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DEPARTMENT OF TRANSPORTATION

Identification of Aggregates for Tennessee Bituminous Surface Courses - Phase III

FINAL REPORT

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16. Abstract

Current methods of pre-evaluation of aggregates for bituminous surface courses are only able to clearly identify aggregates with a very high probability of performing well. There is no general agreement between researchers as to what engineering properties will provide adequate skid performance at various average daily traffic levels. The lack of agreement has led to very conservative polish resistance specifications by many state DOT's and subsequently higher pavement costs.

In 1992, the Tennessee Department of Transportation (TDOT) initiated a project to pair aggregate performance with the functional needs of the pavements (based on ADT) so that all Tennessee aggregate sources can be used most efficiently. The principal result of the project was a new aggregate polish resistance pre-evaluation procedure called the Tennessee Terminal Textural Condition Method (T^3CM).

In this evaluation, using twenty Tennessee and Kentucky aggregates, the T^3CM was used to characterize aggregate polish-resistance performance by comparing the results obtained on other aggregates to the results from proven field performers. The T^3CM ranked five of six Tennessee proven performing siliceous limestones in the upper two performance categories. The test method had a coefficient of variation for aggregate ratings of less than one percent for a nine sample repeatability test.

The results of this study have shown the T^3CM to be a logistical success. Ease of performance, repeatability, substantially reduced costs (compared to British Wheel and British Pendulum) and increased productivity are advantages indicating that this test may be an ideal addition to normal aggregate pre-qualification tests. The research team recommends that the T^3CM be used as a pre-evaluation procedure for aggregate sources. In addition, the T^3CM should be used as a verification test for random aggregate lots.

17. Key Words		18. Distribution Statement
Microtexture	Surface Texture	
Angularity	Void Content	
Particle Shape	Coarse Aggregate	
	Polish Resistance	

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INTRODUCTION

Pavement surface aggregates should be pre-evaluated for the safety of the motoring public, as well as for economic reasons. If unsatisfactory materials can be eliminated, savings in accident costs, maintenance and reconstruction will result. However, there is ambiguity in the term "unsatisfactory". An aggregate, which is satisfactory for most average daily traffic (ADT) applications, may be unsatisfactory for a high ADT interstate application. In eliminating "unsatisfactory" materials, caution is often considered prudent and subsequently some materials, which could provide adequate performance in most ADT applications, are eliminated from consideration because these materials will not meet the specifications for highest ADT applications.

The state of Tennessee has an abundance of carbonate aggregates especially in middle and east Tennessee. However, in the past, Tennessee also had multiple sources of highly polish resistant bituminous surface aggregates such as slag in these same areas. Cautious specifications defining what is an "approved" surface aggregate source posed no problem when a large supply of highly polish resistant aggregates was available. However, when the supply of these excellent aggregates began to decline, the cautious specifications continued to produce safe bituminous pavement surfaces but at an ever increasing cost. With only a small number of approved aggregate sources, two problems began to occur. First, as demand increased, the aggregate price increased. Second, the cost of transporting aggregates from approved sources to distant areas greatly increased pavement costs.

In 1992, the Tennessee Department of Transportation (TDOT) initiated a project to pair aggregate performance with the functional needs of the pavements (based on ADT) so that all Tennessee aggregate sources can be used most efficiently.

OBJECTIVES

This project was undertaken to achieve the following primary objectives:

1. Ascertain what laboratory methods are currently available to pre-evaluate aggregate for bituminous surface courses.
2. Determine the relative effectiveness of the methods through a literature review.
3. If no suitable methods are found, attempt to develop a test to characterize an aggregate's ability to retain microtexture over time. The test must be inexpensive, repeatable, and not operator sensitive.
4. Perform a preliminary evaluation of the new method.
5. Make recommendations for implementation of project findings.

LITERATURE REVIEW

One of the primary functions of a bituminous surface course is to provide adequate skid resistance and steering properties under driving conditions (1,2,3). There are major concerns involving accidents due to wet weather skidding along the roadway system. With this concern in mind, many state agencies measure the skid resistance on all or some selected roadways on a routine basis (4). A primary reason for collecting skid data is to try to develop improvement methods for prevention or reduction of skid-related accidents (5). The skid resistance data collected in the field is also used in skid resistance research projects.

Skid resistance is a measure of the tires resistance to slippage along the pavement. Skid resistance is the force developed when a tire is prevented from rotating, thus sliding along the surface (5). Skid resistance is the force developed at the tire-pavement interface that resists sliding of the tires on the pavement surfaces under emergency or panic braking or cornering (6). Skid resistance is a common concern and has been researched since the late 1800's.

There are many factors affecting skid resistance. The three primary factors influencing the skid resistance performance of bituminous roadways are pavement distress, macrotexture, and microtexture. Pavement distress is a major factor affecting the skid resistance. The pavement distress modes of bleeding and rutting greatly decrease skid resistance (7). Rutting of the surface course would produce hydroplaning by allowing water to pond in the rut channels. Bleeding drowns the microtexture thus decreasing skid resistance due to a loss of tire-pavement friction. Macrotexture is the result of the size, shape, and the arrangement of the aggregate particles in the mix. Macrotexture controls the water film thickness developed on the roadway surface and how quickly it is removed (5,8,9,10). A roadway consisting of an adequate macrotexture would reduce the possibility of hydroplaning if the pavement was not rutted. Macrotexture relieves the water pressure, which is built up in the forward portion of the tire-pavement interface, thus allowing a large tire area to remain in contact with the pavement surface (11). Macrotexture is the measure of the general coarseness of the pavement. Macrotexture also controls the seasonal variations seen in the Skid Number (SN) readings taken from the field (12). Microtexture is the fine texture of the aggregate that makes it smooth or rough to the touch. Microtexture provides the adhesion component of skid resistance (11). The microtexture of the coarse aggregates is the most important for bituminous surface mixes.

There are several different laboratory tests that are used to evaluate microtexture, such as the British Pendulum Number at nine hours (ASTM D 3319 and ASTM E 303), Percent Insoluble Residue (ASTM D 3042), Loss-On-Ignition Method (Tennessee Department of Transportation), and the Micro-Deval Test (French origin).

The BPN 9 is achieved using a British Polishing Wheel (ASTM D 3319) and the British Pendulum Tester (ASTM E 303). These apparatuses can be seen in Figures 1 and 2. (13, has a detailed summary of the testing procedure.) The British Pendulum Number after nine hours of polishing is normally assumed to be the terminal polishing value for the aggregate. The main problem with the British Tester is an extensive and ineffective calibration procedure (14). In addition, Won and Fu (15) investigated eleven variables present in the British Test and found that nine had a significant affect on the outcome of the BPN value. The British Test system also has an expensive initial cost of approximately $25,000 (16). Considerable concern has developed over the lack of agreement among the British Pendulum users (14). Table 1 shows BPN 9 requirements for various states.

Table 1. BPN 9 Requirements

Category	ADT *	Alabama (17)	New Jersey (10)	Texas (14)
	Less than 750*			None
Low (poor)	2000 to 750*	27 and less	24 and less	28
Medium (marginal)	5000 to 2000*	28 - 32	25 - 30	30
High (good)	Greater than 5000*	Above 32	31 or more	32
Plan Specifications				35

* - ADT values apply only to Texas specifications.

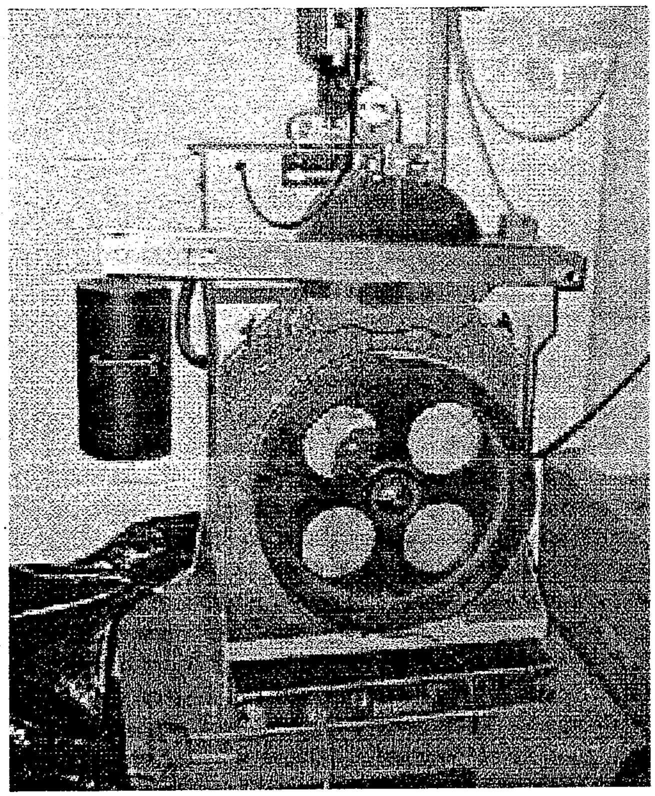


Figure 1. British Polishing Wheel.

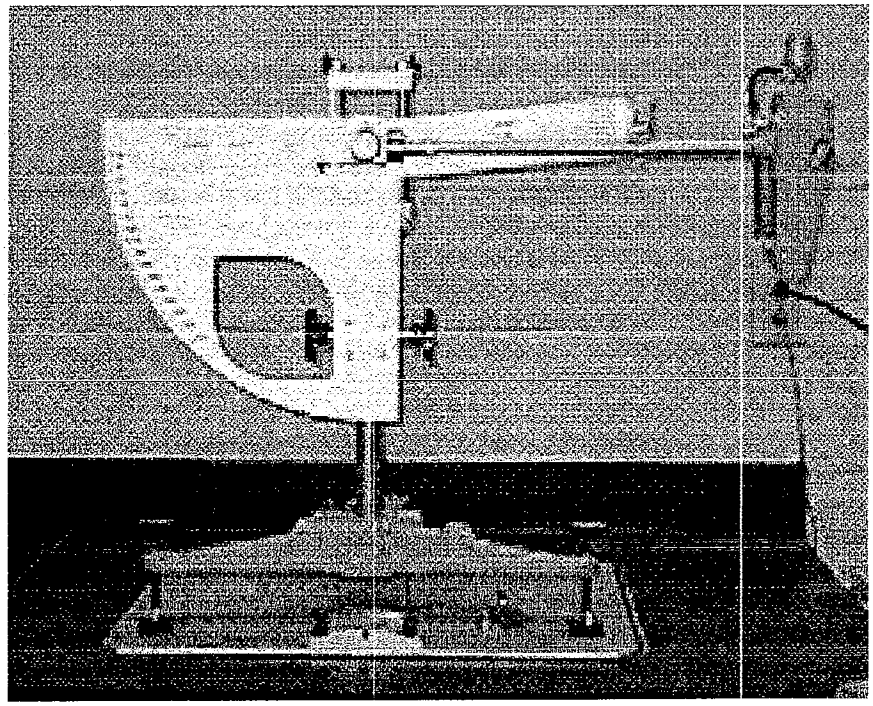


Figure 2. British Pendulum Tester.

The Percent Insoluble Residue Test (ASTM D 3042) has received a great deal of attention during the past years. It is recommended that this test be used as a laboratory evaluation test, but not considered as a principal means of predicting skid resistant characteristics (11). The insoluble residue is commonly referred to as the siliceous materials. Silicates are insoluble in hydrochloric acid and contribute to skid resistance due to particle hardness. Relatively pure carbonate aggregates (less than five percent insoluble residue) are rapidly isolated by the insoluble residue test, and are generally found to be very polish susceptible (11). The main problem with the Percent Insoluble Test is the very small test sample. ASTM D 3042 suggests a 0.25-gram test specimen. Aggregate sources vary in mineralogical composition even within the same geologic formation. Therefore a variety of mineralogical compositions exist in one "shot". The specified sample size introduces a high probability for variability into the test method. For a laboratory evaluation technique, a high degree of variability is not desirable.

The Loss-On-Ignition (LOI) Test (Tennessee Department of Transportation) is another method used for laboratory evaluation of potentially polish resistant aggregates. This method has the same fundamentals as the Percent Insoluble Residue test. The LOI test is superior to the Percent Insoluble Residue test due to a larger sample size and an easier operation. The LOI Test uses a high temperature to burn away the carbonate components of the aggregate, leaving the harder particles. The harder particles can be well dispersed throughout the body of the material or they can be in conglomerations. Aggregates with harder particles well dispersed in a softer matrix are much better polish resistant aggregates. One problem with this particular test is that there is no measurement of how the harder particles of the aggregate are dispersed. A small sample size has the potential to introduce variability into the testing procedure. Kandhal et al. (17) also found that mineralogical methods such as Percent Insoluble Residue (ASTM D 3042) and Loss-On-Ignition (TDOT) tend to reflect the general trend of later polishing values, but polishing values could not be statistically predicted from these tests.

There are also some wet degradation and attrition tests presently being evaluated by some agencies in the laboratory. The most common attrition test is the Micro-Deval Test. This test is being used in Canada (Quebec and Ontario) for the evaluation of fine and coarse aggregate and was developed in France during the 1960's (18). In the Micro-Deval test for coarse aggregate, 500 grams of a graded sample are placed in a 5-L steel jar mill with 2.5-L of water and 5000 grams of 9.5-mm (3/8-in.) steel balls. The device is then rotated at 100 rpm for two hours and the loss is measured by the amount passing the

1.18-mm (No. 16) sieve (18). One problem with this testing procedure is the value obtained is a loss value. Loss is not indicative of skid performance because some slags and sandstones have a high percent loss but have good skid resistance. There is also a possibility that the steel balls would add impact to the aggregate particles creating an impact and shearing affect that is not necessarily seen on the roadway.

The Tennessee Department of Transportation (19) currently has the polish resistance specifications for bituminous surface courses shown in Table 2. The additional requirements for Type II and Type III in Table 2 include, but are not limited to, a field test strip for performance verification (20). These specifications are stringent. Most of the limestones in Tennessee have difficulty meeting these specifications. With currently available methods containing deficiencies, a new laboratory pre-evaluation technique was sought.

Table 2. TDOT Polish Resistance Surface Aggregate Requirements

	BPN 9 (min)	SiO_2 (% min)	$CaCO_3$ (% max)	Restriction
Type I	33	50	32	None
Type II	30	30	-	Additional
Type III*	25	20	-	Additional

- - 12,000 ADT or less, non-interstate

Based on lessons from the field, a highly skid-resistant surface course will reach a terminal skid number during the service life of the pavement. Research work conducted in New Jersey, showed cyclic skid resistance values with a constant mean value, hereafter referred to as the terminal skid number, may be expected after approximately two million vehicle passes on a bituminous surface course (10). After a pavement has reached its terminal skid number, the pavement's skid resistance is predominantly affected by cyclic seasonal effects (10) as shown in Figure 3.

It is hypothesized that with an appropriate pre-evaluation laboratory technique, the terminal skid value could be modeled. A terminal skid number will be more evident as more field skid resistance values are collected during the life of the pavement.

Achieving a terminal aggregate texture with laboratory techniques have been studied by several different researchers in the past. Diringer evaluated a model, which considered the simple relationship between a diminishing microtexture with cumulative polishing over time (10). The British Polishing Wheel and British Pendulum was used as an accelerated polishing tool to achieve a terminal polish value. The specimens were tested far beyond the standard 9-hour test to evaluate whether the specimens would reach a terminal polish value. Subsequent use of this model is based on the hypothesis that the estimated terminal polish value for an aggregate is somehow related to the terminal skid resistance that is achieved on the roadway (10). An aggregate source can be seen approaching the terminal polish value in Figure 4 (10).

There are different aggregate types that perform well for different reasons. Aggregates that are very hard, aggregates that fracture rather than polish, and aggregates that have components with differential polishing resistance are all aggregates that are likely to have good skid performance. The first type of aggregate would need to be very hard, such as Calcined Bauxite or Trap Rock. "Hardness is the single most important

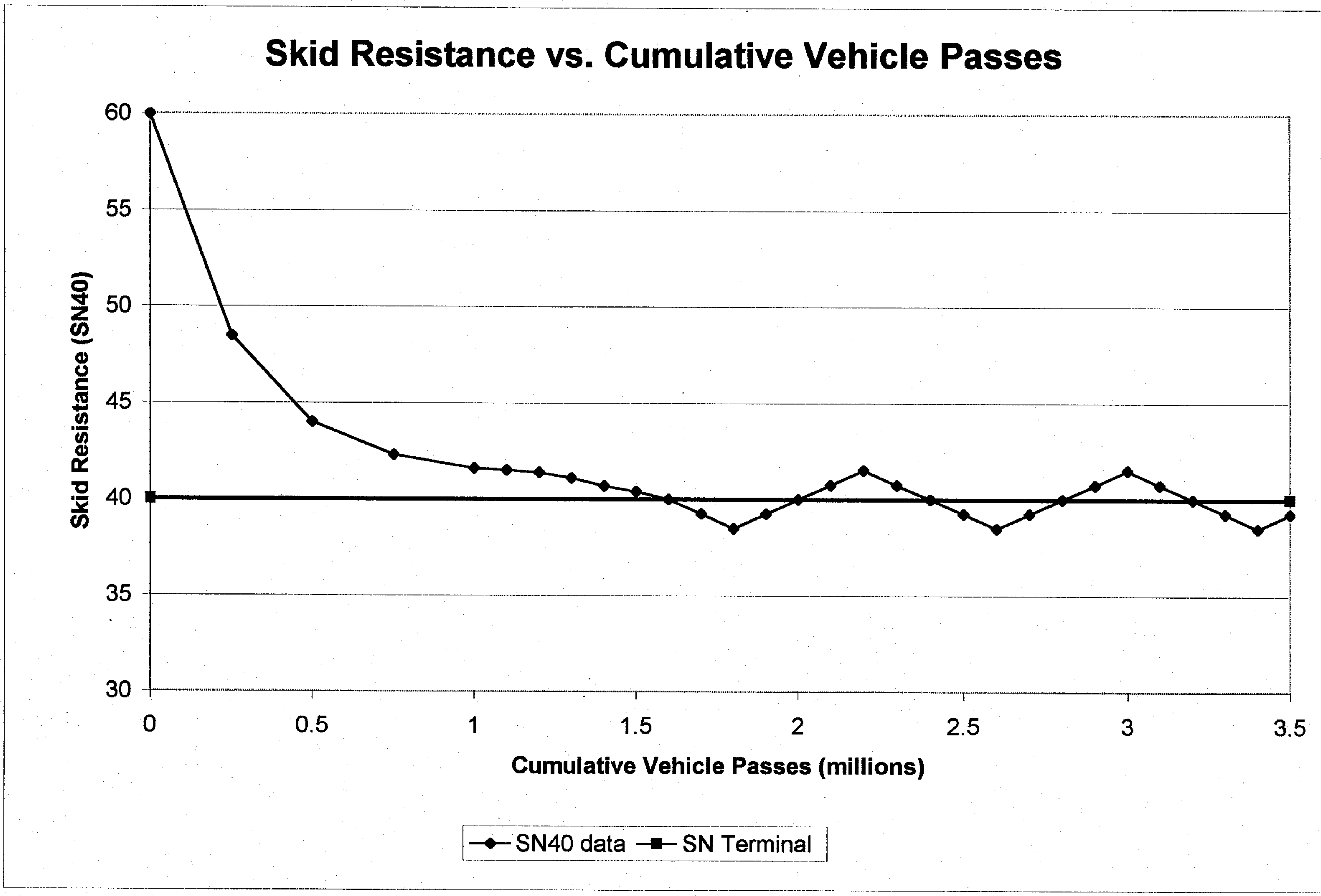


Figure 3. Skid Resistance vs. Cumulative Vehicle Passes.

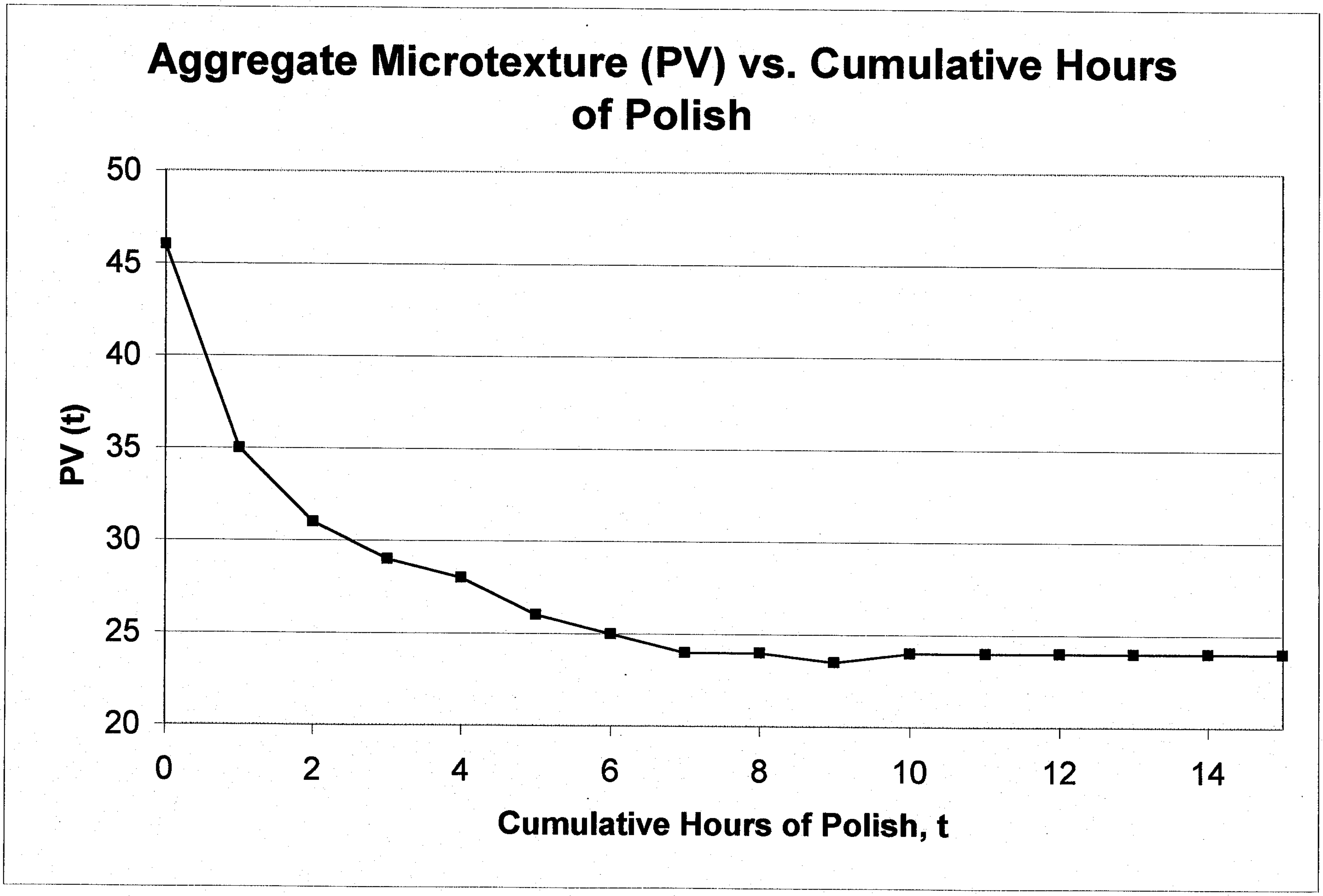

Aggregate Microtexture (PV) vs. Cumulative Hours of Polish
PV (t)
50
45
40
35
30
25
20
0
2
4
6
8
10
12
14
Cumulative Hours of Polish, t

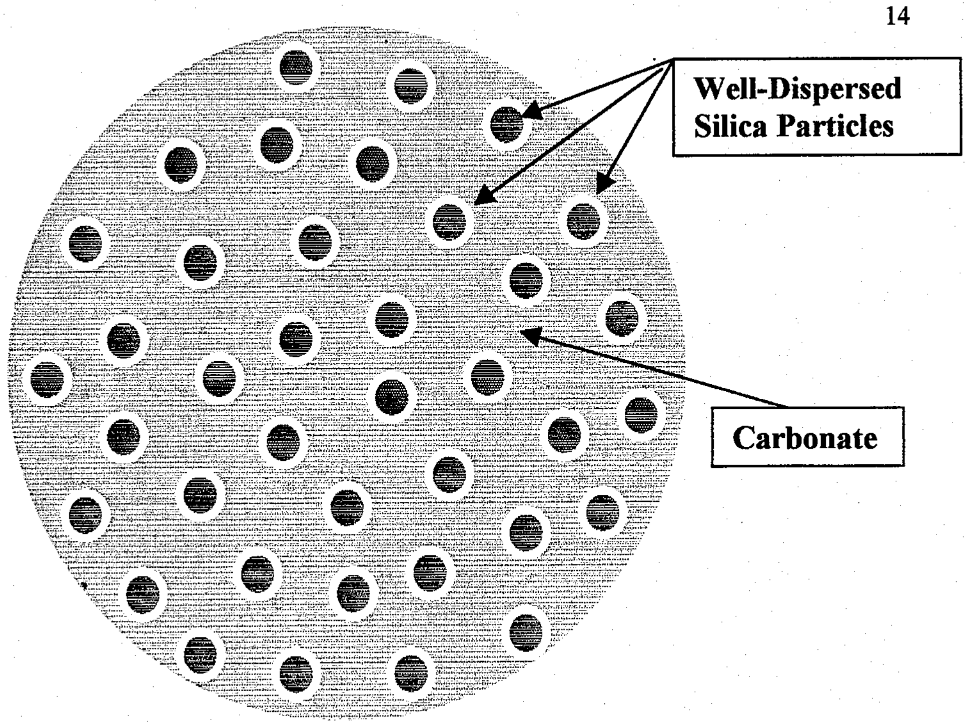
Figure 4.

characteristic that controls aggregate wear," according to Stiffler (18). Pavements with aggregates of similar hardness to the matrix showed uniform wear (18). With harder aggregates, the matrix was preferentially worn down around the aggregates until the particles were exposed increasing the surface area of the tire that was in contact with the particles. Franklin and Calder (18) report that a hard aggregate such as Calcined Bauxite has both good polishing and abrasion resistance.

Secondly, an aggregate that fractures rather than polishes such as some sandstones often produce good skid performance. While using sandstone, friction increases as the absorption and the surface capacity of the particles increase (18). Franklin and Calder (18) report that a gritty sandstone material has a good polish resistance, but a poor abrasion resistance.

Last but not least, an aggregate with differential polishing resistance components can provide adequate skid performance. Polishing occurs when a fine abrasive is used and the surface is made up of materials of similar hardness. Regeneration of the surface can occur when two components of differing hardness are present and the matrix of the softer, weaker material wears away faster causing the harder particles to protrude and eventually be undercut and torn out leaving an unpolished surface (18). An aggregate consisting of well-dispersed siliceous materials acts in this manner. On the roadway, an aggregate with well-dispersed silica particles produces excellent microtexture. The microtexture will exist due to siliceous particles protruding out of the surface of the softer aggregate matrix. As wear continues on this roadway, the protruding siliceous particles are torn away leaving more siliceous particles to be uncovered (Figure 5). As a pavement ages, the aggregate with well-dispersed silica keeps regenerating microtexture.

A good laboratory aggregate pre-evaluation procedure should incorporate cost effectiveness, repeatability, operator insensitivity, and contain an adequate sample size to minimize variability. Cost effectiveness is a major factor in the pre-evaluation of aggregates. The laboratory test must also be highly repeatable. Some of the current evaluation techniques do not have the desired repeatability. If a test is developed which is highly repeatable, then agencies will be able to depend more on laboratory pre-evaluation techniques due to decreased variability. A new test method must also incorporate a high degree of operator insensitivity. With some of the existing tests, an aggregate can be evaluated by several different operators, using the same device, producing several different results. The sample size is another major factor influencing the results of a good test. The Percent Insoluble Residue Test, LOI Test, and the Micro-Deval Test all had relatively small samples, which would introduce variability. Variability could be greatly reduced as the sample size in the test increased. Ease of performance, repeatability, reduced costs, and operator insensitivity are desirable for any pre-evaluation method for surface aggregates.



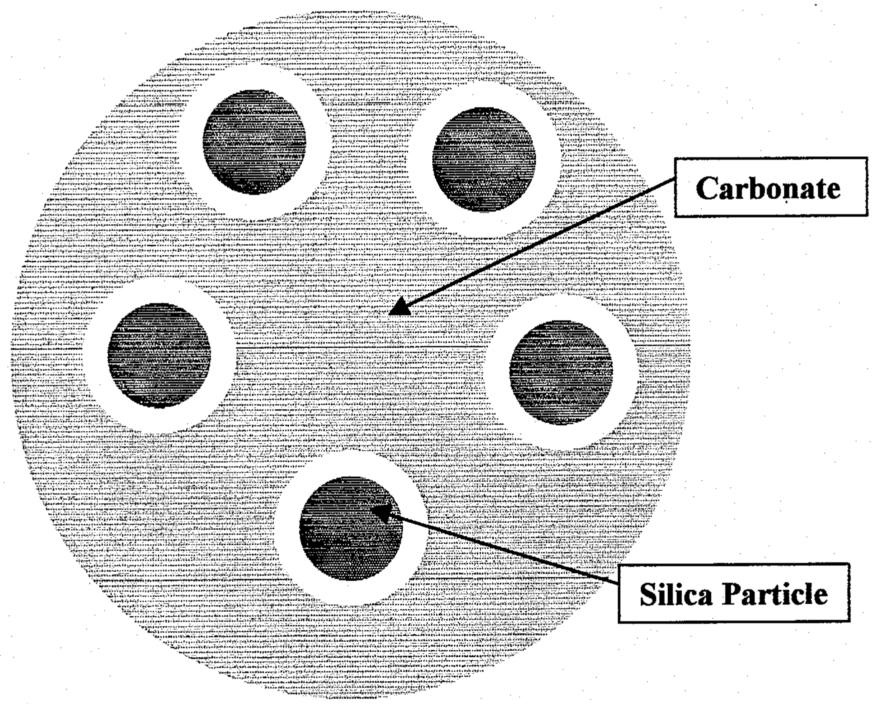


Figure 5. Comparison of well-dispersed silica and conglomerated silica.

OVERVIEW OF PHASE I AND II

Objectives 1 and 2 were accomplished in Phase I of the project (21,22). In summary, information on laboratory test methods for characterizing aggregate polish-resistance currently available or being developed was obtained using a survey (21) of State Departments of Transportation throughout the country, along with associated industry and academia. Only three standardized laboratory tests were commonly used by the respondents, the Percent Insoluble Residue (ASTM D 3042), Petrographic Analysis (ASTM C 295), and British Polishing Wheel / British Pendulum (AASHTO T 278 and AASHTO T 279).

Objectives 3, 4, and 5 were begun in Phase II of the project (13,23). The Tennessee Textural Retention Method (TTRM) was developed and evaluated. In the TTRM, the L.A. Abrasion device (AASHTO T96) with eight steel spheres was used to age the aggregate at an accelerated rate. The TTRM was found to be repeatable, not operator sensitive, and inexpensive. However, the TTRM did not reveal an aggregate's terminal texture. There were two reasons that an aggregate's terminal texture was not revealed. First, the aging was only carried out to 1200 revolutions. Second, the steel spheres introduced an impact component to the aging, thus fracturing aggregate particles. The reintroduction of fractured faces obscured the aggregate's terminal texture.

DEVELOPMENT OF THE TENNESSEE TERMINAL TEXTURAL CONDITION METHOD

Phase III: Initial Concept

Using the TTRM developed by Shirley (13) as a beginning point, the authors attempted to further refine the procedure by increasing the apparatus size, removing the steel spheres from the aging procedure and increasing the number of aging cycles.

First, the 944-mL Standard Proctor Mold (AASHTO T99) was replaced with a 2832-mL unit weight measure (AASHTO T19). The modification resulted in a measure with three times the volume and only 225 percent of the surface area. The authors hoped that the increased size of the measure would result in a reservoir less sensitive to strike-off technique and therefore produce a better estimate of the true uncompacted void content. The remainder of the apparatus was increased in size proportional to the new reservoir. See Appendix A for details.

Second, the steel spheres were removed from the aging procedure to minimize the role impact played in the aging procedure. The new procedure simply aged aggregates by abrasion on other particles and the sides of the L.A. Abrasion device. The authors believed that such abrasion was more like the conditions bituminous surface aggregates were exposed to in service.

Third, the number of aging cycles was increased from twelve to eighteen. Each aging cycle remained 100 revolutions in the L.A. abrasion device. It was hoped that moving farther out on the uncompacted voids versus number of aging revolutions curve would reveal an aggregate's terminal textural condition.

Reaching a Terminal Textural Condition

Originally in Phase III, it was thought that eighteen aging cycles of 100 revolutions in the L.A. Abrasion device would produce a terminal textural condition. However, after several aggregates had been aged in this manner, it was evident that the slope of the curve of percent voids versus number of revolutions curve still had a definite downward trend. The authors decided to continue aging the aggregate samples in 500 revolution increments to determine if a terminal textural condition could be reached. A cycle of 200 revolutions was used to get the aggregate sample to 2000 revolutions of aging before the 500 revolution aging cycles were begun.

Nine of the eighteen aggregates selected by the TDOT Monitoring Committee at the beginning of Phase III appeared to have reached a terminal textural condition after aging varying from 8000 to 16,000 cycles. Initially, aggregates were assumed to be at their terminal textural condition if the voids values increased over two subsequent aging cycles (often called the "double bounce"). Testing of aggregate samples was usually discontinued after the aggregate "double bounced".

Verification of the Terminal Textural Condition

At a meeting of the TDOT Monitoring Committee March 7, 1997, the results of Phase III to date were presented. The TDOT Monitoring Committee Chairman desired additional evidence that the nine aggregates referred to in the previous paragraph had actually reached a terminal textural condition. It was decided that Phase III would be extended. In the extension, new samples of the nine aggregates would be aged to 20,000 revolutions. By this extensive aging of the aggregates, it could be determined if the "double bounce" previously observed was actually a terminal textural condition.

EVALUATION OF THE T^{3}CM

Activity 1. Aggregate Selection

The Tennessee Department of Transportation Steering Committee for the project selected seventeen aggregates in Phase III and fourteen aggregates for the extension of Phase III. A total of twenty different aggregates were tested for the project. The aggregates selected included several aggregates approved by TDOT and the Kentucky Transportation Cabinet for use in bituminous surface courses at various ADT levels. Several of the aggregates selected were believed to be poor performers, and several aggregates were selected whose performance was not known. All samples were collected using standard sampling procedures. Figure 6 shows the location of the quarries in the state of Tennessee, which provided aggregates for the study.

Activities 2 and 3. Textural Retention Testing and Aggregate Property Testing

Phase III

Three 12-kilogram samples of each aggregate were sieved to the gradation requirements of Table 3a, washed and oven dried. Each sample was tested for initial particle shape using the modified Uncompacted Voids apparatus. After initial testing, the

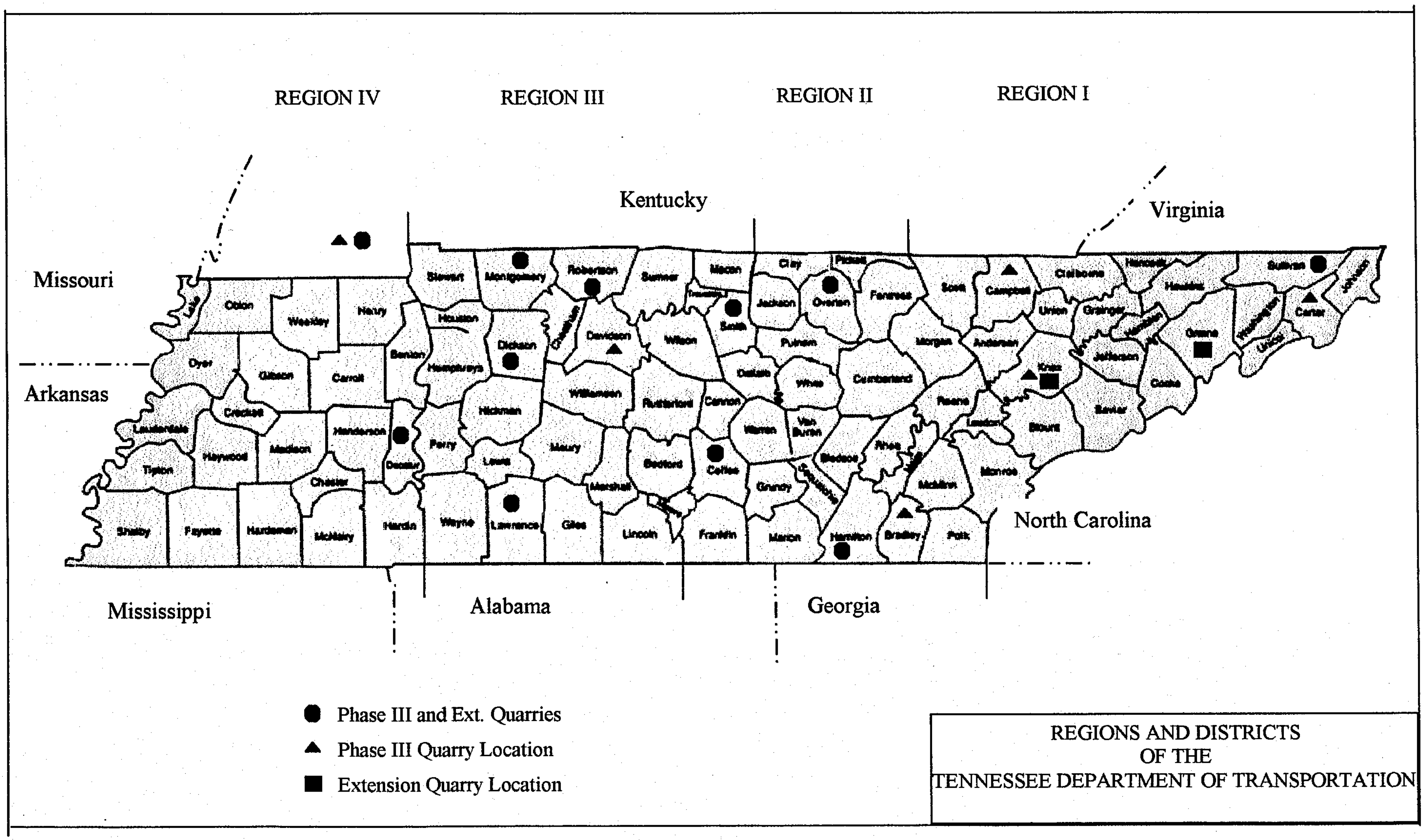


Figure 6. Tennessee Quarry Locations

samples were then subjected to 100 revolutions in the L. A. Abrasion machine. The abrasion of a rotating steel drum changed the particle shape and surface texture. The sample was then resieved to the initial grading and tested in triplicate using the modified Uncompacted Void Content Device. Triplicate samples were used to assure repeatability.

Table 3a. Original Testing Parameters

100 % Passing (sieve)	9.52 mm (3/8")
100 % Retained (sieve)	6.35 mm (1/4")
Sample Size kg. (lbs)	12 (26.5)
Number of Samples / Agg.	3 Initially
	1 @ 1,000 revs
# of Spheres	0
Test Freq. (# rev's)	100 (500 after 1,800 revs)
Number of Testing Cycles	As needed
Device	Modified AASHTO TP 33

This process was repeated for eighteen cycles to compare change in shape and texture over time. A 12-kilogram sample size was chosen to allow sufficient sample left for triplicate testing to nine cycles. After nine cycles, the surviving portions of the three original 12-kilogram samples were combined to obtain a single sample. If the combined sample after nine cycles exceeded 12 kilograms, wasting to 12 kilograms reduced it. After eighteen cycles had been completed, it was felt that the terminal textural condition (TTC) had not been achieved. To shorten the amount of time required in the laboratory, the aging procedure was modified for the remainder of the test. After the first eighteen cycles had been completed, the sample was then aged 200 revolutions, sieved and tested. Thereafter, aging was continued 500 revolutions at a time until the sample reached its TTC or the remaining sample was insufficient for voids testing, whichever came first.

Phase III Extension

Appendix A is an AASHTO type specification that outlines in detail the complete procedure used for performing the T^3CM. To briefly summarize, in the extension of Phase III five 12-kilogram samples of each aggregate were sieved to the gradation requirements of Table 3b, washed and oven dried. Each sample was tested for initial particle shape using the modified Uncompacted Voids apparatus. After initial testing, the sample was then subjected to 500 revolutions in the L.A. Abrasion device.

Table 3b. Extension Testing Parameters

100 % Passing (sieve)	9.52 mm (3/8")
100 % Retained (sieve)	6.35 mm (1/4")
Sample Size kg. (lbs)	12 (26.5)
Number of Samples / Agg.	5 Initially
	2 @ 8,000 revs
	1 @ 14,000 revs
# of Spheres	0
Test Freq. (# rev's)	500 (after 8,000 revs)
Number of Testing Cycles	24 (after 8,000 revs)
Device	Modified AASHTO TP 33

The sample was then resieved to the initial grading of Table 3b. No further uncompacted voids testing were performed prior to 8000 revolutions. Prior to 8000 revolutions, the number of samples may have been reduced depending on the degradation of the aggregate without wasting any material. The samples were continually aged 500 revolutions at a time and sieved until all specimens had been aged 8000 revolutions. No individual sample was allowed to exceed 12-kilograms.

When each sample has been aged and sieved for 8000 revolutions, all samples are combined and mixed. If the combined sample exceeded 24-kilograms, it was reduced to 24-kilograms by wasting. The combined sample was then split into two 12-kilogram samples. The two samples at 8000 revolutions were tested using the Uncompacted Voids Content apparatus. Three tests were conducted on each sample for a total of six tests. Following testing, the samples were continually aged, sieved, and tested every 500 revolutions until each sample had been aged 14000 revolutions.

When each sample reached 14000 revolutions, the two samples were combined and mixed. If the combined sample exceeded 12-kilograms, it was reduced to 12-kilograms by wasting. The sample was then tested with the Uncompacted Voids Content apparatus six times. Following the testing procedure, the sample was continually aged, sieved, and tested every 500 revolutions until the sample had been tested at 20000 revolutions. An example data sheet is shown in the Appendix.

Aggregate Property Determination

Tennessee Terminal Textural Condition ratings (TTTC), percent silica (SI), LOI values, bulk dry specific gravities (BSG), absorptions in percent (ABS), BPN 9 values, and any available SN40 values for the project aggregates are presented in Table 4a and Table 4b. Values from Phase III are found in Table 4a while values from Phase III-Extension are found in Table 4b. TDOT personnel obtained BPN 9, percent silica, and available field data from locked-wheel skid tests (AASHTO T 242) on project aggregates. Data from a long-term test strip to evaluate aggregates Agg 1, Agg 4, and Agg 6 is shown in Figure 7. Data from a test strip on SR 111 at the Putnam-Overton

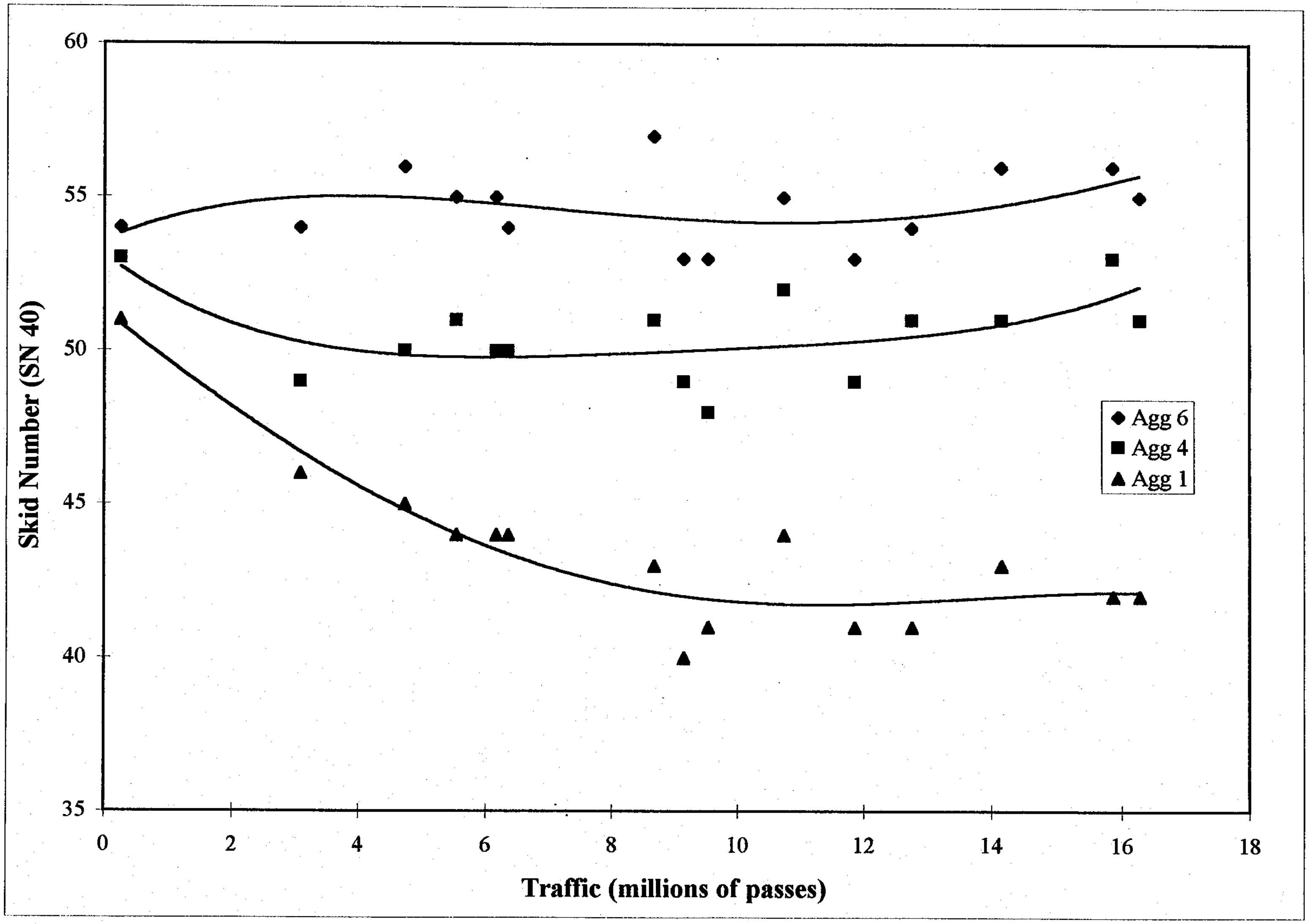


Figure 7. Field Skid Numbers versus Vehicle Passes for Agg 1, Agg 4, and Agg 6.

County Line to evaluate Agg 12 is shown in Figure 8. In this test strip, Agg 12 is being compared to TDOT proven performer Agg 1.

Table 4a. Phase III Aggregate Properties

Aggregate	TTTC	Final U (%)	% Silica	LOI (%)	BSG	% ABS	BPN 9	SN 40
					**	**		
Agg 1	42.64		14.88	35.8	2.733	0.78	24	47
Agg 2*	43.17		50.40	19.2	2.606	1.74		
Agg 3	44.70		20.84	25.7	2.601	1.37	28	
Agg 4	44.82		31.08	23.6	2.554	1.65	27	51
Agg 5	44.33		19.12	25.9	2.618	1.43	29	47
Agg 6*	44.29		53.24	17.0	2.589	1.29	30	55
Agg 7	43.57		46.68	18.0	2.588	1.64	34	51
Agg 8		43.18	16.72	39.9	2.744	0.68	25	
Agg 9	44.06		12.48	31.9	2.693	0.33	20	36
Agg 10		42.05	2.44	40.7	2.682	0.63	27	
Agg 11								
Agg 12		42.62	13.04	37.6	2.678	0.42	24	
Agg 13	43.53		16.44	36.8	2.722	0.73	19	
Agg 14								
Agg 15		42.99	1.96	41.6	2.641	0.87		
Agg 16		42.83	2.80	37.8	2.689	1.02	36	
Agg 17		42.79	6.40	39.3	2.727	0.35	19	
Agg 18		42.66	6.88	42.2	2.693	0.37	25	
Agg 19		42.54	2.08	40.3	2.699	0.53	26	
Agg 20		42.25	24.3	38.4	2.705	0.59	25	

* - Agg 2 and Agg 6 are samples from the same quarry. However, the two samples were quarried at least two years apart.

** - All BSG and ABS tests met AASHTO T 85 precision requirements.

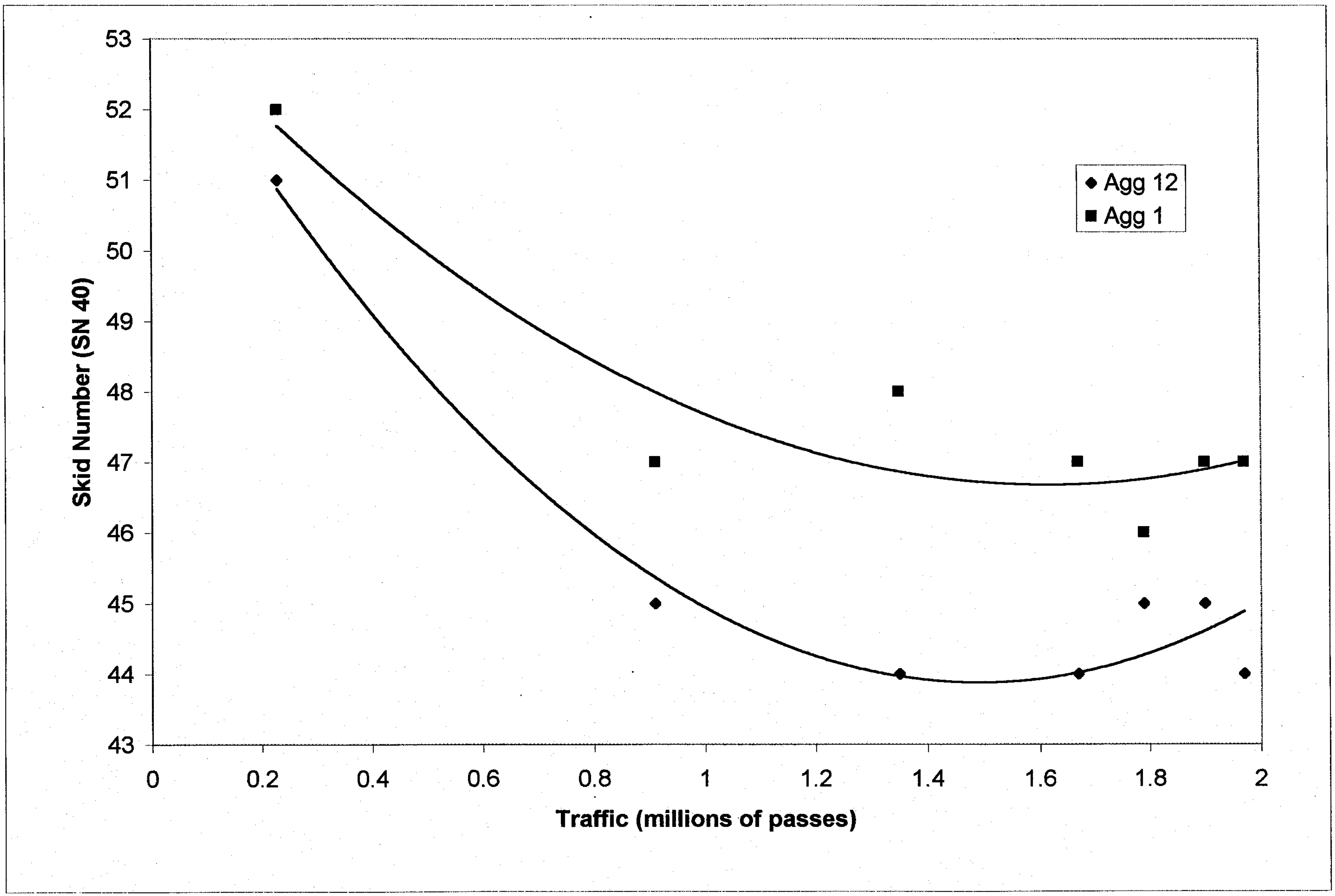


Figure 8. Skid Numbers versus Vehicle Passes for Agg 1 and Agg 12.

Table 4b. Phase III-Ext Aggregate Properties

Aggregate	TTTC	Final U (%)	% Silica	LOI (%)	BSG **	% ABS **	BPN 9	SN 40
Agg 1	42.91		22.84	35.8	2.734	0.759	24	47
Agg 2*	42.76		39.12	19.2	2.573	2.180	35	
Agg 3	44.32		20.84	25.7	2.594	1.504	28	
Agg 4	44.50		18.56	23.6	2.541	1.885	27	51
Agg 5	44.70		53.12	25.9	2.600	1.051	29	47
Agg 6*	44.05		50.06	17.0	2.589	1.369	30	55
Agg 7	42.69		46.48	18.0	2.637	1.548	34	51
Agg 8		42.57	16.72	39.9	2.764	0.614	25	
Agg 9		44.49	6.84	31.9	2.678	0.292	20	36
Agg 10		42.23		40.7	2.665	0.863	27	
Agg 11		42.67	5.52		2.790	0.422		
Agg 12		43.57	8.20	37.6	2.660	0.578	24	45
Agg 13		43.39	7.44	36.8	2.709	0.419	19	
Agg 14		41.57			Variable	Variable		

* - Agg 2 and Agg 6 are samples from the same quarry. However, the two samples were quarried at least two years apart.

** - All BSG and ABS tests met AASHTO T 85 precision requirements.

Activity 4. Analysis of Results

Uncompacted voids versus aging revolutions curves were plotted for all aggregates tested in Phase III extension. The slope of the last seven points on each curve was evaluated by linear regression. An aggregate was assumed to have achieved a terminal textural condition if the slope of the line was greater than -0.00003. This value was determined experimentally and may be adjusted should more data become available. The limiting slope value was chosen for two reasons. First, all TDOT proven-performing limestones (except Agg 12) had a slope greater than this value. Second, it allowed for some oscillation about the terminal textural condition similar to the oscillation of field skid numbers shown in Figure 7.

Three aggregates were deleted from further consideration. Agg 9 was found to be a mixture of relatively low silica limestone with chert and flint nodules. At the beginning of the testing the chert and flint nodules account for approximately 15% of the sample by weight. After 20000 aging revolutions, chert and flint nodules account for approximately 30% of the sample. The enrichment of the silica content of the total sample led to two problems. First, it was no longer modeling in-service behavior. Second, the specific gravity of the sample was continually changing as the percentage of high silica particles increased with continued aging, thus producing incorrect voids results. The authors researched the skid history of Agg 9 from other states and found that performance below TDOT expectations was common. It was reasoned that the small amount of high silica particles was inadequate to produce the desired level of skid resistance.

Agg 7 was also removed from consideration at this time. Figure 9 shows a plot of SN 40 vs. Vehicle Passes for a TDOT test strip containing Agg 7 as coarse aggregate in the bituminous surface course. Although both previous laboratory tests and the TDOT test strip suggest that Agg 7 is an excellent surface aggregate, Agg 7 is currently not in production and existing stockpiles have been depleted. The authors could not obtain a satisfactory sample of Agg 7. Finally, Agg 14 was removed from consideration. Agg 14 was the only gravel used in Phase III and therefore there was no basis for comparison.

The remaining aggregates tested in Phase III extension were placed into four groups by comparing them with TDOT proven performing aggregates. The first group had a TTC

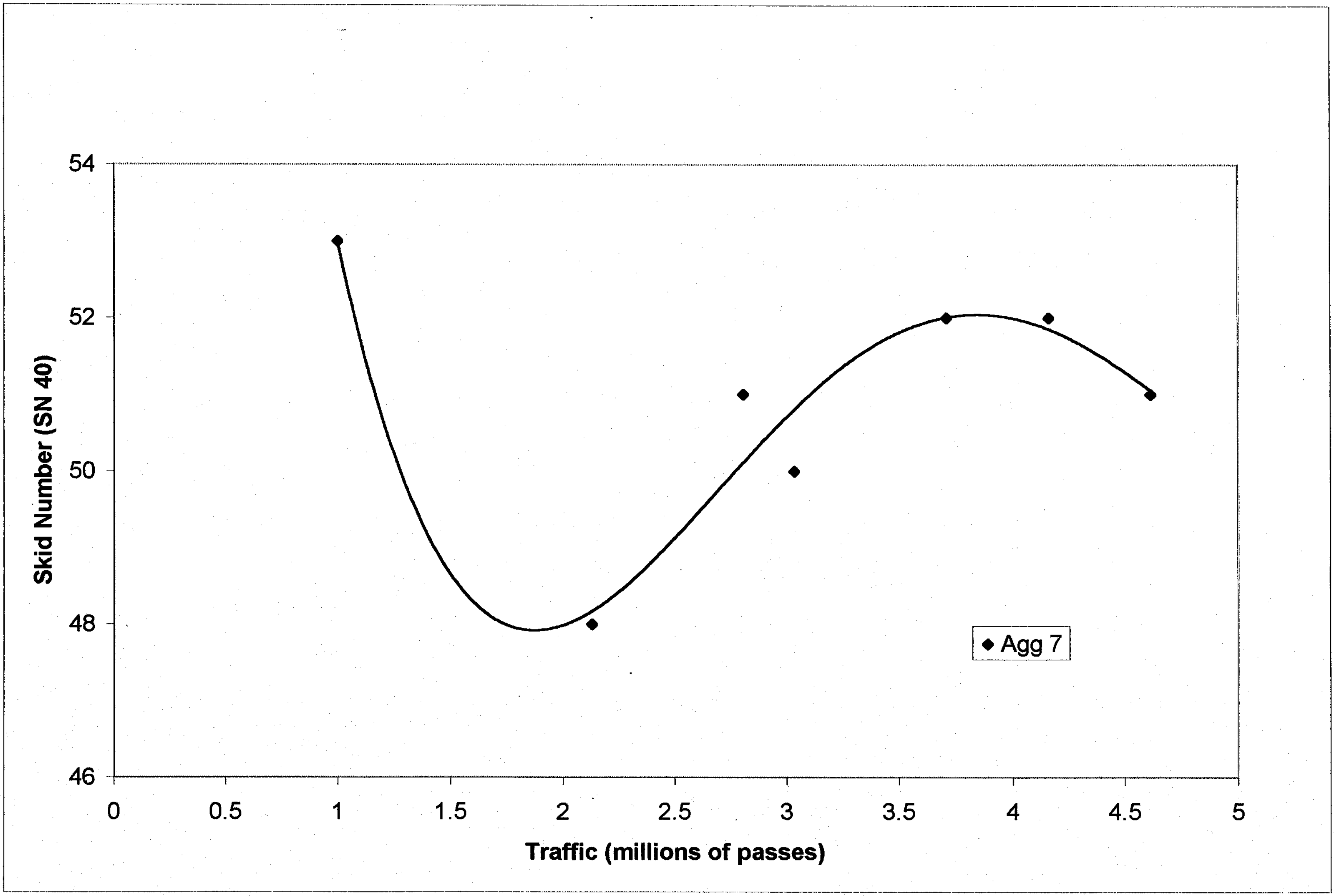


Figure 9. Field Skid Numbers versus Vehicle Passes for Agg 7

value greater than 43.5%. This group contained all limestones approved by TDOT for unlimited ADT use except Agg 2. The second group had a TTC value between 42.5 and 43.5%. This group contained two of the three other TDOT approved surface aggregates used in the project. The remaining TDOT approved surface aggregate, Agg 12 had a final voids value above this range but had not reached TTC when the sample was exhausted. It is probable that a third performance group exists, although no aggregates contained in the current study finished in this group. The existence of TDOT proven performing siliceous limestones at the < 12000 ADT level suggests that the category exists. The current TTC limits for this performance can only be estimated. The fourth and final group of aggregates did not reach a TTC value and continued to polish with continued aging. In this group, Agg 11 and Agg 13 appear very promising due to their high voids values at 20,000 aging revolutions, however insufficient sample was available to carry these samples out further. Figure 10 shows a plot of uncompacted voids versus aging revolutions for Agg 11.

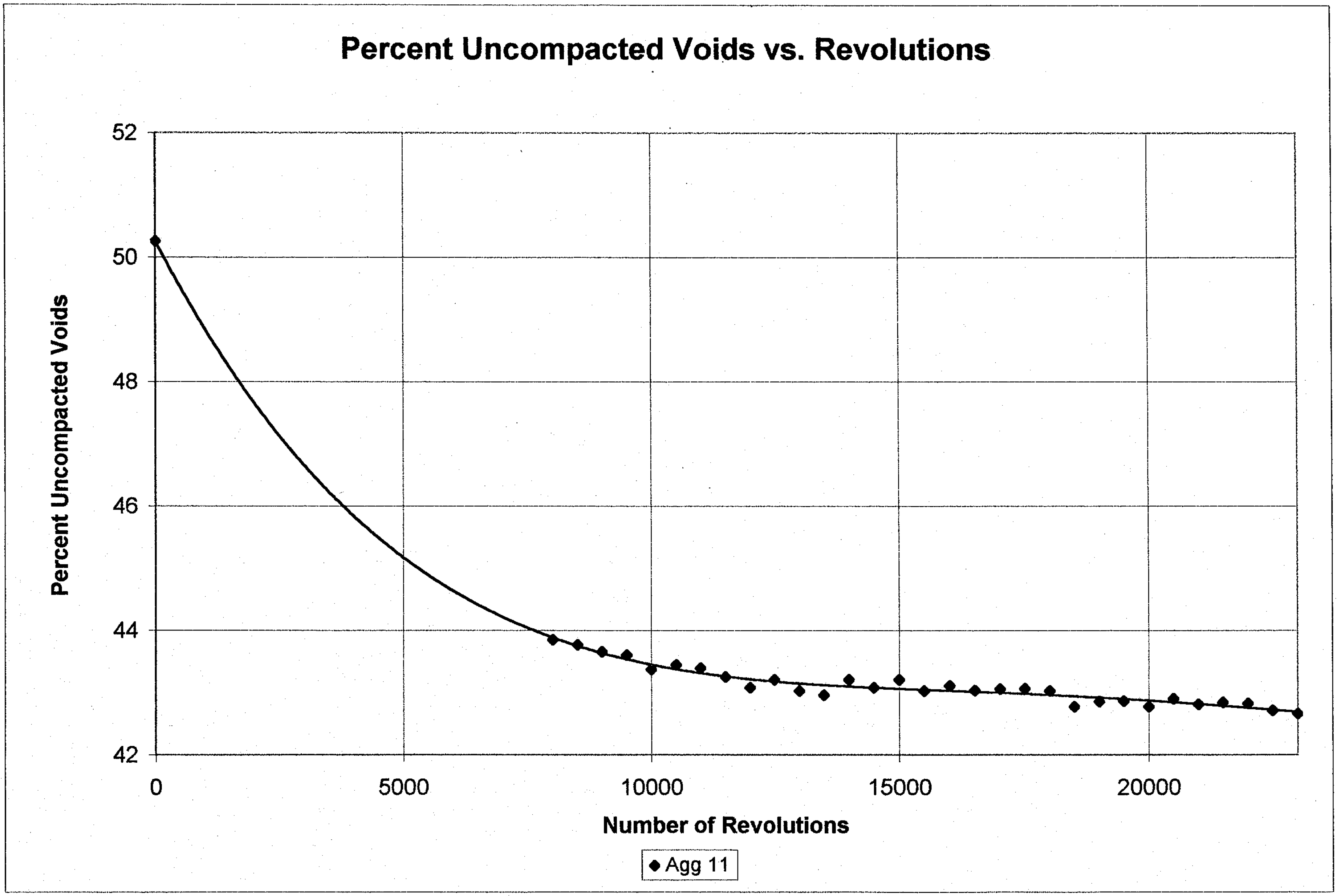


Figure 10. Percent Uncompacted Voids vs. Revolutions for Agg 11.

T^{3}CM Calibration

The T^{3}CM Uncompacted Voids Testing Apparatus was calibrated for a theoretical textural minimum condition. Steel ball bearings were used for the calibration. The ball bearings were 7.94 mm in diameter meeting the (6.35 to 9.52-mm) gradation for this test. Two specific gravities and six uncompacted voids test were conducted. The minimum textural value obtained from the testing procedure was 38.78%. The results from the calibration of the T^{3}CM can be seen in Table 5.

Table 5. Calibration Parameters

Aggregate	Steel Ball Bearings
Size	7.94 mm diameter
# of SG Tests	2
Avg. Specif Gravity	7.815
Range of SG Tests	0.008
Absorption (%)	Assumed to be 0
# Uncompacted Voids Tests	6
Average AASHTO TP 33 U%	38.78
% COV of Uncompacted Voids Test	0.07

T^{3}CM Repeatability

A limited procedural repeatability analysis was conducted on a large sample of Agg 6. The sample was obtained from a local pavement contractor. The sample was sieved to the appropriate gradation, thoroughly mixed, and divided into six large containers. Eighteen 12-kg samples were weighed out using 2 kg from each large container. The three students working on the project were instructed to conduct three terminal textural condition tests each. Each student was to obtain two pre-weighed 12-kg samples to perform each test. Operator Insensitivity was also looked at in Phase III under Tucker using the T^{3}CM.

During the repeatability testing, three different operators were used for the testing. The results showed that the method appeared to be both repeatable and operator insensitive (20). A total of 12 BSG and ABS tests and 2 LOI tests were also conducted on the same material. The results are shown in Table 6. According to ASTM C 670 this number of tests and operators is insufficient to draw conclusions. However, the results of these preliminary repeatability tests appear promising.

Table 6. Preliminary Repeatability Testing of Agg 6

Operator	TTC	Average	Std. Dev.	% COV
1 - 1	44.32			
1 - 2	44.21			
1 - 3	44.35	44.29	0.07	0.17
2 - 1	44.25			
2 - 2	44.06			
2 - 3	44.38	44.23	0.16	0.36
3 - 1	44.21			
3 - 2	43.96			
3 - 3	44.36	44.18	0.20	0.46
Overall		44.23	0.14	0.32

Ease of Performance

The results of this study have shown the T^3CM to be a logistical success. Cost effectiveness is a major factor of the Tennessee Terminal Textural Condition Method (T^3CM). Compared to the British Test involving the Polishing Wheel and the Pendulum, T^3CM has an initial cost of approximately $200 (assuming the lab is already equipped with the L.A. Abrasion and sieving devices), while the British Test has an initial cost of approximately $25,000 (16). Sample size was not a problem since the method used a sample size of 36-kilograms for Phase III and 60-kilograms for the extension. Ease of performance, repeatability, reduced cost (compared to the British Wheel and Pendulum), and operator insensitivity are advantages indicating that this test may be an ideal addition to normal aggregate pre-qualification tests. In addition, the maximum coefficient of variation of a set of voids tests at a given aging revolution never exceeded one percent for any project aggregate.

Comparison of Phase III and Phase III Extension

Figure 11 is a comparison of Agg 2 and Agg 6, which both came from the same quarry. Figure 11 shows both the Phase III and Phase III Extension results for Agg 2 and Agg 6. Initially the differing performance of Agg 2 and Agg 6 caused concern about the ability of the T^3CM to evaluate aggregate polish resistance. Agg 6 was quarried at least two years prior to Agg 2. The authors made inquiries to determine the cause of the difference. The quarry supervisor indicated that Agg 6 was obtained from much deeper in the pit, was harder and had a higher silica content. The operator of the TDOT locked-wheel trailer later confirmed that Agg 2 SN 40 values were typically lower than those of Agg 6. BPN data showed Agg 2 to be superior to Agg 6, however the T^3CM was able to accurately determine that Agg 6 was superior to Agg 2.

Figures 12 through 19 show plots of uncompacted voids versus aging revolutions for the remaining aggregates contained in both Phase III and Phase III Extension expect for the previously discussed Agg 9 and Agg 7. Figures 11-17 show that the TTC value achieved is not sensitive to the number of revolutions per aging cycle. Figures 11-15, 17 and 19 show that the number of revolutions required to reach a TTC value is dependent on the number of revolutions per aging cycle. One hundred revolutions per cycle aging require less revolutions than 500 revolutions per cycle to reach a TTC value.

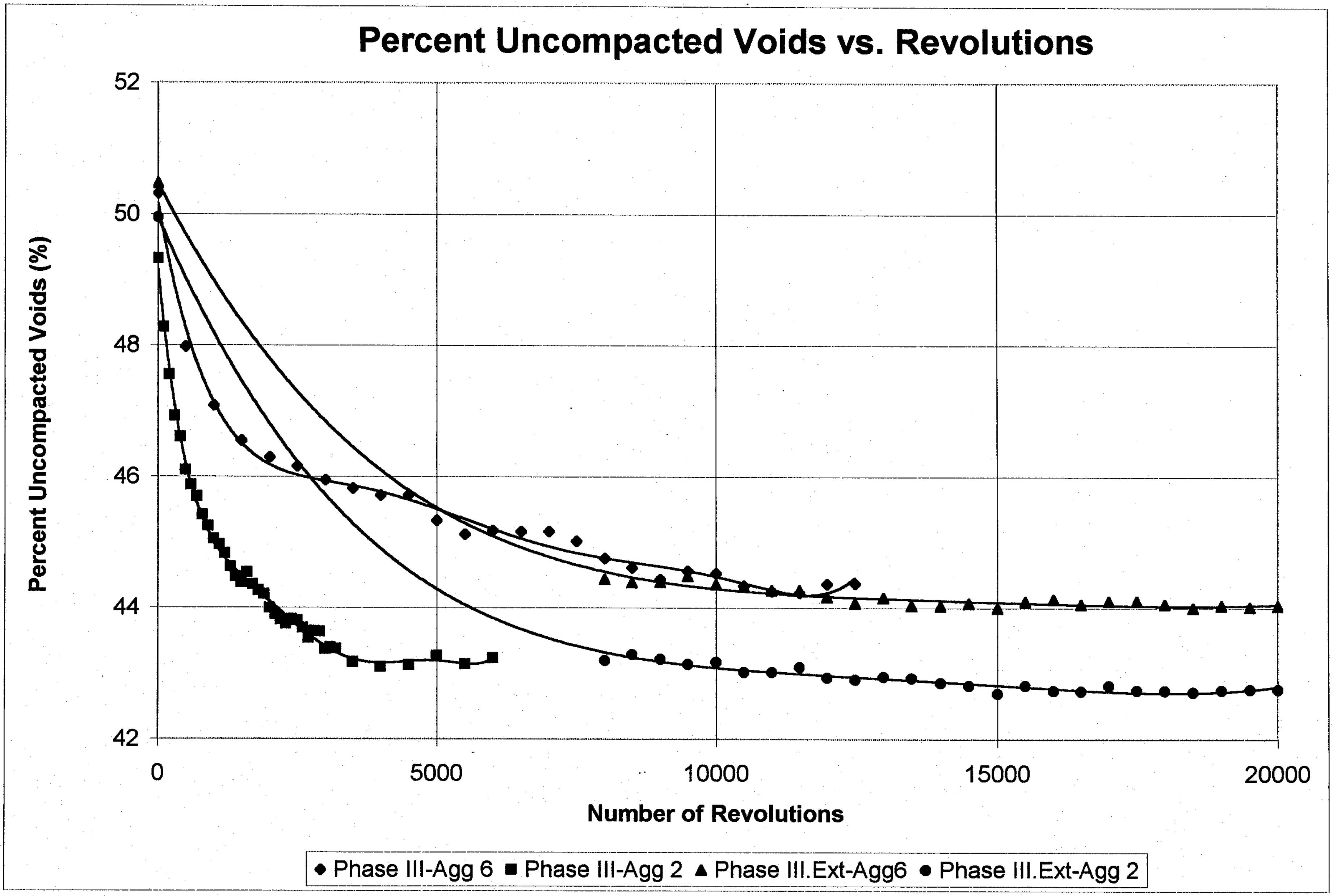


Figure 11. Comparison of Agg 2 (Phase III and Ext) and Agg 6 (Phase III and Ext)

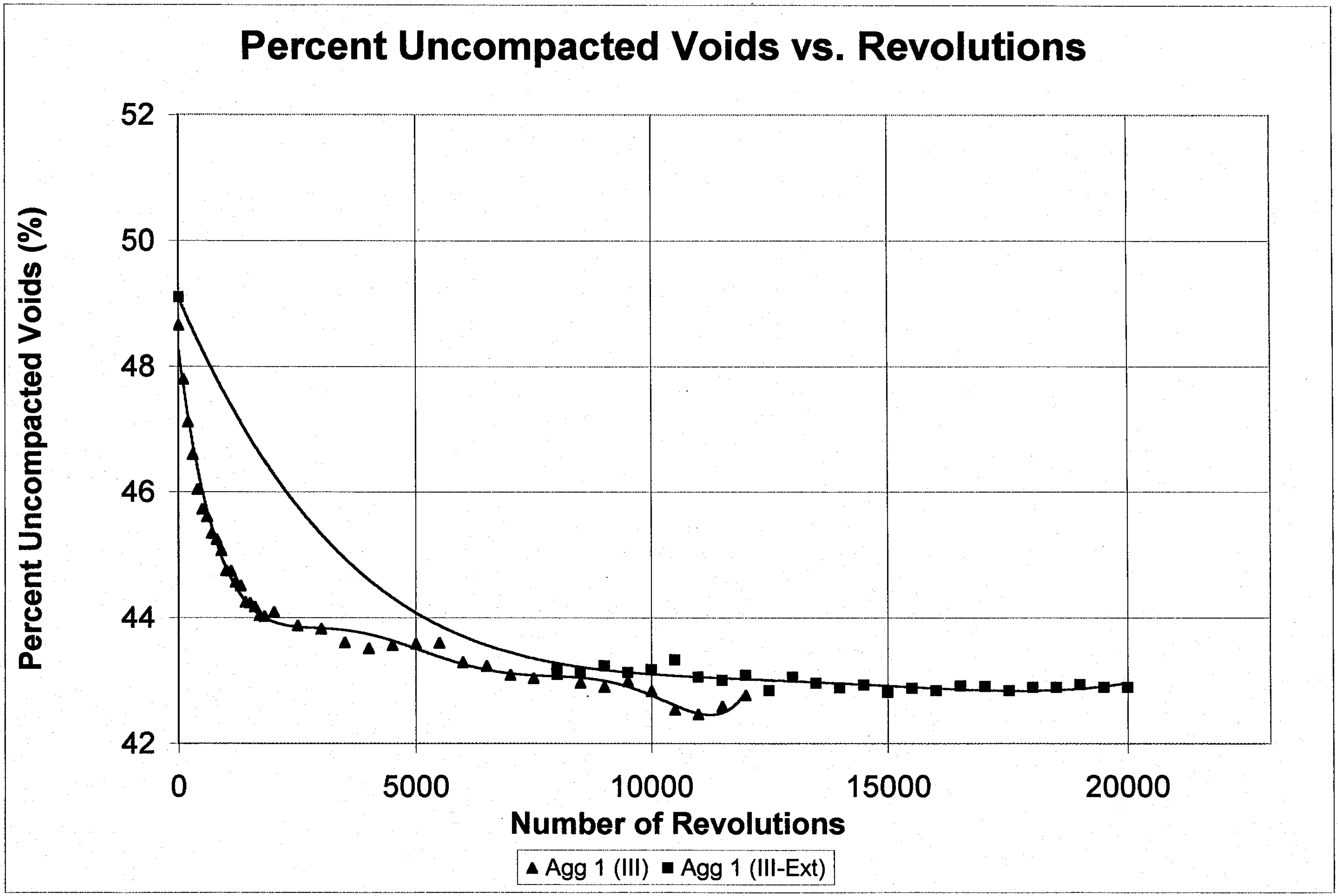


Figure 12. Comparison of Agg 1 (III) and Agg 1 (III-Ext)

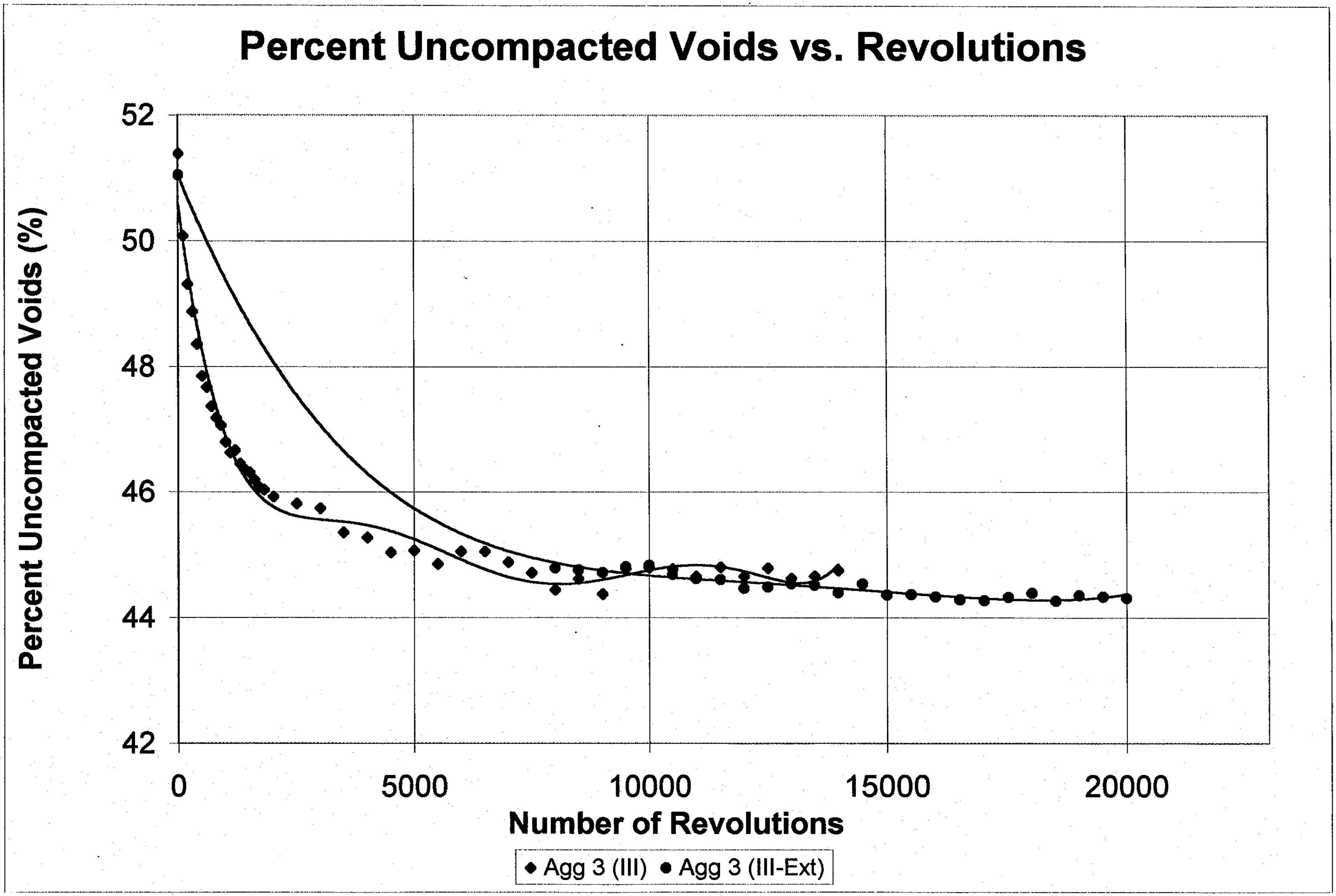


Figure 13. Comparison of Agg 3 (III) and Agg 3 (III-Ext)

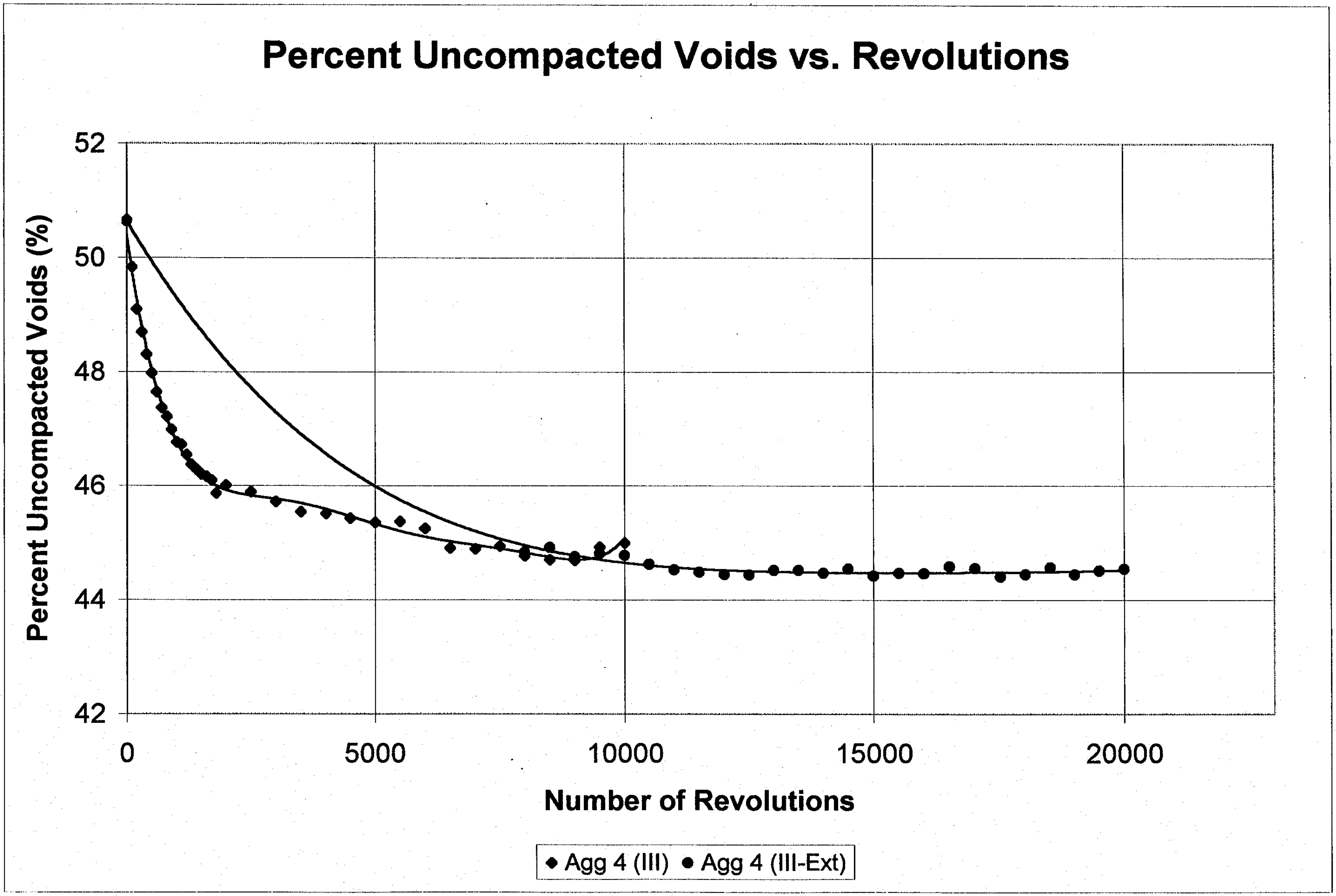


Figure 14. Comparison of Agg 4 (III) and Agg 4 (III-Ext)

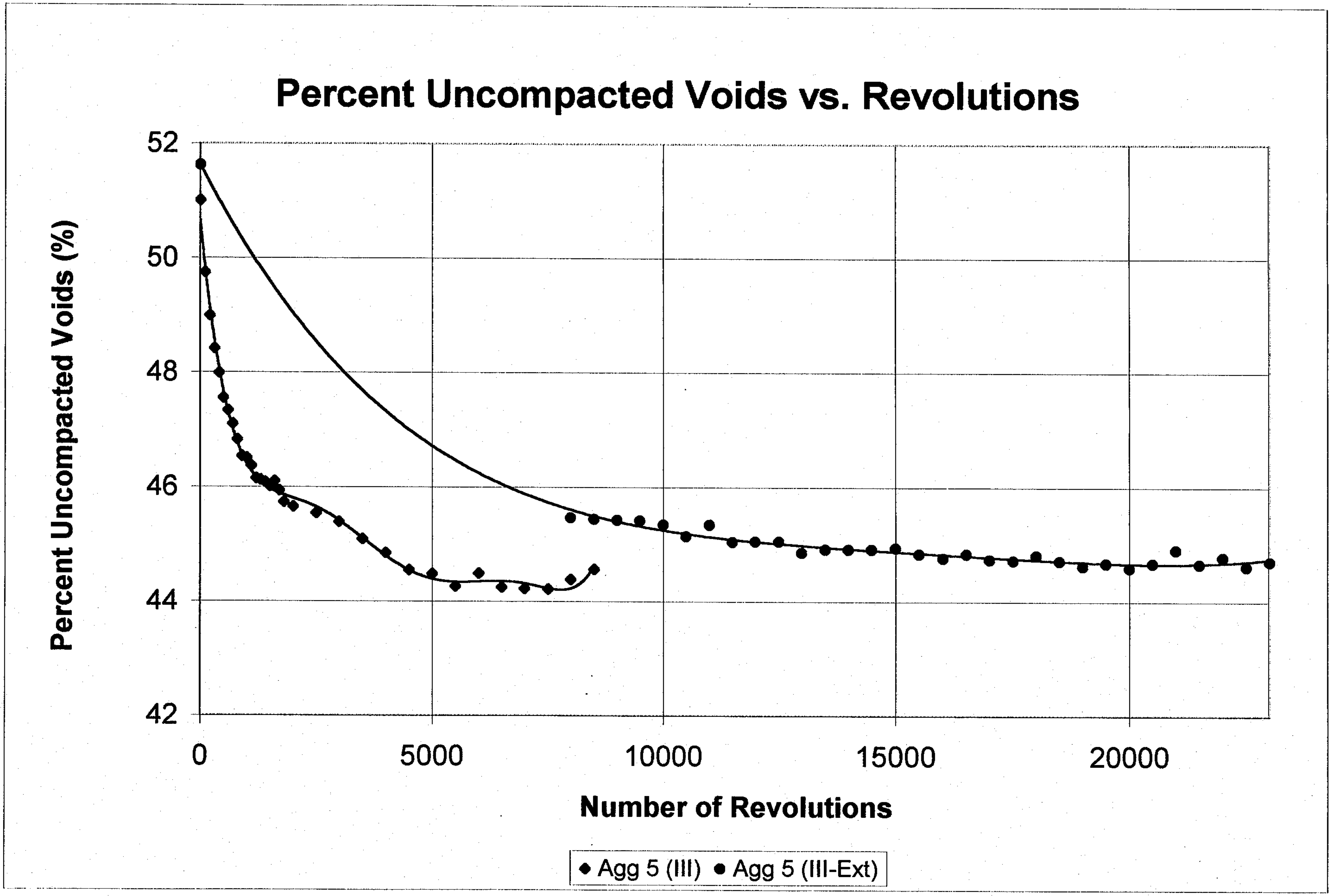


Figure 15. Comparison of Agg 5 (III) and Agg 5 (III-Ext)

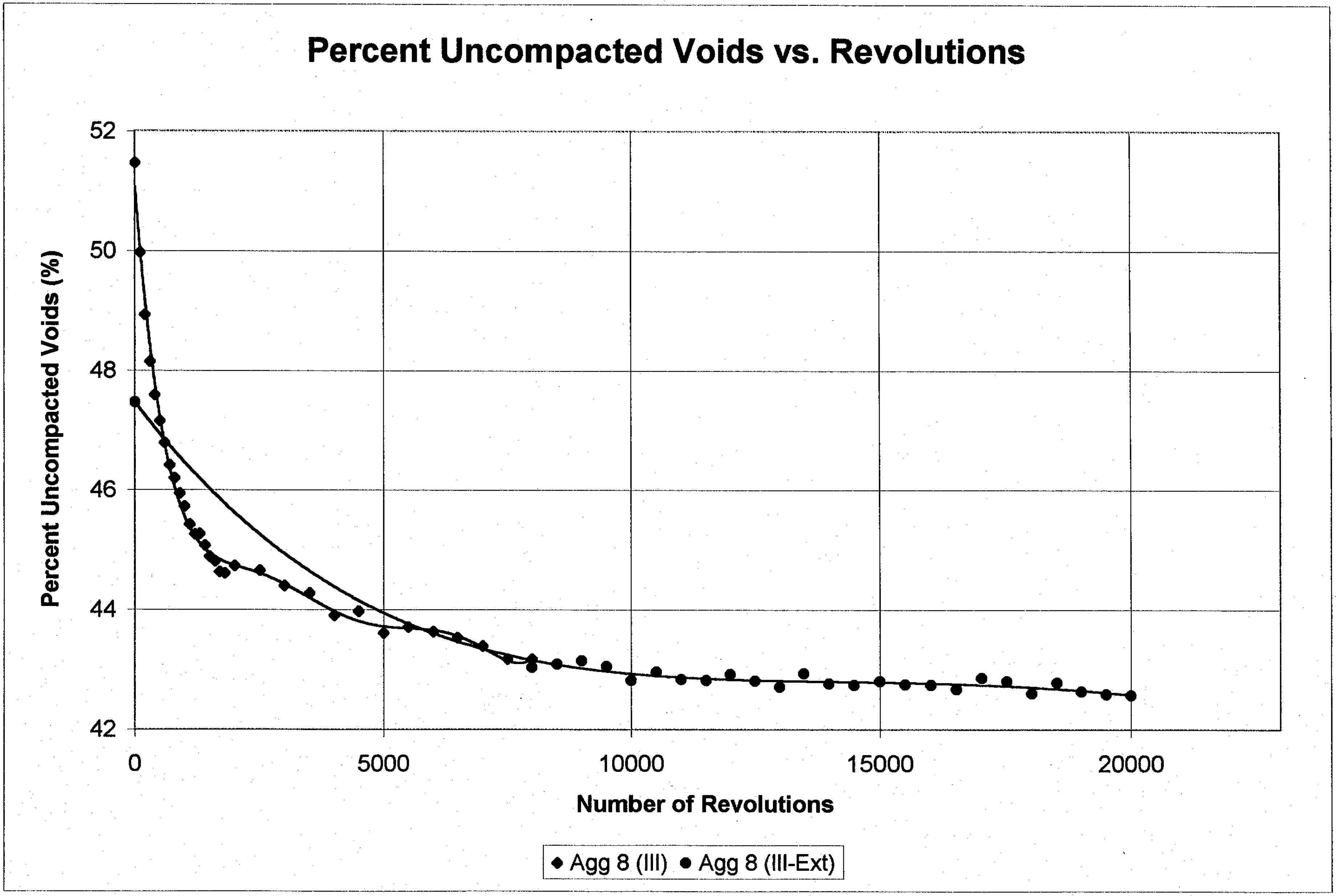


Figure 16. Comparison of Agg 8 (III) and Agg 8 (III-Ext)

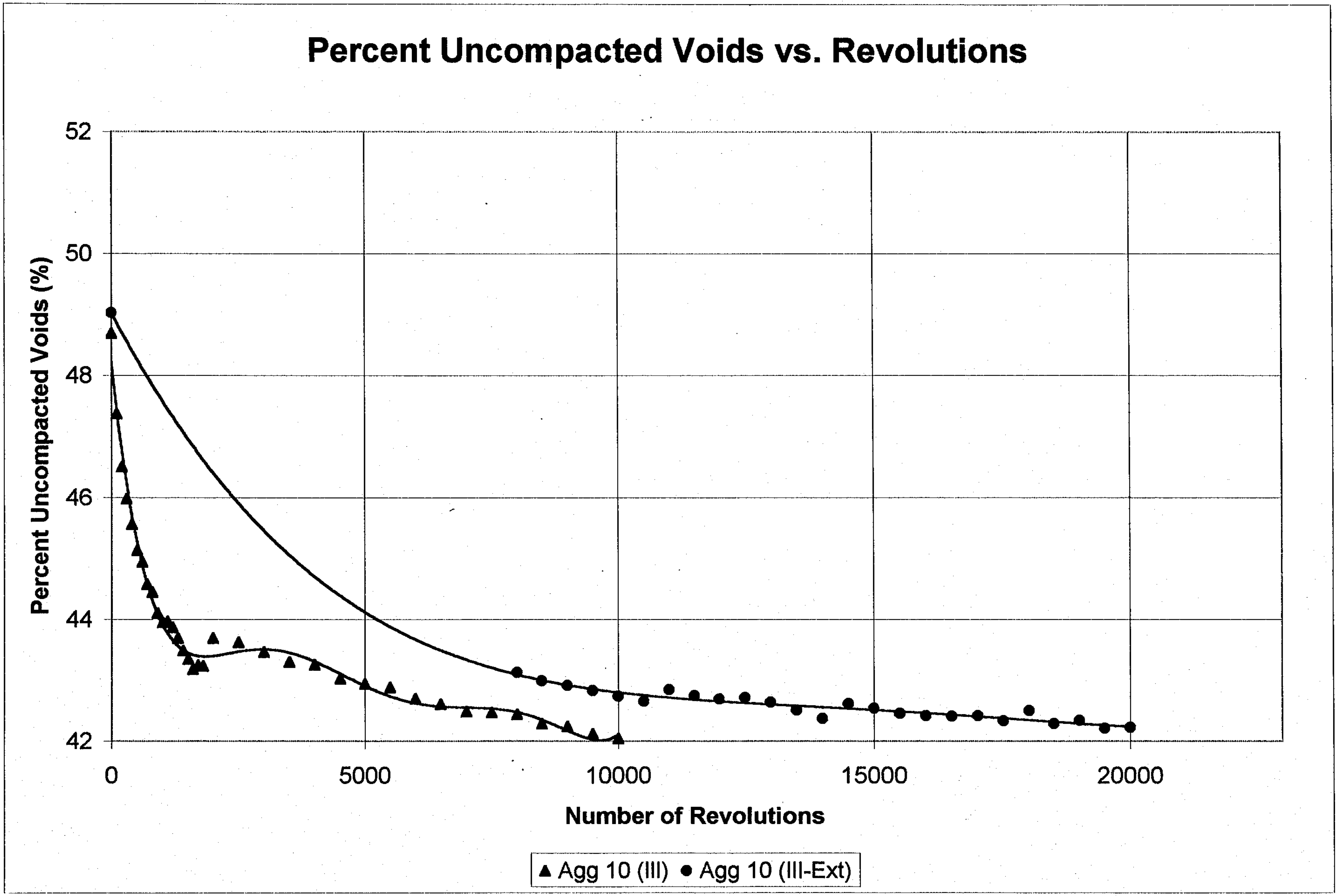


Figure 17. Comparison of Agg 10 (III) and Agg 10 (III-Ext)

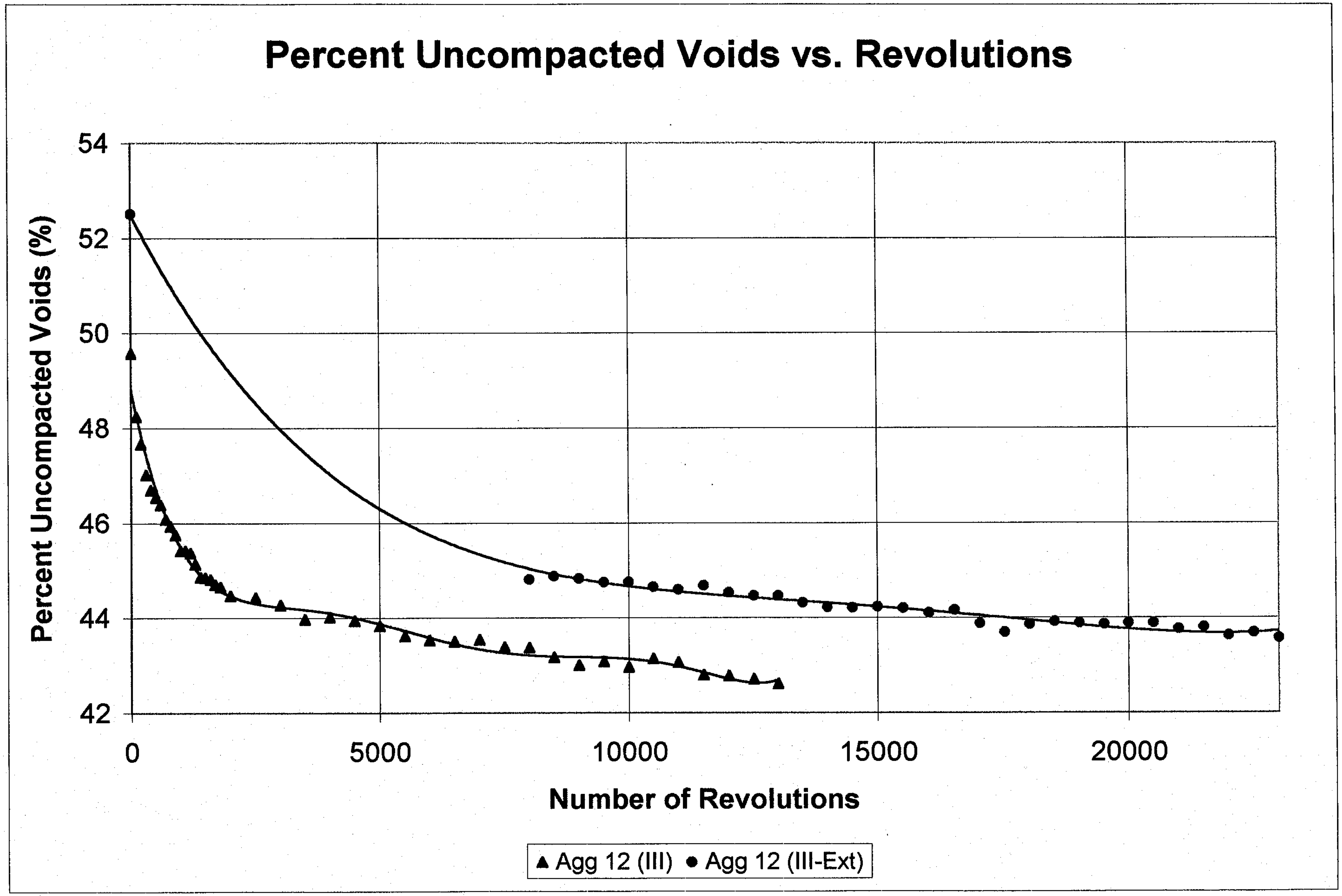


Figure 18. Comparison of Agg 12 (III) and Agg 12 (III-Ext)

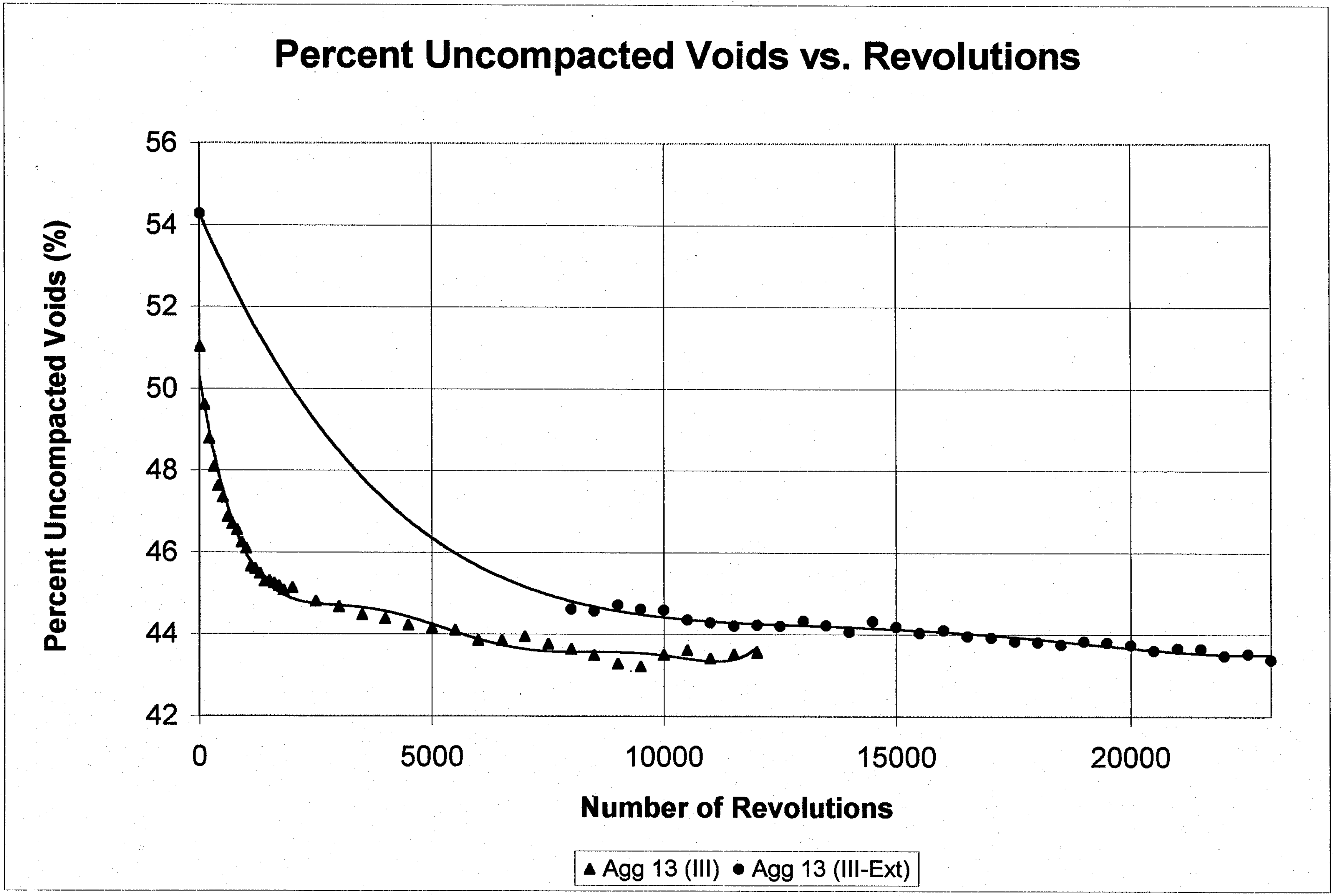


Figure 19. Comparison of Agg 13 (III) and Agg 13 (III-Ext)

Figures 16, 18, and 19 show that the initial angularity and surface texture condition of the aggregate effect the test only by requiring more aging to reach the later portion of the curve, especially for initial voids contents greater than 52.5%. Initial voids numbers greater than approximately 52.5% therefore require much larger samples to reach the later portion of the curve. These facts suggest that TTC is a function of mineral composition and distribution and is independent of crushing technique.

Activity 5. Correlation with Pavement Performance

Currently, only four aggregates have both extensive field data from a test strip and reliable TTC values available. Four sets of data are insufficient to draw meaningful conclusions from a correlation analysis. Table 7 shows the correlation of various aggregate properties with terminal skid numbers, SN 40, for these four aggregates. Due to the small amount of data available, the correlation of SN 40 values with T^3CM values is very poor.

The T^3CM only measures the aggregates polish resistance, a multitude of other factors also effect the SN 40 value obtained. The T^3CM ranked three of the four TDOT proven performing limestones approved for unlimited ADT use in the highest category. The remaining TDOT proven performing limestone approved for unlimited ADT use, whose performance has recently declined, was ranked in the second highest category. Also in the second highest category, a TDOT proven performing limestone was approved for use on surfaces with less than 30000 ADT. The only TDOT proven performing limestone not ranked in the upper two categories had voids numbers, which would have ranked it in the second highest category, when the sample was exhausted before it reached a TTC. In addition, the T^3CM ranked a promising aggregate currently performing well on a TDOT test strip in the highest category. Finally, T^3CM identified two promising aggregates in East Tennessee, one of which will be placed on a test strip in 1998.

Table 7. Correlation with Pavement Performance (SN 40)

SILICA %	0.199
LOI %	0.855
BSG	0.543
ABS	0.596
BPN 9	0.592
TTC	0.209

In comparison, BPN ranked Agg 16, a soft limestone with less than three-percent silica as the best surface aggregate in Tennessee. BPN also ranked Agg 10, another soft limestone with less than three-percent silica, superior to Agg 1, a TDOT proven performer. Further, it appears AASHTO was correct, percent silica is a good indicator of aggregates which are likely to be highly polish susceptible and should not be used as a principle means of predicting polish resistance. Finally, LOI is simply an improved percent silica test, easier to perform and more repeatable, but providing the same information as percent silica. Both LOI and percent silica were unable to detect the hetrogeneity of Agg 9, which had a few particles high in silica and the vast majority of particles virtually devoid of silica. Field performance records from other states indicated that Agg 9's polish resistance was unsatisfactory for most surface applications. T^3CM was able to correctly identify this condition.

In summary, T^3CM appears to be the conservative, reliable surface aggregate pre-evaluation method. T^3CM measures what is really important in selecting a bituminous surface aggregate, the aggregate's terminal textural condition. It is not simply an indicator of probable poor performers. T^3CM appears to be superior to BPN, percent silica and LOI since to date it has not produced a false positive result, it is more repeatable, not operator sensitive, is easy to perform, and inexpensive. Further, T^3CM's ability to identify aggregates which will perform well in limited ADT applications has the potential to reduce the cost of surface aggregate to TDOT while maintaining a high level of safety for the motoring public. As T^3CM identifies more promising surface aggregates, haul distances for approved aggregates decrease and aggregate price competition increases resulting in reduced cost of surface aggregates without jeopardizing the safety of the motoring public.

Activity 6. Implementation Recommendations

It is recommended that the T^3CM be used as a pre-evaluation procedure for aggregate sources. In addition, the T^3CM should be used as a verification test for random aggregate lots. The groupings shown in Table 8 are suggested for the consideration of the TDOT Division of Materials and Tests. The first column is the TTC value of an aggregate; not simply the final voids number, and may change in the future should more data become available. The second column is the probable performance level based on the TTC values of the TDOT proven performing siliceous limestones. The final column is the recommended ADT value of the initial test strip. The performance of all new aggregates should be confirmed with one or more test strips prior to receiving approval.

The ADT selected for the test strip should be directly proportional to the aggregate's TTC value.

Table 8. Implementation Recommendations

T^3CM (% Voids)	Probable Performance Level (ADT)	Recommended Initial Test Strip (ADT)
> 43.5	Unlimited	< 30,000
42.5 - 43.5	< 30,000	< 20,000
42.0 - 42.5	< 12,000	< 12,000

In addition to the above recommendations, it was also recommended that TDOT consider placing a test strip of Agg 13 and additional test strips of Agg 5 based on their performance with the T^3CM. The recommendation for Agg 13 is based on its potential for polish-resistance as well as the lack of fully approved aggregate sources in its geographical location of Tennessee.

Activity 7. Training Seminar

As per the request of the monitoring team chairman, the training seminar will be held in February 1998.

CONCLUSIONS

On the basis of the aggregate tested and the analysis done, the following conclusions can be drawn:

1. The T^3CM ranked five of six TDOT proven performing limestones in the upper two performance categories. The remaining TDOT proven performing limestone sample was exhausted before testing was concluded.

2. The T^3CM appears to be able to better discern the performance of Tennessee bituminous surface aggregates than the British Pendulum and British Polishing Wheel Method, Insoluble Residue or Loss-On-Ignition. Unlike the other methods, to date the T^3CM has not produced a false positive result.

3. The T^3CM is logistically superior to the British Pendulum and British Polishing Wheel Method in terms of repeatability, ease of operation, cost, operator sensitivity and operator skills needed.

4. The T^3CM has identified several promising new aggregate sources. Some of these new sources are in areas where approved bituminous surface aggregate sources are scarce.

FURTHER RESEARCH NEEDS

1. Additional testing, with larger sample sizes, needs to be conducted on Agg 11, Agg 12, and Agg 13. These aggregates had high final voids content and their samples were exhausted. Due to either small particle size or high angularity, the standard sample size was insufficient to achieve a definitive result.

2. More aggregates from East Tennessee and Eastern Middle Tennessee need to be evaluated due to the scarcity of approved bituminous surface aggregates in these areas of the state.

3. Additional high and mid-level performance aggregates need to be tested to confirm the proposed cut-off values in Table 8.

4. Other types of aggregates such as granites need to be tested to confirm the applicability of the T^3CM to these aggregates.

5. The modified AASHTO TP 33 voids device used herein might be ideal for determining coarse aggregate angularity for the Superpave asphalt mixture design and analysis system. Superpave currently uses a fractured face count for coarse aggregate angularity determination. The modified AASHTO TP 33 voids device produces low coefficient of variation results of a more quantitative nature in a fraction of the time. Further research is needed to determine the applicability of the device to Superpave needs.

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APPENDIX A

Standard Test Method for

Pre-evaluation of Coarse Aggregate for

Bituminous Surface Courses by the

Tennessee Terminal Textural Condition Method

Standard Test Method for

Pre-evaluation of Coarse Aggregate for

Bituminous Surface Courses by the

Tennessee Terminal Textural Condition Method

1. SCOPE

1.1 This test method is intended for use in determining the terminal textural condition of coarse aggregate for use in bituminous surface courses. The method uses single size aggregate (6.35 - 9.52 mm) and a modified version of the AASHTO TP 33 uncompacted voids device as well as the L. A. Abrasion device (AASHTO T 96).

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards:

M 92 Wire-Cloth Sieves for Testing Purposes

M 231 Weighing Devices Used in Testing Materials

T 2 Sampling Aggregates

T 19 Unit Weight and Voids in Aggregate

T 85 Specific Gravity and Absorption of Coarse Aggregates

T 96 Test Method for Resistance to Degradation of Small-Sized Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

TP 33 Standard Method for Uncompacted Void Content of Fine Aggregate

3. DEFINITION

3.1 Tennessee Terminal Textural Condition - A numerical rating developed from average percent air voids measurements indicative of an aggregate's susceptibility to polishing in use as coarse aggregate in a bituminous surface course.

4. SIGNIFICANCE AND USE

4.1 The Tennessee Terminal Textural Condition Method (T^3CM) is intended as an aggregate source pre-evaluation procedure for coarse aggregates to be used in bituminous surface courses. In addition, the T^3CM should be used as a verification test for random aggregate lots.

4.2 The T^3CM provides a basis for quantitative comparison of polish resistance of various aggregate sources.

5. APPARATUS

5.1 Modified uncompacted void content apparatus conforming to the requirements of Figure A-1.

5.2 Cylindrical measure - $0.0028 m^3$, conforming to AASHTO T 19 (see Figure A-1).

5.3 A metal funnel (see Figure A-1).

5.4 Sieves - 9.52 and 6.35 mm sieves, conforming to AASHTO M 92.

5.5 Balances - a balance or scale conforming to the requirements of AASHTO M 231, Class G 2. A balance or scale conforming to the requirements of AASHTO M 231, Class G 5.

5.6 Los Angeles Machine conforming to the requirements of AASHTO T 96.

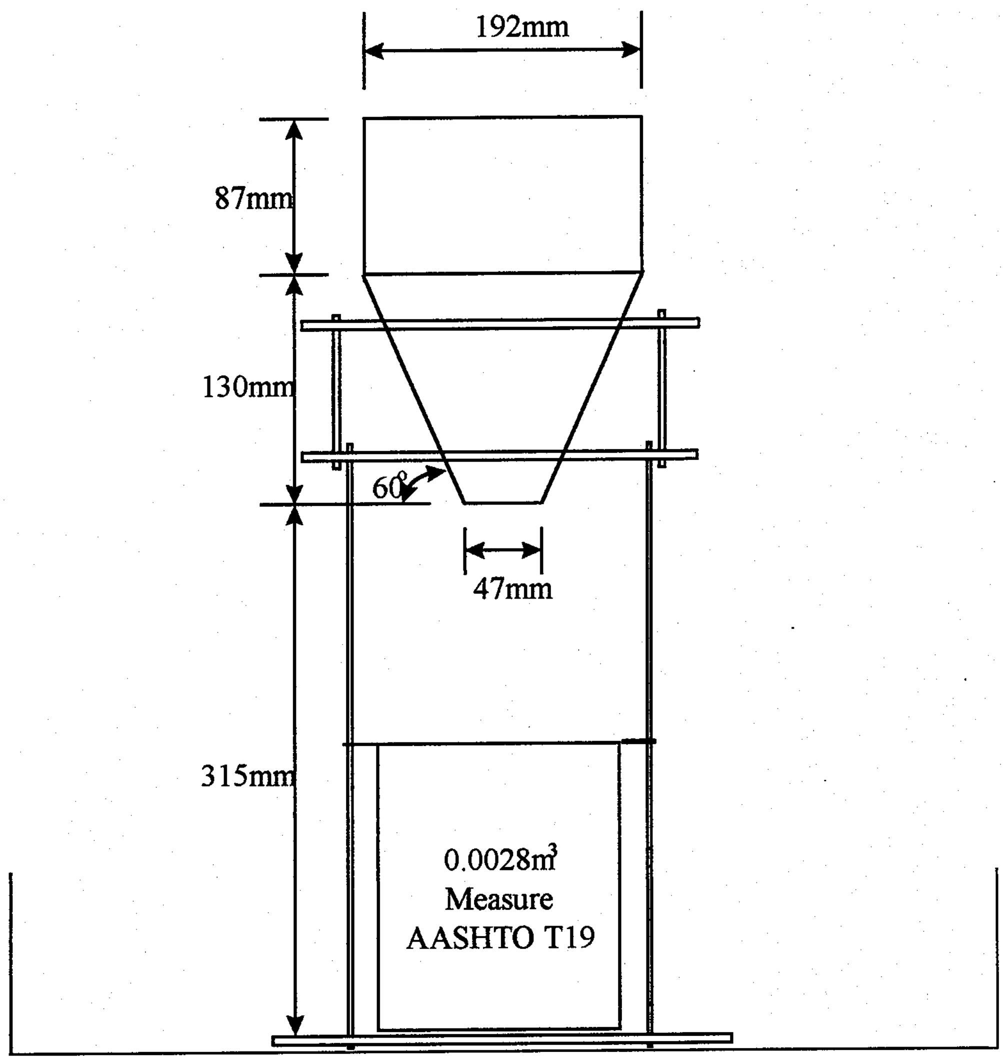

Figure A-1. Schematic T^3CM Uncompacted Voids Content Apparatus
Modified AASHTO TP 33

5.7 Drying Oven - A thermostatically controlled drying oven capable of maintaining a temperature of 110 +/- 5° C for drying aggregates.

5.8 Straightedge - A hardened-steel straightedge at least 254 mm in length. It shall have one beveled edge, and at least one longitudinal surface shall be plane within 0.1 percent.

5.9 Containers - suitable containers made of material resistant to corrosion and not subject to change in weight or disintegration on repeated heating and cooling.

6. SAMPLE

6.1 Obtain a sample large enough to produce at least 72 kilograms of oven-dry material passing the 9.52 mm sieve and retained on the 6.35 mm sieve in accordance with AASHTO T 2 Section 4.3.3. Discard all materials coarser than 9.52 mm and finer than 6.35 mm. Wash the sample over a 1.70-mm sieve and oven-dry for 24 hours or to an essentially constant mass.

6.2 Divide the sample into five 12-kilogram samples and one 12-kilogram sample for specific gravity determination.

7. SPECIFIC GRAVITY DETERMINATION

7.1 Conduct five bulk dry specific gravity tests on portions of the 12-kilogram sample in accordance with AASHTO T 85.

8. UNCOMPACTED VOIDS TESTING PROCEDURE

8.1 For the remaining five 12 kilogram samples (or remainder thereof) conduct three voids test at 0 revolutions to obtain an initial voids number. No void testing occurs between 0 and 8000 revolutions.

8.2 When the samples have been aged 8000 revolutions, the entire sample will be weighed and distributed into two samples. If the individual samples exceed 12 kilograms, reduce them to 12 kilograms by wasting. Conduct three voids tests on each individual sample, establishing six voids tests for the age.

8.3 For each simulated age from 8000 through 14000 revolutions, conduct three tests on each sample for a total of six voids tests.

8.4 When the samples have been aged 14000 revolutions, the entire sample will be combined, weighed and distributed into one 12-kilogram sample. If the sample exceeds 12 kilograms, reduce it to 12 kilograms by wasting. Conduct six voids tests on the sample.

8.5 For each simulated age from 14000 through 20000+ revolutions, conduct six tests on the sample. (See sample data sheet attached at the end of this specification.)

8.6 To conduct a voids test, determine the mass and volume of the AASHTO T 19 measure.

8.7 Reassemble the modified AASHTO TP 33 device and place on a stable, vibration-free table or counter. A large pan placed under the uncompacted voids apparatus is useful in containing the overflow.

8.8 Block the funnel opening with flat plate and fill the funnel with aggregate.

8.9 Remove the plate and allow the aggregate to flow through the funnel over-filling the measure.

8.10 Strike off the excess aggregate with the steel straightedge, being careful not to compact aggregate into the mold during strike off.

8.11 Determine the net mass of aggregate in the measure.

9. SIMULATED AGING PROCEDURE

9.1 Age all samples by placement of the sample in the L. A. Abrasion device with no steel spheres and rotating for 500 revolutions.

9.2 During the aging procedure the samples will begin to diminish. Upon this degradation the sample may be combined and re-weighed to establish a new sample mass. The number of samples may be reduced to either three or four samples at a convenient age prior to 8000 revolutions limiting each sample to twelve kilograms. No sample shall be wasted.

9.3 At 8000 revolutions the samples will be combined, weighed, and distributed into two 12 kilogram samples. If the individual samples exceed 12 kilograms, reduce them to 12 kilograms by wasting.

9.4 At 14000 revolutions, the entire sample will be combined, weighed into one 12-kilogram sample. If the sample exceeds 12 kilograms, reduce it to 12 kilograms by wasting.

9.5 After each 500 revolutions, each sample must be sieved over a 6.35-mm sieve to maintain an individual size gradation.

9.6 In an alternating manner, perform voids test as per section 8 and age the sample as per section 9 until the sample has been aged 20000 revolutions. The voids test procedures and aging may be extended past the 20000 revolutions if terminal texture is in question. For the terminal texture to be in question, the sample may still have a tendency to polish.

10. CALCULATIONS

10.1 Calculate the uncompacted air voids, U, in percent as follows:

$$U = \{[V - (F / G)] / V\} * 100$$

where: V = volume of cylindrical measure, ml;

F = net mass (grams) of aggregate in measure (gross mass minus the mass of the measure); and

G = bulk dry specific gravity of aggregate.

10.2 Calculate the Tennessee Terminal Textural Condition Rating as follows:

An aggregate has reached the terminal textural condition if the linearly regressed slope of the last seven points has a –0.00003 or greater slope. This small negative slope is allowed due to the cyclic oscillations, which occur due to well-dispersed siliceous materials. After having reached the terminal textural condition, the Tennessee Terminal Textural Condition Rating is equal to the average of the last seven average percent air voids tests. If the sample is insufficient for conducting an air voids test, the Tennessee Terminal Textural Condition Rating is reported as non-terminal and the final air voids value is reported. An example can be seen in Table A1.

Table A.1

Number of Revolutions	Percent Uncompacted Voids
17000	44.56
17500	44.41
18000	44.45
18500	44.57
19000	44.45
19500	44.51
20000	44.55
Average	44.50
Slope	0.00001

11. REPORT

11.1 Report the Tennessee Terminal Textural Condition Rating to the nearest hundredth of a percent.

11.2 Report the bulk-dry specific gravity and absorption in percent.

12. PRECISION

12.1 No precision statement is currently available. However, limited experience to date has shown that the coefficient of variation of individual void tests to produce an average at a given number of aging revolutions should be less than one percent.

Further, the coefficient of variation for aggregate ratings by two different operators should not exceed two percent.

Aggregate ________________ Quarry location ________________ Technician ________________

Date Recieved ________________ Test dates ________________

BSG Test #	1	2	3	4	5	Avg.	Actual Range	
SSD Wt. (g	2084.4	2083.6	2084.0	2081.9	2083.0			
Sumb. Wt.	1281.0	1279.1	1279.1	1276.5	1278.2			
OD. Wt. (g	2045.8	2044.0	2046.5	2042.9	2045.0			Min 2000g OD wt
Bulk Dry S	2.5464	2.5407	2.5426	2.5365	2.5410	2.541	0.0099	Max Range = 0.0351
Absorption	1.887	1.937	1.832	1.909	1.858	1.885	0.1050	Max Range = 0.34%

T19 Mold Wt. (g) 1704.6 T19 Mold Volume (ml) 2825.5

Total Weight of T19 Mold + Sample (g)

Void's test #	1	2	3	4	5	6	# Ind.
0	5254.3	5260.1	5239.3	5258.2	5251.8	5255.3	
0	5277.5	5234.3	5240.0	5252.8	5253.3	5256.1	
0	5224.7	5228.8	5249.7				15.5
8000	5671.8	5661.3	5661.2	5675.2	5654.6	5670.6	5.6
8500	5643.6	5643.3	5660.2	5666.2	5677.0	5669.6	5.4
9000	5655.7	5657.2	5676.6	5679.6	5682.4	5676.9	5.3
9500	5656.4	5669.7	5660.4	5678.2	5673.3	5666.0	5.2
10000	5673.0	5642.4	5670.7	5670.1	5680.5	5682.6	5.1
10500	5696.3	5670.9	5678.0	5666.7	5700.0	5671.9	4.8
11000	5690.1	5685.3	5681.1	5688.2	5682.1	5699.1	4.6
11500	5693.8	5695.5	5689.6	5711.4	5682.3	5673.3	4.5
12000	5692.1	5677.9	5668.3	5712.4	5695.3	5714.6	4.4
12500	5684.1	5688.8	5701.5	5697.3	5696.3	5695.7	4.3
13000	5678.7	5681.3	5703.8	5691.8	5695.1	5680.0	4.2
13500	5697.0	5688.4	5687.9	5679.9	5696.0	5680.0	4.1
14000	5693.3	5680.4	5699.6	5697.0	5689.5	5689.9	2.8
14500	5685.2	5679.2	5673.0	5693.6	5698.3	5689.5	2.7
15000	5696.4	5674.5	5711.8	5682.6	5708.2	5700.3	2.6
15500	5693.9	5678.2	5698.7	5706.5	5689.7	5683.5	2.6
16000	5698.8	5693.0	5689.8	5681.8	5685.2	5707.4	2.5
16500	5671.7	5668.5	5684.2	5681.4	5702.1	5695.8	2.5
17000	5687.0	5686.0	5694.7	5678.2	5687.9	5682.0	2.5
17500	5695.8	5678.4	5703.8	5691.6	5690.6	5719.1	2.5
18000	5689.7	5681.7	5712.6	5696.5	5688.6	5693.1	2.4
18500	5673.9	5682.7	5694.3	5662.2	5683.7	5712.5	2.4
19000	5694.4	5700.4	5690.4	5695.9	5691.7	5690.1	2.3
19500	5677.9	5686.0	5698.1	5691.0	5692.7	5688.7	2.3
20000	5676.0	5679.6	5670.2	5705.5	5682.2	5704.4	2.3

Percent Uncompacted Voids (U %)

Void's test #	1	2	3	4	5	6	Avg.	% CV
0	50.567	50.486	50.776	50.513	50.602	50.553		
0	50.244	50.846	50.766	50.588	50.581	50.542		
0	50.979	50.922	50.631				50.64	0.37
8000	44.753	44.899	44.901	44.706	44.992	44.770	44.84	0.25
8500	45.146	45.150	44.914	44.831	44.681	44.784	44.92	0.43
9000	44.977	44.956	44.686	44.644	44.605	44.682	44.76	0.37
9500	44.967	44.782	44.912	44.664	44.732	44.834	44.82	0.25
10000	44.736	45.162	44.768	44.777	44.632	44.603	44.78	0.45
10500	44.412	44.765	44.667	44.824	44.360	44.752	44.63	0.44
11000	44.498	44.565	44.623	44.525	44.610	44.373	44.53	0.21
11500	44.447	44.423	44.505	44.201	44.607	44.732	44.49	0.40
12000	44.470	44.668	44.802	44.188	44.426	44.157	44.45	0.58
12500	44.582	44.516	44.339	44.398	44.412	44.420	44.44	0.20
13000	44.657	44.621	44.307	44.474	44.428	44.639	44.52	0.32
13500	44.402	44.522	44.529	44.640	44.416	44.639	44.52	0.23
14000	44.454	44.633	44.366	44.402	44.506	44.501	44.48	0.21
14500	44.566	44.650	44.736	44.449	44.384	44.506	44.55	0.29
15000	44.410	44.715	44.196	44.603	44.246	44.356	44.42	0.46
15500	44.445	44.664	44.378	44.270	44.504	44.590	44.48	0.32
16000	44.377	44.458	44.502	44.614	44.566	44.257	44.46	0.29
16500	44.754	44.799	44.580	44.619	44.331	44.419	44.58	0.41
17000	44.541	44.555	44.434	44.664	44.529	44.611	44.56	0.18
17500	44.419	44.661	44.307	44.477	44.491	44.094	44.41	0.43
18000	44.504	44.615	44.185	44.409	44.519	44.456	44.45	0.33
18500	44.724	44.601	44.440	44.887	44.587	44.186	44.57	0.54
19000	44.438	44.355	44.494	44.417	44.476	44.498	44.45	0.12
19500	44.668	44.555	44.387	44.486	44.462	44.518	44.51	0.21
20000	44.694	44.644	44.775	44.284	44.608	44.299	44.55	0.47