

# Laboratory Tests for Predicting Coarse Aggregate Performance in Ontario

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Coarse aggregates used in granular base and asphaltic and portland cement concrete must be sound and capable of withstanding the prevailing environment. In Canada, aggregates must be frost resistant. Durability of coarse aggregate is normally evaluated in the sulfate soundness test and water absorption tests, and by measuring resistance to impact in the Los Angeles abrasion and impact test. These tests suffer from some disadvantages: poor precision and inadequate correlation with field performance. The Ministry of Transportation has been developing and evaluating new test procedures for a number of years. Some of the major findings are summarized. The likely performance of aggregates in granular base is best measured by the micro-Deval test and water absorption. The physical quality of portland cement concrete aggregates is best measured by the micro-Deval test, water absorption, and unconfined freezing and thawing. The quality of asphaltic concrete aggregates is best measured by the micro-Deval test, polished-stone value test, and unconfined freezing and thawing test. Petrographic examination is also an essential tool in the evaluation of aggregate quality.

The Ministry of Transportation uses aggregates in road construction for granular base, asphaltic concrete, and portland cement concrete. These aggregates must be sufficiently durable to withstand the effects of construction, weathering, and vehicle loads.

Temperature changes, seasonal and daily freezing and thawing cycles, and wetting and drying cycles contribute to the breakdown or weathering of the aggregates. Deicing salts also contribute to aggregate deterioration and have a marked accelerating effect on damage caused by freezing and thawing (1).

Increased traffic volumes and higher axle loads subject pavements and structures to higher stresses and more frequent loading cycles. High interparticle stresses lead to particle breakdown, reducing permeability and causing permanent deformations in granular base and asphaltic concrete. Abrasion of exposed aggregate by tires on asphalt and concrete surfaces can result in particle wear and polishing, thus reducing surface friction.

High-quality aggregates may not always be available at a reasonable price. Competition for land use from urbanization or other uses such as agriculture, forests, and wetlands has diminished the availability of some aggregate resources in areas of high demand. Compromises in material quality must be made where marginal or lower-quality aggregates are more readily available than good ones. The decision to accept marginal aggregates has hidden costs if they perform below expectations and reduce pavement life.

Aggregates must be carefully selected if they are to perform satisfactorily in highways. The selection process is made by subjecting aggregates to a series of quality tests designed to measure their physical properties, or to apply an appropriate simulation of the field conditions the aggregates will be exposed to and measure the response. By using appropriate tests, the risk of acceptance of marginal aggregates is reduced.

The physical requirements of coarse aggregates used for road construction in Ontario are currently measured using the following tests: Los Angeles impact and abrasion test (MTO LS-603, ASTM C131); magnesium sulfate soundness test (MTO LS-606, ASTM C88); 24-hr water absorption test (MTO LS-604, ASTM C127); and petrographic evaluation leading to a petrographic number, or PN (MTO LS-609).

The acceptance of aggregates is dependent on the material meeting all of the minimum requirements as outlined in specifications. However, poor performance of a suitable aggregate in an inappropriate test may prevent it from being used. For example, a quarried sandy dolostone (sandy dolomite) from eastern Ontario typically gives losses in the magnesium sulfate test up to 17 percent (considerably outside the specification for asphalt aggregate), yet it is not a frost-sensitive material. It has excellent frictional properties and is used as a premium-quality asphalt wearing course aggregate.

Although the four tests can help distinguish between an excellent aggregate and a poor one, they are not as good at predicting material behavior where borderline or marginal aggregates are concerned. In particular, the use of the sulfate soundness test for aggregate soundness and the Los Angeles test for aggregate abrasion resistance both have demonstrated poor correlation with field performance. These tests do not reflect the conditions of the weathering environment, or the construction and in-service pavement conditions.

## AGGREGATE QUALITY AND SOUNDNESS

Aggregate quality is assessed mainly with respect to physical parameters, that is, processes that cause particle fragmentation without any associated mineralogical alteration. Much of this type of degradation occurs during the construction processes of material processing or manufacture, transportation, mixing, placement, and compaction. Sudden impact and short-lived dynamic loads are imparted to the aggregates at this time.

Long-term aggregate breakdown occurs when the material is in service and undergoes ongoing stresses of loading and unloading. Numerous weathering factors are involved in the physical changes that occur to aggregates, including temper-

ature and moisture fluctuations. A comprehensive review of in situ physical weathering of materials in engineering applications is given by Fookes et al. (2).

Measurement of aggregate resistance to impact and abrasion in Ontario has relied exclusively on the Los Angeles test. This test uses a large, horizontally mounted steel drum into which 5000 g of sample are placed along with a specified number of steel spheres 45 mm in diameter. The drum is rotated 500 times at 33 rpm. A steel plate attached to the inside of the drum picks up the steel spheres, which then fall directly onto the test sample. After the test, the sample is screened on the 1.70-mm (No. 12) sieve with the material passing indicated as a percent loss of the original mass.

The Los Angeles test is not always appropriate because the steel balls impart a severe impact loading on the test sample, overshadowing any interparticle abrasion, which is the predominant process in pavement subject to traffic stress. Coarse-grained crystalline materials, particularly brittle granites and gneisses, yield high losses in this test yet perform well in service. However, high losses (>45 percent) indicate a potential breakdown problem during the construction process. In contrast, fine-grained, soft-rock aggregates, such as argillaceous carbonates or shales, tend to absorb the impact energy of the steel balls resulting in low test values, well within normal acceptance limits. These materials are usually susceptible to slaking and particle degradation when wet, which results in poor pavement performance.

The test conditions of the Los Angeles test do not simulate the in-service pavement conditions because only oven-dried aggregates may be properly and easily tested in the apparatus. When aggregates are tested in a moist or saturated condition, fines adhere to the side of the drum, altering the test conditions and making it difficult to retrieve them for analysis (3). This consideration is important because the moisture condition of an aggregate may significantly alter its behavior. Pintner (4) reported in a study of fines production in a shaker test that the loss was increased nine times for an aggregate sample with 5 percent moisture, as contrasted with the same material in a dry state.

Soundness is a synonym for the long-term durability of an aggregate as a result of the material's ability to resist weathering forces. In a highway pavement environment, the weathering of aggregates varies greatly according to their exposure. Granular base courses are the least protected from the effects of weathering. Wetting and drying cycles are most likely to affect these materials. Asphalt aggregates are only slightly better protected from moisture by a coating of asphalt cement. Concrete aggregates are the most protected by the dense microporous cement paste. All aggregates are within the upper 1 m of the road surface and are exposed to thermal cycling. In the presence of moisture, this becomes much more severe freeze-thaw cycling.

The Ontario Ministry of Transportation, like many highway agencies in North America, has relied on the sulfate soundness test as a simulation of the weathering environment. The crystallization of soluble salt in rock pores bears little resemblance to the environmental conditions found in Ontario. The sulfate soundness test also subjects the aggregate to thermal expansion and contraction cycles as well as wet-dry cycling. Salt crystallization is used to simulate ice crystallization, a model that may have been acceptable when the test was originally

developed, but is no longer so. Equipment is now available to accurately recreate freezing and thawing conditions in the laboratory (1).

## ALTERNATIVE TEST METHODS

The objective has been to investigate alternative methods of measuring the performance of coarse aggregates using tests that are relatively quick and simple to perform, yet give repeatable and reproducible results. The goal has been to select tests that are better indicators of aggregate quality than those currently used. The expected benefits are that the test results would be more effective in selecting or rejecting marginal aggregates. Selection criteria require that each test demonstrates good correlation with field performance and has excellent reproducibility of results within, and between, laboratories. Ideally, new test procedures should be reliable, precise, quick, and cheap compared to the standard tests. In order to attain these objectives, tests that simulated the field environment as nearly as possible were used because it was likely that they would be more inclined to correlate with field performance. It was also desired that these tests used, as far as possible, simple and inexpensive equipment.

The tests under investigation have either been developed within the Ministry or adopted from other agencies. Although a number of tests have been studied (5), only the following tests are discussed in this report:

1. Unconfined freeze-thaw test for coarse aggregate (MTO LS-614),
2. Micro-Deval abrasion test (BNQ 2560-070/82),
3. Aggregate impact value test (BS 812),
4. Polished stone value test (BS 812), and
5. Aggregate abrasion value test (BS 812).

The evaluation of the conventional and the alternative tests has been conducted using a suite of over 100 coarse aggregate samples collected from across Ontario. These samples represented a wide cross section of rock types and aggregate sources.

Ontario aggregates are composed of either a mixture of rock types from glaciofluvial deposits, or quarried Paleozoic sedimentary or Precambrian igneous and metamorphic rock types. Most of the sources had previously been used by the Ministry so that their field performance in various environments and value ratings could be applied. Evaluation criteria used for the ratings are presented in Table 1.

### Unconfined Freeze-Thaw Test

This test has been under development at the University of Windsor and the Ministry of Transportation over the last 10 years. It is designed to measure the frost resistance of aggregates by simulating the conditions of freeze-thaw cycling in the presence of moisture and deicing salts. The results of this investigative work and a copy of the procedure have been published by the Ministry of Transportation (1,6).

The unconfined freeze-thaw test is conducted by placing three fractions of an aggregate (Table 2) into separate 1-L jars. The samples are soaked for 24 hr in a 3 percent NaCl

TABLE 1 FIELD PERFORMANCE  
EVALUATION CRITERIA OF  
AGGREGATES TESTED IN THIS STUDY

Evaluation	Description
GOOD	• used for many years with no reported failures, popouts, or other signs of poor durability
FAIR	• used at least once where popouts or some reduced service life had resulted, but pavement or structure life extended for over 10 years
POOR	• used once with noticeable disintegration of pavement after one winter, severely restricting pavement life

TABLE 2 GRADATION AND MASS OF FREEZE-THAW TEST SAMPLE

PASSING	RETAINED	MASS (g)
19.0 mm	13.2 mm	1250
13.2 mm	9.5 mm	1000
9.5 mm	4.75 mm	500

solution, drained, sealed, and cycled five times, frozen for 16 hr at  $-18^{\circ}\text{C}$ , and thawed at room temperature for 8 hr. Following the test, the material is drained, dried, and resieved on the original sieves. A weighted average loss is determined from the "as received" coarse aggregate gradation (percent retained) and the percent loss from all three fractions.

The equipment and procedure of this test are calibrated by testing a control material (slightly shaley dolomitic limestone with an average freeze-thaw loss of 24.5 percent) along with any samples under investigation.

### Micro-Deval Abrasion Test

This test was developed in France during the 1960's (7) and is based on equipment used in the grinding industry. This test is currently being used in the province of Quebec and the procedure has been adopted from its standards (8). An aggregate sample (consisting of 250 g retained on the 13.2-mm sieve, and 250 g retained on the 9.5-mm sieve) is initially soaked for 24 hr and then placed in a jar mill with 2.5 L of water and an abrasive charge consisting of 5 kg of steel balls of 9.5-mm diameter. The jar, aggregate, water, and charge are revolved at 100 rpm for 2 hr. The sample is then washed and oven-dried. The loss is the amount of material passing the 1.18 mm (No. 16) sieve expressed as a percent by mass of the original sample. Comparison with the magnesium sulfate test indicates similarity of test results but with a greater amount of precision. Linear regression analysis gives a correlation coefficient of 0.85 for 106 samples (Figure 1). A comparison of the standard deviation of test results from the micro-Deval abrasion test and the magnesium sulfate soundness test is shown in Figure 2. The precision of the micro-

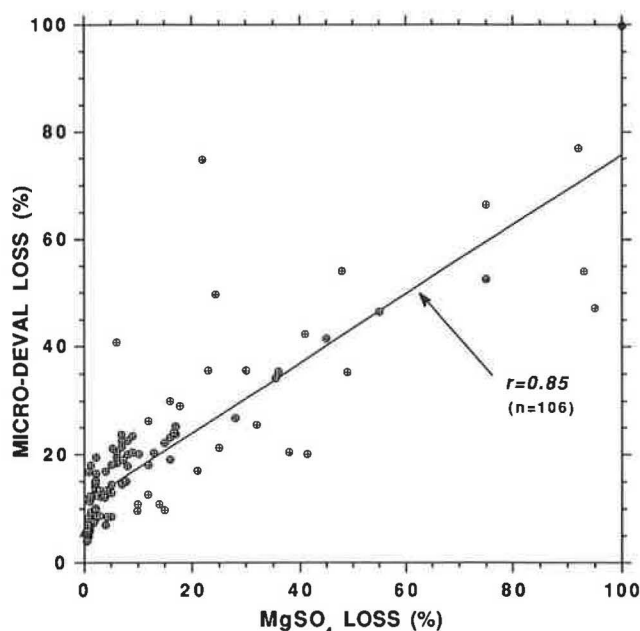


FIGURE 1 Correlation of micro-Deval abrasion against magnesium sulfate soundness.

Deval test, especially for materials with high losses, is greater than the precision measured by the soundness test.

### Aggregate Impact Value Test

This procedure assesses aggregates passing the 13.2-mm sieve and retained on the 9.5-mm sieve (9). It measures fines production by the repeated impact of a falling weight (13.5 to 14.0 kg) onto a small confined sample (300 to 350 g). The percent fines is calculated as the mass of material passing the 2.36-mm (No. 8) sieve as a ratio to the original mass. Two samples are tested and the resulting average is known as the aggregate impact value (AIV). This test has demonstrated good correlation with the Los Angeles impact and abrasion test, which is shown in Figure 3. Linear regression analysis of the two data sets illustrates a significant similarity between the two tests. This test has the advantage over the Los Angeles impact test in that the equipment is inexpensive and portable, uses less material than the Los Angeles test and can easily test samples in a moist or saturated condition if desired, thus better simulating field conditions.

### Polished-Stone Value Test

This test is a laboratory simulation of polishing of aggregate by vehicle tires (9). Selected aggregate particles are placed and cemented in a mould so that an aggregate surface is exposed for study in a tablet. The tablet is placed on the outside of a steel wheel that brings the sample into contact with a rubber tire. The samples are subjected to wear by a coarse and a fine emery abrasive powder under the rubber tire for 3 hr each. Water is continually added to the aggregate surface. The resulting microtexture, or polish, of the sample is measured by evaluating the resistance of a rubber testing

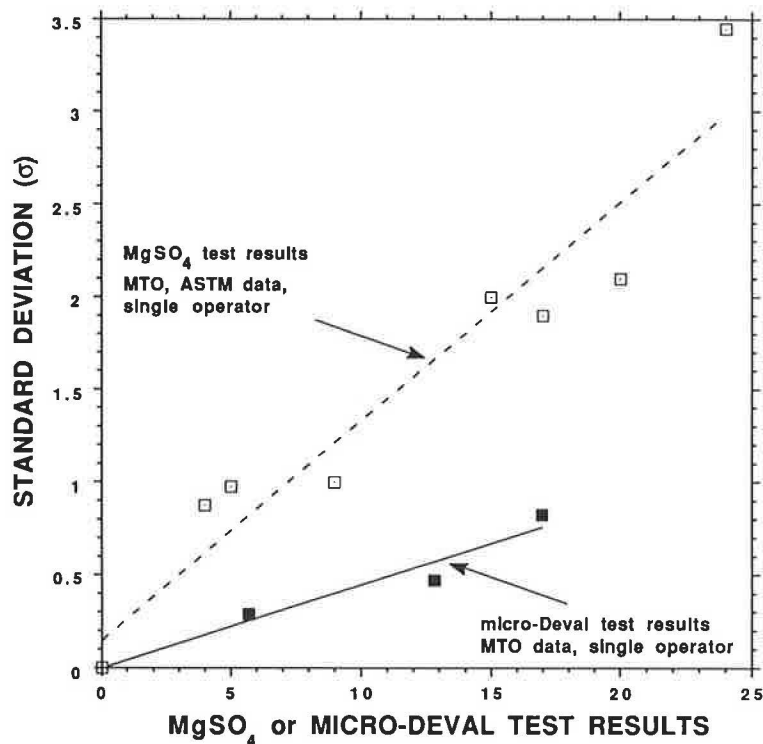


FIGURE 2 Standard deviation against loss in magnesium sulfate soundness or micro-Deval abrasion test.

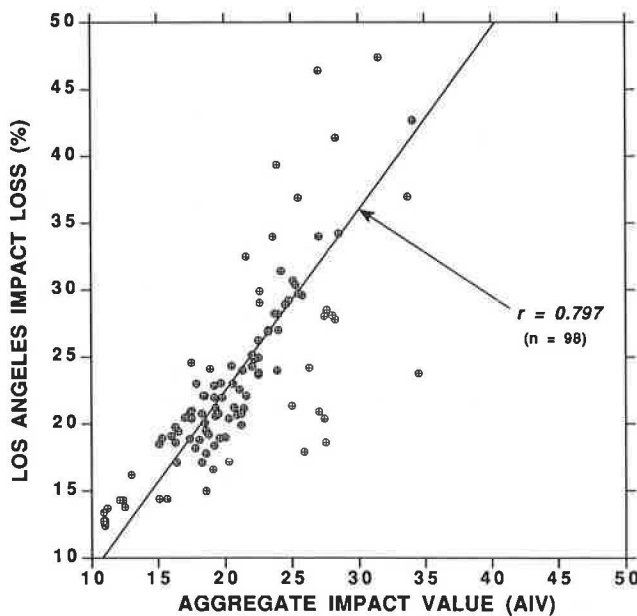


FIGURE 3 Relationship between Los Angeles impact and aggregate impact value.

pad at the end of a free-swinging pendulum arm across the aggregate surface. The travel of the pendulum arm after the pad has contacted the aggregate surface is measured by a calibrated scale and the resulting number is known as the polished stone value (PSV). Rough surfaces offer more resistance to the rubber pad and give higher values, whereas highly polished surfaces, offering little resistance, give low values.

A good correlation of PSV with friction levels of asphalt pavements has been demonstrated for different coarse aggregates, used in similar asphalt mixtures, on the same section of highway (10). In other words, everything else being equal, a material with a high PSV will provide higher friction than a material with a low PSV.

#### Aggregate Abrasion Test

This test evaluates overall wear resistance of aggregate, measuring both mineral hardness and bonding between individual grains, by abrasion (9). Aggregate particles are held in a mould and an exposed test surface is placed on a flat, rotating steel plate. A standard weight is placed on the mould to bring the exposed aggregate surface into direct contact with the plate, while silica sand is metered onto the plate surface as it rotates and is used to abrade the aggregate. No water is added to the sample and all abrasion is done dry. The sample mass is taken before and after the test. The resulting percentage loss, normalized for density of the aggregates, is the aggregate abrasion value (AAV). Wear-resistant aggregates yield low values and soft aggregates yield high values.

## RESULTS AND DISCUSSION

### Granular Base

Current granular base design in Ontario is a matrix-supported system. Most granular base failures have been caused by low permeability as a result of the presence of plastic fines or the

presence of platy pore-blocking minerals such as chlorite and biotite mica derived from high-grade metamorphic rock. During service, granular bases are subjected to loading, freeze-thaw, and wet-dry cycling.

The Los Angeles test indicates little correlation with field performance when the loss is less than 50 percent (Figure 4). The aggregate impact value has a similar lack of relationship to field performance. During construction, aggregate handling of granular base materials is minimal. Any resulting aggregate breakdown is easily accommodated within the wide gradation band that is acceptable for these materials. Stone with losses in excess of about 45 percent may be susceptible to excessive breakdown during handling, although gneissic materials with losses up to 60 percent can still be used provided they do not contain excessive amounts of mica.

Petrographic examination is useful in predicting performance of granular base aggregates (Figure 4). This test examines individual particles retained on standard sieve sizes (about 200 particles from each fraction), starting with the coarsest fraction until a minimum of 70 percent of the material is examined. The particles are separated into quality categories of good, fair, poor, or deleterious using a variety of techniques and criteria. The percent weight of each category is multiplied by a factor of 1, 3, 6, or 10, respectively, and summed. The resulting number is the PN value (11). For example, an aggregate sample consisting of material determined to be 75 percent good, 15 percent fair, 8 percent poor, and 2 percent deleterious would have a PN of 188  $[(75 \times 1) + (15 \times 3) + (8 \times 6) + (2 \times 10)]$ . Aggregates that have yielded poor performance in granular base courses generally have a PN value greater than 200, whereas satisfactorily performing aggregates have PN values much less than this. Marginal aggregates are not easily separated using petrographic and impact tests together.

The micro-Deval test is useful for separating good- from poor-quality aggregates (Figure 5). Material with a micro-

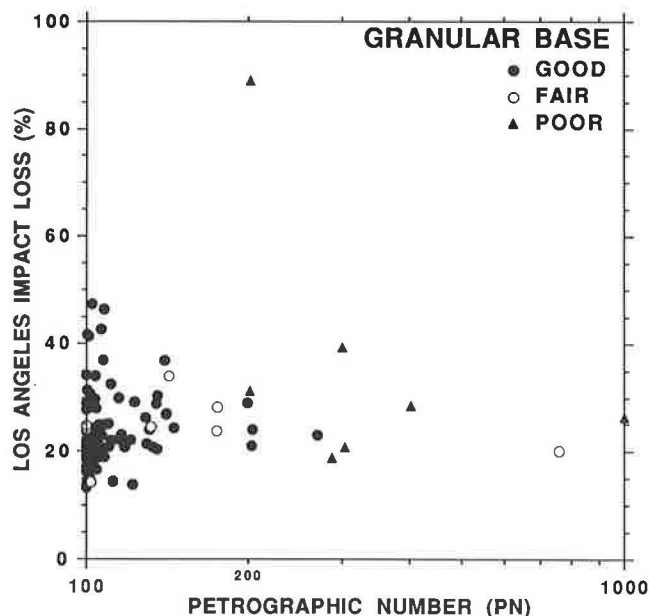


FIGURE 4 Field performance for granular base: relation between Los Angeles impact and PN value.

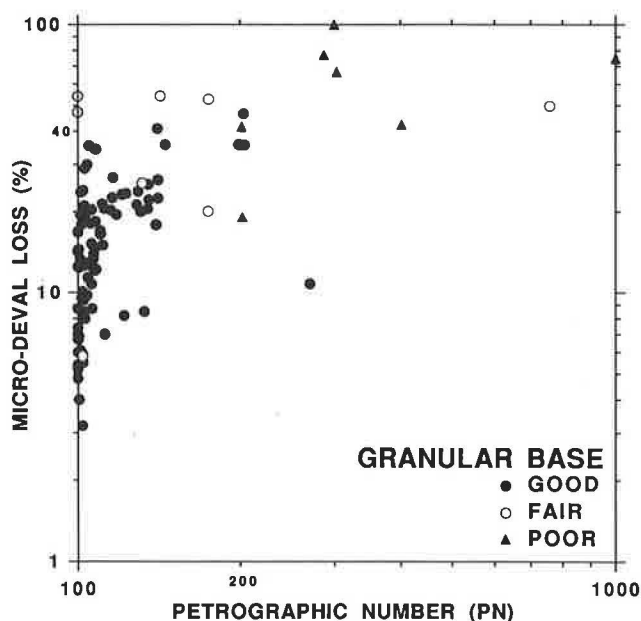


FIGURE 5 Field performance ratings for granular base: relation between micro-Deval abrasion and PN value.

Deval loss less than 40 percent generally has performed well in granular base, whereas losses greater than this value identify shaley material that is marginal or poor. Figure 6 also shows how the micro-Deval test can distinguish between good and fair-to-poor performing aggregates that are not identified by water absorption values.

The micro-Deval test demonstrates considerable promise as a relative indicator of coarse aggregate performance in granular base, particularly when used with petrographic number. The PN is not invariably capable of separating out poor performers, but the micro-Deval test is able to identify poor aggregates. Not all marginal or poor performing base course

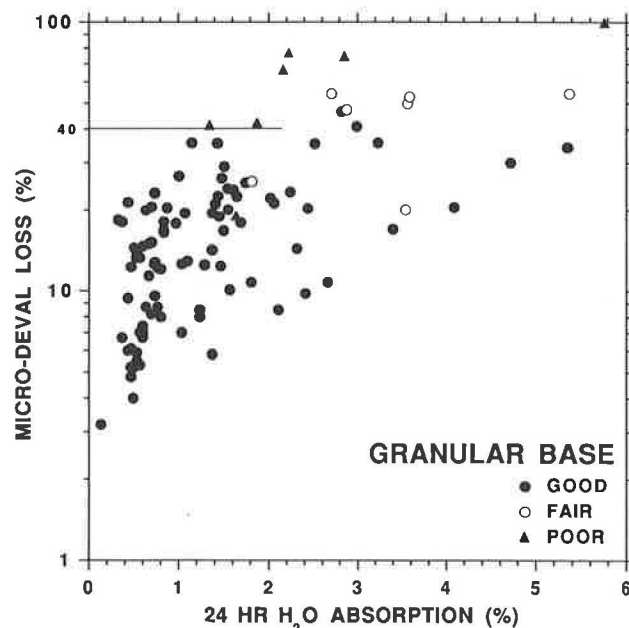


FIGURE 6 Field performance ratings for granular base: relation between micro-Deval abrasion and water absorption.



aggregates are identified by this test alone, because failures of these materials are often caused by unsatisfactory properties of the sand-sized fraction. More work needs to be done on fine aggregate properties in this regard, and a modification of the micro-Deval test for fine aggregate demonstrates promise (12).

### Concrete

Current tests for concrete aggregates include the magnesium sulfate test, the Los Angeles abrasion test, water absorption, and petrographic evaluation in addition to tests for chemical stability.

The impact tests conducted on aggregates used in concrete have demonstrated little relation to their field performance behavior. Impact tests do not reflect the in-service, or the construction environment, of portland cement concrete. Although it is important to identify weak and weathered materials, it may be done more effectively by petrographic examination.

Figure 7 shows the relationship of field performance to test results of petrographic examination and micro-Deval loss for concrete aggregates. Poor-quality materials are indicated with a micro-Deval loss of greater than 20 percent and a PN value greater than 160. A number of marginal aggregates yield test values less than these but they are usually aggregates that contain shale or chert particles that produce objectionable popouts and are more readily recognized by a petrographic examination.

Figure 8 shows similar fields when micro-Deval loss is plotted against water absorption. Water absorption is perhaps to be preferred to petrographic examination because it is less subjective, although there are some aggregates with high absorption values that still perform satisfactorily.

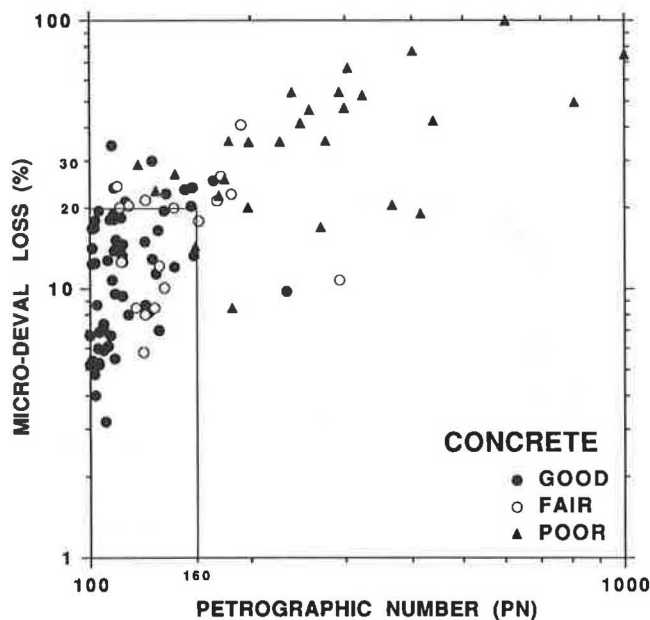


FIGURE 7 Field performance ratings for concrete: relation between micro-Deval abrasion and PN value.

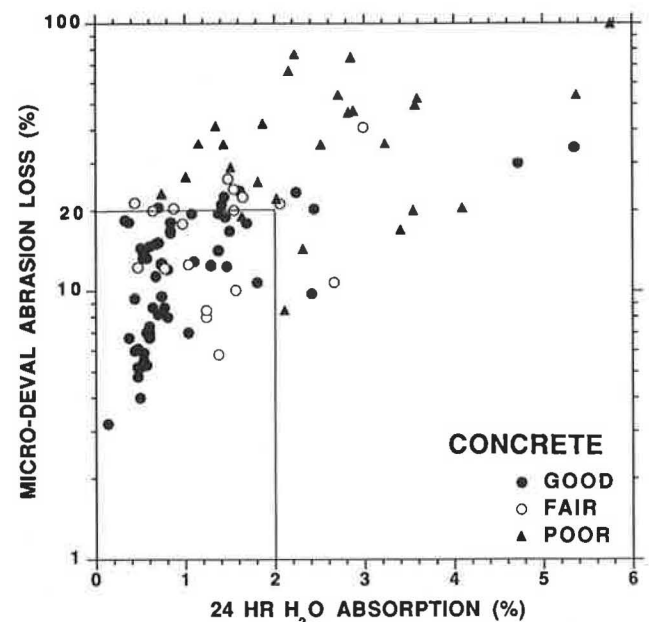


FIGURE 8 Field performance ratings for concrete: relation between micro-Deval abrasion and water absorption.

Figure 9 shows freeze-thaw test results plotted against water absorption. The freeze-thaw test can identify marginal aggregates (those of fair performance), separating them from poor and good performers. Materials with unconfined freeze-thaw losses of less than 6 percent and water absorption less than 1.5 percent are mostly aggregates exhibiting good field performance, with some marginal materials plotting in the higher water absorption portion of this range (water absorption between 1.0 and 1.5 percent). Marginal aggregates are further separated in the range of unconfined freeze-thaw losses be-

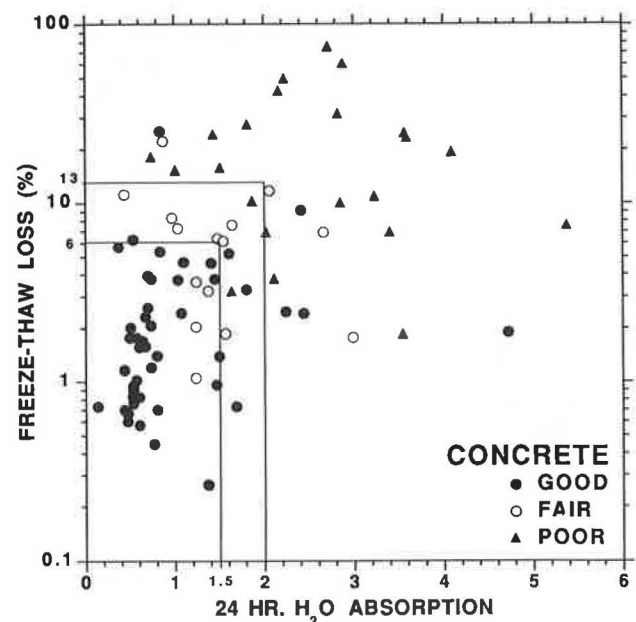


FIGURE 9 Field performance ratings for concrete: relation between unconfined freeze-thaw and water absorption.

tween 6 and 13 percent and water absorption between 1 and 2 percent. Freeze-thaw losses in excess of 13 percent and water absorption greater than 2 percent are usually, but not always, associated with poor-performing aggregates. Figure 10 combines both the unconfined freeze-thaw and the micro-Deval test results. On this plot, poor and marginal aggregates are identified with freeze-thaw losses greater than 6 percent and micro-Deval losses greater than 10 percent. Aggregate performance decreases as test results increase for these two tests.

No test procedure by itself is totally reliable for separating good, fair, and poor aggregate performance in concrete. If two tests are chosen, then micro-Deval combined with unconfined freeze-thaw seems the most reliable. The micro-Deval simulates the construction environment that includes wet mixing and abrasion, and the environment of the unconfined freeze-thaw test simulates low-temperature thermal cycling in the presence of moisture and road salts. The petrographic evaluation and water absorption have also been useful in predicting the performance of concrete aggregates (12).

### Asphalt Surface

Asphalt surface or wearing course is the layer of asphaltic concrete exposed to traffic. It resides in a severe environment where, in addition to maximum temperature and moisture fluctuations, it is subject to the abrasion and polishing of vehicle tires, shear forces, and impact loads. Aggregate for this application on high-volume roads is normally of the highest quality. Such tough materials as trap rock and other hard indurated rock or slags are typically used. The aggregates, in addition to being unaffected by thermal cycles, wetting and drying, and impact loads, must also have the ability to resist abrasion and polishing action.

Asphalt paving aggregates are normally tested with the Los Angeles impact and abrasion, magnesium sulfate soundness,

and water absorption tests, and petrographic examination. They have the most stringent requirements of all aggregates tested in Ontario.

Figure 11 shows that the performance of these aggregates is not related to water absorption. Those with high sulfate soundness loss (>15 percent) usually are poor performers. There are, however, a number of fair and poor performers with sulfate soundness losses less than 10 percent. Figure 12 shows that PN value is also useful in separating out poor material but not a totally reliable indicator of likely perfor-

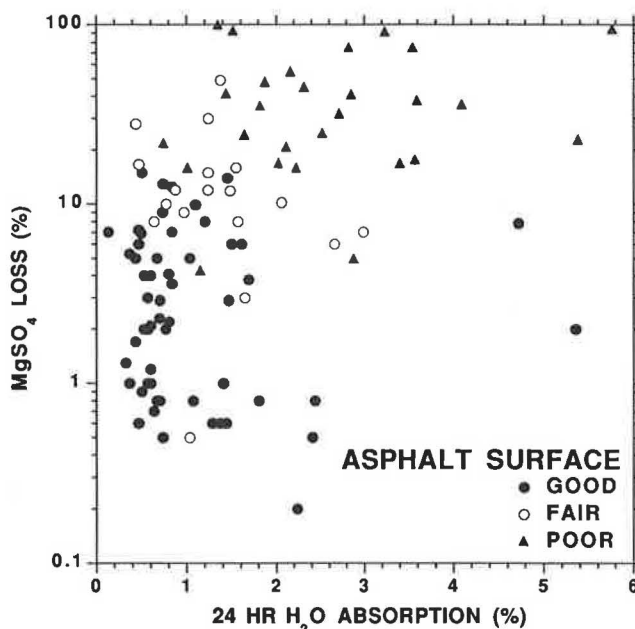


FIGURE 11 Field performance ratings for asphalt surface: relation between magnesium sulfate loss and water absorption.

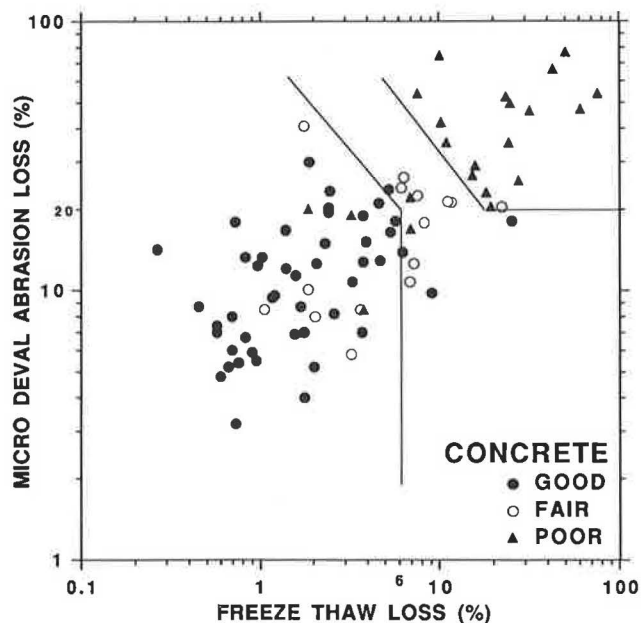


FIGURE 10 Field performance ratings for concrete: relation between micro-Deval abrasion and unconfined freeze-thaw.

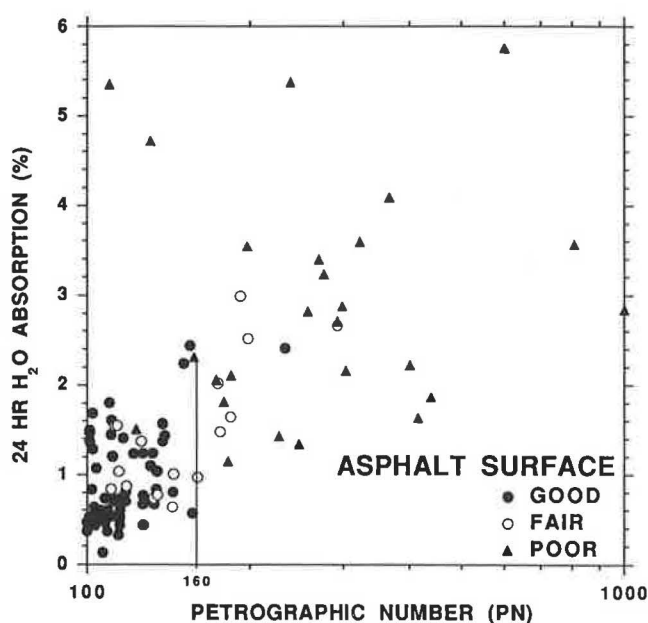


FIGURE 12 Field performance ratings for asphalt surface: relation between water absorption and PN value.

mance. The combination of magnesium sulfate loss and petrographic number shows a fairly good separation (Figure 13). The unconfined freeze-thaw test (Figure 14) is to be preferred because it shows better discrimination than the sulfate test and is more precise.

Wear resistance of noncarbonate aggregates is not related to material loss in impact tests, but there is a relationship within the carbonate group. The lower the wear resistance as measured by the AAV, the higher the Los Angeles impact loss for carbonate rocks (10). The results of these tests, when

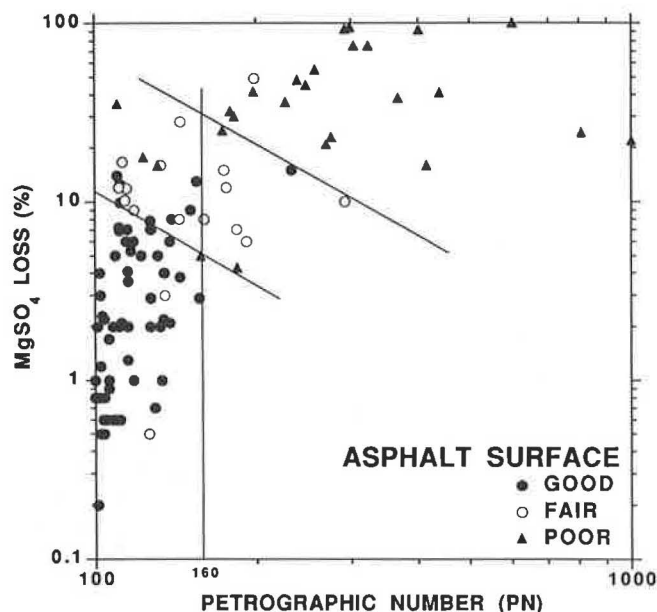


FIGURE 13 Field performance ratings for asphalt surface: relation between magnesium sulfate loss and PN value.

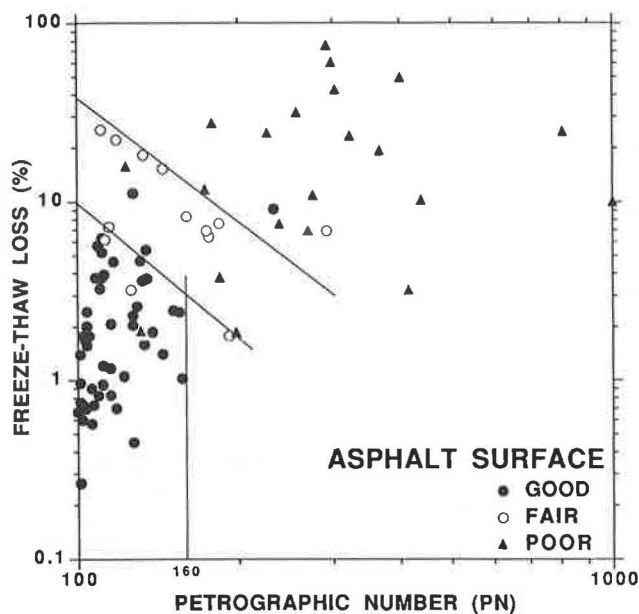


FIGURE 14 Field performance ratings for asphalt surface: relation between unconfined freeze-thaw and PN value.

applied to poor-quality carbonates, are good indicators of materials that do not develop sufficient macrotexture and may cause problems related to frictional properties.

At the present time, for surfaces with high traffic volume, it is desirable to have an AAV of about 6 or less. For lower-volume roadways, the AAV may be as high as 18. Above this value, no good-quality aggregates were found. Figure 15 shows that the micro-Deval is also related to AAV, at least for values less than 20 percent. This is to be expected because the test environments both expose the aggregate to abrasive deterioration except that the aggregate abrasion test is done dry and the micro-Deval is done in the presence of water. In the test results shown (Figure 15), good performance of aggregates in asphalt surface course is identified, with one exception, by a micro-Deval loss less than 10 percent and AAV less than 6 percent. For micro-Deval abrasion losses greater than 15 percent, performance is generally worse and the AAV can vary from low to high. The AAV test is a more expensive, time-consuming procedure than the micro-Deval test. The micro-Deval test is preferable as a quicker method of assessing resistance of aggregates to traffic wear.

Another desirable aggregate property is an adequate, long-term surface microtexture that provides adhesion of tires to the road surface. Microtexture is measured by the PSV test. Figure 16 shows the association between PSV and AAV in which there is no obvious relationship. This independence is to be expected because each test measures complementary aggregate properties. High-polished stone values of poor-performing aggregates are caused by their generally soft and friable nature. Because this test is done in the presence of water, material is lost from the surface, so that little polishing takes place, resulting in high frictional values for shaley materials. A high-polished stone value is desirable provided that the aggregate is durable. The lower target for roadway surfaces of high traffic volume is a PSV of approximately 50.

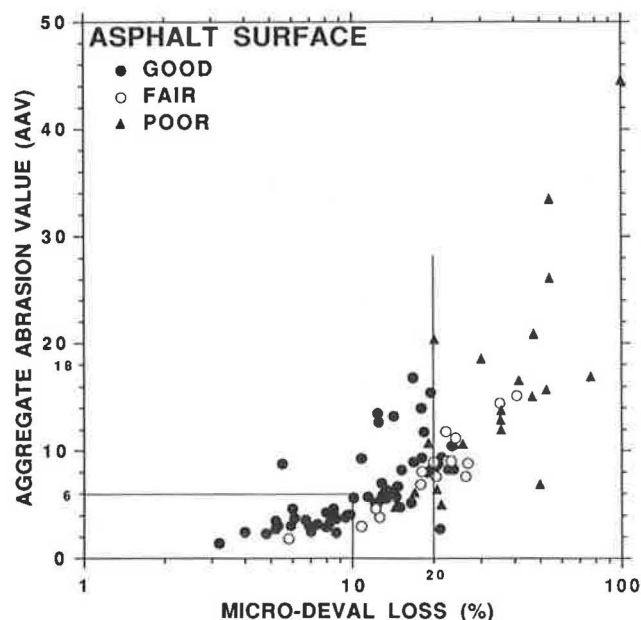


FIGURE 15 Field performance ratings for asphalt surface: relation between AAV and micro-Deval abrasion loss.



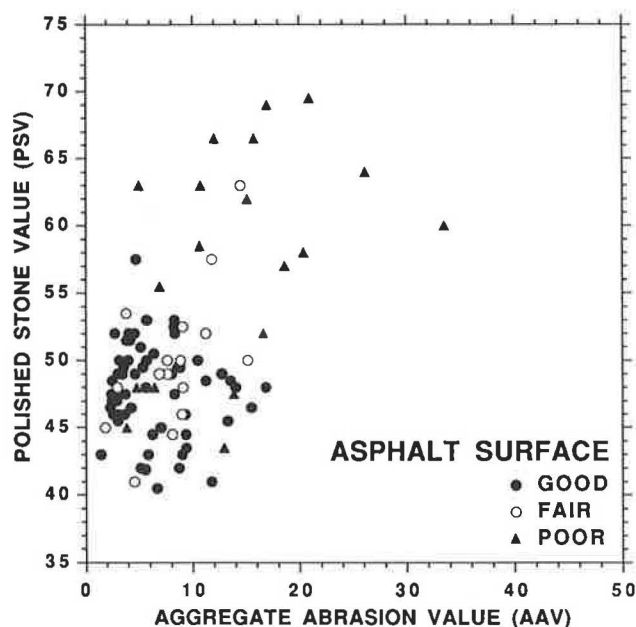


FIGURE 16 Field performance ratings for asphalt surface: relation between PSV and AAV.

For other uses, a PSV of greater than 40 may be adequate. No materials tested in this study had values less than 40.

Figure 17 shows PSV versus micro-Deval abrasion loss. The micro-Deval test separates durable and nondurable aggregates well. For high-volume roads, acceptable aggregates would have a micro-Deval loss of less than 10 percent and a PSV of 50 or better. Additional selection criteria shown in Figures 14 and 18 require that these aggregates also have PN values of less than 160 and freeze-thaw losses of less than 6 percent.

For lower-volume roads, a PSV of greater than 40 combined with a micro-Deval loss of less than 20 percent and a freeze-

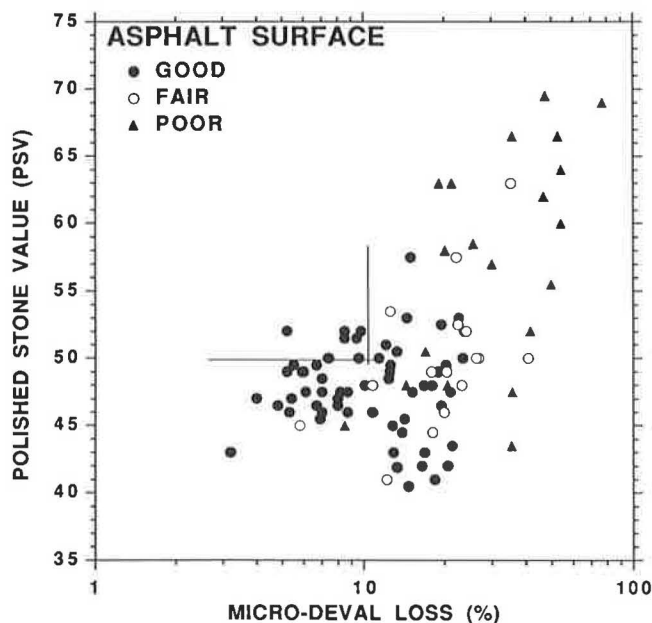


FIGURE 17 Field performance ratings for asphalt surface: relation between PSV and micro-Deval abrasion.

thaw loss of less than 30 percent would be acceptable (Figures 17 and 18). A petrographic number of less than 160 would still be required. This range includes aggregates of fair performance. Materials outside this range may occasionally be used but only after a thorough examination, including actual field performance evaluations of test sections, has been completed.

## CONCLUSIONS

In addition to the standard quality tests for coarse aggregate, several alternative tests have been under investigation by the Ministry of Transportation that provide reasonable simulations of the field environment of aggregates used in granular base courses, portland cement concrete, and asphaltic concrete.

The aggregate impact value test is seen as a practical substitute for the Los Angeles impact test for determining the extent of material breakdown caused by processing and construction handling. Both of these tests measure aggregate degradation by direct impact energy. Comparison of test results with field performance indicate that both of these tests have limited capability in predicting in-service behavior. The AVI test, however, may be done using simple, portable equipment.

The unconfined freeze-thaw test and the micro-Deval abrasion test are two tests that approximate the deterioration of materials in the weathering environment. These tests have shown a fair correlation with the sulfate soundness test but, when used in conjunction with the 24-hr water absorption and petrographic examination tests, are better at predicting field performance for marginal aggregates. The micro-Deval test has proved to be the more precise of the two tests and can be completed in a fraction of the time required to conduct a sulfate soundness test. The unconfined freeze-thaw test is a better simulation of the weathering environment experi-

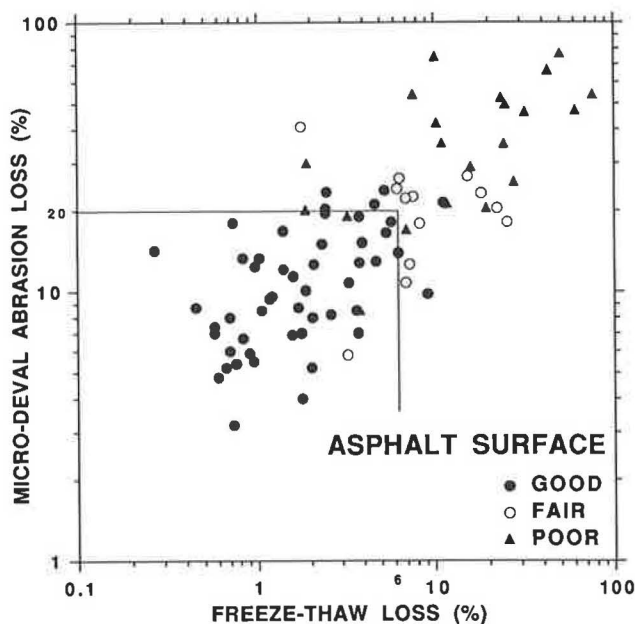


FIGURE 18 Field performance ratings for asphalt surface: relation between micro-Deval abrasion and unconfined freeze-thaw.

enced by aggregates in Ontario's highways. Both the micro-Deval and the freeze-thaw tests have good multilaboratory precision.

Performance of aggregates in granular base course is best identified using the micro-Deval abrasion test and petrographic examination. The micro-Deval test is reasonably able to separate marginal aggregates from good ones. Petrographic examination, although not able to consistently separate marginal aggregates from good ones, is useful in separating poor aggregates from both good and fair aggregates. The water absorption test is useful in identifying poor aggregates when used in conjunction with the micro-Deval test.

The unconfined freeze-thaw test and the micro-Deval abrasion test have shown that they are useful in differentiating marginal and poor-quality aggregates for use in portland cement concrete. Water absorption has also been shown to be useful in identifying potentially poor-quality aggregates when used with either one of these tests.

Aggregates for use in surface course asphaltic cement concrete are best identified by the freeze-thaw test, which is shown to be marginally better than the magnesium sulfate test when used with petrographic examination. The AAV test is a good measure of wear resistance. An association has been shown between this test and the micro-Deval abrasion test where high-quality aggregates are concerned. The micro-Deval test is preferred as it is the simpler of the two tests to complete. The PSV test is valuable in differentiating potentially good aggregates when used in conjunction with the micro-Deval test.

No single test or set of tests can adequately identify the weathering stability of an aggregate source. By using more appropriate simulations of the weathering and construction environment with simple, rapid tests, this potential may be better realized.

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