Dear Colleague:

Enclosed are 2 copies of the report

"Continuing Research on Friction and Wear of Materials"

prepared under Contract/Grant No. N00014-92-J-1608

We have enjoyed working with you on this project and trust that this report is satisfactory. We look forward to the opportunity of working with you again in the future.

Sincerely,

Joy Ann Fischer
Joy Ann Fischer
Director, Editorial and Printing Services

This document has been approved for public release and sale; its distribution is unlimited.

MPN 769801
Date July 30, 1993
RF Project No. 726020
Type of Report Fiscal Year
Shipped By Certified/Return Receipt

Form RE-004 (Rev. 8/87)
FY92 End of Fiscal Year Letter

ONR CONTRACT INFORMATION

Contract Title: Continuing Research on Friction and Wear of Materials
Performing Organization: The Ohio State University
Principal Investigator: D. A. Rigney
Contract Number: N00014-92-J-1608
R & T Project Number: pri 6014-05
ONR Scientific Officer: P. P. Schmidt, ONR Code 3312

DTIC QUALITY INSPECTED 3

Enclosure (1)

A.1
FISCAL YEAR REPORT on CONTINUING RESEARCH ON FRICTION AND WEAR OF MATERIALS to The Office of Naval Research July 26, 1993 D. A. Rigney Materials Science and Engineering The Ohio State University 116 West 19th Avenue Columbus, OH 43210-1179

A. DESCRIPTION OF THE RESEARCH GOALS AND APPROACH

This project was designed to provide new information on the effects of ion implantation on surface (adhesion) and subsurface (deformation) effects during unlubricated sliding of metals. The base materials are copper and iron, and the implanted species are also copper and iron. Thus, in some samples there should only be structural changes caused by implantation (e.g., Fe into Fe, Cu into Cu), while in others there will be composition changes as well (e.g., Cu into Fe, Fe into Cu). Copper and iron were chosen because of the considerable amount of literature available for comparison of results from testing of these metals. Also, their hardness values and deformation behavior are different, the OSU group has experience with both metals, and the phenomenon of selective transfer, extensively studied in the former USSR, usually involves both Cu and Fe.

The project was originally designed to address questions raised at a workshop at Argonne National Laboratory in 1988 (1), in particular questions associated with separating surface and subsurface effects. Recognizing that these may interact in ways which make them difficult to separate, we have attempted to use ion implantation of samples tested in vacuum in a pin/disk sliding system. Because geometric effects are known to be important, we are using both Cu/Fe and Fe/Cu configurations (pin/disk). There are thus 36 different combinations of pin/disk for each implanted thickness used, because each component can be Cu, Fe, Cu(Cu), Fe(Fe), Cu(Fe) or Fe(Cu), where the species in parentheses is the implanted species.
B. PROGRESS AND SIGNIFICANT RESULTS IN THE PAST YEAR

The graduate student working on this project passed her General Examination during Winter Quarter, 1991. Since then, she has been working full-time on her research. She has had to surmount a number of difficult problems which slowed initial progress. For example, the first set of implanted specimens was contaminated with unacceptable amounts of carbon and cadmium. The student found that the source of the carbon contamination was the furnace used earlier for annealing the specimens. She also traced the Cd contamination to plated screws used in the implantation chamber at Mound Laboratories. Another problem involved silicon contamination during preliminary sliding tests. The student traced this to the diffusion pump oil and the vacuum grease used in the vacuum system. We therefore changed to a different pin/disk device enclosed in a cleaner vacuum system which is pumped by a turbomolecular pump. At the same time, disk shaped pins were replaced by hemispherical pins which provide before reproducibility of the contact geometry, especially at small sliding distances. The student also discovered that the balls purchased to be used for the Cu pins contained embedded SiC particles, making them unusable without further surface preparation. The problem here is the ease of embeddability of hard particles in the soft copper. Therefore, rather than use standard metallographic polishing to remove the SiC, we used chemical polishing. This created some waviness but provided a smooth surface uncontaminated with hard particles. Other problems involved electrical noise in the friction measuring system. Changes in grounding and shielding greatly reduced this problem. All of these problems were identified and solved by the student herself.

By far the most serious problem has been the delay in obtaining implanted specimens from Mound Laboratories, Miamisburg, OH. Soon after the problem with Cd contamination was solved, it was announced that Mound Laboratory would shut down, as casualty of the nations budget problems and changes in the world related to the collapse of the former USSR. The person doing our implantations was reassigned to paperwork associated with the clean-up and shut-down of the Labs. We scrambled to find an alternative source which would not charge a large amount for the service. The project budget had been planned with donated implantation services, because Mound Labs personnel had agreed earlier to do this work for us without charge. Personnel at Oak Ridge National Laboratory agreed to help. However, due to differences in equipment and laboratory policy, that would require months of our being present at Oak Ridge, with associated unbudgeted costs. At the end of this reporting period, we still had not solved this problem, and we had not received implanted specimens suitable for testing for this project. [Note: A few months later, at beginning of 1993, Mound Labs personnel agreed to start up their implantation equipment again and implant our samples. Sliding tests then proceeded during 1993. The results will be described in the next fiscal year report.].
A delay of nearly a year was caused by the several factors listed above, particularly the delay in obtaining suitably implanted test specimens. However, the student did not waste that time. She became proficient with several scanning and transmission electron microscopes and with specimen preparation for those instruments. She has also reviewed the literature systematically and she has written a section of her thesis based on that review.

Two series of samples are being implanted. These use different accelerating voltages and fluences to give different implantation depths and concentration profiles. For example, Fe is implanted with Cu at 5 keV and a fluence of $2 \times 10^{15}$ Cu+/cm$^2$, giving a calculated concentration peak depth of about 2.6 nm and a concentration of about 5 at. %. For a thicker modified region, higher implantation energy is used. In that case, a more uniform layer is created by using multiple implantations: $2 \times 10^{16}$ Cu+/cm$^2$ at 200 keV, $3 \times 10^{15}$ Cu+/cm$^2$ at 60 keV and $3.5 \times 10^{15}$ Cu+/cm$^2$ at 35 keV, giving a peak depth of about 100 nm and a maximum concentration of about 8 at. % Cu. These calculated values will be checked by using Auger electron spectroscopy combined with sputter profiling, as well as profilometry of the sputter crater.

C. RESEARCH PLANS FOR THE NEXT FISCAL YEAR

1. Implanted specimens received from Mound Laboratories will be tested in vacuum, using both short and long sliding distances. This will allow checking behavior before and after any mild to severe transition which may appear.

2. If the 50 g load being used for preliminary tests is too large, we will reduce this by at least ten times. If the friction in the journal bearings of the present pin/disk system is too large to be used with smaller loads, we will replace it with a system using ball bearing mounts. [Note: This was found to be necessary in the following reporting period.]

3. Nanohardness measurements on both implanted and unimplanted specimens will be made. Correlations with the $H_d/H_p$ ratio of Kato can then be attempted (2). Also, it can then be determined if the sign of the hardness gradient at the surface affects the sliding behavior. With hardness and hardness gradient data available, the energy-based model of Heilmann can be applied (3).

Report References:

1. Workshop on Wear Modeling, Argonne National Laboratory, Argonne Laboratory, Argonne, IL, June 16-17, 1988.


D. LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals


2. Non-Refereed Publications and Published Technical Reports

none

3. Presentations

a. Invited


b. Contributed

none

4. Books (and sections thereof)


Enclosure (2)
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Enclosure (3)

### F. PARTICIPANTS AND THEIR STATUS

1. Dr. D. A. Rigney, Professor, Materials Science and Engineering, The Ohio State University, Project P.I.

2. L. H. Zhang, Graduate Research Assistant, Ph.D. candidate; passed General Examination for candidacy for Ph.D.--working full-time on this project. Expected date of receiving degree: 12/93.

### G. OTHER SPONSORED RESEARCH DURING FY92

1. D. A. Rigney, Selective Transfer in Tribology, NSF, Engineering Division (Surface Engineering and Tribology), SGER program, $35,000, 7/1/91-9/14/93, for one graduate student.

H. SUMMARY OF FY92
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/PARTICIPANTS
(Number Only)

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Enclosure (4)

ONR FOREIGN TRAVEL POLICY
FY92 End of Fiscal Year Letter

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Principal Investigator: D. A. Rigney

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