International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 3, July 2014

Research Paper

THE GENERATION OF MECHANICALLY MIXED LAYERS (MMLS) DURING SLIDING CONTACT

Aadarsh Mishra[1]*

*Corresponding Author: Aadarsh Mishra, ✉ aadarshm9@gmail.com

In unlubricated and boundary lubricated sliding, materials touch only at a restricted numberof isolated, typically microscopically small ‘contact spots’ that occupy but a small fraction of the macroscopic interfacial area.The intermittent local shear strains at thecontact spots in the course of sliding are very large. This behavior has been simulated, both for dry sliding and lubrication, by means of stacked foils of pure copper and silver shearedunder high superimposed pressure in a Bridgman-anvil apparatus. Strain hardening curves were obtained and the samples, now equivalentto material at wear tracks and specifically ‘echanically Mixed Layers (MMLs), were examined microscopically by means of a variety oftechniques.

Keywords: Contact spots, Mechanically mixed layers, Bridgman-anvil apparatus

INTRODUCTION

In unlubricated or boundary-lubricated sliding, the normal force between two sides *P*, is almost always supported at only a restricted number of ‘contact spots’ at which thelocal pressure compares with the hardness of the softer side (*H*) and whose total area (*A*) is controlled by local plasticdeformation so that $P = AH$.

As the contact spots move, the interfacialzone between the two materials becomes severelysheared. In this zone there occurs very fine mixingbetween the two sliding metals. In connection with the local shear strains, numerous studies have been performed on sliding interfaces. Dautzenberg (Dautzenberg, 1980) embedded an aluminum foil marker in a copper pin, atright angles to the interface. After sliding the pin on a rotating steel surface and examining the cross-section of the pin, he found that the marker had been sheared with increasingintensity from the bulk towards the surface. This was indicatedby a gradual turning of the aluminum foil marker parallelto the sliding direction of the copper pin. The demonstratedshape of the aluminum marker illustrates the verylarge shears that commonly develop at the tribo-interfacesof ductile materials. For another example, Ives (Ives, 1979) foundafter abrading copper with

[1] Department of Mechanical Engineering, Manipal Institute of Technology, Manipal University, Manipal, Karnataka 576104, India.

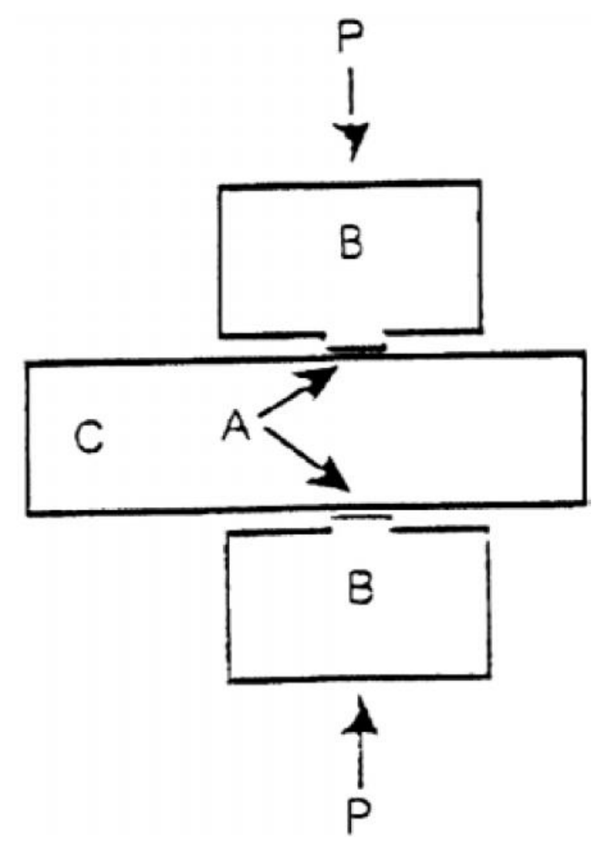
sand, that some of the sand hadbecome embedded in the copper in what he called 'highly irregularsurface deformation'. Next, Rigney *et al.* (1986) found the same extremely strong shear strain gradient adjacent to tribo-interfaces. Following are conclusions regarding MMLs for the case of sliding between two materialsof comparable hardness.

- During unlubricated as well as solid and boundary lubricatedsliding, MML's originate from the statistical movements of the small asperities which from moment to moment form the load bearing 'contact spots'. Heat transfer, electrical conduction, friction and wear arise atthose contact spots.
- MML's form through the cumulatively extremely largeshear strains and incidental mixing between the two sidesthat statistically occur at the contact spots under normal pressures comparable to the local hardness of the softerside.

EXPERIMENTAL STUDIES

The study of actual contact spots is difficult not so much on account of their small area and shallow depth in thematerial but because they are hidden from view. When inspectingworn surfaces due to sliding contact, one cannottell where specifically the contact spots were located fromone moment to the next and even less how long they lastedor how far they moved. Local conditions at contactspots, which cause mechanical alloying and the formationof MMLs, involve the already discussed extensive plasticdeformation and extremely large shear stains. A Bridgman-anvil apparatus was employed. Herein, foil disk samples are placed between twopairs of anvils, one rotating and the other stationary. The shear stains achievable in this device are enormous.The Bridgman apparatus is an effective and efficient way of studying the behaviors of materials under the conditions known to prevail at contact spots specifically, and at tribo-interfaces after substantial wear, in general. Bridgman invented his anvil apparatus in the 1930s. Two disk samples are at positions A and are sheared between stationary anvils B and the rotating platen C under applied pressure P. The specific apparatus, in which all of the experiments of the present and previous cited research were done. Itis modified from the original Bridgman apparatus in order to permit continuous measurement of both sample thickness and applied torque during shearing so as to obtain the already indicated stress-strain curves. Here the average shearstress is inferred from the torque required to rotate the platenand thus to internally shear the specimens. It is measured by the load cell. The shear strain is determined from the anvil rotation in conjunction with the simultaneous thinning of the sheared samples. These same conditions also apply to the deformation of interlocked plastic contact spots that inactual friction and wear leads to the formation of MML's. Because work hardening of the specimens increases their shear strength during the simulation, the desired conditionof non-slip sample/anvil contact may not persist during the course of an experiment. The higher is the applied normal pressure, the larger the shear strain that canbe imposed on the samples before slipping occurs. A minimal pressure comparable to the beginning hardness of the sample is always required to obtainany interior sample shearing at all. Increasing friction

Figure 1: Pressure is Applied as Indicated by the Arrows Labeled P. Two Similar Samples are Placed Symmetrically Between the Two B and A Anvil Pairs



between samples and anvils reduces the probability ofslipping.

The average thickness h of the two samples is monitored by the proximity probe whose output voltage (V_p) varies linearly with distance as:

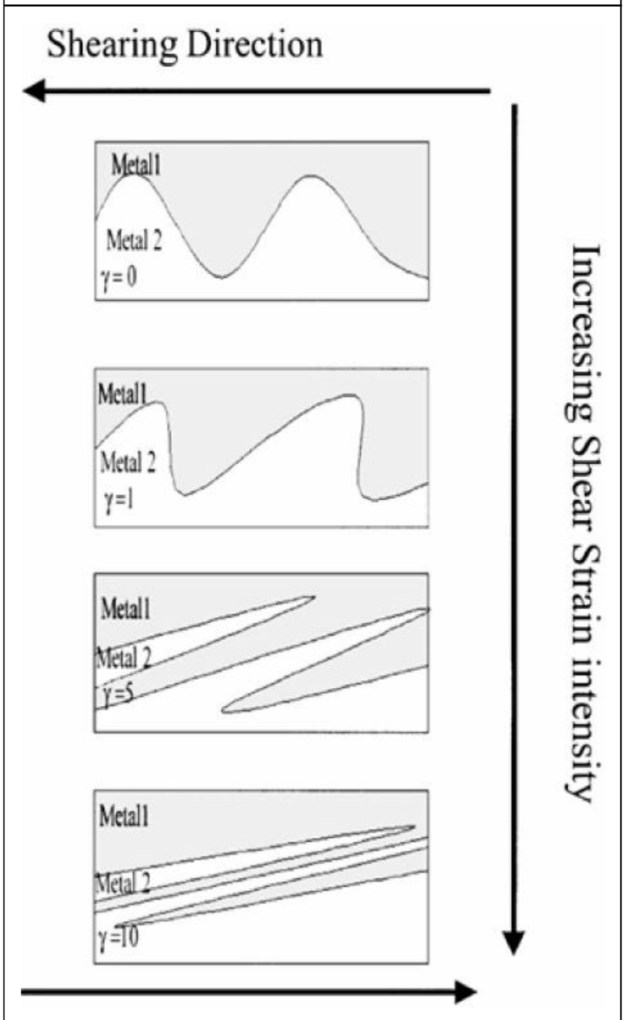
$$h = C_p V_p$$

where C_p is the proximity probe constant.

Gradual thinning of the sample sets in simultaneously with the onset of interior shearing, but not necessarily directly on activation of anvil rotation. Experimentally, any delay of the thinning and extrusion of material in the sample is thus due to slippage whether between the anvils and the sample surface or between layers within the samples. Whether anvil-sample slipping occurred can be ascertained by viewing the specimen surfaces under an optical microscope and noting whether the specimen surface morphology matches that of the adjacent anvil. Scoring marks on the sample show when slipping has occurred.

This effect poses an additional problem to the inherent in homogeneous strain when trying to quantify the amount of strain.

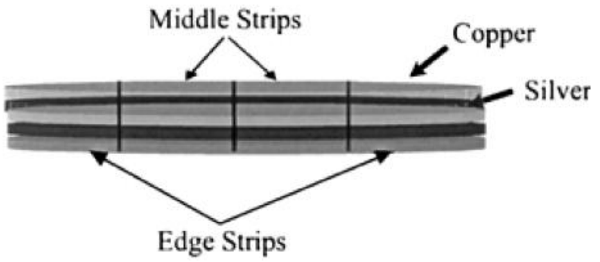
Figure 2: Schematic of the Formation of MML's at the Interface Between Two Metals



RESULTS AND DISCUSSION

In order to study how lubricants affect sliding interfaces, a system was designed for the controlled application of lubricant. Herein, the 15 µm thick 8 cm*8 cm foils thatare used for sample material, are placed one by one 4 cm below a downward facing nozzle in a stack on a moderately larger supporting cardboard square. Two separate tubes feedthe nozzle, one for an oil-solvent mix and the other fora propellant. 0.25 cc of the lubricant-solvent mixis measured into a syringe and is injected into the flowing propellant at the nozzle tip. The result is a spray of approximately 75 mm diameter droplets propelled by the Argon. Protected by the two pieces of cardboard, the stack is next pressed in a hydraulic press at 80 MPa for 3 min. This pressing largely, though not entirely, removes air bubbles from between the individual foils. There after, the cardboardis removed and the foil stack is ready as a sheet material from which Bridgman anvil shear test samples may be cut. So as to obtain the greatest possible information from the sheared samples, the cross-section of the sample layers has to be oriented parallel to both the FIB beam direction. In order to accomplish this feat, the following novel technique for mounting cross-sectional FIBM samples was developed.

Figure 3: Geometry of Layered Disk Sample Being Cut into Strips



Although there is an increase of initial thickness change with the decreased hardness of the material as discussed, most remarkably the subsequent rate at which the sample thins during anvil rotation depends on the hardness of the material in the opposite direction. Considering initial sample compression, it is clear that whatever pressure is applied, the sample material must harden accordingly since otherwise force equilibrium would not be achieved. For an initiallysofter material this requires a larger compression as indicatedby a smaller initial thickness. Therefore, on initial loading, samples of lower strength (i.e., samples which include Ag orlubricant) squeeze out more material, resulting in a smaller initial thickness. Once equilibrium is established the rotationof the anvils squeezes out even more of the material. Gradual thinning of the sample sets in simultaneously with the onset of interior shearing, but not necessarily directly on activation of anvil rotation. Experimentally, any delay of the thinning and extrusion of material in the sample is thus due to slippage whether between the anvils and the sample surface or between layers within the samples. Whether anvil-sample slipping occurredcan be ascertained by viewing the specimen surfaces underan optical microscope and noting whether the specimen surfacemorphology matches that of the adjacent anvil. Scoring marks on the sample show when slipping has occurred.The uneven shearing of sample material is typically enhancedby unavoidable very slight anvil misalignments relativeto the plane of rotation. Normally, the two anvils whileat rest before the shearing begins, are parallel to each other but slightly tilted relative to the axis of rotation. After one half turn, as one anvil is fixed, during rotation this misalignment causes a maximum pinching effect on one side of the samples where the anvils squeeze together, while on the oppositeside the pressure is at a relative minimum. Due to this slight misalignment of the anvils during rotation, all of the measured curves exhibit some apparent shear strength undulation that is periodic with the anvil rotation. Moreover, the discussed pinching after one half turn and then again after one and a half turn can cause a perforation in the samples and thereby effectively end the experiment. Contact spots arethe means by which materials in sliding contact become interlocked at the interface and cause the statistical strong shear. Initially, then, it is expected that during ordinary sliding the tangential pull between interlocked spots causes elongations in the form of easily recognizable 'tongues' which gradually refine and overlap into the lamellation that simulates MML's.

CONCLUSION

From this research, the following conclusions emerge: (1) At least some types of adhesive wear result from shearing at tribo-interfaces which, beginning with interlocked contact spots, causes geometrice longations dubbed 'tongues.' (2) Through a simple geometric distortion of surface waviness, continued shearing leads to fine lamellation of these tongues.

ACKNOWLEDGMENT

I would also like to dedicate this research work to my father late R S Mishra and mother K L Mishra.

REFERENCES

1. Bowden F P and Tabor D (1973), *Friction: An Introduction Tribology*, Anchor Press/ Doubleday, Garden City, New York.
2. Cai B, Kuhlmann-Wilsdorf D, Nelson R B, Rohatgi P K, Blau P J and Yust C S (Eds.), (1990), *Tribology of Composite Materials*, pp. 81-91, ASM International, Materials Park, OH.
3. Dautzenberg J H (1980), *Wear*, Vol. 60, p. 401.
4. Holm R (1967), *Electrical Contacts: Theory and Application*, 4th Edition, Springer, Berlin, New York.
5. Ives L K (1979), "Microstructural Changes in Copper Due to Abrasive", *Dry and Lubricated Wear*, p. 246, AMSE, Dearborn, MI.
6. Rigney D A, Naylor M G S, Divakar R and Ives L K (1986), *Mater. Sci. Eng.*, Vol. 81, pp. 409-425.
7. Uenishi K, Kobayaski K F, Ishihara K N and Shingu P H (1991), *Mater. Sci. Eng. A*, Vol. 134, pp. 1342-1345.