Development of Standardized Test Procedures for Carbide Insert Snowplow Blade Wear

Braun Intertec Corporation

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16. Abstract

The research identified laboratory tests that appear to predict the wear performance of carbide inserts in snowplow blades. Internal voids and cracks were identified as the sources of poor wear performance of carbide inserts. Laboratory tests that identify voids and cracks were among the tests recommended for use in specifying requirements and testing for suitability of blades with carbide inserts. The report includes a recommended purchasing procedure with revised specifications and testing requirements. The report also includes an implementation plan.

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Development of Standardized Test Procedures for Carbide Insert Snowplow Blade Wear

A Report for

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Wisconsin Department of Transportation

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The Technical Advisory Committee also made valuable contributions to the direction and results of this research. The committee included Lynn Bernhard, Utah DOT, Chairperson; Tim Jackson, Missouri DOT; Tim Croze, Michigan DOT; Brad Osborne, Iowa DOT; and Colleen Bos, Clear Roads Administrator of CTC and Associates, Inc.

The Utah DOT provided the blade samples, snowplow and staffing to conduct the field testing. Lynn Bernhard was responsible for accomplishing this testing.

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EXECUTIVE SUMMARY

The goal of this research was to improve the performance of carbide inserts in snowplow blades thus reducing the costs of snowplowing. A new set of laboratory tests and a purchasing process will minimize the risk of poor performance of the inserts. States, counties and cities spend tens of millions of dollars each year on snowplow blades with carbide inserts. Historically, some of the carbide inserts have had poor wear performance, increasing the cost of snowplowing. This research tested three sets of plow blades in the laboratory and in a controlled field test to identify laboratory tests that correlated to the field performance of the carbide inserts. We found that poorly performing inserts had excessive voids and internal cracks. A new set of purchasing tests and a statistical evaluation process are recommended to identify those types of deficiencies, preferably during the manufacturing process but at least before purchasing acceptance.

A literature search and personal contacts of people in the industry found no accepted tests in documented studies of carbide insert performance. Previous studies were particularly limited by a lack of correlation to real field performance.

Also, the available studies did not identify a cause of the poor performance. The search for available information did find that people studying the problem feel that fracturing of the inserts was a likely cause of the poor performance. Our initial laboratory testing and then the field testing confirmed that is the cause.

A number of existing tests and new tests were considered in the laboratory. Our evaluation of potential tests was based on four criteria – the ability to predict insert performance, ease of use of the tests, how much development work would be required to implement the tests, and testing costs. We were led to one new simple test and four laboratory tests commonly used in the powdered metals industry to evaluate the quality of the carbide inserts.

The field testing was conducted by the Utah Department of Transportation. They tested each of three sets of blades by “plowing” 300 miles at an average speed of 45 miles per hour on a specific section of bituminous highway. All three sets of blades met the specifications required by the respective purchasing processes for the three sets. The field tests were not able to accommodate all the variables of real plowing conditions. Rather, the testing controlled all variables except the carbide inserts. The wear of the carbide inserts was determined by measuring the length of the inserts before and after the field tests. In addition to the wear identified by these measurements, we also measured the number of cracks and chips visible in the face of each of the inserts.

The laboratory and field testing found that the cause of poor performance appears to be an excess of large voids, void clusters and internal cracks in the carbide inserts. These deficiencies are from manufacturing processes rather than from poor materials. Thus, the tests we selected evaluate the materials and the manufacturing processes. Previous purchasing requirements generally specify only materials properties and rely on manufacturers certifications for acceptance.

The recommended process has an approval framework with three “steps” for full evaluation of the suitability of the inserts. Step 1 is the new test, a visual examination of the face of the inserts to identify the percent of inserts with cracks visible with a 3x, hand-held microscope. If the inserts are acceptable at Step 1 they are subjected to Hardness and Density testing in Step 2. These tests evaluate the materials used in manufacture of the inserts. Inserts meeting the requirements of Step 2 are then tested for Porosity and Grain Size, including the identification of voids and cracks, in Step 3. Limits are placed on the amount of large voids, void clusters and cracks that will be acceptable. Step 3 evaluates the manufacturing quality.

We recommend the tests be used in a statistically valid Quality Control system during manufacture of the inserts. The firms assembling the inserts into the plow blades may want to conduct Quality Assurance tests. The purchasing agency must conduct a statistically valid program of Quality Assurance tests. It is important that a metallurgical laboratory experienced in powdered metals testing conduct the tests. Purchasing agencies will likely need to retain independent testing laboratories for this work.

Our analyses and recommendations are based on limited test data and available information. We tested three sets of new blades, examined another set of worn blades, and obtained anecdotal information in the literature search and personal contacts. However, the statistical evaluation of the laboratory and field testing is quite conclusive as to the variation in performance and the correlation between laboratory test results and field test results. The tests confirm the anecdotal analyses of the causes of poor performance.

Thus, we are confident that use of the recommended process and specifications for testing and acceptance of carbide inserts will greatly minimize the poor performance of blades with carbide inserts. The Implementation Plan included in Appendix B recommends that the recommendations be implemented by the sponsoring Clear Roads agencies and be brought to the attention of all transportation agencies that buy blades with carbide inserts. The recommendations can be used to develop a national standard that may reduce the costs of manufacturing and thus the costs of snowplow blades in the future. Implementation will also require education of all the stakeholders in the causes of poor performance and the new testing procedures. Stakeholders include the carbide insert manufacturers, snowplow blade assemblers, purchasing agencies, and testing laboratories.

It should be noted that, while it was not specifically a part of the research scope, we heard significant anecdotal indications that the snowplow operators have a great effect on the life expectancy of snowplow blades. It appears that considerable savings are available through better training and accountability of snowplow operators in “best practices” for factors such as avoiding impact on pavement objects, vertical angle of blade, down pressure on blade, use of back blades, and others.

The results of this research can be improved by testing additional sets of blades. Additional testing may refine the limits of acceptable results of the specified tests. A general description of this testing is included in the Implementation Plan.

CHAPTER 1. BACKGROUND

MAGNITUDE OF PROBLEM

State Departments of Transportation (DOT's) operating where there is snow or ice in the winter spend on the order of $0.5 to $1 million for snowplow blades with carbide inserts each year.[1,2,3] County and City agencies also use these blades. Thus, a means of improving the cost effectiveness of these blades would have immediate, significant impact on the resources required to maintain highways in optimum winter-travel condition. Further, reducing the wear of these blades will reduce the amount of time needed to change blades, often done during winter storm conditions, and reduce the risk of injury during the process.

TYPES OF BLADES WITH INSERTS

Several types of blades are used. Most have small, tungsten carbide inserts brazed into a groove at the bottom of a six-inch high steel plate. The steel plates are three or four feet long so that three or four of these blades are required to provide the cutting edge for a normal snowplow. Typically, the tungsten carbide inserts are rectangular or trapezoidal in shape. Their dimensions are typically 1-inch wide, 3/8-inch thick, and 3/4-inch high. However, newer forms such as bullet-shaped inserts set in a rubber carrier are becoming common. Snowplows vary in length, shape and weight. The angle of the cutting edge relative to the pavement surface also varies.

CURRENT STATUS OF PURCHASING AND TESTING CARBIDE INSERTS

The various states purchase these blades from a relatively limited number of suppliers. Most suppliers purchase the carbide inserts from a manufacturer and braze them into the steel plates. The states typically have specifications for the steel blades and the carbide inserts. These specifications are similar from state to state but there is not a national standard or accepted "best practice" for specifying the materials and properties of the carbide inserts.

It is well known in the carbide industry that certain properties of the carbide provide better wear and other properties provide better fracture resistance. Abrasion resistance increases with increased Hardness but shock resistances decreases. Abrasion resistance increases with decrease in grain size but shock resistance decreases.

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[1] MINUTES, Clear Roads 2009 Technical Advisory Committee Summer Meeting: Pooled Fund Project #TPF-5(092), July 29-30, 2009

[2] *PROPOSAL INVITATION TO BID*, Wyoming DOT, June 5, 2007

[3] Phone Survey of Clear Roads Representatives, October, 2007

Since those properties are generally opposites the specifications have generally been set to "balance" the properties to get the best wear possible while providing adequate fracture resistance.

NO ESTABLISHED TESTS THAT BEST PREDICT PERFORMANCE OF THE INSERTS

Probably one of the reasons there are no standard specifications or a "best practice" for the purchase of snowplow blades with carbide inserts is a lack of standard tests that have been shown to be good predictors of the performance of the carbide inserts. State specifications typically use test requirements common to the tungsten carbide industry (hardness, density, porosity, and transverse rupture strength).

Generally, evaluations of carbide inserts have relied on undocumented field observations and judgments of snowplow drivers rather than standard tests. We found only limited instances of laboratory testing to evaluate carbide inserts for snowplow blades.

One test, a "scratch test" to evaluate the wear resistance of carbide inserts, was developed in the laboratory for the South Dakota Department of Transportation.[4] The test procedure was not advanced to a "standard" and the test's ability to predict actual performance was not determined. The test has not been standardized or used in the purchase or evaluation of carbide inserts.

ASTM B611 Standard Test Method for Abrasive Wear Resistance of Cemented Carbides was used in one laboratory comparison of three sets of blades by the Iowa Department of Transportation.[5] In this study the laboratory test was unable to statistically differentiate abrasion wear between two of the three samples. The laboratory results could not be correlated to the field performance of the three sets of blades.

The Missouri Department of Transportation has evaluated fracture failures and now tests for some manufacturing defects by non-destructive testing (ultrasonic) at the time of purchase as a means of preventing the purchase of products prone to premature failure.[6]

Michigan DOT has a laboratory test method to evaluate the brazing of inserts in grader blades.[7] Such a test could be adopted if the brazing seemed to be a problem for snowplow blades. However, this has not been reported to be a problem.

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[4] Nixon, W. and Wei, Y., *SNOW PLOW CUTTING EDGE EVALUATION*, Study SD95-14 Final Report, Iowa Institute of Hydraulic Research, April, 1996

[5] Younkin, K., *A LABORATORY EVALUATION OF TUNGSTEN CARBIDE INSERTS FOR SNOWPLOW BLADES,* Final Report for MLR-95-06 Iowa Department of Transportation, April 1996

[6] MacIver, J., *EVALUATION OF CRACKING IN PRE-SERVICE AND IN-SERVICE SNOW-PLOW CARBIDE WEAR* SURFACES, Missouri Department of Transportation, December, 2003

[7] *TEST METHOD FOR TUNGSTEN CARBIDE INSERTS IN UNDERBODY BLADES*, Michigan Test Method 719-95

BENEFITS TO HIGHWAY MAINTENANCE ENGINEERS

For approximately 75 years transportation agencies have bought construction materials using a well-defined set of specifications. These specifications generally rely on physical or chemical tests to confirm that the materials are what was specified and will perform as expected. However, purchases of other materials have had to rely on representations of vendors as to suitable specifications and performance predictions. For those materials, performance is not always as expected. Carbide inserts for snowplow blades are one of those materials.

Developing standardized test procedures for evaluating and specifying the materials' qualities and measuring the product performance of carbide inserts will benefit highway maintenance engineers in the same way that those tests benefit construction engineers. It is often said that, "What is measured is improved." Standardized tests can be expected to lead to improved performance of the purchased products. Improved performance translates into reduced costs for snowplow operations.

Cost reductions will occur because the carbide inserts will last longer. Benefits will also include a reduction in the time and cost of replacing them, a reduction in downtime of plows during storms, and a reduction of injuries to mechanics or drivers who have to change the plow blades containing the inserts. Longer lasting carbide inserts will likely do a better job of removing snow and ice, reducing the amount of time and resources required to return the roadways to the usefulness the public has come to expect. Snowplow driver morale will be improved. Standardized tests will improve purchasing processes, reducing management time required and documenting the validity of the purchase decisions.

PURPOSE OF RESEARCH

Thus, the purpose of this research is to identify or develop standardized test procedures for evaluating how well carbide inserts in snowplow blades perform during snowplowing activities. Purchasers would use these tests to specify material properties and set acceptance or rejection limits that would optimize the performance and longevity of the carbide inserts.

Carbide inserts fail through wear (abrasion) and through durability (fracture). This research project sought to identify test procedures that have potential to predict the wear and durability performance of the carbide inserts. We evaluated the most promising test procedures in the laboratory and compared them to the performance of carbide inserts in field tests of simulated snowplowing to determine the effectiveness of the tests at predicting performance of the carbide inserts. The final deliverable is this report that documents the testing, provides a process for use of the test procedures in recommended purchase specifications, recommendations for additional studies, and an Implementation Plan.

An achievable plan for implementing the results of this study is also important. This research provides recommendations for future work needed to "standardize" the tests and recommended test limits, get them accepted by American Association of State Highway and Transportation Officials (AASHTO), and get them implemented by transportation agencies, equipment manufacturers and independent test laboratories. This plan can provide a guide for future activities of Clear Roads.

CHAPTER 2. RESEARCH APPROACH

LITERATURE SEARCH

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.

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). The list of factors is shown in the following table.

Table 2.1 Factors Affecting Carbide Insert Snowplow Blade Wear & Fracturing

CATEGORY	FACTOR	COMMENT/ASSUMPTIONS
Blade Material Composition and Specifications	Carbide insert: Density Porosity Hardness Grain Size Impact Resistance Brittleness Fracture Toughness	*Some or all may relate to wear resistance (or rate of wear) and the degree that carbide inserts extend the service life over that of regular or hardened steel blades.*
	Steel blade material: Tensile strength Yield strength Percent of elongation Chemical Analysis	*The degree of fracture is related to the strength of the steel substructure holding the insert.*
Blade Attributes	Degree or amount of fracture	*Fracturing reduces the surface area touching the road surface, expediting the rate of wear.*
	Design of blade with insert: Brazing method Manufacturing Temperature	*The better the connection at the interface of the insert and the substructure, the less fracturing.* *The manufacturing temperature may affect the connection.*
	Back blade, presence/absence: Rigidity Wearing capability Thickness of blade	*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.*

CATEGORY	FACTOR	COMMENT/ASSUMPTIONS
Blade Configuration In Relation To Pavement Surface	Surface area touching the pavement surface	*The greater the surface area on the road, the slower the rate of wear*
	Down pressure of plow: Weight of plow Hydraulic down pressure Fulcrum of hitch (distance pivot point to blade)	*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.*
	Vertical angle to pavement surface	*Theoretically, "scraping of ice" causes more wear to the blade then "slicing ice off"*
	Horizontal angle to road centerline	*The greater the angle from "bulldozing position", the less the impact to obstructions and high spots on the pavement*
	Reversible Plow vs. One-way	*Wear varies from leading edge of blade compared to middle as compared to trailing edge.* *Can assume reversible plows have consistent angles due to operators reversing to full stops (except when" bulldozing").*
Pavement Surface Properties	Pavement material type: Concrete Bituminous Gravel	*It is common knowledge that concrete wears blades out faster than bituminous, especially the first two to three years of new concrete pavement* *Exposure to gravel shoulders can wear the steel portion of the blade, thus increasing risk of carbide inserts fracturing or falling out..*
	Oil on surface	*Although slight, oil could serve as lubricant, extending service life.*
	Pavement rutting	*The greater the rutting, the less surface of the blade is on the pavement and the faster the rate of wear on the portion of the blade in contact with the surface.*
	Skid resistance	*Relates to presence of sharp and asperities properties on the surface; The higher the skid resistance, the higher the abrasive qualities of the pavement, thus expediting wear.*
	Obstruction on road surface: Raised manhole Raised pavement markers Bridge expansion joints Raised pavement panels Raised shoulders	*Presence or absence of obstruction relate to fracturing; fracturing relates to surface area subject to wear; reduced surface area leads to more rapid wear.*

CATEGORY	FACTOR	COMMENT/ASSUMPTIONS
Operational Issues	Distance plowed (plow in down position)	*Obviously, wearing only occurs in “plow down” position, not during total plowing distance, which is what operators normally record/report in accomplishment reporting.* *Note that some operators are known to keep plow down even when plowing is not necessary, thus causing unnecessary wear and shortened service life, unrelated to quality of the blade itself.*
	Speed of plowing	*The faster the plowing speeds, the higher the impact to obstruction and skid resistance.*
	Impact of blade lowered onto pavement: Dropped Gradual, more gentle	*The greater the impact of the plow being placed on and off the pavement, the greater chance of fracturing.*
Operating Temperature	Air temperature	*The lower the temperature of carbide inserts, the higher the brittleness.* *Low air and surface temperature will lower carbide insert temperature.* *Friction can raise temperature of carbide insert to a higher level than air and surface.*
	Surface temperature	
	Carbide Insert temperature	
Snow & Ice Characteristics	Material being plowed: Snow Loose vs compacted Ice Black Ice Slush	*Rate of wear would depend on whether water is in form of liquid, loose snow, compacted snow, ice, black ice, etc* *Slush means presence of liquid water which serves as a lubricant, reducing wear.* *Slush and heavy snow are “harder to push” but this probably does not relate to blade wear, except when vertical blade angle to pavement deviates from 90 degrees.* *Heavy snow, black ice and regular ice need to be scrapped off, perhaps affecting wear.* *Slush and loose snow lead to blade having more contact with the abrasive pavement surface.*
	Anti-icing vs de-icing mode	*Anti-icing lead to less ice to remove, thus more wear (increase friction surface).*
	Density of snow: Natural Compaction wind Compacted by traffic	*Harder snow is harder to remove and causes more wear than soft fluffy snow.* *Traffic compacted snow can become as hard on blades wear as solid ice.*

CATEGORY	FACTOR	COMMENT/ASSUMPTIONS
Snow & Ice Materials	Abrasives: Sand (natural) Sand (recycled) Grit (crushed)	*Presence or absence may relate to rate of wear.* *Gradation of sand/grit may be a factor.* *Loose sand as opposed to sand imbedded in ice or compacted snow may be a factor.* *Recycled sand (like from street sweepings) has reduced abrasive power.*
	Chemicals: Corrosive salts Less corrosive alternatives	*Corrosive materials may cause surface corrosion, but probably insignificant to rate of wear.* *Chemicals melt snow & ice into liquid, which is a lubricant, thus affecting rate of wear.*

PERSONAL CONTACTS

We made personal contacts of people in the transportation industry associated with snow removal and of people in the powdered metal industry to find on-going 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 included in Appendix A.

The Clear Roads members were surveyed by phone to learn of their experience using carbide insert snowplow blades and to 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 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 AASHTO that had developed specifications for carbide inserts. No master set of specifications was found. Table 2.2 shows a listing of the requirements commonly included in the various states' specifications. Not all of the listed requirements are found in individual state specifications. The range of acceptable limits indicates the lowest and highest limits found. Individual state's requirements generally have a smaller range of acceptable limits.

Table 2.2 Summary of Common Material Specifications for Purchase of Tungsten Carbide Inserts for Snowplow Blades

REQUIREMENT	SPECIFICATION or TEST METHOD	RANGE OF ACCEPTABLE LIMITS
Percent Cobalt Content	Not indicated	11 to 13 percent
Density	ASTM B311 or not indicated	14.1 to 14.6
Hardness	ASTM B294 Rockwell Hardness "A" Scale	87.5 to 89.0 "A" Scale
Transverse Rupture Strength	Not indicated	300,000 to 400,000 psi
Porosity	ASTM B276	A06 B02 C00
Certification		Vendor shall furnish "certification" that carbide inserts meet the required specifications.
Material Source		No recycled or reprocessed carbide may be used.

POTENTIAL LABORATORY TESTS

Identification of "Best" Wear Indicator Tests

Wear can be evaluated either indirectly or directly. 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 more easily 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, although correlation will still have to be documented. The path to using this type of test for bidding and product acceptance will require more test development, test procedure acceptance by organizations such as ASTM to establish international test validity, and time and money by manufacturers and test laboratories to implement.

We 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 Standard Test Method for Apparent Porosity in Cemented Carbides

- Hardness
    - ASTM B294-92 Test Method for Hardness Testing of Cemented Carbides
    - ASTM E18 Tests for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
    - ISO 3738-1 (test method)
    - ISO 3738-2 (calibration method)
- Grain Size
    - ASTM B390-92(2006) Standard Practice for Evaluating Apparent Grain Size and Distribution of Cemented Tungsten Carbides
    - ASTM B657 Metallographic Determination of Microstructure in Cemented Carbides
- Density
    - ASTM B311-08 Standard Test Method for Density of Cemented Carbides
    - ASTM B328 Test for Density and Interconnected Porosity of Sintered Powder Metal Structural Parts and Oil-Impregnated Bearings
    - ISO (ANSI) 2738
- Abrasive Wear
    - ASTM B611-85(2005) Standard Test Method for Abrasive Wear Resistance of Cemented Carbides

We also identified a number of potential test methods that would need to be developed. These include:

- 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 Iowa Institute of Hydraulic Research.
- A modification of ASTM B611 Standard Test Method for Abrasive Wear Resistance of Cemented Carbides to conduct the test on a complete blade assembly
- A modified Vickers Hardness (Indentation) Test for Fracture Toughness

LABORATORY TEST DEVELOPMENT RESULTS

Our initial investigation was a brief evaluation of the influence of temperature on the performance of the carbide inserts. We obtained samples of carbide inserts from worn blades provided by Hennepin County DOT (Minnesota). We learned that temperature should not be an issue for performance of the inserts. An unexpected result was the observation of cracks in the faces of the samples we fractured for the testing. These cracks suggested that poor manufacturing processes could be a cause of poor performance of the carbide inserts.

In the test development phase of this research we considered which of the indirect and direct test methods identified above would have the best potential for successfully predicting the performance of the carbide inserts and would have the best potential for successful implementation for transportation agencies.

The literature search and our experience indicate the best indirect testing to evaluate the wear performance will be hardness, density, grain size analysis, and porosity. These tests evaluate chemical composition of the material and the strength and durability of the material against wear. Most transportation agencies' material specifications for the purchase of tungsten carbide inserts currently include some of these tests, and percentages of cobalt and tungsten as well. Grain size is not currently part of most existing specifications but is very important to the performance of the material and is expected to be a good predictor of performance. The following tests were selected for the laboratory evaluation of the sample inserts:

- ASTM B294-92 Test Method for Hardness Testing of Cemented Carbides
- ASTM 311-08 Standard Test Method for Density of Powdered Metal Materials Containing Less Than Two Percent Porosity
- ASTM B276-05e1 Standard Test Method for Apparent Porosity in Cemented Carbides
- ASTM B390-92(2006) Standard Practice for Evaluating Apparent Grain Size and Distribution of Cemented Tungsten Carbides

Hardness and density are indirect measurements of the percentages of tungsten and cobalt and other properties. The percentages of tungsten and cobalt are responsible for wear and fracture resistance capabilities of the carbide.

Apparent Porosity and Apparent Grain Size are valuable to evaluate the physical characteristics created by the quality of the powdered materials and the manufacturing processes. Porosities reflect the quality of powder blending and compaction operations. Grain size is a more direct measure of wear and fracture resistance. It is also useful to refine the interpretations of the other test results.

These ASTM test methods are well known and accepted. They have good precision within tests and between laboratories. They are relatively inexpensive and conducted in most laboratories that have metallurgical capabilities.

Our evaluation of the direct test methods indicated that much development work would be required to refine the test methods such that they would have adequate repeatability to be useful and successful. New test methods must provide consistent results in laboratories around the world to fairly represent the carbide materials used in the blade assemblies. Manufacturers of carbide inserts, blade assemblers and suppliers, and transportation agencies must all be able to trust that the results mean what is represented.

We had difficulty repeating the indentations and measurements of the Scratch test. A microscope with 200x magnification was adapted to the test instrument we received from the South Dakota DOT, as suggested in the recommendations for further study of the test method. The test procedure used a surface preparation apparatus that clamps onto the edge of the blade to put a “uniform smooth finish” on the surface of the area to be tested. With different operators and different blade geometries we felt there would be a significant problem accomplishing this step with consistent results between operators and/or laboratories. While the microscope clamped on to the same part of the apparatus easily and consistently the scratches observed were very difficult to repeat. Each operator needed to hold the indenter against the blade and move it back and forth while trying to keep the angle and path of the indenter unchanged over a duration of many strokes. On some test specimens the inserts had slight gaps or changes in height between them making this a difficult feat to accomplish. It was our opinion that the method would not have adequate repeatability between operators and between laboratories without significant modifications of the equipment and possibly the test procedure. This would require time and resources to accomplish. Thus, we chose not to pursue this test in the final phase of the testing evaluations.

The existing test for ASTM B611 is a standard test but one that is generally to be used for “comparative” purposes, comparing one material against another in the same laboratory with the same test equipment. Recent automation of this test by test-equipment manufacturers may be increasing the repeatability of this test. However, the automated test equipment is not in general use because it is expensive and is part of a machine equipped to conduct a number of metallurgical tests. While it may be possible to develop this test to predict wear performance of the carbide inserts the process would be long and costly.

Similarly, adapting the existing ASTM B611 to conduct the test on a blade assembly, rather than a sample of the carbide insert was found to be too extensive to be practical. As noted above the existing test is best conducted by automated machines that are set up to conduct multiple tests. Implementing the automation is extremely costly. Performing the tests without automation is also costly because of the need for specialized equipment and high labor costs. There are long test periods for each sample and the need to have someone oversee each test to ensure test conditions do not change during the test. Adapting such a machine to apply the wet abrasive material to a blade assembly would be difficult and each type of machine would be different. Further, the means of holding the assembled blade against the wearing surface would require adaptation to each size and weight of blade. ASTM B611 discusses precision and bias, indicating that precision depends on the abrasive resistance of the carbide and because carbides vary greatly precision cannot be determined.

A modification of the Vickers Hardness (Indentation) Test for Fracture Toughness is being discussed by the Saskatchewan Ministry of Transportation. The specific modification had not been identified at the time of our inquiry. Generally, the Vickers Indentation test is a “micro” hardness test. The microhardness feature will yield errors since it may reflect only the hardness of one or the other of the two phases present (Cobalt and Tungsten Carbide). It will also be adversely affected by grain size and porosity in the vicinity of the indentation. Operator measurements and nonsymmetrical indentations also introduce variations. This suggests that the test would not have the repeatability desired for the evaluation of wear performance of the carbides. Again, it appears that the track for development and implementation would be exceedingly long and costly.

LABORATORY EVALUATION

In Phase 3 of this research, we examined cemented carbide plow blade inserts in compliance with the following standards:

1. ASTM 294-92 Test Method for Hardness Testing of Cemented Carbides
2. ASTM 311-08 Standard Test Method for Density of Powder Metallurgy Materials Containing Less than Two Percent Porosity
3. ASTM B276-05e1 Standard Test Method for Apparent Porosity in Cemented Carbides
4. ASTM B390-92(2006) Standard Practice for Evaluating Apparent Grain Size and Distribution of Cemented Tungsten Carbides

The nominal composition of these inserts is 11% cobalt (Co) and 89% tungsten carbide (WC), with provision for trace amounts of other metallics, graphite and lubricant, generally limited to about 1.0% maximum.

Plow blade assemblies (with inserts brazed in place) from three suppliers were provided for testing. Twelve plow blade assemblies were provided from each supplier. Nine of each were reserved for lab tests and three of each were field tested for service life.

To obtain samples for testing inserts were torch cut from one end of the blade assembly. Carbon steel was then machined off three sides of the inserts (the fourth side was exposed). Final removal of the brazing alloy was performed with nitric acid. A transverse segment of each insert (about 1/8" thick and about 1/8" from one end) was removed from the 1" length using a diamond abrasive wheel. One insert was selected from each of eight blade assemblies for the following examinations. All tests were conducted in compliance with the ASTM standards listed above.

Hardness

Eight samples from each of the three suppliers were tested. Five hardness tests were taken on each sample and the average was tabulated (see Table 2.2). Total overall average hardness was determined for each of the three suppliers:

- Supplier E: HRA = 88.1
- Supplier M: HRA = 88.4
- Supplier V: HRA = 88.9

Differences in these average values between suppliers are not statistically significant. All averages are within and near the minimum value of the anticipated range for this alloy. The slightly low values could be attributed to a coarse grain size. A medium or fine grain size would yield a hardness of about 89.5 - 90.5 respectively.

Table 2.2 Hardness HRA

Insert	Measurements					Average	Standard Deviation
EB3	88.4	88.2	88.2	88.4	88.4	88.3	0.1
EC3	87.8	87.9	87.8	88.0	88.0	87.9	0.1
ED3	87.6	87.6	87.9	87.8	87.6	87.7	0.1
EE3	88.5	88.4	88.2	87.8	88.2	88.2	0.3
EF3	88.0	87.8	88.0	88.1	87.9	88.0	0.1
EG3	88.4	88.6	88.1	88.2	88.0	88.3	0.2
EH3	87.8	87.6	87.9	87.9	87.8	87.8	0.1
EJ3	87.6	87.9	88.0	87.6	88.0	87.8	0.2
MC4	88.8	88.9	88.9	89.0	88.9	88.9	0.1
MD4	88.2	88.4	88.6	88.6	88.4	88.4	0.2
ME4	88.2	88.2	88.1	88.0	88.2	88.1	0.1
MF4	88.4	88.8	88.5	88.6	88.6	88.6	0.1
MG4	88.2	88.6	88.8	88.8	88.8	88.6	0.3
MH4	88.6	88.6	88.9	88.8	88.8	88.7	0.1
MJ4	88.1	88.0	88.4	88.2	88.0	88.1	0.2
MK4	88.8	88.8	88.9	88.6	88.8	88.8	0.1
VB2	89.0	88.8	88.6	88.9	88.8	88.8	0.1
VC2	90.0	89.6	89.6	89.6	90.0	89.8	0.2
VD2	88.6	88.2	88.6	88.6	88.6	88.5	0.2
VE2	88.2	88.6	88.8	88.8	88.2	88.5	0.3
VF2	88.2	88.2	88.4	88.5	88.2	88.3	0.1
VG2	88.6	88.6	88.8	88.8	88.2	88.6	0.2
VH2	90.1	89.8	90.0	90.0	90.0	90.0	0.1
VJ2	89.0	89.0	88.8	89.0	89.0	89.0	0.1

Density

The same samples were tested (in a water displacement method) and results tabulated in Table 2.3. Average density was determined for each supplier (g/cc)

- Supplier E: 14.36
- Supplier M: 14.49
- Supplier V: 14.44

These averages are very close to the anticipated 14.45 - 14.50 for this composition. The low value for supplier E is likely caused by low carbide composition and high porosity. Fine grain size with acceptable composition and low porosity will have a density of about 14.55 g/cc.

Table 2.3 Density g/cc

Insert	Measurement
EB3	14.25
EC3	14.44
ED3	14.42
EE3	14.28
EF3	14.41
EG3	14.25
EH3	14.47
EJ3	14.40
MC4	14.56
MD4	14.46
ME4	14.47
MF4	14.47
MG4	14.52
MH4	14.49
MJ4	14.48
MK4	14.49
VB2	14.42
VC2	14.37
VD2	14.46
VE2	14.43
VF2	14.47
VG2	14.44
VH2	14.51
VJ2	14.43

Porosity

Porosity examinations are performed on polished, unetched samples. Samples are compared to standard micrographs to evaluate size and distribution. Porosity is divided into three classifications:

- Type A : pores up to 10 micron size
- Type B : pores from 10 - 25 microns
- Type C : uncombined carbon

Distribution of porosity or carbon is reported as:

- 00 : none detected
- 02 : .02% volume
- 04 : .06% volume
- 06 : .20% volume
- 08 : .60% volume

The same 24 samples (8 from each of three suppliers) were evaluated and tabulated in Table 2.4. The number of samples in each classification is summarized for each of the three suppliers:

- Supplier E : A02 = 7 B00 = 2 C00 = 7
  A04 = 1 B02 = 6 C02 = 1
  - Four samples had void clusters which included large void sizes.
  - Three samples had a few large voids present.
- Supplier M : A02 = 8 B00 = 7 C00 = 7
  B02 = 1 C06 = 1
  - Two samples had a few large voids present.
- Supplier V : A02 = 8 B00 = 2 C00 = 4
  B02 = 6 C04 = 2
  C06 = 2
  - Two samples had internal cracks present.

The porosity ratings are relatively low for both small and medium sizes, with supplier M showing a better rating, in medium sized pores, than the others. This could contribute to a longer service life. No observable, free carbon was common for suppliers E and M, which could approach a situation of concern. A sufficient carbon deficiency could lead to an embrittlement problem. Supplier V could be slightly better in this respect. The most significant problem is with supplier E and the clusters of voids. The large voids are, generally, elongated and measure about 20 -25 microns wide and 55 - 65 microns long. There are also circular or elongated, numerous areas present which indicate low density and insufficient cobalt binder. These areas of low density measure about 15 - 80 microns in size. This can adversely affect service life, resulting in cracking and chipping (particle removal). Supplier V also had two samples with significant problems. Internal cracks were present, oriented along the length of the inserts (perpendicular to the manufacturing compaction punch faces). In addition, unlike any of the other samples, there was conclusive evidence of multiple fill operations into the die cavity during manufacturing. These fracture surfaces were nearly flat (very large radius of curvature). Visually, they appeared smooth, dark and nonreflective. Detailed investigation was not pursued, but they were likely pre-existing to the brazing assembly process. Excess free graphite and low compaction density could have contributed to these flaws.

Table 2.4 Porosity

Insert	Type A	Type B	Type C
EB3	A02	B02	C00
EC3	A02	B02	C00
ED3	A02	B02	C00
EE3	A02	B02	C00
EF3	A02	B02	C02*
EG3	A02	B00	C00
EH3	A02	B00	C00
EJ3	A04	B02	C00
MC4	A02	B00	C00
MD4	A02	B02	C00
ME4	A02	B00	C00
MF4	A02	B00	C00
MG4	A02	B00	C06
MH4	A02	B00	C00
MJ4	A02	B00	C00
MK4	A02	B00	C00
VB2	A02	B02	C00
VC2	A02	B00	C06*
VD2	A02	B02	C00
VE2	A02	B02	C04*
VF2	A02	B02	C00
VG2	A02	B00	C00
VH2	A02	B02	C06*
VJ2	A02	B02	C04*

* = Rating for local area; most areas were C00.

Grain Size

The same samples were etched and examined at 1500x. Comparisons were made to standard micrographs and the evaluations tabulated in Table 2.5. The prefix "10" indicates a cemented carbide with 10% cobalt as the standard of comparison. The suffix "F", "M" or "C" indicates a fine, medium or coarse grain size respectively. Results are summarized for the three suppliers:

- Supplier E: 10-C = 5 10-M = 3
- Supplier M: 10-C = 8
- Supplier V: 10-C = 8

Supplier E has a more desirable mix of grain sizes but this is not considered to be a notable difference. The coarse grain size will contribute to fracture strength but will reduce wear resistance. This is a concern for this application.

Table 2.5 Grain Size

Insert	Grain Size	Other Features
EB3	10-M	void clusters & large voids #
EC3	10-C	void clusters & large voids #
ED3	10-C	void clusters & large voids #
EE3	10-M	void clusters & large voids #
EF3	10-C	a few large voids #
EG3	10-M	a very few large voids #
EH3	10-C	a few large voids #
EJ3	10-C	
MC4	10-C	
MD4	10-C	two large voids #
ME4	10-C	a few large voids #
MF4	10-C	
MG4	10-C	
MH4	10-C	
MJ4	10-C	
MK4	10-C	
VB2	10-C	
VC2	10-C	
VD2	10-C	internal cracks
VE2	10-C	internal cracks
VF2	10-C	
VG2	10-C	
VH2	10-C	
VJ2	10-C	

= “large voids” are 25 to 100 microns or more.

In the examinations above, visual comparisons are subjective and a precision and bias statement cannot be made (as per ASTM specification statements). The evaluations were made by a materials engineer with approximately 15 years experience in powdered metals, and reviews were made by two professional engineers, each with 30 years minimum experience.

As part of the laboratory testing, magnified photographs were taken of the samples for the porosity and grain size analysis. Refer to Figures 2.1 through 2.3.

Figure 2.1 Supplier M, Polished, Magnification 200X Showing Few Voids and No Cracks

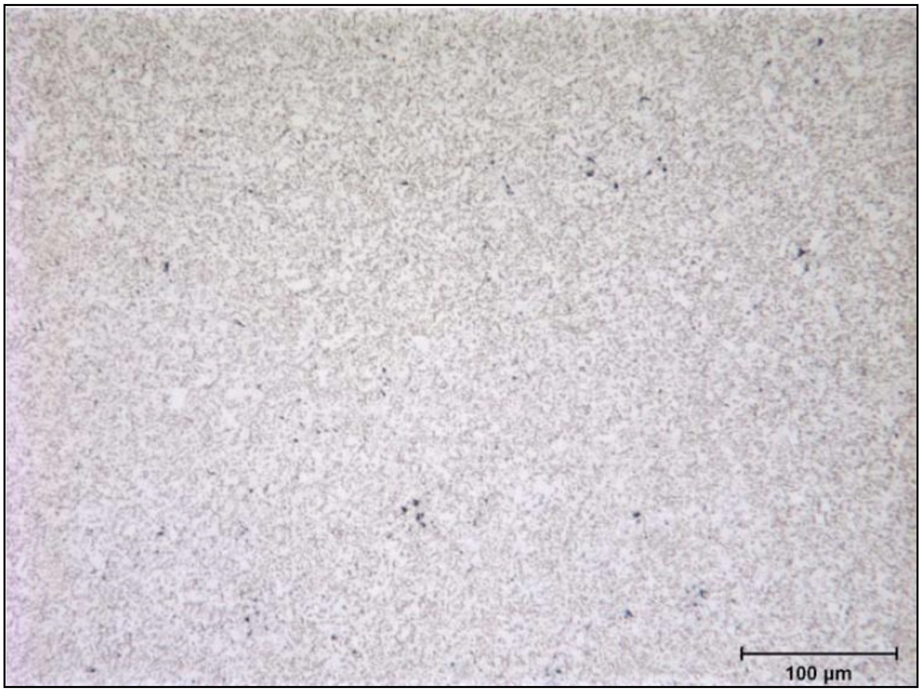


Figure 2.2 Supplier E, Polished, Magnification 200X Showing Voids and Void Clusters

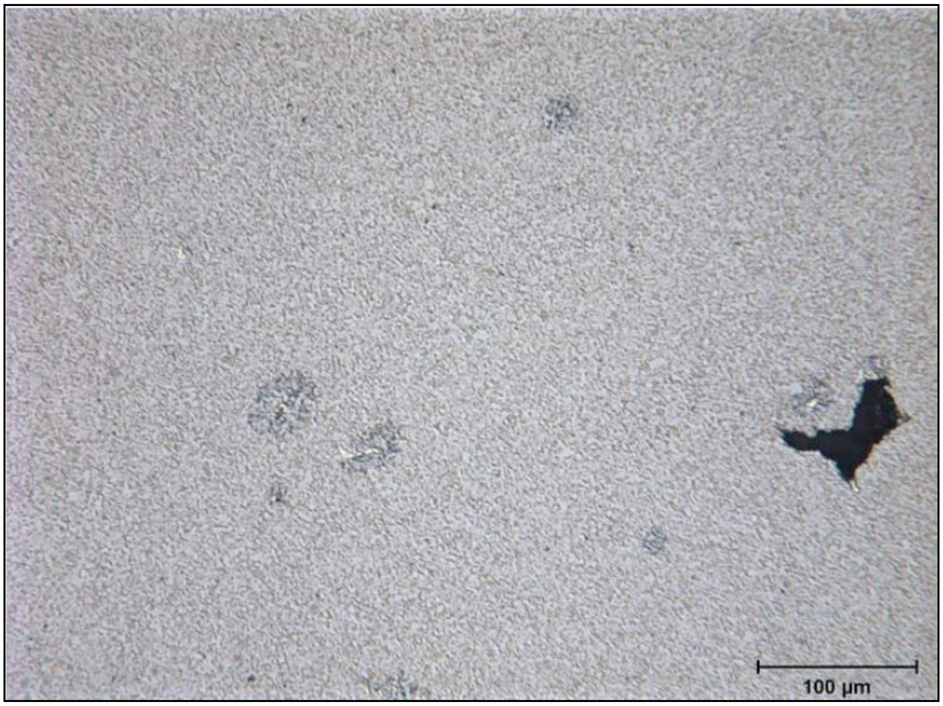
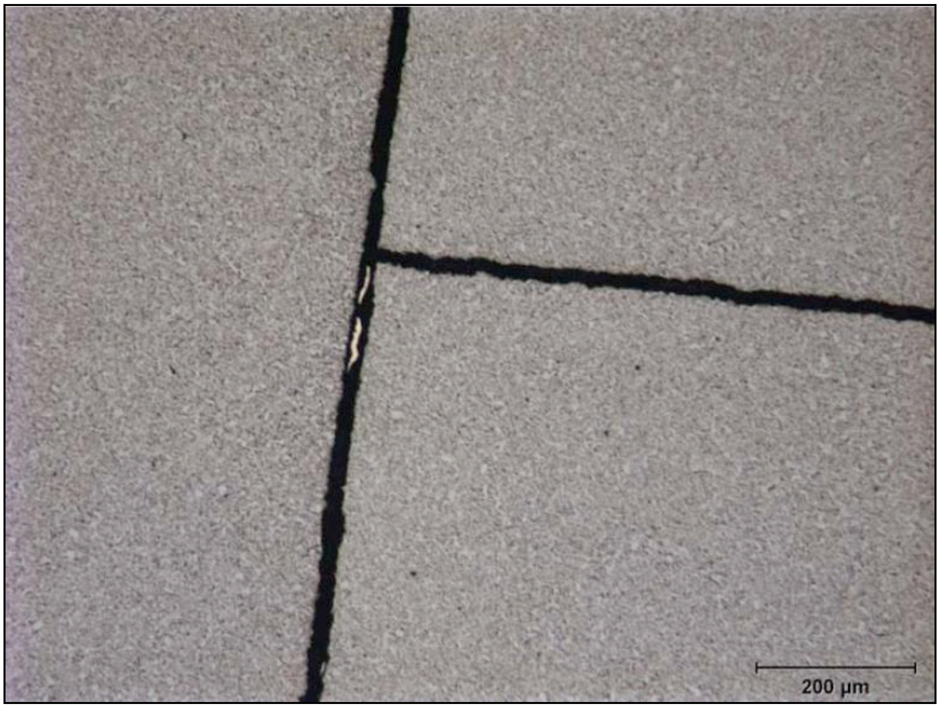


Figure 2.3 Supplier V, Polished, Magnification 200X Showing Internal Cracks



DESIGN OF FIELD TEST

This research was limited to evaluating samples from three different suppliers for laboratory testing and field testing. It was important to expose each set of field blades to identical wear conditions so the amount of wear was determined by the performance of the tungsten carbide inserts rather than non-insert variables. Many factors affect carbide insert snowplow blade wear and fracturing. The list below identifies most of the conditions known to affect wear in the field. Table 2.1 includes a more detailed list of the identified factors.

- Carbide insert properties: assumed to be consistent within a shipment provided by a supplier.
- Steel blade properties: assumed to be consistent within a shipment provided by a supplier.
- Back blade: a back blade may be used to protect the insert from impact shocks.
- 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: practices vary from 0 to 30 degrees inclination
- Pavement type: bituminous or concrete pavement.
- Surface state: testing will only be conducted when the pavement is dry and free from any contaminants such as oil or sand.
- Pavement obstructions: minimal expected at test site.
- Speed of plowing: 45 mph proposed.

After discussions with the TAC it was agreed that the best method for field testing would be to have a snowplow with the test inserts operated on a given route over dry pavement using the same driver. The TAC identified the Utah DOT as an agency that would provide the required equipment and personnel. Mr. Lynn Bernhard, Utah DOT, arranged for the test schedule, equipment usage, operator availability, and test expenses. He also defined the protocols and record keeping for the field study.

For analysis of the field tests, the inserts were measured for size before and after the field wear tests were performed. The measurements were compared to determine the change in length, or wear, of the blade during the tests. Data analysis focused on the comparison between readings from the samples tested in the field conditions and laboratory data sources to evaluate precision, accuracy and variability.

FIELD TESTING

Field tests were performed by the Utah DOT. Blades were tested by a truck with a front-end plow (See Figure 2.4).

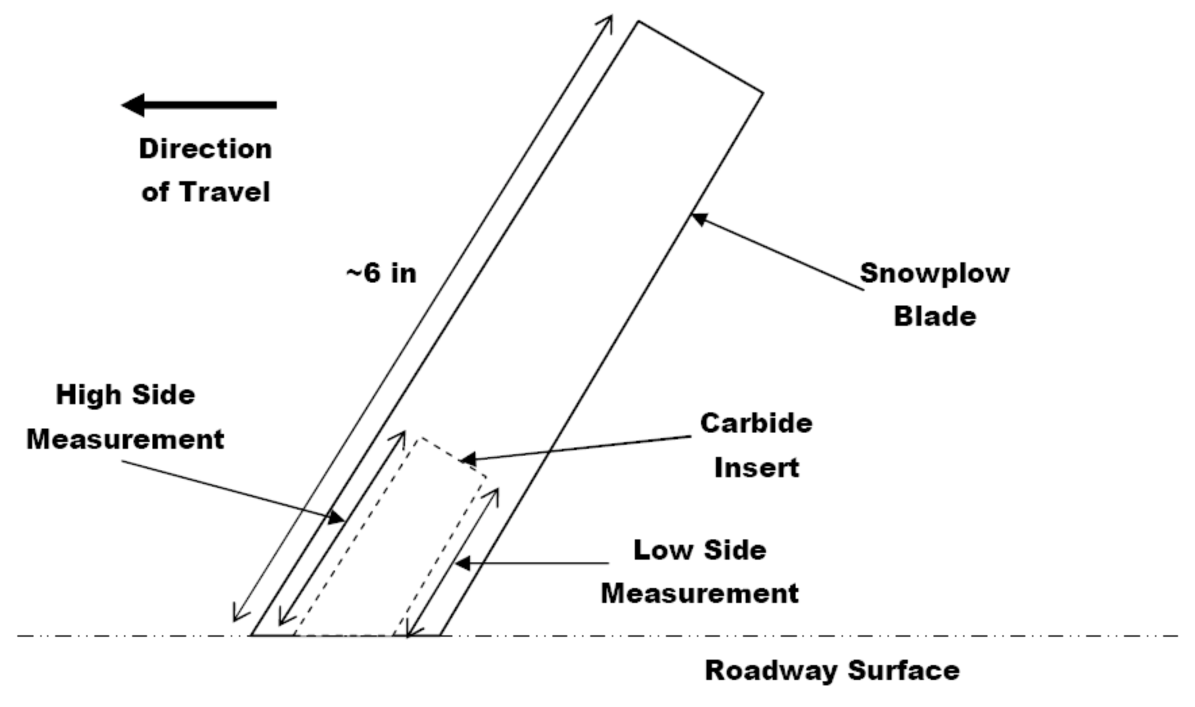
Figure 2.4 Field Test in Progress

Three four-foot long, carbide-insert blades from each supplier were used to provide full coverage (12 feet) for the plow. A back blade was not used. The blades from each supplier were tested for 300 miles at 45 miles per hour. The snowplow blades were set an an angle of 18 degrees from vertical. The order of testing was E (from Utah DOT operations supply), V (from Wyoming DOT operations supply), and M (ordered for this project using Utah DOT purchasing process and specifications).

Tests were conducted on Utah State Route 122 from MP 0 to MP 6. This route has an annual daily traffic of 40. It is a 2-lane asphalt pavement with a chip seal surface. No significant loss of chips or binder was observed after the tests were complete. The pavement condition was dry during the tests. Ambient air temperatures during testing ranged from 18 to -10 degrees Fahrenheit. The pavement temperature was below 20 degrees.

Temperatures of the blades at the cutting edge of the blade were measured periodically using a Raytech Raynger ST, an infrared temperature measurement instrument with a laser to maintain correct positioning of the device. The V blades had edge temperatures up to 300 degrees Fahrenheit. M blades had edge temperatures exceeding 500 degrees Fahrenheit. Measurements also showed that temperatures of the blades 4 inches above the edge were at ambient temperature.
Before field testing began, the height of the carbide inserts in the test plow blades were measured on the left and right sides of each blade. The measurements were taken on the “high” and “low” sides of the blade inserts. Figure 2.5 below provides a schematic of the carbide inserts in the blades and the measurements that were taken.

Figure 2.5 Carbide Insert Blade Schematic and Field Test Measurements



It should be noted that blades from supplier V had a different shape for the carbide inserts. Two of the suppliers had a beveled edge on the bottom, with the steel casing and carbide inserts milled flush with the contact angle on the roadway surface. Blade assemblies from Supplier V were rectangular in shape. This design is intended for plow applications where the blade is held in a vertical position. However, the field test of these blades had the blade at an 18 degree angle to the surface. As a result the back edge of the rectangular blade contacted the pavement surface until the blade wore enough for the complete face to be on the pavement surface. These different designs made it difficult to compare the blades of the three suppliers.

The specifications for the purchase of these blades are shown in Table 2.6. It should be noted that we did not receive test results or other documentation that the inserts met these specifications.

Table 2.6 Specifications for Test Specimens

Sample	Percent Cobalt	Density	Hardness	Transverse Rupture Strength	Porosity
E and M	11 – 12 1/2	14.1 – 14.6	87.5 – 89.0	350,000 psi	A06 B02 C00
V	Not specified	14.1 minimum	87.5 – 89.0	Not specified	Not specified

Measurements from the blades used in the field performance tests are provided here. These measurements are used in subsequent analysis of wear performance and other characteristics. Each four-foot blade section includes 48 individual one-inch carbide inserts, resulting in 144 blade inserts from each supplier. Table 2.6 provides the measurements taken before the field testing was performed. Each measurement is the average height along the length of the insert, repeated for each of 3 inserts.

Table 2.6 Lab Sample Measurements (in)

Sample	High Edge	Low Edge	Difference Hi-Lo
E1	0.626	0.522	0.104
E2	0.629	0.523	0.106
E3	0.627	0.519	0.108
E Average	*0.627*	*0.521*	
M1	0.645	0.542	0.103
M2	0.642	0.538	0.104
M3	0.639	0.531	0.108
M Average	*0.642*	*0.537*	
V1	0.750	0.749	0.001
V2	0.749	0.748	0.001
V3	0.750	0.750	0.000
V Average	*0.750*	*0.749*	

Following the 300-mile field test plow runs, the blades were removed from the plows and shipped to the laboratory for measurement. The measurements were recorded in the same location as the initial measurements and recorded such that the initial and final measurements for each location could be matched. The measurements, as well as the blade section and locations of the measurements, are denoted in Table 2.7. Left is defined as the left edge of the blade as viewed by the driver of the plow, and corresponds to insert #1 on the lab testing blades.

Table 2.7 Field Blade Measurements After Wear

Left Section Blades			
	High Edge (in)	**Low Edge (in)**	**Difference Hi-Lo (in)**
E Left	0.553	0.431	0.122
E Right	0.595	0.457	0.138
Difference L-R	*0.042*	*0.026*	
M Left	0.630	0.507	0.123
M Right	0.618	0.498	0.120
Difference L-R	*0.012*	*0.009*	
V Left	0.753	0.645	0.108
V Right	0.591	0.467	0.124
Difference L-R	*0.162*	*0.178*	
Center Section Blades			
E Left	0.531	0.403	0.128
E Right	0.540	0.398	0.142
Difference L-R	*0.009*	*0.005*	
M Left	0.560	0.456	0.104
M Right	0.645	0.524	0.121
Difference L-R	*0.085*	*0.068*	
V Left	0.734	0.616	0.118
V Right	0.748	0.689	0.059
Difference L-R	*0.014*	*0.073*	

Right Section Blades			
E Left	0.622	0.488	0.134
E Right	0.551	0.458	0.093
Difference L-R	*0.071*	*0.030*	
M Left	0.589	0.475	0.114
M Right	0.618	0.495	0.123
Difference L-R	*0.029*	*0.020*	
V Left	0.751	0.615	0.136
V Right	0.737	0.638	0.099
Difference L-R	*0.014*	*0.023*	

The blades were also inspected visually and photographed after the field tests were performed. The carbide inserts were checked for the presence of cracks and chips that resulted from the field tests. Photos of three sections of field blades with varying amounts of cracks and chips are shown in Figures 2.6, 2.7 and 2.8.

Figure 2.6 Field Tested Blade from Supplier V (cracked and chipped)

Figure 2.7 Field Tested Blade from Supplier M (no cracks or chips)

Figure 2.8 Field Tested Blade from Supplier E (end view)

A summary of the crack and chip observations is given in Table 2.8.

Table 2.8 Crack and Chip Observations

Supplier	**E**	**M**	**V**
Number of Inserts with Cracks	44	0	46
Percent of Inserts with Cracks	31%	0%	32%
Number of Inserts with Chips	9	4	22
Percent of Inserts with Chips	6%	3%	15%

Cracks and chips are expected to have a negative impact on wear performance. Cracks are detrimental since they reduce fracture resistance and lead to loss of inserts. Chips negatively affect performance because chipped inserts do not have as large a surface area in contact with the roadway surface. The area of the insert in contact with the roadway surface is a direct determinant of wear performance. Chips are areas where some of the insert material has been removed due to impact with an obtrusion on the roadway surface.

The observations in Table 2.8 show that supplier M has the fewest chips and no cracks following the field test. Supplier E had a large number of cracks present, but only a moderate number of chips. Supplier V had both the highest number of cracks and chips, and together these are expected to result in performance below expected levels. As noted earlier, supplier V had a rectangular-shaped blade. In the initial stage of wear this geometry creates stress concentrations due to a significant reduction of area in contact with the pavement. This could cause early cracking and subsequent chipping of the carbide inserts.

CHAPTER 3. FINDINGS AND APPLICATIONS

This chapter presents our analysis of the research conducted and describes how to use the results to improve the performance of snowplow blades using carbide inserts.

BASIS FOR TEST SELECTION

We based our test selection for final evaluation on several factors:

- The ability of the test to predict the wear performance of the carbide insert
  - Statistical evaluations of test results
  - The availability of information necessary to set acceptable test limits
- The potential for successful implementation of the tests
  - Need for test development and standardization through ASTM
  - Familiarity of the carbide insert manufacturers with the tests
  - Familiarity of the snowplow blade suppliers with the tests
  - Availability of laboratories to do the tests for manufacturers
  - Availability of laboratories to do the tests for buyers

This study evaluated a variety of test methods, both existing tests and new tests, or a new application of an existing test. The test results indicate that the existing tests had the best potential for meeting the selection factors identified. Clearly, existing test methods common to the powdered metal industry would be the easiest to implement.

This study attempted to improve the "Scratch Test" method from the South Dakota study. This study also considered adapting ASTM B611 or modifying it to test inserts in place in a steel blade. It appeared that all of these methods would require considerable additional development to prove the ability to predict performance of the carbide insert and to get either of these tests implemented in the powdered metal industry. Most, if not all, of the carbide inserts are manufactured in China. There may be limited manufacturers in other nations. This industry uses ASTM specifications primarily. Thus, the path to implementation would have to go through the ASTM processes of test standardization and acceptance. This typically requires several years of committee study, research and voting. Thus, when the existing test methods showed significant promise, they were used for subsequent testing.

SUMMARY OF LABORATORY EVALUATION RESULTS

The results of testing with the existing tests indicated that the three sets of blades tested had very similar chemical characteristics. What was different was the presence of voids and cracks within the inserts. In particular, the microscopic visual examination of the porosity test found these flaws. The presence of the voids and internal cracks correlated directly to the wear performance of the field-tested blades.

These flaws appear to be caused by poor manufacturing processes and not the result of the wrong mix of tungsten and cobalt or the wrong gradation of particle sizes. The Hardness, Density, and Grain Size tests are valuable to establish the correct mix of tungsten and cobalt and the correct gradation of particles that will allow good manufacturing processes to produce good carbide inserts. Porosities reflect the quality of powder blending and compaction operations (also affected to a lesser extent by particle size). Thus, we recommend that these tests be included in the final test requirements.
Supplier E could have been challenged with:

1. Low tungsten carbide content, resulting in lower hardness and density.
2. Poor powder blending and low compaction pressures, resulting in porosity problems and insufficient cobalt binder in some areas.

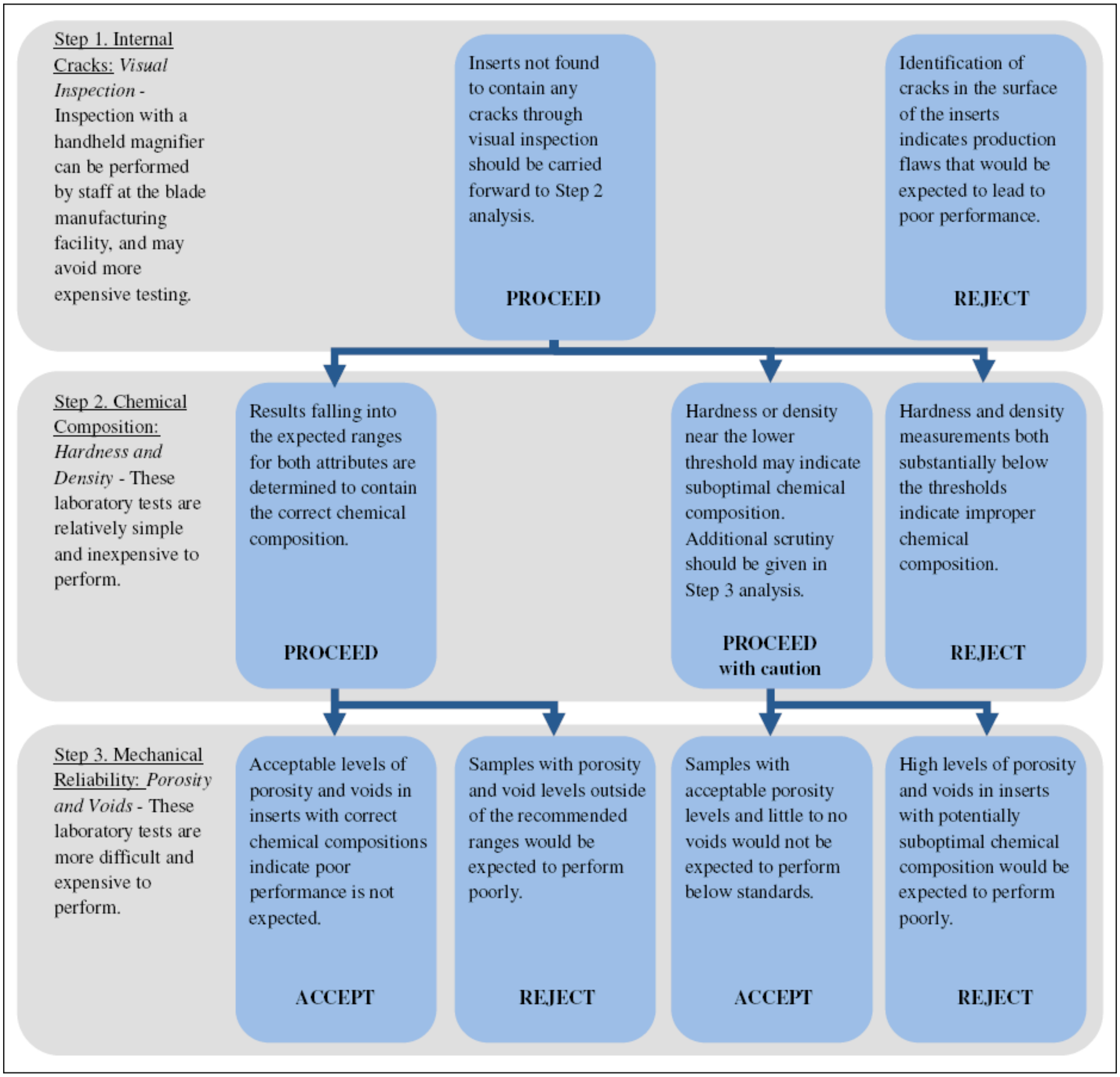
Supplier V could have had problems with low compaction pressures, resulting in variations in the shrinkage of parts. The rectangular geometry of these inserts may have contributed to cracking and chipping in field tests. Initial wear would have been on the trailing edge, resulting in more severe stress levels than with the other (trapezoid) geometries.

Grain size evaluation relates to hardness and wear resistance. Fine grain sizes will yield higher hardness and greater wear resistance. Fine grain size also enhances the compaction process and could help avoid porosity. The determination of grain size in this series of tests is also used to further refine the interpretation of the other test results.

STATISTICAL EXPERIMENT DESIGN

The laboratory results were analyzed statistically in an effort to quantify the effects of the laboratory test results on field performance of the carbide blade inserts. The flow chart in Figure 3.1 depicts the framework of the recommendations for selection of carbide blade inserts that was identified through the lab tests.

Figure 3.1 Carbide Blade Insert Selection Framework for Lab Tests and Results



Step 1. Internal Cracks: *Visual Inspection* - Inspection with a handheld magnifier can be performed by staff at the blade manufacturing facility, and may avoid more expensive testing.

Inserts not found to contain any cracks through visual inspection should be carried forward to Step 2 analysis.

PROCEED

Identification of cracks in the surface of the inserts indicates production flaws that would be expected to lead to poor performance.

REJECT

Step 2. Chemical Composition: *Hardness and Density* - These laboratory tests are relatively simple and inexpensive to perform.

Results falling into the expected ranges for both attributes are determined to contain the correct chemical composition.

PROCEED

Hardness or density near the lower threshold may indicate suboptimal chemical composition. Additional scrutiny should be given in Step 3 analysis.

PROCEED with caution

Hardness and density measurements both substantially below the thresholds indicate improper chemical composition.

REJECT

Step 3. Mechanical Reliability: *Porosity and Voids* - These laboratory tests are more difficult and expensive to perform.

Acceptable levels of porosity and voids in inserts with correct chemical compositions indicate poor performance is not expected.

ACCEPT

Samples with porosity and void levels outside of the recommended ranges would be expected to perform poorly.

REJECT

Samples with acceptable porosity levels and little to no voids would not be expected to perform below standards.

ACCEPT

High levels of porosity and voids in inserts with potentially suboptimal chemical composition would be expected to perform poorly.

REJECT

STATISTICAL FINDINGS OF LABORATORY TESTS

The laboratory measurements described in the evaluation results above were subjected to the blade selection framework contained in Figure 3.1.

Step 1

Internal Cracks: Table 3.1 provides a summary of the inspections for internal cracks in the laboratory test samples. Eight samples from each supplier were inspected.

Table 3.1 Results of Visual Inspection for Internal Cracks

Supplier	**E**	**M**	**V**
Internal Cracks	0	0	2
Percent Containing Internal Cracks	0%	0%	25%

Samples from suppliers E and M were not found to contain any internal cracks and should be carried forward to Step 2 of the screening process. Samples from supplier V were found to contain cracks in 25 percent of the samples. This exceeds the recommended maximum of 10 to 15 percent and should result in the rejection of this shipment of inserts.

Step 2

Hardness: The laboratory evaluation report identified a recommended range of acceptable hardness values. This range is 88.0 to 90.5 HRA. The hardness measurements were compared against this range to determine the proportion that fell within the desired range, out of 40 measurements taken from the samples of each supplier. In addition, the mean and standard deviation of the measurements were tested using a t-distribution. The t-distribution provides a good statistical model in this case because it is capable of approximating a normal distribution for small sample sizes. The test results on these samples provide a level of confidence that the entire shipment of inserts fall within the desired range. The results of the hardness evaluation are shown in Table 3.2.

Table 3.2 Results of Hardness Measurements and Statistical Analysis

Supplier	**E**	**M**	**V**
Mean (HRA)	88.0	88.5	88.9
Standard Deviation	0.3	0.3	0.6
Counts Within Threshold	21	40	40
Percent Within Threshold	53%	100%	100%
Confidence Level (t-test)	47.7%	100.0%	100.0%

Density: The recommended range of density values provided in the laboratory evaluation report was from 14.40 g/cc to 14.55 g/cc. The eight measurements from each supplier’s inserts were compared against this range to determine the proportion falling within the desired range. A t-distribution was also used to determine the level of confidence of the entire shipment falling within the desired range. The results are provided in Table 3.3.

Table 3.3 Results of Density Measurements and Statistical Analysis

Supplier	E	M	V
Mean (g/cc)	14.37	14.49	14.44
Standard Deviation	0.09	0.03	0.04
Counts Within Threshold	5	7	7
Percent Within Threshold	63%	88%	88%
Confidence Level (t-test)	13.9%	100.0%	99.7%

Based on these results, suppliers M and V were found to have hardness and density values within the desired ranges with at least a 95% confidence level. Therefore, these should not be rejected based on these tests. Hardness and density measurements for supplier E were not within the desired ranges at a 95% confidence level, and should either be rejected or accepted conditionally pending Step 3 results.

Step 3

Porosity: The laboratory evaluation report provides recommended ranges for porosity measurements for Type A, B, and C classifications. As described in the lab report, Type A includes pores less than 10 microns, Type B include pores from 10 to 25 microns, and Type C is uncombined carbon. The rating system for porosity measurements is provided using codes indicating the proportion of the volume that is porous. The maximum recommended porosity for Type A pores is A04, or 0.06%; the maximum for Type B pores is B02, or 0.02%; and the maximum for Type C (uncombined carbon) is C04, or 0.06%. Similar to the analysis performed in Step 2, the number out of eight observations falling into the recommended range was tabulated and a t-distribution was used to determine a level of confidence. The results of the analysis are provided in Table 3.4.

Table 3.4 Results of Porosity Measurements and Statistical Analysis

Supplier	E	M	V
Type A			
Mean (proportion of volume)	0.0003	0.0002	0.0002
Standard Deviation	0.0001	0.0000	0.0000
Counts Within Threshold	8	8	8
Percent Within Threshold	100%	100%	100%
Confidence Level (t-test)	100.0%	100.0%	99.7%
Type B			
Mean	0.0002	0.0000	0.0002
Standard Deviation	0.0001	0.0001	0.0001

Counts Within Threshold	8	8	8
Percent Within Threshold	100%	100%	100%
Confidence Level (t-test)	91.7%	100.0%	91.7%
Type C			
Mean	0.0000	0.0003	0.0007
Standard Deviation	0.0001	0.0007	0.0009
Counts Within Threshold	8	7	6
Percent Within Threshold	100%	88%	75%
Confidence Level (t-test)	100.0%	90.0%	56.2%

Based on these results, none of the suppliers were found to have porosity characteristics that were consistently outside of the recommended ranges. Suppliers E and V did not meet a 95% confidence level for Type B porosity, however all 8 of the sample measurements did fall within the recommended range. Similarly, suppliers M and V did not meet a 95% confidence level for Type C porosity. Since none of the suppliers' inserts were outside of the recommended ranges for all 3 porosity levels, rejection based on this information alone is not warranted. However, all suppliers were found to have at least one porosity classification not meeting a 95% confidence level, indicating that additional scrutiny should be given to results of subsequent analysis.

Voids and Void Clusters: Observation of voids and void clusters in the samples is performed during the grain size analysis. These measurements did not lend themselves to a statistical analysis, but a qualitative analysis of voids and void clusters together with the hardness, density, and porosity results provides valuable information regarding the expected performance of the inserts. Eight samples were observed from each supplier. A summary of the void and void cluster observations is provided in Table 3.5.

Table 3.5 Results of Void and Void Cluster Observations (found using Grain Size test)

Supplier	**E**	**M**	**V**
Void Clusters	4	0	0
Percent Containing Void Clusters	50%	0%	0%
Large Voids	7	2	0
Percent Containing Large Voids	88%	25%	0%

Based on a qualitative review of voids and void clusters present, inserts from supplier E should be rejected due to the combination of potentially suboptimal chemical composition identified in Step 1 and the presence of voids and void clusters. Inserts from supplier M were observed to have a few large voids in two of the samples, however because few concerns were identified in Steps 1 or 2 these are not expected to negatively influence performance.

SUMMARY

The results of the selection framework provide a clear indication of the expected performance of the carbide inserts. The inserts of Supplier E were not found to have internal cracks in Step 1, but were found to contain a suboptimal chemical composition in Step 1, necessitating heightened sensitivity to the tests in Step 2. The Step 2 tests show that Type B porosity did not meet a 95% confidence level and that a majority of samples contained voids. Taken together, these results indicate these inserts will not have a high level of performance and should be rejected.

Inserts from Supplier V were found to contain internal cracks in 25% of samples. This is a significant concern, and would be adequate to reject this shipment of inserts. Tests in Steps 2 and 3 would not have been sufficient to conclude that these inserts would be expected to perform poorly. This demonstrates both the importance of the visual inspection for internal cracks as well as the opportunity to avoid costly testing and analysis for Steps 2 and 3.

Supplier M's inserts were not found to have any internal cracks in Step 1 or any concerns regarding chemical composition in Step 2. Step 3 showed that porosity measurements exceeded a 95% confidence level for Types A and B, and that Type C had a 90% confidence level. A few large voids were observed in 25% of the samples. However, since hardness, density, and porosity measurements were not found to deviate significantly from recommended levels, there is not sufficient evidence to suggest that these inserts would perform below expected levels. These inserts should be accepted.

The sample sizes that were used in this screening were limited to the number of inserts made available for laboratory testing. In practice, a sample size should be selected that will provide an adequate representation of the entire shipment. A sample that includes at least a few inserts from each shipping container would be a reasonable starting point. The t-tests used in Steps 2 and 3 are sensitive to sample size, providing greater levels of confidence with a larger sample. One approach that can assist in establishing adequate sample size is the history of inserts from a given supplier. If recent shipments have been identified as including inserts with questionable results, the sample size could be increased to achieve a tighter inspection.

ANALYSIS OF FIELD TEST RESULTS

Field test measurement results were analyzed to make comparisons between the blade wear performances of different suppliers. In an effort to account for the different blade shapes described above, a method of volume calculation was used. This is intended to provide a representation of the total wear of the inserts during the field test runs.

The volume calculation was performed by calculating the surface area on each end of a blade section for initial and final conditions. The difference in area between initial and final conditions provides the area on the end of each blade worn during the field test runs. The areas on each end of the blade section were averaged and multiplied by the length of the blade section to estimate the volume worn during the field test runs. The results of the volume wear calculations are provided in Table 3.6.

Table 3.6 Results of Volume Wear Calculations (in3)

Supplier	**E**	**M**	**V**
Left Section Blades	1.560	0.726	3.252
Center Section Blades	2.592	1.050	1.242
Right Section Blades	1.038	0.978	1.554
Average of All Three Blades	*1.730*	*0.918*	*2.016*

These results show that supplier M experienced the least wear during the test runs, supplier E experienced the next most wear, and supplier V experienced the greatest wear. In addition, the wear experienced by supplier M was nearly half of the wear of supplier E, and less than half of supplier V. These differences would be expected to result in significantly different useful lifetimes for the snowplow blades.

Field wear measurements were compared statistically to estimate the extent to which the blades from different suppliers provide different performance. The measurement used in these comparisons is the area of wear calculated on each end of each blade section used in the volume calculations described above. Three blade sections from each supplier were used in the field tests, resulting in six areas used in the comparisons. A summary of the means and standard deviations of the areas worn is provided in Table 3.7.

Table 3.7 Summary of Field Wear Areas (in2)

Supplier	**E**	**M**	**V**
Mean	0.036	0.019	0.042
Standard Deviation	0.018	0.013	0.034

Field wear measurements were compared using a t-test. This test provides an indication of the confidence that the blades from a given supplier have better wear performance than blades from another supplier. Table 3.8 provides a matrix of comparisons between the suppliers. Each row shows the comparison between suppliers listed in the left column and the other two suppliers. Low percentages indicate a small degree of confidence that the performance would be expected to be better than blades from the benchmark supplier, while high percentages indicate a large degree of confidence that the performance would be expected to be better than blades from the benchmark supplier.

Table 3.8 Statistical Comparisons of Field Wear Measurements

	Comparison Benchmark Supplier		
Supplier	**E**	**M**	**V**
E	-	3%	78%
M	99%	-	100%
V	34%	8%	-

These comparisons show that the field performance of the blades from supplier M were better than those from suppliers E and V at a high level of confidence, of 99% and 100% respectively. Conversely, there is very low confidence that blades from suppliers E and V would be expected to perform better than blades from supplier M (3% and 8%). Comparisons between blades from suppliers E and V are not meaningful, as the differences between the mean wear measurements are small compared to the standard deviations of the samples. It should be noted that the standard deviation of the sample measurements from supplier V was substantially greater than those from suppliers E and M, resulting in confidence statistics that appear higher than if a smaller standard deviation had been observed.

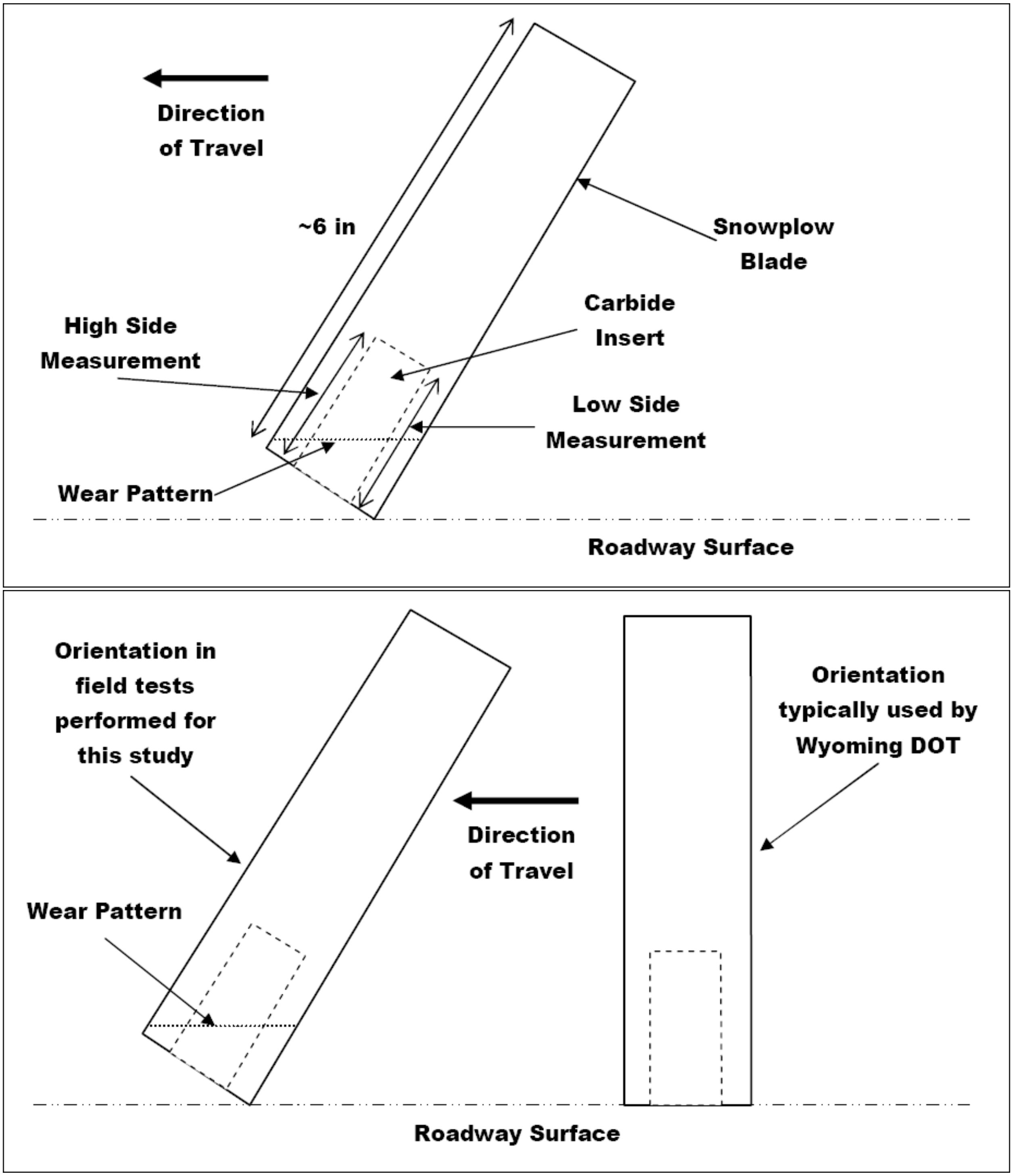
COMPARISON OF LABORATORY AND FIELD TEST RESULTS

The results of the laboratory tests and insert selection framework indicated that inserts from suppliers E and V were not expected to perform near expected levels, and that a blade supplier or transportation agency may reasonably reject those parts. Conversely, the selection framework did not suggest that inserts from supplier M presented substantial enough concerns to reject the parts or expect compromised performance. The field tests validate these results. Supplier M was found to have the fewest cracks and chips, and the wear performance was the best. Both suppliers E and V were observed to have higher numbers of cracked and chipped inserts, and had significantly more wear during the field tests.

DISCUSSION OF BLADE SHAPES

As noted previously, blades from supplier V had a different shape compared to blades from suppliers E and M. As depicted in Figure 2.5, the bottom surface of blades from suppliers E and M were beveled to provide a flat surface at the area of contact with the roadway surface. Blades from supplier V did not have a beveled edge, but a square edge that initially contacts the roadway surface with an edge. See Figure 3.2. After a period of use in the field, wear reduces the square edge to a beveled surface providing greater contact area with the roadway surface.

Figure 3.2 Carbide Insert Blade Schematic and Field Test Measurements (Supplier V)



The influence of the shape of the blades from supplier V is not fully understood, however the field test results demonstrated that it performed poorest in all categories including wear, cracks, and chips. It is probable that the stress placed on the edge of the blade from the roadway surface exhibits different characteristics than stress on a flat surface for blades from suppliers E and M. This may have contributed to the extensive cracking observed in blades from supplier V. Further, the cracks that developed in the tungsten carbide inserts of blades from supplier V would have reduced the surface area in contact with the roadway as wear progressed through the blades. This combination of factors may have led to the high wear measurements observed in the field performance tests.

Blades from this supplier are commonly used by Wyoming Department of Transportation. Contact with Wyoming DOT staff has revealed that blades on their plows are mounted vertical, as opposed to an angle as shown in Figure 3.2. A vertical mount, providing a flat surface at impact with the roadway, might be expected to reduce the high stresses of the edge contact and could result in improved wear performance.

POTENTIAL APPLICATION OF RESULTS

These findings and recommendations can be implemented to improve the performance of carbide inserts manufactured and purchased in the future. The implementation will require changes in the manufacture of the inserts that can be directed by changed specifications and testing methods.
The recommendations of this research provide a starting place for these changes. Additional testing will be required to confirm the acceptance or rejection limits developed in this research.

Standards and Specifications

The results and recommendations from this research can be used to develop a national set of standards and specifications for use by all transportation agencies in need of snowplow blades. Having a national standard will provide an opportunity for manufacturers and suppliers to improve their products because it will be simpler to produce to a single set of standards and specifications.

Policies

Policies of DOT’s and other transportation agencies should be revised as necessary to include Quality Control and Quality Assurance testing as part of the acceptance of blade assemblies. The recommended specifications and acceptance limits are based on statistical evaluations of the Quality Assurance testing. It is in the best interests of the insert manufacturer and the blade assembly supplier to require Quality Control testing to avoid rejection of products that do not meet the Quality Assurance testing. The current practice of accepting a “Certification” that the materials meet the requirements will not be adequate to effect the improvements desired.

Procedures

Procedures for purchasing and acceptance must be revised to require the new specifications and testing. The Quality Assurance testing will require an elapsed time of two to four weeks after receipt of a shipment of blade assemblies. Requiring Quality Control tests that document that the blade assemblies meet the specifications will reduce the risk that an agency will be pressured to accept less than specified products simply because there is not time to get replacements.

Costs

There will be a worthwhile return on the investment required to implement new specifications and purchasing procedures. The cost to plow per mile should be significantly reduced by the improved performance of the blades and the reduced time spent changing blades. One of the three sets of blades tested had half the wear of the other two. This suggests yearly savings opportunities in the magnitude of $1/4 to $1/2 million for each state DOT and proportional savings for Counties and Cities.
Initially, the cost of DOT Quality Acceptance testing by independent laboratories should be in the magnitude of $5,000 to $10,000 per shipment of blades. These costs will trend lower with increased volumes of tests and with laboratory familiarity with the acceptance process.

Advantages to Driving Public

Implementing these recommendations will help DOT's provide better driving conditions quicker, since less time will be spent changing blades during snow events. The resources saved with the new specifications can be applied to other activities within the agency to improve driving conditions in other ways. This would include testing performed by an outside lab as well as metallurgical interpretations and statistical support to draw conclusions about the testing results.

Limitations

This research is based on three sets of blade assemblies and the information gathered in the literature search and personal conversations. The information gathered and the test results mutually reinforce the findings and recommendations. However, additional testing and field performance evaluations are recommended to refine the acceptance limits and improve the life expectancy of the blades with carbide inserts.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

WERE GOALS ACCOMPLISHED?

The initial goal of this research was to "produce testing procedures that could be used by an independent testing laboratory to determine life expectancy of any carbide insert snowplow blade … under real plowing conditions."[8] The findings indicate that the recommended tests can differentiate between blades that will perform well and those that won't. That evaluation can be roughly correlated with life expectancy of the blades.

However, the research identified that life expectancy is affected by many factors besides the performance of the carbide insert so it is not possible for the tests to determine life expectancy "under real plowing conditions." Factors such as the agency policy on the condition of roadway that is acceptable, the speed of plowing required by traffic conditions, operator care in avoiding impacts that fracture the carbide inserts, and many others, all have a significant influence on the life expectancy of the blades.

More importantly, the research has developed a method of specifying and purchasing carbide inserts that have the properties necessary for good wear performance and life expectancy. Current methods do not accomplish that.

MOST IMPORTANT FINDINGS

The testing indicated that the carbide inserts being provided by manufacturers generally have the chemical constituents needed for successful performance. However, poor manufacturing processes result in inserts that have voids and cracks that lead to more rapid wear. Thus, tests that confirm the chemical requirements and evaluate the manufacturing process results will be valid indicators of the wear capacity of the carbide insert blades.

The physical flaws we observed in the research test samples, and that have been reported by others, are not specifically identified in the current typical specifications and implied testing requirements.

While not a part of the specific goal of the research it was learned that there are opportunities to improve the life expectancy of the carbide inserts through training of snowplow operators and minimizing conditions that lead to excessive fracturing and wear.

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[8] Request for Proposal for Development of Standardized Test Procedures for Carbide Insert Snowplow Blade Wear, RFP #262060, Wisconsin DOT, June 2007, Section 1.3

CAN FINDINGS BE EXTENDED

The recommended acceptance criteria may be suitable for new types of carbide inserts, such as the bullet-shaped, isolated inserts, being brought to the market. It may be that the optimum abrasion and fracture characteristics will be slightly different because of the different shape and isolation. However, the policies and procedures for purchase and acceptance should be valid.

The specifications and acceptance criteria may be applicable to the carbide inserts in items such as motor grader blades and blade shoes or curb protectors.

The factors affecting blade life expectancy identified in Table 2.1 offer opportunities to identify "best practices" and implement them in DOT's. Back blades appear to reduce fracturing of inserts and may be cost effective. This benefit may be minimized if the insets are of higher quality and less prone to fracture. Operator training to avoid impacts that fracture is another opportunity for cost improvement. Documenting rates of wear by operator could be a simple means to improve performance. It is said that what is measured improves.

RECOMMENDATIONS

This research has developed recommendations regarding the tests that could be used by blade manufacturers to accept or reject carbide blade inserts received from suppliers and ultimately by transportation agencies to accept or reject the assembled blades. These recommendations have been organized into a framework that should guide insert manufacturers, blade assemblers, and end users to identify inserts that should be rejected as well as those anticipated to provide a high level of performance.

We recommend that these tests and specifications be used as Quality Control tests by the carbide insert manufacturer. If a statistical sample does not meet acceptable quality levels at the 95 percent confidence level, the lot should be rejected. The company receiving the inserts for brazing into the blades may wish to conduct Quality Assurance testing. Finally, the purchasing agency must conduct Quality Assurance testing to verify the suitability of the blades and carbide inserts.

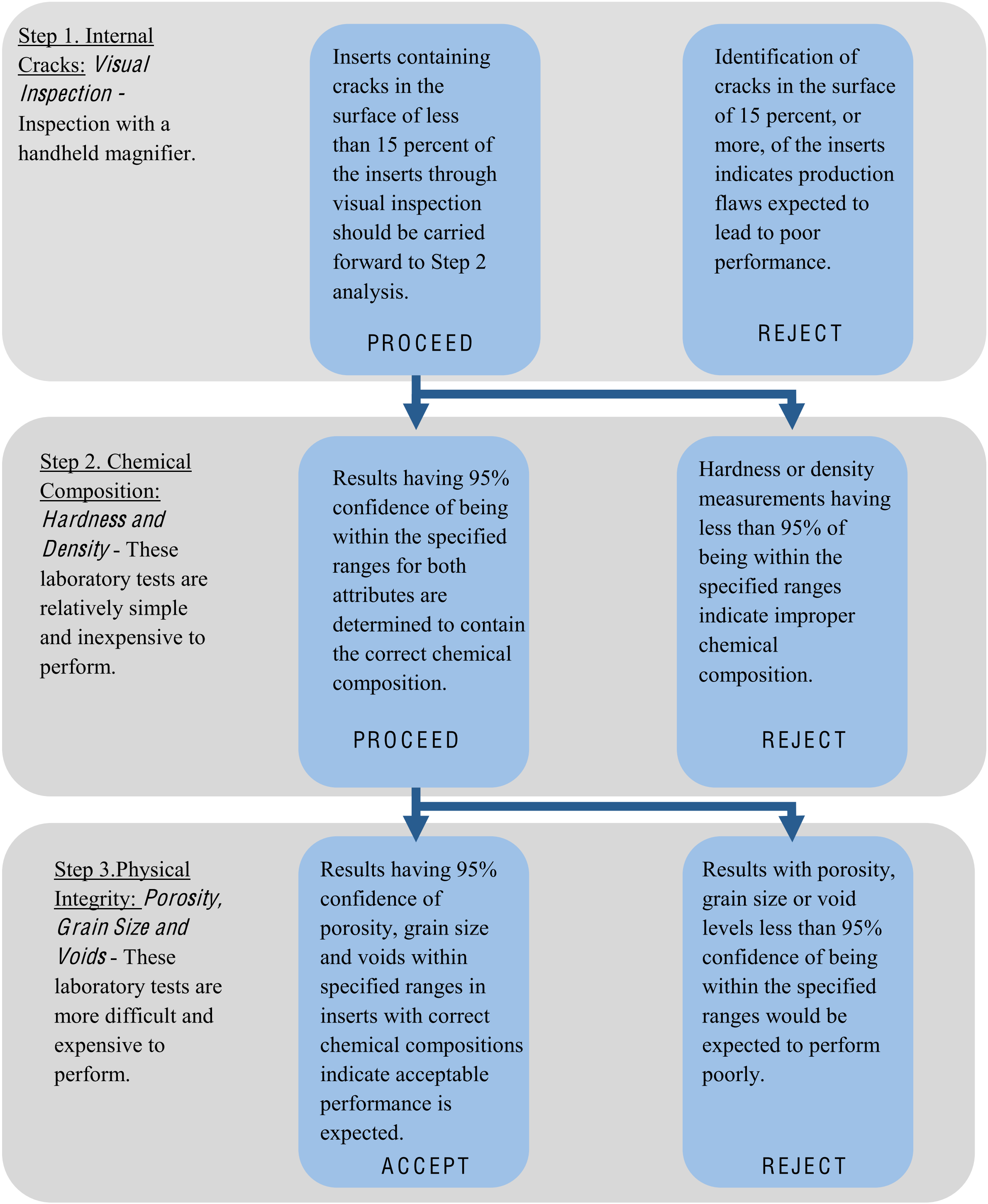
Recommended Specifications

1. Cobalt content – 11.0 to 12.0%; Tungsten Carbide – 87.0 to 88.0%; All other elements 1.0% maximum
2. Visible surface cracks in a maximum of 15 percent of the inserts
3. Hardness HRA: 88.0 - 90.5
4. Density g/cc : 14.40 - 14.55
5. Porosity : A00 - A04 B00 - B02 C00 - C04
6. Grain size : 10-M / 10-C

First, visually inspect the carbide inserts to identify the presence of cracks in the samples. Cracks should be visible using a 2x to 3x handheld magnifier. If more than 15 percent of the samples have visible cracks reject the lot. If both hardness and density are at the minimum levels, caution should be exercised in accepting the lot of parts. Grain size alone, should probably not be grounds for rejection. However, void clusters, especially if containing large pores, should be considered for rejection of the lot.

The flow chart in Figure 4.1 depicts the framework identified through the lab tests that is recommended for acceptance of carbide blade inserts.

Figure 4.1 Recommended Carbide Blade Insert Acceptance Framework



Step 1. Internal Cracks: *Visual Inspection* - Inspection with a handheld magnifier.

Inserts containing cracks in the surface of less than 15 percent of the inserts through visual inspection should be carried forward to Step 2 analysis.

PROCEED

Identification of cracks in the surface of 15 percent, or more, of the inserts indicates production flaws expected to lead to poor performance.

REJECT

Step 2. Chemical Composition: *Hardness and Density* - These laboratory tests are relatively simple and inexpensive to perform.

Results having 95% confidence of being within the specified ranges for both attributes are determined to contain the correct chemical composition.

PROCEED

Hardness or density measurements having less than 95% of being within the specified ranges indicate improper chemical composition.

REJECT

Step 3.Physical Integrity: *Porosity, Grain Size and Voids* - These laboratory tests are more difficult and expensive to perform.

Results having 95% confidence of porosity, grain size and voids within specified ranges in inserts with correct chemical compositions indicate acceptable performance is expected.

ACCEPT

Results with porosity, grain size or void levels less than 95% confidence of being within the specified ranges would be expected to perform poorly.

REJECT

Use of this specification requires the carbide insert manufacturer to have a documented Quality Control program so they know that their product will meet the specifications. We recommend that the program and the results be provided as part of the bid for products. This will minimize the risk that an agency will end up with blades that don't meet the Quality Assurance testing conducted after the shipment has arrived.

This recommendation relies on the Quality Assurance testing for acceptance of a product. As such the Quality Assurance testing will be an absolute requirement for success of the process. It will be necessary for a Transportation Agency to select an independent testing laboratory experienced in the metallurgical testing associated with tungsten carbide products. That laboratory should also have a documented Quality Control/Quality Assurance program as their basis for making the acceptance/rejection decisions. Laboratories can be located by searching the Internet for "metallurgical engineer" or "metallurgical laboratory."

We recommend that the specifications and acceptance criteria be brought to the attention of all Transportation Agencies that purchase snowplow blades and be developed as a national standard purchasing process. This will improve the opportunities for reducing manufacturing costs and improving manufacturing products by limiting the number of products that must be produced.

The Implementation Plan included in Appendix B is recommended to bring this research to fruition in Transportation Agencies. The plan includes recommendations for educating all the stakeholders in the supply chain. It includes a more detailed "typical" set of specifications and purchasing procedures for adoption by purchasing departments.

FURTHER RESEARCH

These findings can be improved by similar testing of other blades. The additional test data will allow refinement of the acceptance criteria. As noted previously, this research and the findings and recommendations are based on three sets of blades subjected to the complete testing, observations of a fourth set of worn out blades, and information gathered as part of the literature search and personal discussions. We recommend that the laboratory and field testing be expanded by asking DOT's to have the laboratory tests conducted on their blades and have the operators conduct documentation of the wear performance of the blades.

Factors other than carbide insert performance that were identified as affecting blade life expectancy provide other opportunities to improve the life expectancy. Some research is in progress on some of these factors but more can be learned, particularly about operator performance and training. More than one agency reported that some operators were able to go long periods without having to change blades while others only went "2 days". This common experience indicates that operators have a significant effect on blade life expectancy. There is likely a need for training and setting expectations for blade life expectancy. As noted above the simple act of measuring the blade life by operator will highlight the importance of being careful with the blades and improve the blade life.

APPENDIX A
Carbide Insert Snowplow Blade Wear Research
Literature Research - Contacts made

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 Axelson 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.
Saskatchewan Ministry of Highways and Infrastructure	Dan Palmer, (306) 787-4805; Zev Lavic, Director of Maintenance, (306) 933-6203; and Murray Zulak, Fleet Standards	Considering "fracture toughness" testing by Alberta Research Council – using a modified Vickers test. The problem they have is the inserts crack and fall out. Materials meet their specifications but fail prematurely.

APPENDIX B

DRAFT IMPLEMENTATION PLAN

PROBLEM

State Department of Transportations (DOT's) operating where there is snow or ice in the winter spend on the order of $0.5 to $1 million for snowplow blades with carbide inserts each year. County and City agencies also use these types of blades. Thus, a means of improving the cost effectiveness of these blades would have immediate, significant impact on the resources required to maintain highways and streets in optimum winter-travel condition. Further, reducing the wear of these blades will reduce the amount of time needed to change blades, often done during winter storm conditions, and reduce the risk of injury during the process.

SOLUTIONS

As reported in *Development of Standardized Test Procedures for Carbide Insert Snowplow Blade Wear*, Clear Roads, August 2010, the life expectancy of snowplow blades with carbide inserts is dependent on two general factors – the quality of the carbide inserts and the specific ways in which the blades are used. That research found that voids and cracks in the carbide inserts significantly affect the wear performance of the inserts. Similarly, the research found that the life expectancy of blades is affected by how careful the operator is when plowing, the speed of the plowing, blade impacts on items such as bridges or traffic markers, and other factors. However, the operator's care may be the most important non-material factor.

The quality of the carbide inserts can be improved by changing the processes and specifications used for purchase of the blades with carbide inserts. This plan provides a recommended specification and a recommended process for future purchases. The specifications include suggested Quality Control testing by the carbide insert manufacturer, suggested Quality Assurance testing by the blade assembler, and required Quality Assurance testing by the purchaser. The purpose of the changes in the specifications is largely to improve the quality of the manufacturing processes and eliminate the voids and cracks that have been observed in inserts that do not wear well.

We recommend training of operators and establishing accountability for their performance through measurements of the wear performance of their snowplow blades. Quality improvement techniques have recognized that what is measured gets improved. Thus, with training and measurement the ability of most operators can be improved and the life expectancy of the blades increased.

NEW SPECIFICATIONS AND PROCESSES FOR PURCHASING

The research recommended use of more detailed specifications for purchasing the blades with carbide inserts. These specifications will require more testing to document the quality of the raw materials used and results of the manufacturing processes. The typical specifications that have been in use resulted in materials in the carbide inserts that are generally suitable for the intended use. However, the testing typically specified did not result in detecting flaws in the carbide inserts resulting from poor manufacturing. Thus, additional test types are recommended to evaluate the physical continuity. Also, documented Quality Control testing should be required from the carbide manufacturer. The purchasing agency must conduct Quality Assurance testing in lieu of the typical "certification" that the product meets specifications currently being required.

A suggested specification for purchasing is included in Appendix A of this Implementation Plan. The specification includes test types, acceptable limits, and a decision process to evaluate the interrelated test results for acceptance or rejection. Further, the specification requires documentation of testing in a Quality Control program by the manufacture of the carbide inserts, a suggested testing for Quality Assurance by the blade assembler receiving the carbide inserts, and required testing for Quality Assurance and acceptance by the purchasing agency.

The testing is a critical part of the improvement in life expectancy of the inserts. The observed flaws in the blades have not been identified in past manufacturing and purchase practices. Thus, additional testing will be required to correct this. Manufacturers are expected to have the expertise within their companies to conduct the testing for Quality Control. The companies that assemble the blades and the purchasing agencies will likely have to use the services of competent, independent testing laboratories experienced in powdered metals testing for the Quality Assurance tests. These laboratories may be found by searching the Internet for "Metallurgical Engineer" or "Metallurgical Laboratory."

The various stakeholders in this issue must be educated about the results of this research and the new specifications. Carbide manufacturers and snowplow blade suppliers can be reached through the purchasing process. The recommended purchasing specification includes text that summarizes the research findings and conclusions, particularly regarding manufacturing flaws. Purchasing departments in transportation agencies must be made aware through various transportation associations. Clear Roads can begin this process by disseminating the research report and this implementation plan to their member states. It is also recommended that the report be disseminated through AASHTO, National Association of County Engineers, and APWA. There may be other organizations that reach managers of snowplowing operations and their purchasing departments.

IMPROVING OTHER FACTORS

There are many factors that influence the life expectancy of blades with carbide inserts. Some factors, such as the material to be plowed (ice or snow) cannot be controlled. However, operator skill and care is a factor that can be controlled and appears to have a significant opportunity for improvement. During the research Clear Roads DOT's were asked how long their blades lasted. A common comment was that, "Some drivers go all year with one set of blades; others can only go 2 days." This anecdotal evidence was heard often enough to give some validity to the idea that operator training and accountability can improve the life expectancy of blades.

The specific operator performance issues that need improvement were not identified in the research. That may be a subject for further research. However, the operators may be able to identify what works and what doesn't work for them in group meetings. Then "best practices" can be established for use by all. A method of measuring the operator performance can then be adopted as a way for operators to evaluate themselves, or be evaluated by others. This measuring can be included with the measurements needed to obtain more information on the performance of carbide inserts purchased under the new specifications (see Appendix B).

FURTHER RESEARCH

The research referenced above was limited to tests on three samples of blades with carbide inserts, observations of another set of worn blades, a literature search and personal contacts with people in the industry. While the test results appear very conclusive it is recommended that additional tests be conducted to confirm the initial findings and recommendations and to refine the acceptance limits recommended.

State DOT's or other agencies can conduct the additional research as part of their normal snowplowing operations. First, the agencies must have the recommended tests conducted on the carbide inserts of the blades being used on the snowplows. This will establish the quality of the inserts. Second, the snowplow operators will keep track of the performance of the blades, filling out a measurement sheet to provide needed information. A suggested measurement sheet is included as appendix B-2.Then, a researcher assigned to the problem will conduct a statistical evaluation of the results. Alternatively, Clear Roads could provide funding and select a research team to conduct the studies in agencies that agree to cooperate.

Tasks required for individual DOT's or a research team include:

1. Contact agencies to explain research and get agreements for cooperation.

2. Acquire samples of blades being used by the agency, with any documentation of the purchasing requirements and tests conducted on the carbide inserts or certifications provided by the supplier.
3. Provide Measurement Form for agency snowplow operators to fill out over the length of one season.
4. Retain independent laboratory(s) to conduct recommended tests on each set of blade samples and accumulate data for analysis.
5. Collect Measurement Forms from snowplow operators to evaluate insert performance in the field.
6. Compare laboratory and field test results.
7. Report findings and recommendations to Clear Roads for dissemination.

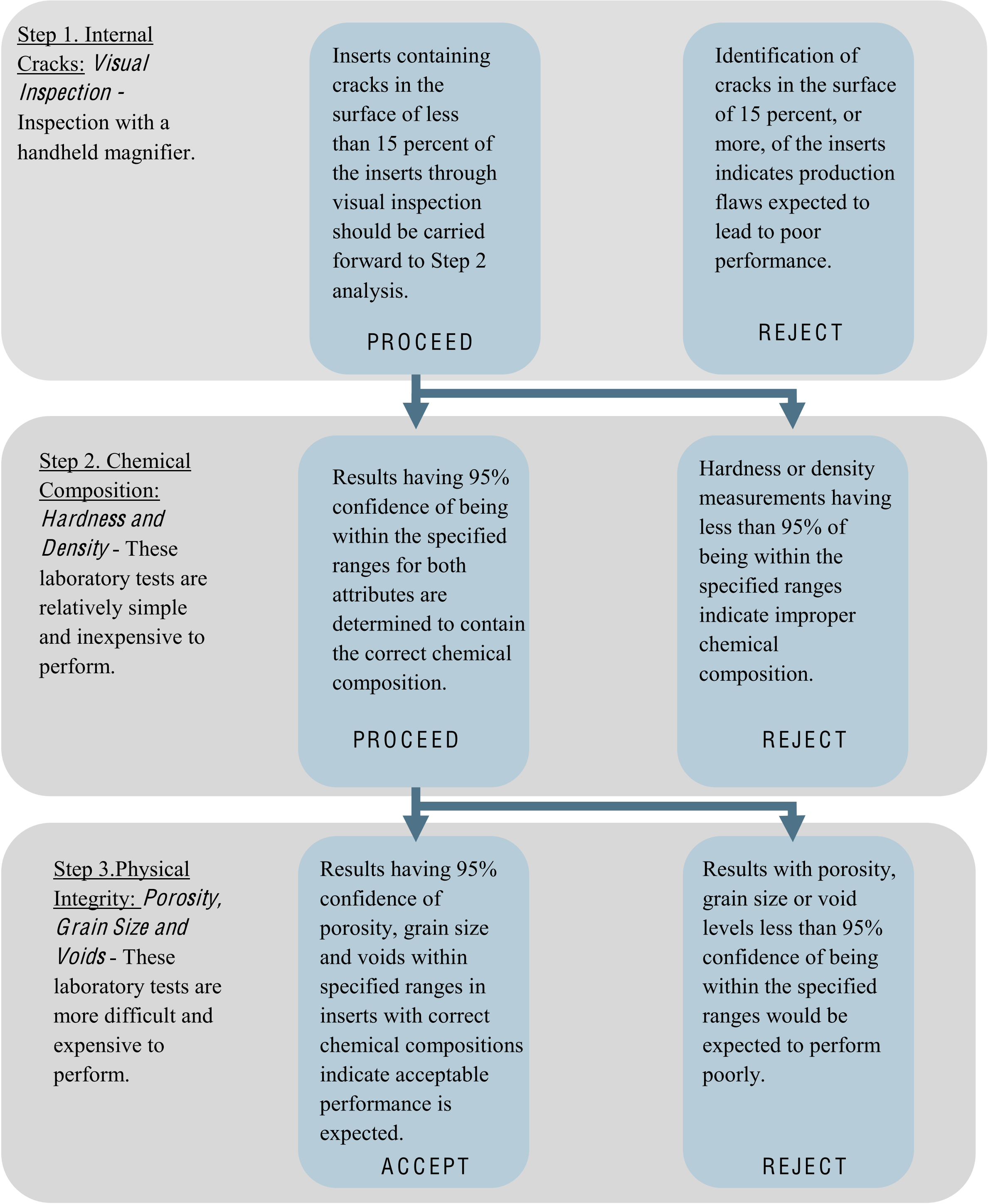
APPENDIX B-1

RECOMMENDED PURCHASING SPECIFICATIONS FOR CARBIDE INSERTS IN SNOWPLOW BLADES

TUNGSTEN CARBIDE INSERTS

1. Each blade section to contain one insert, one-inch nominal length, for each inch of blade section length.
2. The inserts shall be a high shock WC grade of tungsten carbide with the following constituents
    a. Cobalt content – 11.0 to 12.0 percent
    b. Tungsten Carbide content – 87.0 to 88.0 percent
    c. All other constituents content – 1.0 percent maximum
3. Inserts shall be rectangular in shape with the following dimensions.
    a. Height – 0.760 inches +/- 0.010 inches
    b. Width – 0.360 inches +/- 0.005 inches
    c. Length – 1 inch nominal
4. Using a statistically valid sampling plan determine that the following parameters are met with a minimum confidence level of 95 percent:
    a. Surface cracks as determined by visual examination under a 3-power magnification – maximum of 15 percent of inserts.
    b. Hardness, as determined by ASTM B294-10 (or most recent edition) Test Method for Hardness Testing of Cemented Carbides – 88.0 to 90.5 HRA
    c. Density, as determined by ASTM B311-08 (or most recent edition) Standard Test Method for Density of Powdered Metal Materials Containing Less than Two Percent Porosity – 14.0 to 14.5 g/cc
    d. Porosity, as determined by ASTM B276-05E1 (or most recent edition) Standard Test Method for Apparent Porosity in Cemented Carbides –
        i. A00 – A04
        ii. B00 – B02
        iii. C00 – C04
    e. Grain Size, as determined by ASTM B390-92(2006) (or most recent edition) Standard Practice for Evaluating Apparent Grain Size and Distribution of Cemented Tungsten Carbides –
        i. 10M/10C
        ii. 15 percent or less of samples have no large voids or “void clusters” when viewed under 200x microscope.
5. See the following Figure B-1 for an Acceptance Decision Tree

Figure B-1 Acceptance Decision Tree



Step 1. Internal Cracks: *Visual Inspection* - Inspection with a handheld magnifier.

Inserts containing cracks in the surface of less than 15 percent of the inserts through visual inspection should be carried forward to Step 2 analysis.

PROCEED

Identification of cracks in the surface of 15 percent, or more, of the inserts indicates production flaws expected to lead to poor performance.

REJECT

Step 2. Chemical Composition: *Hardness and Density* - These laboratory tests are relatively simple and inexpensive to perform.

Results having 95% confidence of being within the specified ranges for both attributes are determined to contain the correct chemical composition.

PROCEED

Hardness or density measurements having less than 95% of being within the specified ranges indicate improper chemical composition.

REJECT

Step 3.Physical Integrity: *Porosity, Grain Size and Voids* - These laboratory tests are more difficult and expensive to perform.

Results having 95% confidence of porosity, grain size and voids within specified ranges in inserts with correct chemical compositions indicate acceptable performance is expected.

ACCEPT

Results with porosity, grain size or void levels less than 95% confidence of being within the specified ranges would be expected to perform poorly.

REJECT

6. Quality Control Documentation – Vendor shall furnish documentation that Quality Control Testing of the Carbide Inserts was conducted at the manufacturing plant to confirm that the inserts meet the requirements.
7. Quality Assurance Testing – The DOT will select samples from the shipment and subject them to Quality Assurance Testing. If Quality Assurance testing does not confirm that the inserts meet the specifications the blades will be rejected. Note: Sample preparation of brazed inserts includes “torch cut” or sawed removal of selected inserts from selected blades. Steel is then milled from the three sides of the inserts. Brazing can be removed with nitric acid. Inserts are cut for testing with a typical diamond abrasive wheel.

Appendix B-2

Snow Plow Blade Performance Record

Department/Location Identifier: ______________________________

Blade(s) Identification: Manufacturer - ______________________________

Date of Purchase - ______________________________

Location on Plow - ______________________________

Installation Date: ____________________ Removal Date: ____________________

Height of Insert at Installation (0.xxx in.): ____________________

Average Height of Insert at Removal (0.xxx in.): ____________________

PLOWING HISTORY

Date	Hours Down	Operator	Comments

NOTES: Location on plow is relative to left edge of plow. Measure height of insert with micrometer if possible. Hours Down is actual time of plowing with blade down on pavement. Comments could include air temperature, snow or ice conditions, average speed of travel, etc.

RETURN RECORD TO: ______________________________

CLEAR ROADS
research for winter highway maintenance

Lead state:
Wisconsin Department of Transportation
4802 Sheboygan Ave.
P.O. Box 7965
Madison, WI 53707-7965