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Effect of surface roughness parameters and surface texture on friction and transfer layer formation in tin–steel tribo-system

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ABSTRACT

Surface texture of the tool is one of the most influential factors that affect friction at the interface during metal forming operation. In the present investigation, experiments were conducted using a pin-on-plate inclined sliding tester to study the effect of the surface texture of the tool on the coefficient of friction and the transfer layer formation in tin–steel tribo-system. 080 M40 steel plates were ground to attain surfaces of different texture with varying roughness. Pins made of pure tin were then slid against the prepared steel plates. Scanning electron micrographs of the contact surfaces of pins and plates were used to reveal the morphology of transfer layer. It was observed that the coefficient of friction, formation of transfer layer, and the presence of stick–slip motion depend primarily on the surface texture of tool surfaces, and independent of surface roughness (R_a) of tool surfaces. However, it is seen that a single surface roughness parameter, namely, average slope of the profile, ‘Del a’, of the tool surface plays an important role in determining the frictional behavior of the surfaces studied. The effect of surface texture on coefficient of friction was attributed to the variation of plowing component of friction, which in turn depends on the average slope of the profile.

1. Introduction

Pure tin has been used in capacitors, electrodes, fuse wires, and ammunitions. In addition, its alloys such as soft solder, bronze, and phosphor bronze are also important in electrical and automotive component industries. These components have been developed by different forming operations. Friction plays an important role during forming operations and the surface texture of the tool is a major factor that influences the friction. Attempts have been made to study the tribological properties of Sn and its alloys. Wang and Rigney (1995) studied the sliding behavior of Pb–Sn alloys for a wide range of composition from pure lead to pure tin in different environments and found that the coefficient of friction is approximately independent to composition. Taga et al. (1977) investigated the friction and wear loss in Cu–Sn alloy systems with varying Sn content. The authors (Taga et al., 1977) concluded that the wear and frictional properties could be explained on the basis of compositional changes at the interface during the sliding process.

The role of tool surface texture on friction has not yet been studied for tin and its alloys. However, for other metals or alloys, attempts have earlier been made to study the effect of tool surface texture on coefficient of friction and

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Nomenclature

Del a	average slope of the profile
Del q	root mean square (RMS) slope of the profile
FD	fractal dimension
Htp	profile section height difference
Lam a	average wavelength of the profile
Lam q	RMS wavelength of the profile
Mr1	peak material component
Mr2	valley material component
P_c	peak count
R_a	average roughness
R_{max}	maximum roughness depth
R_k	core roughness depth
R_{ku}	kurtosis
R_p	maximum profile peak height
R_{pk}	reduced peak height
R_{pm}	average maximum profile peak height
R_q	RMS roughness
R_{sk}	skewness
R_t	maximum height of the profile
R_v	maximum profile valley depth
R_{vk}	reduced valley depth
R_{vm}	average maximum profile valley depth
R_z	average maximum height of the profile
S	mean spacing of local peaks of the profile
S_m	surface material volume

wear (Lakshmipathy and Sagar, 1992; Määttä et al., 2001; Hu and Dean, 2000; Malayappan and Narayanasamy, 2004; Wakuda et al., 2003; Xie and Williams, 1996). Lakshmipathy and Sagar (1992) studied the effect of die surface texture on die work interfacial friction. They (Lakshmipathy and Sagar, 1992) found that the friction factor, based on ring tests, was lower for a die surface that had the criss-cross surface pattern. Määttä et al. (2001) studied the friction of stainless steel strip against different tool steels. The authors (Määttä et al., 2001) concluded that the surface topography of the tool has a marked effect on the friction between the tool and the work piece. The relation between friction and surface topography using various lubricants was studied by Hu and Dean (2000). The authors found that a random smoother surface could retain more lubricant and reduce friction. Malayappan and Narayanasamy (2004) studied the bulging effect of aluminium solid cylinders and concluded that the barreling depends on friction, which in turn depends on surface texture on the flat die surfaces. Many authors performed experiments using a scratch test to measure coefficient of friction (Nieminen et al., 1989; Menezes et al., 2005, 2006a,b,c; Liu et al., 2002). Nieminen et al. (1989) reported that scratch tester could be useful for friction measurements simulating low speed sliding. Menezes et al. (2006a) studied the effect of surface texture on friction and transfer layer formation using scratch test and concluded that the plowing component of friction was highest for the surface that promotes plane strain conditions and lowest for the surface that promotes plane stress conditions near the surface.

In some instances a phenomenon called "stick–slip" motion occurs during sliding if the frictional force does not remain constant, i.e., an oscillatory function of sliding distance or time. During stick phase, the friction force continuously builds up to a certain value, and once a large enough force has been applied to overcome the static friction force, slip occurs at the interface. This stick–slip motion occurs when the coefficient of static friction is greater than the coefficient of kinetic friction. Bowden and Tabor (1954) suggested that static friction is larger than kinetic friction due to molecular bonding between the surfaces. Hwang and Gahr (2003) studied the static and kinetic friction for different pairs of bearing steel 100Cr6 and a commercial alumina under unlubricated and oil lubricated conditions as a function of normal loads and surface finish. Hwang and Gahr (2003) concluded that stick–slip phenomena occurred in both unlubricated and lubricated pairs under high-normal loads depending on the surface finish. Bouissou et al. (1998) studied the influence of normal load, slip rate and roughness during sliding of self-mated polymethylmethacrylate (PMMA) under dry conditions and concluded that normal pressure is the main parameter influencing the transition between stable sliding and stick–slip motion.

Surface roughness parameter like R_a is used in general, to describe a surface. However, such a single roughness parameter cannot describe a functional characteristic like friction and it is possible that two surface textures can have the same R_a, but their frictional characteristics could be different. Many roughness parameters have been formulated to characterize the surface textures (Myers, 1962; Bello and Walton, 1987; Singh et al., 2005; Feder, 1988; Hasegawa et al., 1996; Gadelmawla et al., 2002; Torrance, 1995; Bhushan and Nosonovsky, 2004). In addition, attempts have been made to correlate these roughness parameters with coefficient of friction. Myers (1962) reported that the RMS of first derivative of surface profile was most useful in predicting friction. Bello and Walton (1987) formulated a new surface roughness parameter called bearing length product (a product of average peak width and R_a), and showed it to have a functional relationship with the coefficient of friction. Based on a detailed 3D surface characterization, Singh et al. (2005) accounted that the amplitude parameter S_q (RMS deviation of surface), spatial parameters S_{ds} (density of summits) and S_{td} (texture direction) play important roles in determining the frictional behavior of the surfaces.

Considerable amount of work has also been done by FEM and other computational methods to study the effect of various parameters on the contact between two surfaces (Challen and Oxley, 1979; Petryk, 1987; Subhash and Zhang, 2002; Yoshioka, 1997; Sahoo and Chowdhury, 2002; Varadi et al., 1996; Wang et al., 1991; Hamrock and Dowson, 1981; Ai and Cheng, 1996).

Most of the available research results from literature discussed above were based on variation in roughness values rather than on the texture of the surfaces and consequently most authors are unable to explain the importance of surface texture effects on friction during sliding processes and no single surface roughness parameter relates to the friction. Therefore, for allowing more application orientated testing, a method called the pin-on-plate inclined sliding test was used