7. MAINTENANCE, REPAIR, RECYCLE

A. Effects of Highway Ice-Clearing Treatments on Corrosion of Heavy Vehicle Materials and Components

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Objective

- Evaluate the corrosion that may be associated with the various ice-clearing chemical systems that are in use by the various states and regions for snow and ice control.
- Develop a more fundamental understanding of the interaction of these chemicals with representative heavy vehicle materials and structures.
- Develop a unified modeling procedure to represent "rust jacking" (displacement of brake friction materials) caused by stresses induced by corrosion products at the interface of the brake shoe and the friction liner.

Approach

- Evaluate heavy truck corrosion damage to identify materials, components, and safety-related systems affected by anti-icing/deicing treatments.
- Identify and characterize $MgCl_2$ solutions and corrosion-inhibiting additives.
- Perform accelerated corrosion testing and corrosion characterization of heavy vehicle materials.
- Evaluate brake shoe failures to identify aggressive corrosion species and extent of corrosion.
- Determine the thermo-elastic and mechanical properties of the lining material, brake shoe table, and corrosion products.
- Incorporate the mechanical properties of the lining material, brake shoe, and corrosion products into computer-aided engineering (CAE) codes to predict the stresses associated with swelling of oxides on the shoe/lining interface.

- Identify more desirable ice-clearing chemical formulations and application methods.
- Generate “best practice” recommendations for reduced vehicle corrosion and improved safety.

Accomplishments

- Established an advisory/steering committee consisting of representatives from the American Trucking Association, industry, and the Montana Department of Transportation (MDT). (MDT is also a member of the Pacific Northwest Snowfighters Association).
- Surveyed and assessed materials, components, and safety-related systems affected by anti-icing and deicing treatments.
- Conducted a literature survey of past and current ice-clearing chemical corrosion investigations to (1) assess the status of ice-clearing chemicals on heavy vehicle corrosion and (2) assess appropriate corrosion test methods.
- Acquired commercial ice-clearing chemical products prevalently used in the northwestern states for evaluation.
- Acquired test equipment to evaluate and characterize the corrosion potential and corrosion rates of the ice-clearing chemical products.
- Completed indentation tests to determine the mechanical properties of the brake shoe metal and oxide.
- Began tests to determine the mechanical and thermal properties of the brake pads.
- Measured the as-machined surface roughness on each brake shoe metal test disc.

Future Direction

- Evaluate and characterize $MgCl_2$ anti-icing/deicing solutions and other ice-clearing chemical products ($CaCl_2$-based and nonchloride solutions).
- Conduct accelerated corrosion testing of heavy vehicle materials.
- Conduct in-service field evaluation (coupons will be attached to selected trucks in the field that are exposed to regions that use only one method of snow and ice control (i.e., $MgCl_2$ applications, rock salt).
- Conduct forensic analysis of failed brake shoes.
- Determine the remainder of the thermal and mechanical properties of the brakes.
- Develop a finite element model and incorporate the material property data.
- Determine the stresses that arise from the growth of corrosion products between the pads and the table.

Introduction

In recent years, many states have introduced anti-ice liquid treatments, particularly $MgCl_2$ road treatments, to prevent the bonding of ice and snow before the onset of a winter storm. Spraying the treatment on roads before the onset of a storm potentially can expose vehicles to concentrated solutions for longer periods of time because the solution is not immediately diluted by snow or water. Increased corrosion damage on heavy truck components has been reported by truck fleets and owner/operators. Vehicle safety concerns have arisen, based on the observation of accelerated corrosion damage in heavy

(a)

(b)

Figure 1. An illustration of rust jacking: (a) corrosion product buildup on the brake shoe table displaces the brake lining; (b) shoe table/friction liner interface.

truck brake systems, also known as "rust jacking" (Figure 1).

Although there is a strongly voiced opinion within the trucking community suggesting that accelerated damage is being caused by $MgCl_2$ road treatments, there is a lack of significant data to quantify the role of various $MgCl_2$ treatments on heavy truck component corrosion.

In May 2003, Pacific Northwest National Laboratory and Oak Ridge National Laboratory began collaboration on a two-year research effort focused on developing a more fundamental understanding of the interaction of these chemicals with representative heavy vehicle materials and structures. The project consists of six tasks, with the first two primarily focused on establishing a steering committee to ensure unity among the trucking industry and to assess the heavy truck corrosion damage that may be associated with the application of anti-icing/deicing treatments on roadways. Following is a description of the remainder of the four project tasks.

Characterization of $MgCl_2$ Solutions and Corrosion-Inhibiting Additives

The purpose of this task is to identify the commonly used $MgCl_2$ treatments and application methods, characterize the corrosive behavior of the various formulations, and establish appropriate accelerated corrosion test methods. Based on a state-by-state survey of operating highway departments, the project will identify the commonly used $MgCl_2$ treatments. In addition, the project will evaluate the methods by which $MgCl_2$ treatments are applied and how $MgCl_2$ is used in conjunction with deicing treatments.

Selected $MgCl_2$ treatments will be characterized chemically, and corrosion inhibitors will be identified for each of the selected $MgCl_2$ solutions. Analysis of the $MgCl_2$ treatments and the exposure conditions will be used to establish subsequent materials test methods. Other ice-clearing chemical products will also be investigated for a comparison.

Corrosion Testing and Corrosion Characterization

Using the information generated on ice-clearing chemical compositions and corrosion potential, a selected series of accelerated corrosion tests using representative heavy-vehicle materials will be conducted. A principal objective of this task will be to determine the effects of various accelerated test parameters and to help specify meaningful accelerated test methods for use by the heavy-vehicle manufacturers. To this end, tests will be conducted at selected temperatures to determine the effects of realistic winter temperatures on corrosion behavior. The parametric variables are solution composition, test temperature, and time of wetness.

Simple coupon specimens, stress corrosion cracking specimens, and selected advanced materials (such as metal matrix composites and magnesium castings) will be included in the accelerated corrosion tests.

In-service vehicle testing will also be conducted during the 2003 winter season to compare with the laboratory test results. Coupons will be attached to selected trucks that operate in regions that are exposed to only one method of snow and ice control (i.e., $MgCl_2$ applications, rock salt) as well as to selected trucks that are exposed to many methods. Half of the coupons will be examined at the end of the winter season and the remainder at the end of summer 2004.

At the end of the corrosion tests, detailed surface examinations (microscopy and scanning electron microscopy) will be conducted to characterize the type of corrosion damage that is occurring (such as general corrosion, pitting corrosion, and stress corrosion cracking) and to identify the corrosive species.

Brake Shoe Evaluation

Forensic analyses of failed brake shoes will be performed to assess the extent of corrosion and to identify the aggressive species that were incorporated into the corrosion product. Optical metallography and back-scattered electron imaging and X-ray microanalysis in scanning electron microscopes will be used to characterize these failed parts.

Samples of the present materials used in construction of the brake shoe table, as well as appropriately chosen materials that would be economically viable replacements, will be included in the accelerated corrosion testing. The data generated will allow for selection of appropriate materials for future brake shoe manufacture and comparison of the effect of various anti-icing/deicing compounds on corrosion rates.

An initial forensic evaluation of a failed brake system showed that corrosion is nonuniform (as is to be expected for plain carbon steel) in chloride environments. Banding of the oxide scale was observed. This may reflect the changing corrosion conditions to which the brakes are exposed. Variations in composition and concentration of anti-icing and deicing salts, pH, moisture, temperature, and frequency and pressure of braking could all impact the corrosion rate and resultant products. Salt composition and concentration and pH, which affect the corrosion potential of the plain carbon steel, are the major contributors to the banding. A small change in salt composition and/or concentration, with or without a slight change in pH, can result in shifts between Fe_3O_4 and Fe_2O_4 phase fields.

The recently introduced anti-icing and deicing compounds result in increased "time of wetness" and hence increased corrosion. Cracking, porosity, and localized spalling of the scale would provide new pathways for water ingress and exposure of fresh metal to the corrosive environment. However, this initial analysis found no evidence of calcium and magnesium chlorides, which are the newly introduced deicing and anti-icing compounds and are less soluble in water than the chlorides of sodium and potassium that were identified in the scale. This may be a result of nonexposure of the examined brake table to calcium and magnesium chloride. The mechanisms for the increased failure rate are postulated as being an increased rate of corrosion due to positive shifts in the corrosion potential, as well as an increased amount of corrosion due to an increased time of wetness that results from the presence of hygroscopic salts.

Modeling of Brake Lining Failure

A model is being developed of the lining material fracture phenomenon caused by the forces produced by the growth of corrosion products at the shoe table/lining interface. This model will require information on the mechanical properties of the constituents, namely, elastic properties for the lining material and shoe, and the corrosion products that exert a force on the lining surface, as well as flexural strength of the lining material. The mechanical properties of the lining material and oxides will then be incorporated into CAE codes to predict the stresses associated with swelling of oxides on the shoe/lining interface.

Elastic Property Indentation Tests

Instrumented indentation tests were performed on brake pad material (new and worn) and on the brake table (including oxide layer) to determine the elastic modulus of these materials.

Indentation tests on the metal from the worn brakes were done in two locations. These tests were performed around the rivet holes, away from the rivet holes, and through the oxide layer. The results of the modulus data from these tests show that the modulus of elasticity in the metal, away from the oxide layer and the rivet holes, is about 170 GPa. There is some variation in the modulus depending on whether the indentation is in a grain. The modulus of the metal is slightly higher in the grain. The average modulus for the indentations in the material grain is about 194 GPa.

In the region of the oxide layer, the modulus is significantly reduced. There is some variation for the oxide layer, depending on whether it is right on the surface. The average modulus of elasticity for the oxide on the surface is about 63 GPa. Indentation tests on the oxide away from the surface show the average modulus for the oxide is about 125 GPa, which may be higher as a result of less porosity.

The results of the indentation tests on the worn brake pad material show that the modulus is affected by the location of the indentation. The brake pads are a mixture of several different materials, and the indentation test yields the modulus of the individual material at the location of the indentation. The modulus in the brake pads varies from an average of 11.4 GPa in one area to an average of 89.4 GPa in another area. The average of all the indentation tests in the worn brake pads is 37 GPa. Similar variations were obtained for new brake pads, and the overall average modulus of elasticity determined was 20.6 GPa.

Flexure Tests

Two flexure tests have been completed on the brake pad material at room temperature. The results of the completed tests are shown in the graph in Figure 2. Future flexure tests will be conducted at elevated temperatures.

SPECIMEN	CONDITIONS	B=IN	H=IN	LOAD(LBS)	STR(LBS)*	STR(MPA)	STDEV	AVG.STR
B1	ROOM TEMP	0.5030	0.3750	352.42	5884.05	40.56	3.15	38.34
B2	ROOM TEMP	0.5000	0.3800	320.28	5238.88	36.12		

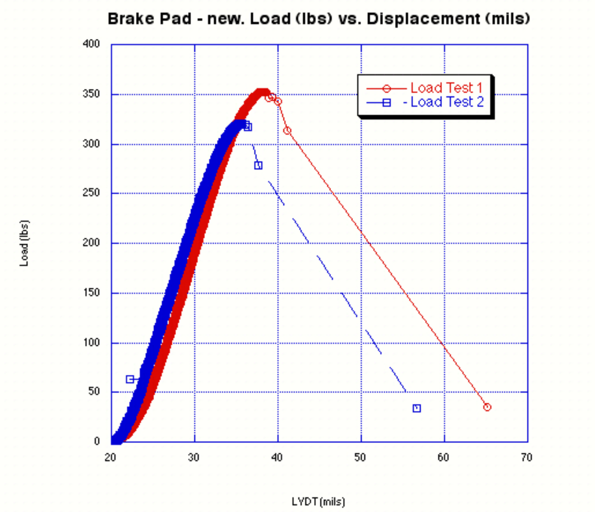

Figure 2. Flexure test results.

Thermal Diffusivity Tests

Tests have been completed to determine the thermal diffusivity of the brake pads. Tests were conducted on three different pad specimens at temperatures ranging from 103 to 508°C. Figure 3 is a plot of the average values of diffusivity for each of the specimens tested vs. temperature.

Thermal Expansion Tests

Two 25-mm-long samples with 3 × 4 mm cross sections were heated and cooled at 3˚C/min to 400˚C in a dilatometer to

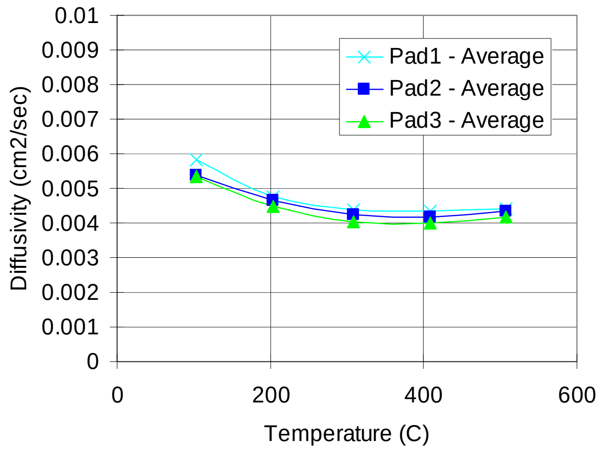

Figure 3. Diffusivity test results.

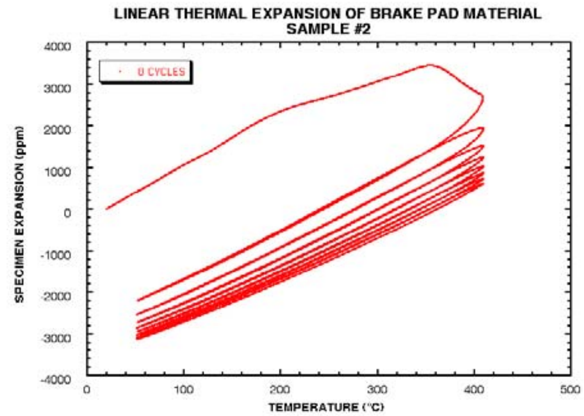

Figure 4. Linear thermal expansion of sample 2.

determine the thermal expansion of the brake pad material. The test results of the second sample are shown in Figure 4. During the initial heating and cooling cycle, both samples exhibited a permanent shrinkage of about 2500 ppm or 0.25%. Most of this change in length occurred during an event that starts at around 360˚C. Repeated cycling of the samples indicated that the sample was still changing after as many as eight cycles. The coefficient of thermal expansion (CTE) of the materials was also determined. The mean or average CTE was calculated. This is the expansion at a given temperature divided by the temperature interval between 20˚C and that given temperature.

Modeling Efforts

The modeling effort to determine the stresses that arise from the growth of corrosion products between the brake pads and brake shoe table interface has begun. Figure 5 shows a worn brake and a sketch of the interface of the brake pad and shoe table containing a corrosion product. A two-dimensional (2D) model is being developed. The 2D model will be used to gather some basic information about the problem and to assist in understanding how variations in temperature and model geometry affect the problem. After the 2D calculations are complete, a 3D model will be developed that accounts for the nonsymmetric features of the brake pad and brake shoe table.

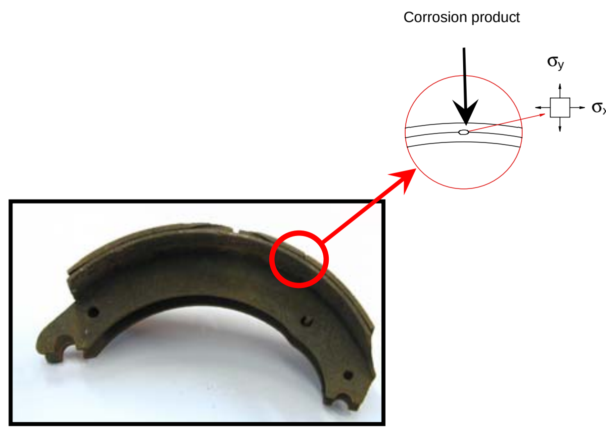

Figure 5. Worn brake pad and brake shoe table.

Deliverables

Project deliverables will include the following:

- A numerical ranking of the corrosion potential of various ice-clearing chemicals, with emphasis on the newer magnesium-chloride formulations.
- Specification of a recommended accelerated corrosion test method for use by the truck original equipment manufacturers.

- A listing of existing material corrosion potential and corrosion rates, with recommended alternative materials (where appropriate).
- A list of recommended "best practices" for use by the truck-operating fleets and owners.
- A detailed report including the forensic analyses of failed brake tables, the corrosion types and rates of chosen brake materials in various anti-icing/deicing solutions, and recommendations of viable materials.
- An initial model of rust jacking
- A final report at the conclusion of the project.