy with temperature using MoS_2 lubricant.

From Fig. 6 it is apparent that low shear strength alone does not ensure lubrication if the material does not adhere to the lubricated surface. It must be thermodynamically stable in the environment of an application, too. The change in friction factor with respect to temperature is negligible in the case of graphite lubricant compared to MoS_2 where the change is highly significant. "Layer lattice" is a term used to describe crystal structures that consist of basal planes that are parallel to each other and consist of hexagonally oriented atoms, Fig. 7. The spacing between the planes is the d-spacing. The spacing between the atoms within the basal planes is the a-spacing. The disulfides of molybdenum have this structure.

Oxidation kinetic data for MoS_2 as determined by high-temperature x-ray diffraction were reported by Sliney [16]. The data show that the oxidation rate is strongly influenced by airflow rate through the reaction chamber. Increasing the airflow rate by a factor of about 6 increased the oxidation rate by a factor of 10 or more. Comparison of these data with the results of friction experiments shows that the loss of lubricating ability of these compounds in air coincides with the temperatures at which rapid oxidation takes place.

The results shown by MoS_2 lubricant is in accordance to the above study. In spite of its desirable crystal structure, graphite is not an intrinsic solid lubricant. It lubricates in a normal air atmosphere, but fails to lubricate at high altitudes or in vacuum. Savage [17] reported experimental results which reveal the lubricative property of graphite only in the presence of moisture or some other condensable vapour such as hydrocarbons. The presence of condensable vapour can not give a lubricative property to graphite at temperature above desorption. Peterson and Johnson [18] found that lubricative property of graphite are further achieved at high temperatures when the lubricated metal becomes visibly oxidized.

Restoration of lubrication at about 698 K was due to interaction of graphite with oxides of the metal. The surface oxides are thought to promote adhesion of the graphite to the lubricated surfaces. The maximum temperature for lubrication with graphite films is limited by oxidation to about 823 K. Al-5Zn-1Mg, chosen for this study, readily oxidizes at higher temperature and thus must have promoted adhesion of the graphite to them. Therefore the result shown by graphite lubricant is also in accordance with the study in [18].

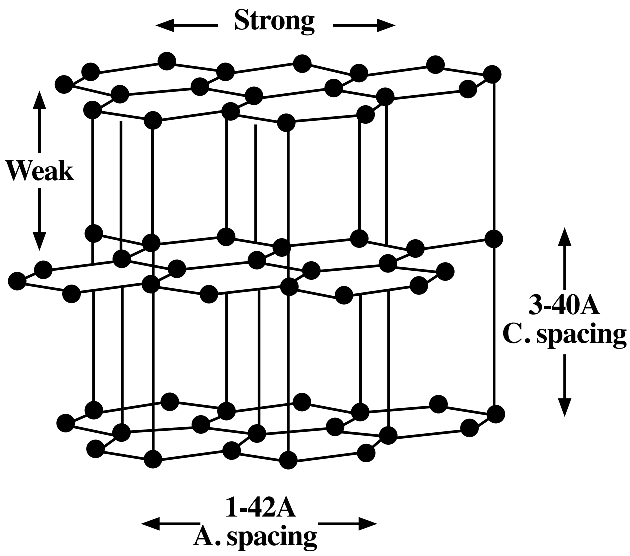

Fig. 7. Structure of graphite. The individual sheets consist of closely packed atoms, separated by a relatively large distance from neighbouring sheets. [15].

4. Conclusion

Extreme environmental conditions frequently favor solid lubricants, which can survive temperatures well above the decomposition temperatures of oils. They can also be used in chemically reactive environments. Graphite and molybdenum disulfide are layered lattice compounds that shear easily along preferred planes of their structure. From the present study, it can be concluded that graphite acts as a better lubricant, compared to MoS_2 for Al-5Zn-1Mg alloy at all temperatures, especially at higher temperatures, from the aspect of lower frictional forces. Lower frictional forces imply less wear and tear of tooling, hence, an increase in tool life.

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