Friction and Wear Performance of Diffusion Coatings Produced by Pack Cementation Processes

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Purpose of Project: This project was designed to provide needed information on the friction and wear behavior of diffusion coatings recently developed at The Ohio State University by R. A. Rapp and his colleagues (1-7). These coatings have superior corrosion and oxidation resistance. They can be produced on various steels and on alloys of nickel and titanium. The process involves codeposition of desired species, e.g., Cr and Si, by pack cementation. Such coatings may be suitable as replacements for Cr plating. Cr plating processes have been associated with serious environmental problems, so processes which can produce adequate coating substitutes are of great interest. Various carbide coatings can also be produced by the pack cementation process. Potential applications in the aerospace and automotive industries include gears, cams, shafts, tappets, valves and low friction hydrostatic bearings.

Background: Cr plating is widely used for protection against corrosion and oxidation and control of friction and wear. Unfortunately, the electrolytes used are problems in the work place and in the environment. Therefore it is desirable to identify alternatives which retain the benefits from Cr but without the problems associated with electroplating. Desirable characteristics would be strong bonding of the coating to the substrate, a good surface finish, limited dimensional changes, good corrosion and oxidation resistance and good tribological behavior. Substrates of interest would be various steels and alloys based on Al, Ni or Ti.

The approach taken in this work has been pack cementation, as in the familiar processes of aluminizing, chromizing and siliconizing. The traditional pack includes the sample or samples to be coated, a masteralloy or powder mix, a halide activator and inert filler powder. Chemical reaction yields a volatile halide which transports the desired species, e.g., Cr, to the specimen surface. Diffusion then creates a coating of desired thickness, which can be controlled by varying time and temperature.

R. Rapp et al. at Ohio State have significantly modified the traditional process to allow controlled codeposition of two components, e.g., Cr and Si. The composition is controlled by the choice and relative amounts of two activator salts. The choice is guided by a computer program which predicts vapor pressures. Examples are coatings of 25Cr-3Si or $Cr_{23}C_6$ on various steels, including low and medium carbon steels.

It should be noted that the pack cementation process does not substitute one environmental or work safety problem for another, despite the fact that it involves halide vapors. Prof. Rapp confirms that the metal halides condense in the cooler parts of the system and are not expected to be a problem. To assure that none escape, one could pass the vapors through any basic aqueous solution to trap all of them.

Project Work: We have used pack cementation processes to produce Cr-Si and $Cr_{23}C_6$ coatings at OSU on specimens for friction and wear testing at Rockwell Science Center, Thousand Oaks, CA (8). The Rockwell tribometer (see Figure on page after bibliography) is a unique instrument which can operate with various geometries in sliding or sliding with rolling, and it has *in situ* SEM, AES and XPS capabilities. Our substrate materials were 8620, 1045 and 4140 steels with Cr-Si and carbide coatings. Sliding speeds were about 1 m/s and about 3 m/s and the typical test time was 300 s. The mean Hertz stress was about 1000 MPa, and the test environments were vacuum and dry air. Post-test characterization of specimens has been done both at Rockwell and at OSU.

During the early part of this project, work concentrated on Cr-Si coatings on 8620 steel. The activator salts used were NaF and $MgCl_2$. The inert filler materials were alumina or silica. A flowing argon environment was used. Good coatings of Cr-Si were produced, but the wear results were disappointing, so the emphasis of the project shifted in the later stages to the $Cr_{23}C_6$ coatings.

The Figure on the page following the bibliography includes information on the geometry and dimensions of the specimens. The large size of the specimens required a larger furnace and furnace tube size than had been used for most of Rapp's earlier work. Therefore some additional development work was needed. Variables involved pack composition, mass of components, number of specimens per run, tube size, time, temperature and heating/cooling rates. We were successful in producing sound Cr-Si coatings on 8620 steel, with compositions near the surface of about 25% Cr and 2.5-3% Si. Coating thicknesses were in the range of 100-200 μm. We have also produced good carbide coatings. These are of course much thinner because of the effective diffusion barrier assocated with carbide coatings.

All friction and wear testing was done at Rockwell by P. Min, working with Y. Naerheim and his group. The first set of tests at Rockwell provided data which guided us in producing the next series of coatings at OSU. The worn specimens were characterized both at Rockwell and at OSU.

The experimental results showed that, for the sliding distances used in these tests, the Cr-Si coatings have disappointing sliding wear resistance compared with the Cr plated specimens. The carbide coatings, however, have improved wear resistance. From these tests alone, the order of merit for the wear resistance would be $Cr_{23}C_6$ > Cr plate > Cr-Si coatings. Therefore, in the later stages of this project, the focus of our efforts was on the $Cr_{23}C_6$ coatings.

Summary and Main Conclusions:

- Cr-Si coatings were produced on 8620 steel by codeposition using pack cementation technology developed at Ohio State. These had shown outstanding corrosion, oxidation and erosion resistance, but this project showed that their sliding wear resistance compared with Cr plated samples was disappointing. Therefore work on these coatings was abandoned and the later part of the project focused on carbide coatings instead.

- $Cr_{23}C_6$ coatings were produced on 1045 steel by pack cementation technology developed at Ohio State. These were much thinner than the Cr-Si coatings, but adherence to the substrate was excellent in both cases. Wear resistance was better than that of Cr plated samples.

- It should be noted that cross-sections of Cr plated specimens showed cracks suggesting that the coating would wear by removal of pieces equal in thickness to that of the coating. Therefore, sliding tests of longer duration are likely to change the order of merit of pack cementation coatings, with their outstanding adherence, compared with Cr plated coatings. Also, all tests were done at room temperature, and the order of merit obtained is not necessarily the same as what would be obtained at elevated temperature. It is even possible that the Cr-Si coatings would compare better at longer times and at elevated temperatures, compared with Cr plated coatings or even the $Cr_{23}C_6$ coatings.

- All sliding tests were run dry, i.e., without lubrication. However, it was noted that the $Cr_{23}C_6$ coatings had a micro-pit surface topography which might be ideal for retaining lubricant.

Future Work:

- It is clear that tests for much longer sliding distances are needed. Tests with combined rolling/sliding and tests at elevated temperatures (using laser heating) may also be included.

- Decarburizing of carbide coated specimens in the region below the coating has been noted. This may or may not be a significant problem, but it certainly merits further attention.

- We originally thought we might produce and examine NbC and/or VC coatings, but we are convinced that large differences in thermal coefficient of expansion compared with the substrate steels would make successful production by pack cementation unlikely.

- Looking further into the future, we could produce and test new coatings currently being developed by Rapp et al. for Ti alloys. However, we believe that by far the largest market is for effective coatings on steels, so we should continue to concentrate on coatings for steels.

Acknowledgment:

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Note:

Details of specimen preparation, coating procedures, specimen characterization and friction and wear tests are available from Peter Min, now at Rockwell Science Center, Thousand Oaks, CA.

Bibliography:

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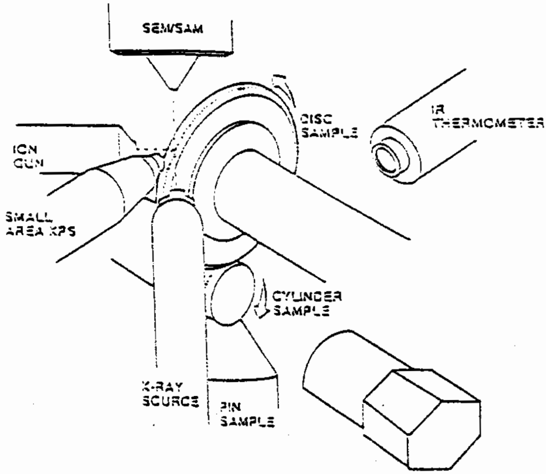
ROCKWELL TRIBOMETER with SEM/AES/XPS

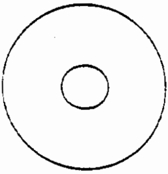


Experimental Conditions:

8620 and 1045 steels
Cr-Si and carbide coatings
~1 and 3 m/s sliding speeds
Mean load of ~18 N
Mean Hertz stress ~250 MPa
Environment: air and vacuum

SAMPLE GEOMETRY

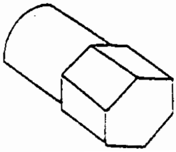
DISK



50.8 mm diam.
12.7 mm thick

127 mm
crown radius

COUNTERFACE



each face:
12.7 mm x 7.9 mm