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The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Research on the thickness of lubricant coatings entrained during hydrostatic extrusion and the transport of solid lubricants is described.

Problem Studied

In heavily loaded, low-speed metalforming operations it is common to use soft solid coatings of soaps, waxes, plastics, conversion coatings (such as phosphates on steel) and even soft metals as lubricants. The present program was aimed at understanding the mechanics of the processes by which such coatings are entrained and act as lubricants in hydrostatic extrusion of metals and at developing practical guidelines for the selection of coatings for particular processing conditions.

Important Results

Early experimental measurements with copper billets coated with lead and lead-tin solder indicated that the thicknesses of the films entrained in steady extrusion were substantially larger than those predicted by the analytical model of Wilson and Halliday (1).

A careful examination of partially extruded billets which had been resin mounted and sectioned revealed the reason for the enhanced film thickness. In contrast to Wilson and Halliday's model which assumes no workpiece deformation in the inlet zone and a sharp corner at the boundary between inlet and work zones, the real workpieces showed appreciable deformation and curvature or "rounding in" of the workpiece. This effectively reduces the inlet angle and increases the thickness of the entrained lubricant film.

An improved analytical model (2) for the entrainment process which allows for the effect of inlet rounding was developed. When this was used in conjunction with experimental measurements of inlet geometry and coating and workpiece strengths, it proved to be a good predictor of the entrained film thickness of lead and lead-tin coatings on copper and steel workpieces.

However, the analysis tended to underestimate the thickness of resin bonded graphite films.

Experiments with lubricant entrainment rod drawing showed that the main reason for the underestimation of the entrained film thickness when polymers were used was due to the increase in the strength of the polymer under hydrostatic pressure.

A refined model (3) which allowed for an exponential increase of lubricant shear strength with pressure was developed. This showed quite good agreement with measurements of entrained film thickness with resin-bonded graphite and polyethylene coatings on aluminum and steel workpieces. Moreover some detailed modifications in the refined model substantially improved the agreement with the earlier experimental work with soft metal coatings.

With some coating materials (particularly harder polymer coatings) thermal softening of the lubricant can substantially reduce the amount of lubricant entrained. A series of mathematical models which allow for this effect have been developed (4) but it has proven difficult to relate these to experimental measurements of entrained film thickness. The primary problem has been in controlling the high extrusion speeds necessary to provide a significant thermal reduction in film thickness. To get over this problem, a series of rod drawing tests are in progress. It is hoped that the superior speed control available in this process will allow a better test of the thermal theories.

The thermal theories predict that under some circumstances high speed billet motion will lead to a breakdown in lubrication. It is encouraging to note that experimental extrusions produced under these circumstances show periodic bands of bare metal apparently associated with high speed excursions during severe stick slip motion. This type of behavior is not found under circumstances where the thermal theories predict adequate films under high speed conditions. Thus, the thermal theories seem to indicate when severe stick slip motion will occur.

A study (5) of the unsteady lubrication during the nosing of the billet at the start of the extrusion process has been conducted with both liquid lubricants and solid lubricant coatings. A temporary lubrication breakdown in lubrication of the type described by Wilson (6) was found in both cases. However, the rate of lubricant transport into the die was somewhat higher than that predicted by existing models for liquid (7) and solid (8) films. This was traced to the effect of frictional heating in the case of liquid films and to workpiece surface roughening in the case of solid films. The pressure peak during the start of extrusion could be adequately explained by the difference in friction between the lubricated and unlubricated parts of the billet nose/die contact.

Some work (9) on the effect of lubricant film thickness on the roughening of workpiece surfaces has also been conducted. It was found that in an upsetting operation with liquid lubricants that the workpiece surface roughness (R_A) was generally about one-quarter of the lubricant mean film thickness or the roughness which an unconstrained surface would attain under the same strain conditions, whichever is smaller. This is what would be expected on the basis of Wilson's analysis (10).

Publications and Presentations

The following technical papers are based primarily on the present research grant.

(a) Wilson, W. R.D. "The mechanics of solid lubrication in metal forming processes," Proc. 1st Int. Conf. on Lubrication Challenges. IITRI, Chicago (1978).

(b) Aggarwal, B. B., Norelius, A. B., and Quist, H., "Lubrication and friction during the nosing of an extrusion billet," Proc. NAMRC VII (SME), pp 129-136 (1978).

(c) White, D. H., and Wilson, W. R.D., "Solid lubricant entrainment in hydrostatic extrusion," Trans. ASLE, V 23, pp 305-314 (1980).

(d) Johnson, J. R., and Wilson, W. R.D., "Entrainment of pressure hardening solid lubricant coatings in hydrostatic extrusion," presented at the ASLE Meeting, Anaheim, 1980, to be published in Trans. ASLE.

(e) Silletto, J. G., and Wilson, W. R.D., "Surface roughening in liquid lubricated upsetting," in "Metalworking lubrication," ASME, pp 87-94 (1980).

The results of the research were also described in some detail in three review papers.

(a) Wilson, W. R.D., "Mechanics of lubrication in metal forming processes," Proc. 5th Leeds-Lyon Sumposium on Tribology, I. Mech. E. (1978).

(b) Wilson, W. R.D., "Friction and lubrication in sheet metal forming," in "Mechanics of sheet metal forming," pp 157-177, Plenum Press, New York (1978).

(c) Wilson, W. R.D., "Friction and lubrication in bulk metal forming processes," J. of App. Metalworking, V 1, pp 1-19 (1979).

The following University of Massachusetts theses are based on research supported by the present grant.

(a) White, D. H., "Solid lubricant entrainment in hydrostatic extrusion," M.S. in Manufacturing Engineering (1978).

(b) Johnson, J. R., "Pressure-sensitive and high-strength solid lubricants in hydrostatic extrusion," M.S. in Manufacturing Engineering (1979).

(c) Kennedy, K. F., "The entrainment of thermal softening and pressure hardening solid lubricants in hydrostatic extrusion," M.S. in Mechanical Engineering (1980).

In addition a presentation on the research was made at the 50th Anniversary Meeting of the Society of Rheologists at Boston in October 1979.

It is planned to submit two additional papers on the research in the near future. One of these will deal with the investigation of thermal softening effects. The second will provide an overview of the research and practical guidelines for solid lubricant coating selection.

Scientific Personnel

The following scientific personnel have participated in the project.

W.R.D. Wilson, Professor, UMass, Principal Investigator

B.B. Aggarwal, Ph.D. Student, UMass, Research Assistant

S. Sheu, Ph.D., Student, UMass, Research Assistant

P. Tsao, M.S. Student, UMass, Research Assistant

J.R. Johnson, M.S. Student, UMass, Research Assistant

K.F. Kennedy, M.S. Student, UMass, Research Assistant

D.R. White, M.S. Student, UMass, Research Assistant

A. Wadhawan, M.S. Student, UMass, Research Assistant

J.G. Silletto, Senior, UMass, Research Assistant

H.G. Quist, Senior, Chalmers Institute, Gothenberg, Sweden, Research Assistant

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A. Beck, Senior, Queen's University, Belfast, N. Ireland, Research Assistant

Dr. Aggarwal received his Ph.D. in Mechanical Engineering in 1980. His thesis is entitled, "Frictional damping at unlubricated metallic interfaces."

Mr. Tsao received his M.S. in Manufacturing Engineering in 1980. His thesis is entitled "Entrainment of lubricant films in rolling of steel and aluminum."

Messrs. Johnson, Kennedy and White graduated in 1979, 1980 and 1979, respectively. Their theses are referenced in the previous section.

Messrs. Sheu and Wadhawan are continuing their studies. The former is conducting research on disruption of thin lubricant films while the latter is completing the research on thermal effects and guidelines for lubricant selection.

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(1) Wilson, W.R.D. and Halliday, K. "An inlet zone analysis for the lubrication of a drawing process by a rigid-plastic solid." Wear, Vol. 42, pp 135-148 (1977).

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(3) Johnson, J.R. and Wilson, W.R.D. "Entrainment of pressure hardening solid lubricant coatings in hydrostatic extrusion" presented at ASLE Annual Meeting Anaheim 1980, to be published in ASLE Trans.

(4) Kennedy, K.F. "The entrainment of thermal softening and pressure hardening solid lubricant coatings in hydrostatic extrusion." M.S. Thesis, Mechanical Engineering. UMass (1980).

(5) Aggarwal, B.B., Norelius, A.B., Quist, H. and Wilson, W.R.D. "Lubrication and friction during the nosing of an extrusion billet," Proc. NAMRC VII (SME), p 129-136 (1978).

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(8) Wilson, W.R.D. and Lak, S. "The transport and breakdown of solid lubricants in a simple forging operation," J. of Lub. Tech., V. 99, pp 230-235 (1977).

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