Journal of Materials Processing Technology 234 (2016) 300–308

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Estimation of hot stamping lubricant efficiency under dynamic loading conditions

Fedor Grechnikov[a], Alexander Khaimovich[a,*], Sergei Alexandrov[a,b]

[a] Samara State Aerospace University, Russian Federation
[b] A. Ishlinskii Institute for Problems in Mechanics, Russian Academy of Sciences, Russian Federation

ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form 4 March 2016
Accepted 19 March 2016
Available online 26 March 2016

Keywords:
Metal forming tribology
Lubricants
Lubricant efficiency
Dynamic loading

ABSTRACT

This paper presents a unique methodology which focusses on the quantitative determination of anti-friction properties of lubrication for large strains under dynamic loading. To compare the anti-friction properties of lubricants, a special-purpose stamp was designed. Workpieces with hubs consisting of eight radial wedge-type branches having different constituent convergence angles were stamped using a stamping tool. Under conditions of dynamic loading, a new criterion (coefficient) of lubricant effectiveness is proposed. Furthermore, a coefficient that quantitatively considers the stability of the technological lubricant properties in relation to geometrical changes is suggested. Regression models were developed for titanium alloys linking these two coefficients to allow the evaluation of the effectiveness of four variants of lubricant. It was found that lubricants composed of cubic bore nitride, water-soluble polymer, polyacrylamide and water have the best anti-friction efficiency of the tested lubricant samples.

1. Introduction

In general, the efficiency of lubricants used in hot plastic deformation depends on the combined action of several different factors. These factors include the thickness of the separating layer, the lubricant's viscosity and the velocity of the friction surfaces' mutual displacement.

For the purpose of improving lubricant efficiency, special methods which consider the characteristic features of the specific process have been developed and applied. For example, for hot forging of carbon steel workpieces which are heated to 1,000–1,200 degrees Celsius (°C), Bay et al. (2010) propose that the die tool temperature interface must be below 600 °C. This is achieved by showering the lubricant that contains cooling components or form heat-insulating films (e.g., glass), or minimising the workpiece contact time.

Hansen and Bay (1990) and Renaudin et al. (1983) found that low deformation stress can negatively impact certain hot stamping processes because it leads to an increase in the relative friction between the workpiece and the stamp tool. This results in higher wear. Therefore, in this case the main role of the lubricant is to release the stamp tool from the die more easily. Saw dust has been widely used for this purpose. Hirai (1984) proposed the use of sprayed suspended colloidal graphite, which is dispersed in water or oil in complicated die forgings. Similar recommendations can be found in Daouben et al. (2008).

Morishita (2007) claimed that despite their simplicity and easiness to apply by spray, graphite lubricants are altered into non-graphite lubricants in hot forging. As a substitute for graphite in lubricating materials, Bertell (1983) developed the first water-soluble compound based on a carbon acid and high-molecular-weight polymer with short chains. The variance of white lubricants' base components was narrowed to the following options in Morishita (2001) for cold forging an Bay et al. (2010) for hot forging (based on Nakamura and Ishibashi (2004)): polymer-based lubricants, carvone-based lubricants and liquid-glass-based lubricants.

Lubrication levels equivalent to graphite at least, can be achieved if the lubricant is composed mainly of polymer Yokoyama (2001). However, it should be noted that the lubricant's efficiency is determined considerably by the stamp tool temperature and lubricant coating conditions on which the separating layer thickness depends. Further detail around these considerations is provided in Morishita (2007).

1.1. Modern friction test techniques

In theoretical studies, it is usually assumed that the lubricant properties affect the friction law, the friction coefficient or the friction factor. Modern friction test techniques under different production conditions can be divided into the following main areas:

* Corresponding author at: Samara State Aerospace University, Department of Engine Production, 34, Moskovskoye shosse, 443086 Samara, Russian Federation.
E-mail address: berill_samara@bk.ru (A. Khaimovich).

http://dx.doi.org/10.1016/j.jmatprotec.2016.03.016
0924-0136/

1.2. Further development of traditional finite element (FE) modelling and test techniques

A traditional FE modelling and test technique, is ring compression at unsteady and non-isothermal conditions in order to quantitatively estimate lubrication quality. Im et al. (1988) used the FE method to simulate the deformation of ring and flange-shaft (spike) type parts under non-isothermal conditions. Classical trials as to the ring specimen compression between flat plates for hot compression by Wang and Lenaid (1992) and cold/hot compression tests by Ebrahimi and Najafizadeh (2004) were conducted. Malayappan and Narayanasamy (2004) and Narayan and Rajeshkannan (2012) studied the bulging effect of solid cylinders, varying the frictional conditions at the flat die surfaces in upset forging. Zhu et al. (2011) determined the friction factor of Ti-6Al-4V titanium alloy with glass lubricant and dry conditions under a hot forging situation by the combined approach of ring-compression tests and FE simulations. Azushima et al. (2012) studied the coefficient of friction at the interface lubricated cylinder using upset tests which were carried out using a specimen of commercially pure aluminium and a liquid lubricant. Ramezani et al. (2014) used a sheet metal forming simulator for evaluation of the frictional behaviour of AZ80 and ZE10 magnesium alloys under lubricated contact conditions by strip draw and bend tests.

1.3. Friction behaviour at varying levels of strain

Where the specimen ring's metal deformation and deformed field geometry are relatively simple or the deformation pressure is low, the free surface (generated after deformation) is small. As a result, Shen et al. (1992) note that the obtained characteristics of the friction process cannot be assessed adequately. For the purpose of investigating friction under more realistic deformation conditions, a number of papers report the use of forward (Bakhshi-Jooybari, 2002) and backward (Kim et al., 2006) extrusion-type forging. Kim et al. (2006) evaluated the effects of lubricants in backward extrusion of the large aspect ratio rectangular aluminium case. Buschhausen et al. (1992) proposed and examined a friction test based on a double backward-extrusion process in order to obtain information on lubrication quality for cold-forging operations. In 2002, the new 'open-die backward extrusion test technique' was developed by Sofuoglu and Gedikli (2002). This technique provides an alternative method to the ring compression test in order to quantitatively evaluate the coefficient of friction at the die/workpiece interface in large deformation processes. Masters et al. (2013) compared the friction behaviour of several automotive aluminium grades at different levels of strain, using a strip draw test.

1.4. Friction behaviour at high strain rates

Alves et al. (2012) presented friction correction for Hopkinson bar compression tests and developed a friction analytical model. The model is verified by finite element analysis and experiments. Sutter et al. (2014) proposed a finite element model for analysing friction processes derived from an experimental tribometer set-up which is able to reproduce severe contact conditions. These conditions can be reproduced under dynamic loading velocities ranging from 15 to 82 m per second (m/s) and a normal pressure of 50 and 200 megapascals (MPa).

1.5. Special tests for specific processes and combined methods with simultaneous or consecutive use of various loading schemes

Wang et al. (2012), summarised the recent development of friction testing techniques for aluminium extrusion processes, and presented detailed comparisons of these techniques. Of the existing friction testing techniques, the combination of extrusion friction tests and short sliding distance ball-on-disc tests were recommended. Sagisaka et al. (2013) proposed a new friction test based on combined forward spline-backward extrusion. It can represent large surface expansion, which is a characteristic of aluminium cold forging. The lubrication performance was evaluated by the friction test.

Friction plays a major role in all bulk metal forming processes. As a material flows along the interface, its properties are continuously changing due to plastic deformation. Moreover, in many cases, strains and strain rates in the vicinity of frictional interfaces are so high that the deformation stress data are impossible to obtain reliably with conventional tensile and compression tests. Therefore, even if friction stress is measured with high accuracy, the friction coefficient (or friction factor) cannot be predicted. This is particularly pertinent in the hot voluminous fabrication of workpieces with large friction interface surfaces under conditions of dynamic loading. Hammers under dynamic loadings and the stamping tool initial velocity are dependent on the dropping hammer's kinetic energy.

1.6. Study aim

Under dynamic loadings, more demanding anti-friction properties are applied to the technological lubricants within broad limits of external conditions of deformation. The instability caused by the use of anti-friction technological lubricants is the cause of workpiece surface defects and accelerated stamping tool wear. However, in order to evaluate the efficiency of lubricants used to produce a specific class of products, it is not necessary to determine the friction coefficient or even the friction stress. The aim of this research is to develop a method of determining the technological lubricants' relative efficiency in the event of hot stamping of parts with large friction interface surfaces. The method will be applicable to conditions of intensive plastic strain where stability is determined by the anti-friction properties of the technological lubricant.

2. Equipment and facilities

In order to evaluate the lubricant's efficiency, a special-purpose stamp was developed enabling workpieces with large contact surfaces (friction surfaces) to be stamped. Varied strain conditions were ensured because of the geometrical variations in the chosen workpiece. The workpieces stamped with the tool had hubs with radial wedge-type branches with different constituent convergence angles. The base dimensions of the forged workpieces are shown schematically in Fig. 1.

Construction of the stamping tool shape-development inserts is illustrated in Fig. 2(a). The local areas of plastic deformation, in which shape development of the branches occurs, are shown in Fig. 2(b).

Table 1 shows the dimensional characteristics of the stamping tool.

Table 1
Canal convergence angles.

Canal No.	1	2	3	4	5	6	7	8
2S (mm)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
2T (mm)	1.5	1.4	1.3	1.2	1.1	1.0	0.9	0.8
L (mm)	50 ± 0.1							
2α (degree (per (1))	1.03	1.14	1.26	1.38	1.49	1.61	1.72	1.84

It is seen from Table 1, that S is constant. Also constant are L and H which both equal 25 millimetres (mm) (Fig. 2(b)). Therefore, the geometry of the canals is completely controlled by the T value. It is