Effects of Texture on the High Temperature Scratch Wear Behavior in Zinc

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Abstract: In this study the effect of texture on the wear behavior was investigated in extruded rod of pure zinc. Different loads and temperatures were used to investigate the effect of texture on wear behavior. Formation of chips at higher temperature marked the transition of wear mechanism from micro-ploughing to micro-cutting. Suppression of twinning at high temperature was also observed suggesting a complete slip dominated deformation at high temperature. The effect of texture was evident at high temperature and high loads.

1. Introduction

Wear is an omnipresent phenomenon in engineering service life of a product. From machining to micro-fabrication the component undergoes wear in some way or the other. However, in some cases, like precision machining, the wear and presence of surface damage becomes critical in deciding the performance of the material/component. Besides being used as a coating, zinc is also used in small electrical housing and medical implants [1, 2]. Most of the wear studies are centered around the wear endurance by conducting the pin on disc tests bringing out the bulk wear response. However, microstructural and texture aspects are often overlooked. Scratch studies offer better control to study the microstructural variables and scale dependent response. Parameters like grain size, microalloying and grain orientations have found to influence the wear resistance. Mezlini et al. [3] investigated the effect of grain size on the scratch wear behavior in Al-alloy and found out that smaller grain sizes can improve the wear resistance. Shishir et al. [4] investigated the effect of Zn addition in Mg on the wear behavior of Mg-Zn binary alloy and found that addition of Zn increased the wear resistance. Pranjal et al. [5] have shown that aging of the AZ80 alloy improves the scratch wear resistance. Shugurov et al. [6] investigated ploughing as a function of grain orientation in Ti. Swadener et al. [7] studied the effect of grain orientation and scratch wear in grains of Ti-Nb alloy and observed that work hardening due to scratch had a strong crystallographic correlation. Csanádi et al. [8] investigated the nano-scratch response in ZrB2 crystals and found that grains having basal orientation was the hardest grain showing highest scratch resistance. Flom and Komanduri [9] performed sliding experiments on different materials including single crystal zinc, however, they did not track the wear mechanism and associated deformation mechanisms. Somekawa et al. [10] investigated small volume wear in single crystal pure Mg. At higher loads the scratch on basal plane resulted in more wear when compared to prismatic plane.
The wear rate was also found to be governed by the prevalent deformation mechanism. Motivated by the fact that harder will resist better, the present work demonstrates the effect of texture and temperature on the scratch wear behavior in pure zinc.

2. Experimental procedure

Extruded rod of pure Zn (99.99%) was obtained from Alfa Aesar (Thermo Fischer Scientific India Pvt. Ltd). Two set of samples were obtained such that the surface to be polished and scratched was perpendicular to the extrusion direction (ED) and in the other the surface was parallel to the ED. The specimen was ground using SiC, followed by cloth polishing in a colloidal silica medium until mirror finish was obtained. The sample was etched using 2% Nital for 8 s to reveal the grains. ASMEC’s Universal Nanomechanical Tester (Bautzner Landstraße 45, Germany) was used to perform scratch. A diamond cono-spherical tip, with tip radius ~10 μm was used with a scratch velocity of 5 μm/s. Room temperature scratch test was carried out at 22°C whereas high temperature testing was carried out at 100°C and 150°C on the two different sets of samples which have different texture. For every temperature, a new sample was used so that the effect from previous heating is eliminated. The sample was placed on the heating plate to ensure direct contact. The scratch test progressed after an initial time of 180 s was provided in order to stabilize the system and ensure the tip is heated. Hitachi’s back-scattered electrons-based tabletop scanning electron microscope (SEM) TM3000 (Tokyo, Japan) was used to observe the nearby areas of the scratch. Macwin Zeta 20 optical profilometer was used to obtain the scratch groove cross section area. For each condition 3 scratches were made, and 4 cross sections were taken making it 12 cross sections.

3. Results and Discussion

The extruded rod of zinc exhibits a basal texture with the majority of the basal planes parallel to the ED [11]. The scratches were performed by scratching in the direction of ED and perpendicular to ED.

3.1 Wear mechanisms

Vlassak and co-worker [12] investigated the change in hardness as a function of orientation in single crystal zinc. It was found that for near basal orientation the hardness was ~0.64 GPa, whereas for orientation perpendicular to <c> axis gives a value of ~0.56 GPa. For a constant load, the wear rate should become a function of temperature wherein the wear rate will increase as the temperature increases. The increase in hardness is 14%, but a marked difference in the wear rate can be seen for two case, shown in Figure 1. The wear rate measured for scratch parallel to ED was lower as compared to scratch perpendicular to ED. At room temperature the wear rate is nearly same for 50 mN. However, as the temperature is increased, one can observe the effect of texture. Considering the Archard equation (eq. 1) for abrasive wear one can relate hardness and wear rate by [13]:

\[
\frac{Q}{L} = K \frac{P}{H}
\]

where \(Q\) is the wear volume, \(L\) is the length of scratch, \(P\) is the load, \(H\) is the hardness and \(K\) is a constant. From eqn. (1), as the slope increases the wear rate increases as a function of temperature, characterized by the change in slope. At higher loads and temperatures, however, the effect of texture is pronounced. At 200°C the effect of texture become evident. For 100 mN and 150 mN the slope does not get affected much. There is a glaring effect of texture and the surface perpendicular to ED shows more wear rate, even at lower loads. Figure 2 shows the wear tracks for a surface parallel to the ED and perpendicular to ED, scratched at different loads and temperature. At the outset, for scratches made parallel to ED, one can observe the chip formation at high temperature. At room temperature micro-ploughing dominated at all loads with lack of chip formation in both the cases. Under large negative rake angle, a brittle material can also develop a continuous chip while machining [14]. Zinc has low ductility and continuous chip formation is absent while machining a low ductile material as continuous chip formation is a signature for ductile material. The high negative rake angle is capable
of developing a high hydrostatic pressure under and ahead of the tool thereby forming a plastic zone. Chip debris were observed on the sides of the scratch groove for both the cases at room temperature. The change in wear mechanism was observed as the temperature changed. For scratches along ED, as the temperature increased the tendency for chip formation also increased, however for scratches perpendicular to ED the chip formation could not be sustained. For scratches perpendicular to ED chip breakage was also more prominent in this orientation.

3.2 Deformation mechanisms

Figure 3 (a-f) and (g-l) shows the deformation mechanisms near the scratched groove for surface parallel to the ED and perpendicular to ED, respectively. Owing to the texture, scratches made perpendicular to ED effectively compresses the crystals in \( \langle c \rangle \) axis. Similarly, the scratch made parallel to ED puts the \( \langle c \rangle \) axis in extension. However, the motion of indenter thus induces stress in different directions activating other deformation modes. Slip was observed to be the major deformation modes associated with the scratch. Besides slip, zinc is known to undergo twinning under compression [15, 16]. Twinning phenomenon progress in steps of nucleation and growth. The twins surrounding the scratch grooves look like the vertebrae of a fish, shown in Figure 2 (j). The twin mode observed is of the type \( \{10\bar{1}2\} \langle 10\bar{1}1 \rangle \) compressive twin. As the scratch progresses the twin is incubated, and further movement of indenter induces more compressive strain in the grain thereby a need for the twin to grow. As the indenter progresses ahead the stress level increases but as soon the indenter progresses, there is not enough stress to cause further growth of the twin. The adjacent region undergoes the same cycle and thereby we see multiple twins of the same type developing in the same grains. Plastic deformation of the material is dependent on the number active slip systems and twin systems. The triaxial nature of stress under the indenter is capable of activating basal slip which is the easiest slip system in zinc. Thus, slip lines are distinctly observed on the surface. Another notable

Figure 1. Wear rate at different temperatures for different orientations.
Figure 2. Wear track of scratches made, at different temperatures, (a-f) parallel to ED and (g-l) perpendicular to ED.

Figure 3. Wear track showing deformation mechanisms for scratches, made at different temperatures, (a-f) parallel to ED and (g-l) perpendicular to ED.

feature is the grain boundary sliding (GBS). The grains have slid past one another giving rise to a ledge. GBS can act as sites for crack generation. At higher temperatures the grain boundaries (GB) are undergoing extensive damage. This points out to the fact that not only a stress is required for incubation but in order for the twin to grow there must be a continued impingement of stress or stress field in order to support the twin growth. The twinning activity has decreased as the temperature has increased. For scratches made at high temperature, the dynamic recrystallization was observed inside the scratch groove, Figure 3 (k). The recrystallized grains are mostly pyramidal, and the twinned region is an active site for recrystallization [11].
4. Conclusion
The present work was able to demonstrate and bring out the influence of texture on the high temperature wear response in zinc. Scratch wear tests were performed on surfaces parallel and perpendicular to ED. For scratches made parallel to ED, chip formation was pronounced more than the other case. Wear resistance for scratches made parallel to ED was more. At high temperature and load, the effect becomes more pronounced and surface parallel to ED gives a better wear resistance. Slip was found to be the major deformation mechanism; however, suppression of twin was observed at high temperature besides GBS.

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