

Quarterly Progress Report:

October 1 – December 31, 2007

Development of Standardized Test Procedures for Carbide Insert Snowplow Blade Wear

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CONTENTS

Summary	1
Summary of Literature Search (Work Task 1)	1
Identification of “Best” Wear Indicator Tests	3
Screening Evaluation of Potential Tests (Work Task 2).....	4
Laboratory Testing of Selected Test Methods (Work Task 3)	5
Field Testing for Baseline Wear Results (Work Task 4).....	6
Analysis and Reporting (Work Task 5)	7
Budget.....	8

Attachments:

Literature Research – Contacts Made

Transportation Agencies’ Material Specifications for Purchase of Tungsten Carbide Inserts

Operations Factors Affecting Carbide Insert Snowplow Blade Wear & Fracturing

SUMMARY

Authorization to begin work was given, effective October 22, 2007. We have completed Task 1 and have begun 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 calls for the TAC to identify a cooperating state agency that will conduct the field tests of the snowplow blades. We understand that is in process. The revised Work Plan requires 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. That work is in process. We are also beginning laboratory testing to identify the most promising test methods.

The proposed schedule will 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 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 contaminants, 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 95 hard copies.

TIMETABLE

It is our intent to meet the timetable we proposed for this project. With cooperative weather, we are confident we can accomplish the work to present the draft report to the TAC for the January 2009 meeting.

It should be noted that the critical part of the schedule is accomplishing the field testing during the winter of 2007-2008. It may not be possible to complete the project within the desired schedule if field testing is delayed until the winter of 2008-2009.

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 within budget at this time.

Carbide Insert Snowplow Blade Wear Research

Literature Research - Contacts made

Rod Pletan & Ed Fleege

Norway	Kjell Levik, Norwegian Public Road Administration (klevik@online.no)	Responded but no leads provided
Sweden	Gudrun Oberg Swedish Road and Traffic Research Institute (VTI) 581 01 Linköping SWEDEN [gudrun.oberg@vti.se] cc: Lennart Axelsson Swedish National Road Administration	Received response. No related research in Sweden or other Nordic Countries Provided contact to Denmark
Denmark	Freddy Knutson fek@vd.dk	No response
Japan	Masaru Matsuzawa Ph. D. Deputy Team Leader of Snow and Ice Research Team Cold Region Road Research Group, Civil Engineering Research Institute for Cold Region, PWRI Address: 1-3 Hiragishi Toyohira-ku Sapporo-city, 062-8602 Japan Tel.:+81-11-841-1746, Fax:+81-11-841-9747, E-mail:masaru@ceri.go.jp	Received response. No additional leads to his knowledge
PIARC Winter Maintenance Committee	Dr. Yasuhiko Kajiya, Civil Engineering Research Institute of Hokkaido	Response covered by Masaru
SICOP	Lee Smithson, Coordinator [Leland.Smithson@dot.iowa.gov] Rick Nelson, Chair Winter Maintenance Technical Service Program (rnelson@dot.state.nv.us)	Received response. No additional leads to his knowledge
TRB Winter Maintenance Committee	John Burkhardt, Chair, Indiana DOT [jburkhardt@indot.IN.gov] on behalf of John: Belter, Dennis [DBELTER@indot.IN.gov]	Received response. No additional leads to his knowledge
University of Iowa	Wilfrid Nixon, Professor/Researcher (wilfrid-nixon@uiowa.edu)	No response

Ontario, Canada	Max Perchanok Research Scientist Research and Development Branch Ontario Ministry of Transportation Phone: (416) 235-4680 Fax: (416) 235-4872 E-mail: max.perchanoka@ontario.ca	Telephone Conversation. No related research in Ontario, CA
Private	Dale Keep, Private Consultant (dalekeep@innw.net)	No response
Pacific Northwest Snowfighters	Mark Zitzka FHWA Montana Phone: 406-449-5302 x 234 Fax: 406-449-5314 E-mail: mark.zitzka@fhwa.dot.gov	No response
Mn/DOT Library	Jerry Baldwin, Mn/DOT Librarian [Jerry.Baldwin@dot.state.mn.us]	Several references, including abstracts from: Missouri DOT Norway, Virginia TRC Maine DOT Minnesota DOT Iowa DOT Alberta Can DOT New York DOT Ontario CAN DOT Some are dated. All posted on ftp site
Bucyrus Blades (ESCO)	Jim Gerhart 1-888-252-3379 jim.gerhart@bucyrusblades.com	Bucyrus bought out Pacal Blade Division of Paper Calmenson. Invited us to send him an email listing what we would like from his firm and he would route it to the appropriate person.

[illegible]

Operations Factors Affecting Carbide Insert Snowplow Blade Wear & Fracturing

FACTOR	COMMENT/ASSUMPTIONS
Steel blade material specification Tensile strength Yield strength Percent of elongation Chemical Analysis	<i>The degree of fracture is related to the strength of the substructure holding the insert Steel blade material specifications requires: Tensile, yield, elongation along with chemical analysis</i>
Surface area touching the pavement surface	<i>The greater the surface area on the road, the slower the rate of wear</i>
Degree of fracture	<i>The extent that even small fracturing reduces the surface area touching the road surface, this expedites the rate of wear</i>
Design of blade with insert Fusion method (Brazing) Manufacturing temperature	<i>The better the connection of the insert to the substructure, the less fracturing: The manufacturing temperature may affect the connection.</i>
Down pressure of plow Weight of plow Hydraulic powered down pressure Fulcrum of the hitch	<i>The greater the pressure of the blade against the road, the greater the friction and the greater the impact causing fracture Surface area touching the pavement surface determines the pressure per square inch.</i>
Horizontal angle to road centerline	<i>The greater the angle (up to perpendicular), the greater the impact to obstructions and high spots on the pavement</i>
Vertical angle to pavement surface	<i>Theoretically, "scraping of ice" causes more wear to the blade then "slicing ice off"</i>
Pavement material type Concrete Bituminous Pavement skid resistance Presence of sufficiently sharp and asperities properties of the surface. Surface contaminates such as sand, ice, snow, and dry verse wet pavement.	<i>It is common knowledge that bituminous wears blades out faster. However, I would disagree. It has been reported by users that concrete has the greatest wear, especially the first two to three years of new concrete pavement. The greater the skid resistance, the faster the wear.</i>
Pavement rutting Presence Absence	<i>The greater the rutting, the less surface of the blade is on the pavement and the faster the rate of wear on the portion to the blade in contact with the surface.</i>
Impact of blade lowered to pavement Dropped Gradual, more gentle	<i>The greater the impact of the plow being placed on and off the pavement, the greater chance of fracturing.</i>
Speed of plowing	<i>The faster the plowing speed, the higher the impact to obstruction and skid resistance.</i>
Air temperature	<i>The lower the temperature the higher the brittleness of carbide inserts.</i>

Surface temperature And temperature of the carbide insert surface due to friction. being generated during plowing	<i>The lower the temperature of the pavement, the lower the temp of the air at contact level, thus the higher the brittleness of the carbide inserts.</i>
Back blade (when used) Rigidity Wearing capability Thickness of blade	<i>The presence of a back up blade adds to the surface area wearing on the roadway as well as providing a higher resistance to fracture of carbide insert.</i>
Distance plow in down position	<i>Obviously, wearing only occurs in "plow down" position, not during total plowing distance, which is what operator normally record/report in accomplishment reporting. Need to specify that during field testing, "plow down" distance needs to be reported.</i>
Degree of obstruction on road surface Raised manhole Raised pavement markers	<i>Presence or absence of obstruction relate to fracturing; fracturing relates to surface area subject to wear; reduced surface area leads to more rapid wear.</i>
Material being plowed Snow Ice Slush	<i>Slush is easier to remove than snow, which is tougher to remove than ice.</i>
Anti-icing vs de-icing mode	<i>Anti-icing lead to less ice to remove, thus more wear(increase friction surface).</i>
Density of snow Natural Compaction wind Compacted by traffic	<i>Harder snow is harder to remove and causes more wear than soft fluffy snow. Traffic compacted snow can become as hard o blades wear as solid ice.</i>
De-icing chemicals	<i>De-icing chemicals are thought to be insignificant to chemical deterioration of the carbide inserts. The lubrication provided by the chemicals may reduce wear of the inserts.</i>