Quarterly Progress Report:

April 1 – June 30, 2008

Development of Standardized Test Procedures for Carbide Insert Snowplow Blade Wear

Wisconsin Department of Transportation Contract No. 406186
Project ID: 0092-08-31

Clear Roads Pooled Fund Research Project #TPF-5 (092)

Cameron G. Kruse, PE
Senior Engineer

July 24, 2008

Braun Intertec Corporation
11001 Hampshire Avenue South
Minneapolis, MN 55438

CONTENTS

SUMMARY

Second Quarter, 2008. Activities during this quarter were limited to further evaluation of the suitability of laboratory test methods and acquiring some of the test equipment that will be evaluated in the laboratory for Work Task 2 (Screening Evaluation of Potential Tests). We were not able to begin any of the actual testing because the blades had not arrived. (Blades from two of the three sources were received in July.)

We had telephone discussions with Mr. Lynn Bernhard of Utah DOT about scheduling the field testing. Because of the summer conditions expected when the blades are available it was mutually decided to delay field testing until late fall or early winter. If the field testing can be completed by December 1, 2008 we think we can complete the analysis, draft report and following activities within the original schedule.

First Quarter, 2008. During this quarter the location for the field testing was established by the TAC. Blades for testing were then ordered by the TAC. We gathered some additional information about the sources of carbide inserts and specifications used by companies providing blades to highway agencies.

We understand the TAC discussed the field testing location at their January meeting. Two states were identified for preliminary discussions. Minnesota was approached first because of expressed interest and favorable location. However, after considering the requirements they declined to participate. Utah was then approached in early March and accepted.

The field site identified is a freeway in southern Utah. This section is 14+ miles of freeway that was constructed in one section so has a relatively consistent pavement surface throughout. It has relatively light traffic so there will be little interference with testing or traffic. The pavement surface is bituminous with a chip seal.

Blades were ordered from three suppliers. The ideal for blade selection was to have blades of varying quality, from poor to very good, so there would be a better opportunity for the tests to identify differences. After reviewing available written and oral information we were not able to identify a method to determine quality before ordering so it was decided to order from three different suppliers and deal with the variations in quality that occur. Since Utah already had blades from Kenametal, Mr. Bernhard ordered from two other suppliers, Winter Equipment and Esco.

During this time we have spoken by phone and e-mail with four of the suppliers of blades to get further information on how they procure the carbide inserts. We communicated with Pacal/Bucyrus, Valk, Winter Equipment, and Black Cat Blades. It appears that most, if not all, carbide inserts are manufactured in China by several companies. Inserts are ordered by sending state DOT specifications to the manufacturer. The blade suppliers of the carbide inserts apparently do little testing to see if the inserts meet specifications.

Fourth Quarter, 2007. Authorization to begin work was given, effective October 22, 2007. We completed Task 1 and began Task 2. Task 1 included a literature search and revised Work Plan, based on information gained in the literature search. The Work Plan was submitted to the Technical Advisory Committee (TAC) and discussed by teleconference on December 14, 2007. The work plan was revised slightly and approved for continuation of the project.

The Work Plan called for the TAC to identify a cooperating state agency that will conduct the field tests of the snowplow blades. The revised Work Plan required operating a snowplow on bare pavement. This was chosen to eliminate several variables that would otherwise cloud the statistical evaluation of the performance of the carbide inserts. This is appropriate because the objective of the research is not to find out which insert lasts the longest in real conditions but to identify a test that will predict the performance life of each type of insert. While it would be somewhat better to be able to make the comparison of laboratory testing to performance in real conditions, the project budget does not allow enough testing to isolate the various factors that affect field performance.

The Braun Intertec team was to attempt to obtain more information on the carbide inserts from the sellers and manufacturers. We also began laboratory testing to identify the most promising test methods.

The proposed schedule would have the field testing completed by the end of late winter or early spring. Laboratory testing to compare test methods to the field results will continue through the summer of 2007. The draft of the final report is to be completed by December 2007 to be available for review and discussion at the next annual meeting of the Clear Roads Committee in January of 2008.

The following report includes the results of the literature search and the Work Plan revised to reflect the teleconference agreements.

SUMMARY OF LITERATURE SEARCH (WORK TASK 1)

The literature was searched to identify the factors that affect the wear of snowplow blades with tungsten carbide inserts and for tests that may be used to predict the wearing performance of the inserts. Searches were conducted for published reports of past research and ongoing research in transportation sources and powdered metal industry sources. We also made personal contacts of people in the transportation industry associated with snow removal, and of people in the powdered metal industry to find ongoing research and personal experience with the issues. These contacts included people in the United States, Canada, Europe, and Japan. A list of these contacts is attached.

All the Clear Roads members were also contacted to learn of their experience using carbide insert snowplow blades and obtain copies of their material specifications for the tungsten carbide inserts. Their material specifications generally spell out requirements for Rockwell Hardness, Density, Porosity, Cobalt Content, and Transverse Rupture Strength. We were surprised by the similarities noted in their specifications. The similarity of their material specifications made it appear that they came from a master set of specifications. Inquiries were made to determine if there were any organization such as American Association of State Highway and Transportation Officials that had developed specifications for carbide inserts. No master set of specifications was found. See the attached, "Transportation Agencies' Material Specifications for Purchase of Tungsten Carbide Inserts for Snowplow Blades" for a summary of each transportation agency's requirements.

The search identified many factors that affect the wear of the inserts in use. These include physical and chemical characteristics of the inserts (porosity, hardness, grain size, density, fracture toughness, and abrasion resistance), environmental factors (temperature and chemicals) and a long list of operations factors (how the plows are used). See the attached, "Operations Factors List," for those details.

We also identified a number of existing "standard" tests that have potential application for evaluating the wearing performance of the carbide inserts. These include:

- Porosity (apparent)
    - ASTM B 276-91: Apparent Porosity in Cemented Carbides
- Hardness
    - ASTM B 294-92: Hardness Testing of Cemented Carbides
    - ASTM E 18-03: Tests for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
    - ISO 3738-1: (test method)
    - ISO 3738-2: (calibration method)
- Grain Size
    - ASTM B 390-92: Recommended Practice for Evaluating Apparent Grain Size and Distribution of Cemented Tungsten Carbides
    - ASTM B 657-92: Metallographic Determination of Microstructure in Cemented Carbides
- Density
    - ASTM B 311-93: Test for Density of Cemented Carbides
    - ASTM B 328-92: Test for Density and Interconnected Porosity of Sintered Powder Metal Structural Parts and Oil-Impregnated Bearings
    - ISO (ANSI) 2738

A test method that has been developed to the "standard" at the state agency level is the "Cobalt Content Test" by Missouri Department of Transportation (MoDOT).

- Impact
    - ASTM E23-02a Standard Test Methods for Notched Bar Impact Testing of Metallic Materials
- Abrasive Wear
    - ASTM G65-00: Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus
    - ASTM G77-98: Standard Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test

- ASTM B611-85: (Reapproved 1991) Standard Test Method for Abrasive Wear Resistance of Cemented Carbides

A test method that has not been developed to the "standard" level is the "Scratch Test" created for the South Dakota Department of Transportation (SDDOT) during a research contract reported in "Snow Plow Cutting Edge Evaluation," SD95-14, dated April 1996, prepared by the Iowa Institute of Hydraulic Research.

IDENTIFICATION OF "BEST" WEAR INDICATOR TESTS

The evaluation of wear can take one of two approaches. Correlating one or more of the physical tests of tungsten carbide to the wear performance is an indirect method. These tests have the advantage of being known and accepted by the powdered metal industry. The established bidding criteria are easily understood and used by the industry. The tests are also known to the testing laboratories and can be implemented easier than a new test method. Measuring the wear of an assembled snowplow blade is a direct measurement of what will actually be used in the field. This has the major advantage of minimizing the need for correlation of the test with field performance. However, the path to using this type of test for bidding and product acceptance will require more development and will take time and money by the manufacturers to be useable.

The literature search and our experience indicate the best indirect testing to evaluate the wear performance will be hardness, grain size analysis, and porosity. These tests evaluate the strength and durability of the material against wear. Most transportation agencies' material specifications for the purchase of tungsten carbide inserts include percentages of cobalt and hardness as well. Grain size is not currently part of existing specifications but is very important to the performance of the material and is expected to be a good predictor of performance. Thus, we propose to include the following indirect tests in the screening of Work Task 2. Development of Standardized Tests:

- ASTM B294: Hardness Testing of Cemented Carbides
- ASTM B 390: Recommended Practice for Evaluating Apparent Grain Size and Distribution of Cemented Tungsten Carbides
- ASTM B 276: Apparent Porosity in Cemented Carbides

We propose to also evaluate the following direct test methods:

- ASTM B611 Standard Test Method for Abrasive Wear Resistance of Cemented Carbides
- "Scratch Test" developed by Iowa Institute for Hydraulics for SDDOT

We will adapt ASTM B611 test equipment to work conveniently on a snowplow blade. As part of the evaluation of the "Scratch Test," we will also look at ways to improve it, as recommended in the Final Report of that research study.

We will begin our testing with a modified impact test (ASTM E23 Notched Bar Impact Tests of Metallic Materials) in environmental chambers to evaluate the effect of temperature on the performance of the tungsten carbide materials. The purpose will be to determine if there is a ductile to brittle transition in the behavior of these carbide materials with temperature change. If a transition exists, it will have the effect of somewhat limiting the test specifications and values that will be used to evaluate the performance and service life. If no transition exists, it will tend to simplify all the remaining test specifications and values that we may utilize. As an example, if a transition exists at a temperature within probable working temperatures, we will be concerned with both the brittle and ductile behaviors and how that affects the performance and service life near the transition temperature.

The limited feedback we have at this time seems to indicate a lack of a transition. Most verbal and unmeasured wear descriptions seem to indicate an abrasive wear mechanism, which limits the service life. If this is confirmed by our preliminary testing, the resulting efforts would likely lead us to focus on various specifications that will evaluate abrasive wear resistance.

We have five inserts on hand that were milled out of a blade assembly we found at Hennepin County (MN) Department of Transportation. We will use another half dozen or so from the same blade. We propose to test three samples at each of three temperatures.

The impact test specimens should be retained for further examinations to give us an indication of the porosity and possibly the grain sizes (or range of grain sizes) present. The porosity test may include ASTM B276 or a modification of that test. Porosity is a property that directly correlates with a number of other properties.

SCREENING EVALUATION OF POTENTIAL TESTS (WORK TASK 2)

The purpose of Work Task 2 will be to conduct enough laboratory testing to evaluate the various tests for the following:

- Temperature for testing
- Ability to predict the actual field wear
- Accuracy of the test
- Ease of use
- Estimated cost in routine use
- Cost to develop and bring to common use in the transportation industry

The snowplow blade samples will be tested in the field, as described in Work Task 4, and in the laboratory, as described in Work Task 3. The ability of each test type to predict actual wear will be evaluated by comparing each sample’s wear in the field with the wear measured in the laboratory tests. The comparison will be made using statistical methods to define a range of results that have statistical significance. Appropriate tests of hypotheses will be used depending upon the population of the samples.

Accuracy of each test will also be predicted statistically. The number of tests that will be conducted during Work Task 2 will not allow a well-defined statistical determination of accuracy. We will also make qualitative judgments about the potential to improve the accuracy and the potential for between-test and between-laboratory variance.

To evaluate ease of use and costs we will have a test method conducted by two or more technicians in our laboratory. The time required becoming proficient with a test and the time to conduct the test when proficient will be documented. The information will be used in this evaluation and as part of evaluating the cost in routine use and cost to implement in the industry.

Results of the screening tests of Work Task 2 will be reported to the TAC in the monthly or quarterly reports. We will seek your feedback through those reports to assist us in selecting the tests that are further developed in Work Task 3.

LABORATORY TESTING OF SELECTED TEST METHODS (WORK TASK 3)

After the screening process of Work Task 2 is completed, we will begin testing the snowplow blade samples in sufficient replications to develop a statistical evaluation of each selected test. We propose to conduct each test five times per blade type, per operator. Three blade types and two operators are included in the experimental matrix. The number of tests may be limited by the number of samples and the number of types of tests being evaluated.

One-way and Two-way ANOVA, as well as linear and non-linear regression methods will be conducted to evaluate precision, accuracy, variability between operators, and other measures of the test methods selected in Task 2. Data analysis will focus on the repeatability and reproducibility to standardize the test methods. The interaction among several different variables will also be examined to identify correlations with laboratory wear performance. Matrices will be developed using ANOVA to identify the relationship, for example, between porosity and laboratory wear performance.

As test results are available and analyzed they will be reported in the quarterly progress reports.

FIELD TESTING FOR BASELINE WEAR RESULTS (WORK TASK 4)

The snowplow blade samples will be first tested in the field, and then in the laboratory. Field test results will serve as the baseline for evaluation of the laboratory testing.

It will be important to expose each set of field blades to identical wear conditions so the amount of wear will be determined by the performance of the tungsten carbide inserts rather than non-insert variables. There are many factors that affect carbide insert snowplow blade wear and fracturing, see Appendix A. This list identifies most, if not all, of the conditions known to affect wear in the field. Given the project schedule and available resources, it will be important to establish a test protocol that controls for as many of these variables as possible so the testing correctly compares the wear performance of the samples.

Ideally, we will receive samples from three different manufacturers, or at least three various grades of materials, that can be installed on a single snowplow. The samples will be moved from the left side, to the center, and to the right side of the plow blade after approximately the same miles of plowing to minimize the wear effects caused by location along the plow, such as wear caused by the of crown of the roadway. The most important variable will be the amount of time, measured in hours, that the blade is in the down position. To the extent practical, other factors that affect blade performance will be controlled for. See the attached, “Operations Factors” list for additional discussion. These factors include the following:

- Carbide insert properties: assumed to be consistent within a sample provided by a manufacturer.
- Steel blade properties: assumed to be consistent within a sample provided by a manufacturer.
- Back blade: a back blade will be used for all field tests because back blades are commonly used in practice.
- Down pressure of plow: weight of the plow (same plow will be used for all tests).
- Horizontal angle of plow: maximum angle to the right (commonly accepted practice).
- Vertical angle of the plow: 5 degrees forward inclination (may revise based on literature search results).
- Pavement type: asphalt pavement.
- Surface state: testing will only be conducted when the pavement is dry and free from any contaminants such as oil or sand. The application of anti-icing or de-icing chemicals in the test area will be documented.
- Pavement obstructions: minimal expected at test site.
- Speed of plowing: 45 mph proposed.
- Impact of blade lowered onto pavement: this variable will be minimized to the extent possible, but given the presence of concrete test sections at the proposed test track, frequent raising and lowering is anticipated. The plow identified for field tests will be carefully observed to identify any abrupt impact when lowered. A plow with a gradual lowering mechanism will be selected if possible.
- Temperature: testing will be conducted when the ambient temperature is 40° F or less. Pavement temperature will be measured and recorded. Blade temperature and carbide insert temperature will not be measured because the literature search did not reveal a practical method of measuring these temperatures during driving conditions.

After discussions with the TAC, it was agreed that the best method for field testing will be to have a snowplow with the test inserts operated on a given route over dry pavement using the same driver. The TAC will find an agency that can provide the required equipment and personnel. These arrangements will include test schedule, equipment usage, operator availability, labor to rotate blades, and fuel expenses. Testing will be done in the January to March 2008 timeframe. The plow operator will be trained in the purpose, protocols, and record keeping required for the study. We will ask for his/her input on the best protocols for their field conditions.

For statistical evaluation, we propose to test each sample three separate times in the field. The blades will be worn until they have reached 50 percent of their carbide insert capacity. Wear will be estimated by observing index marks installed on the blades before the start of testing. At the conclusion of field tests, the blades will be removed from the plow, scraped free of all contaminates, and weighed on a precision scale in order to determine an accurate measure of the amount of wear.

It is expected that samples from different manufacturers will have a significant range of wear performance. This range of wear will allow for definitive statements about quality variation from manufacturer to another. The lack of significant variation will be a valuable research finding as well.

One-way and Two-way ANOVA, as well as linear and non-linear regression methods, will be conducted to evaluate precision, accuracy, variability between jobs, and other measures of the various sensors and calibration methods experienced during Task 4. Data analysis will focus on the comparison between readings from the installed samples in the field conditions and laboratory data sources to evaluate precision, accuracy, and variability. The interaction among several different variables will also be examined to identify correlations with wear performance. Matrices will be developed using ANOVA to identify the relationship, for example, between porosity or laboratory wear performance and field wear performance.

ANALYSIS AND REPORTING (WORK TASK 5)

Our research team will evaluate the data provided by the field and laboratory testing. We will make statistical comparisons of the two sets of data to document the level of confidence that is supported by the data. Conclusions will address the validity and range of conditions represented by the field testing results and the potential for the laboratory test methods to predict the actual field wear and durability. We will report on the ease of use and the costs to implement the testing, and conduct actual tests. The report will submit the data, our analysis, and the conclusions and recommendations of our research team.

The report will be prepared in draft form. It will be formatted in accordance with the requirements of TRB documents so it will be in a familiar form. We will also provide the Technical Document Page required by Clear Roads.

After a period of time for the TAC to review the draft report, we will meet with the TAC to present the information, receive feedback from TAC, and develop final recommendations that represent a consensus of the researchers and TAC. Similarly, the Implementation Plan will be revised to incorporate the comments of the TAC. The TAC meeting is scheduled for January 2009.

The final report will be submitted electronically and in hard copy.

TIMETABLE

The work has slipped behind the proposed timetable because the delayed decisions on site delayed the procurement of blades for testing. If the blades are available soon we will be able to maintain the schedule. It may still be possible to complete the analysis and prepare a draft report by the scheduled date for review at the January, 2009 Meeting of the TAC.

BUDGET

Task 1 is completed. We had budgeted 224 hours and $22,850 for this task. The actual cost was approximately $19,500, so we are below budget for this task. Tasks 2 and 4 have been started. We have expended approximately 50 percent of our hours for Task 2 and 10 percent of our hours for Task 4. Task 2 may overrun our budget but not more than the underrun of Task 1. Thus, we are on budget at this time.

We estimate we are 45 percent complete on the project.