Study of Friction during Forging Operation

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***Abstract*—** This paper presents a review on the effect of friction during forging operation; must especially the double cup extrusion process. The metal forming process, such as forging, is one of the manufacturing processes where metal is pressed or forced under great pressure into high strength parts. Before the process, lubricant is applied to the dies in operation to promote the flow of metal, to reduce friction and wear, and to aid in the release of the finished part. Interfacial friction between the forgings dies and the workpiece such as billet has a significant effect on the forging applications, forming quality, and deformation loads. The most commonly used lubricant is liquid based lubricant, such as water-based graphite, synthetic oils, liquid soap, shear butter etc. Under the high pressure condition and reductions of the lubricant film often breaks down the operation and caused poor metal flow and wears. High interface friction is a primary cause for adhesive pickup in cold forging.

***Keywords*—** Double cup extrusion, forging, friction factor, lubrication

I. Introduction

FORGING is a process in which metal is plastically deformed under the application of temperature and pressure. This is deformed with the help of a compressive load. This new formation has a significant change in the properties of the deformed metal and as well as the shape. However, the grain size structure is refined and improved. Frequently, in producing discrete parts, several preformed forging operations are required to transform simple sample into a complex component, without causing any degradation to the deformed material. For a given operation, either preforming or finish forging operation, such design output basically consists of:

(a) Predicting the material flow between the deformed and undeformed element such as the shape, velocities and strain rates, strains,
(b) Determining whether it is possible to form the elemental part without surface or internal defect,
(c) Predicting the forces and stresses required to accomplish the forging operation in order to facilitate the appropriate selection of tool and equipment [1].

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In the 20th century, a physical explanation for the law of friction called “Adhesive Theory” was described. This theory states that the true area of contact is a very small percentage of the apparent contact area. The true contact area is formed by the roughness, thus, as the normal force increases; more roughness comes into contact [2]. Studies on friction have been varied and detailed in past few decades. Different friction models have been proposed for different applications and researches are going on uninterruptedly [3] [4]. In metal forming operations; friction has great importance since it affects the forming force (or energy), material flow inside the die, and as well as the product quality and tool life. In addition to the operations, a finite element simulation of friction model is one of the key input boundary conditions. It was reported that the higher accuracy of friction models is still unknown and also difficult to establish a unique friction model that includes all forming parameters for all metal forming operations. However, the total contact area for both immigrated and expanded original contact area obtained in friction is always smaller than the area deformed without friction. The friction area ratio was introduced to reveal the effect of friction in contact area expansion [5].

A cylindrical compression test is a wide accepted method for determining the flow stress data for metals at various temperatures and strain rates. In this test, flat platens and cylindrical specimen are maintained at the same temperature so that the die chilling and its influence on metal flow are prevented. For this system to be applicable without corrections or errors, the specimen must be upset without any barreling. In other word, the state of uniform stress in the sample must be maintained. Adequate lubricant such as Teflon or machine oil at room temperature is applied to prevent barreling. It was reported that the load and displacement were measured and the flow stress was also calculated at every stage of deformation for strain increment [6].

The primitive objective of this research is to enable engineers to select the lubrication strategies in metal forming to achieve the best friction and also minimize the consumption of lubricant.

II. Statement of the Problem

Two surfaces in sliding contact produce friction, which is normally characterized by coefficient of friction. This is defined as the ratio of the resisting force to the normal force or load. Under dry conditions, the coefficient of friction is usually a constant and independent of the sliding speed and load known as Amonton's Law of dry friction. In metal forming processes however the situation is quite different. Here the normal die pressure is very high and the coefficient of friction decreases with an increase in the die face pressure due to plastic deformation of the contact points within the contact zone between the die and the workpiece. Also, due to plastic deformation of the deformed material, there is an increase in new surface area that could strongly affect the interface friction. Furthermore, the friction is also affected by the sliding speed, the rate of deformation of the workpiece and, the temperatures in the contact zone. The magnitude of the coefficient of friction depends on the lubrication regime and tribological conditions within the contact zone. However, the problem may be clarified by observing the different lubrication regimes that may exist between two sliding surfaces. For this regime, pressure distribution, lubrication, temperature domain and friction characteristics are described by the hydrodynamic lubrication theory. Friction conditions are decided by the viscosity of the lubricant and the relative velocity between the die and workpiece.

III. DOUBLE CUP EXTRUSION TEST

The double cup extrusion test (DCET) is the combination of a forward-cup and backward-cup extrusion processes. Fig. 1 shows the double cup extrusion tooling setup. It is made up of a lower punch in between the die insert and guide plate. These setups are enclosed in a container.

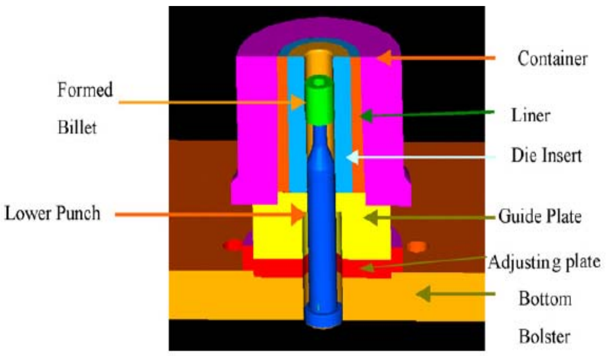

Fig.1 Double cup extrusion tooling setup [3]

The container and the lower punch are fixed on the bed of the press and the upper punch is fixed on the ram of the press. The upper punch moves downwards while the bottom punch and the container is kept stationary. The diameters of both punches are the same. The upper cup is formed by a backward extrusion process and the lower cup is formed by a forward extrusion process. The simultaneous action of the two punches inside the cylindrical container generates the two cups. The initial billet (un-deformed billet) is inserted into the die. Before deformation, the billet is a cylindrical shaped solid as shown in Fig. 2 (a). After the deformation as shown in Fig. 2 (b), double cups are formed above and below the billet, thereby creating two different heights. The deformed billet is sectioned as shown in Fig. 2(c). Here, the ratio of the heights is established. The ratio of the cup heights after deformation, H_1/H_2, is an indication of lubricity [4], and it increases as the friction factor increases.

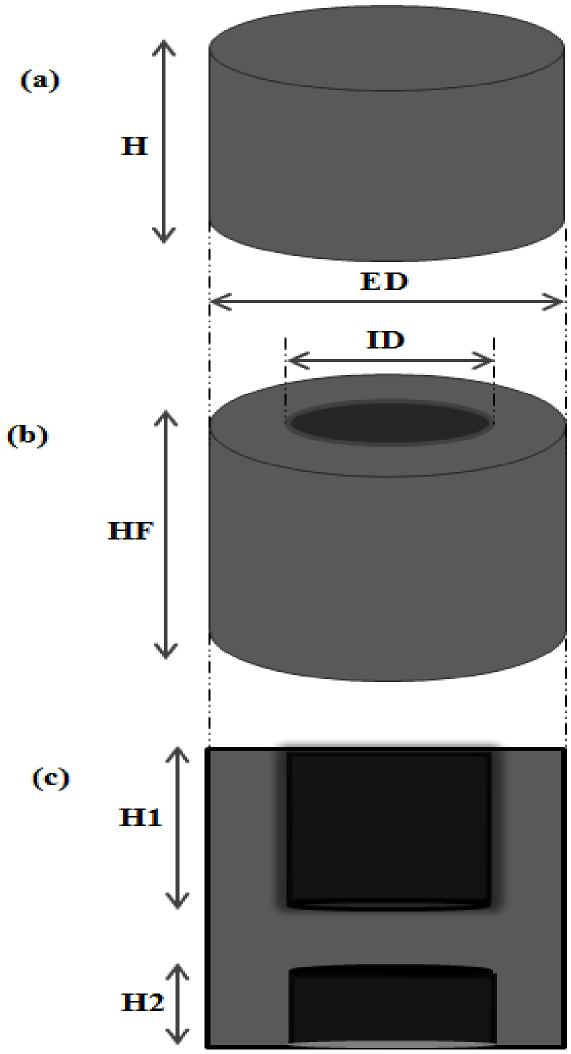

Fig. 2 Schematic view of double cup extrusion test: (a) Original billet, (b) Deformed billet, (c) Cup heights of the sectioned deformed billet.

Where 'H' is the height of the undeformed billet,
'ED' is the external diameter of the billet,
'ID' is the internal diameter of the deformed billet after extrusion,
'HF' is the final billet height after deformation,
'H1 and H2' are heights of the upper and lower cups.

The cup height ratio, R is given as equation (1)

$$R = \frac{H1}{H2} \qquad (1)$$

This ratio is exceptionally sensitive to friction. The punch stroke is expressed as shown in equation (2);

$$P_s = H - HF + H1 + H2 \qquad (2)$$

If no friction is introduced in the setup, the cup heights will be the same and the ratio, H1/H2 is equal to one. In the DCET setup, the upper punch moves down with the ram while the lower punch and container are stationary. However, the container has relative velocity with respect to the upper punch and not with the lower punch. Therefore, the material flow towards the lower punch is more restricted. An indication is the H2 as observed. In the presence of friction in the DCET setup, the height of the upper cup is larger than the height of the lower cup [3].

Finite element simulations were run to verify their investigation on the effect of punch and workpiece friction on the cup height ratio; and this was conducted on 1018 steel. Fig. 3 illustrates the plot of cup height ratio against stoke. This was done for top and bottom stroke with different friction factor.

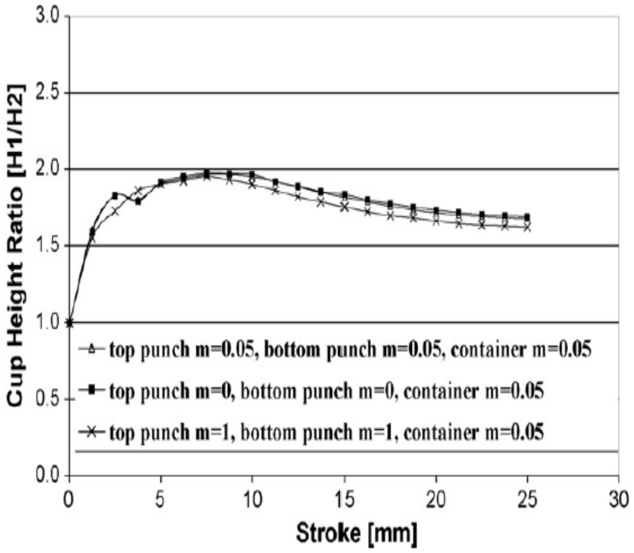

Fig. 3 Effect of punch and workpiece interface friction on the cup height ratio curve 1018 steel [3]

It was reported that the difference between the cup height ratios for zero friction at the punches and sticking friction at the punches was very small. However, the friction of the punch has no effect on the cup height ratio in as much as the friction at the top punch is the same as the friction at the bottom punch. From the plot, the cup height ratio falls between the ratio of 1 and 2.

The strain hardening effects were value of (0). The absence of strain hardening in a perfectly plastic material was reported to have friction at the billet/container interface and this has restricted the formation of lower cup. However presence of strain hardening has restricted the formation of the upper cup with increasing deformation. This behaviour was also revealed to be dependent on the strain hardening effect [3].

Fig. 4 shows another plot of cup height ratio against the stroke. The curves were reported to show an increase in the cup height ratio increases as the friction factor increases. It was also shown that the cup height ratio increases with increasing stroke and get to the peak before gradually descending until a stroke of 20 mm is attained [4].

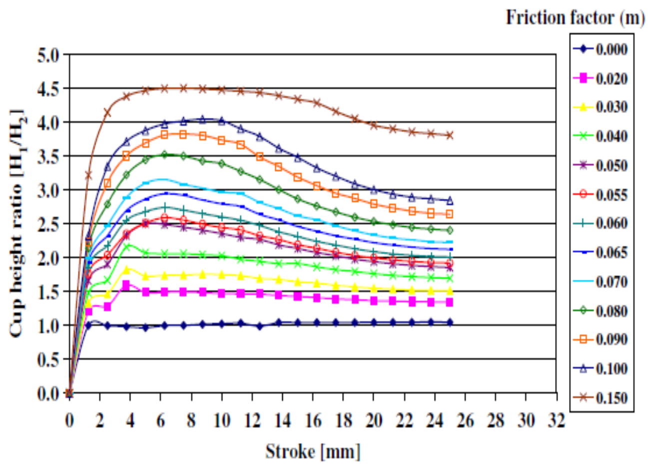

Fig. 4 Friction factor calibration curve [4]

At this point, the cup height ratio became constant with increasing stroke for all friction factor values.

The authors have revealed that at the same friction range, the ratio of cup height varied between 1 and 4.5. Therefore, the cup height ratio was suggested for accurate of lubricant selection [4].

The purpose of the double cup backward extrusion test is to establish a correlation between the ratio of the extruded cup heights and the friction conditions present at the billet-punch and billet-container interfaces. And as such, the existing friction conditions can be measured. The friction conditions at these interfaces are expressed as a number known as the friction factor which varies between 0 and 1 [7].

Studies on friction conditions on cold forging with this method of testing have shown the cup height ratio to be exceptionally sensitive to the friction factor. Hence, by comparing the cup height ratio and punch stroke to the friction factor calibration curves obtained through FEM, the friction factor of various lubricants can be relatedly quantified [8].

However, the prime drawback of this process is the interfacial friction between the die and the workpiece contacted surfaces. Although friction has been studied for many years, experimentally and theoretically using many techniques including finite elements [9] and the mechanisms that give rise to it are quite well-understood [10-16]. However, it is not possible to predict its magnitude for any given pair of materials under specified conditions [17]; nevertheless, there have been a few recent attempts at doing so [18-20]. The main problems facing this objective are the surfaces of two materials in contact (a) having different mechanical properties to the bulk due to surface oxide layers, absorbed dirt or lubricants, (b) roughness, and (c) changing over time during the deformation [21].

Most theoretical and experimental friction studies have been concerned with sliding friction, but there are also considerable publications on its effects in (upsetting forging) due to the importance of the technique developed in the forming of materials into the required shapes and sizes. The friction conditions including surface roughness at the material /die interface greatly influence the metal flow, surface friction, stress, forming load and energy [22].

The effects of such conditions could be significantly controlled by lubrication [23-26]. Many different tests have been developed over the years to determine measurable values of interfacial friction. These tests involved a variety of materials such as aluminum and copper [27].

However, a number of simplifying assumptions have to be made: (a) the specimen dimensions do not change between the time the deformation stopped and the measurement was made, which is probably reasonable for metals; (b) the friction remains constant during the deformation; and (c) the theory is true. These assumptions lead to large errors and uncertainties [28].

IV. Research significant and system benefits

In forging industry, energy consumptions and costs have immensely impacted on the competitiveness in the global forging market. However, there is a continuous need for process development and technological advances. Forging is a discrete part making process that consumes material and energy, and also in addition, it produces scrap and wastes. In hot forging, energy is spent in direct heating of forge stock to required temperatures, operation of press and other equipment, subsequent normalizing and cleaning of forgings. Heating is the prime source of energy consumption in forging industry. Scrap is associated with lack of process control and degradation of tool that is not recognized at interval. Steel processing is one of the highest energy users in the USA. The steel industry accounts for 2-3% of total U.S.A energy consumption. In steel industry, the energy consumed is approximately 6.5 kWh/Kg for primary steel making. AISI reports that 12- 15 % of the cost of steel made is energy cost [7].

Another important ingredient is the cost of tooling involved. Die costs range from 10 to 15 % of the cost of a forging, the indirect cost of tooling could be as high as 70% [29].

This includes the cost of die material and machining of the dies. And also the miscellaneous cost on the completion of the die is very important. The quality of the die must be able to withstand the intended purpose. If the quality and the inspection systems breakdown, it might amount to loss or damage of the die; and this can stop production.

In summary, the reduction of scrap and the longer die life are the most effective ways of reducing energy and cost utilization which are the goals of every forging foreman or plant supervisor. This is essential to the survival of forging plants in the long run as well as the sustainability of the new generation near net shaped components with good precision.

V. Conclusion

The texture patterns can thoughtfully reduce the friction factors no matter what lubricants that will be used for the experiment. Without lubricants the friction factors were very much dependent on the surface area of contact. This reduction is due to the lower area of contact due to texture. With most of the mineral oils, friction factors increase as the viscosity of lubricants decrease. The main thrust of this research to enable engineers to select the lubrication approaches in metal forming in order to achieve the best friction factor and also minimize the consumption of lubricant. These will improve the die life accumulatively. In order to achieve these goals and remain competitive, computational tools such as FE simulation techniques need to be applied for the determination of die-workpiece interface conditions at start-up and under steady-state production. Production trials with the new preform design and an alternative die material predict reduction in scrap rates with significantly abridged thermal fatigue on the critical regions of the die.

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