2011

Development and Implementation of the Next Generation Concrete Surface

Final Report

The Next Generation Concrete Surface (NGCS) is the first new concrete texture introduced in the past 20 to 30 years. It was conceived as a manufactured texture whose properties are consistent and predictable and represents the quietest non-porous concrete texture developed to date. At the time of construction the NGCS is typically 99 dBA in noise level and has a range up to 101 dBA over time. Although the NGCS has only been in service 3 years, it is under evaluation at 13 locations in 9 states with more to come.

NGCS Texture

ACPA
Larry Scofield
5/9/2011

Introduction

The Next Generation Concrete Surface (NGCS) is the first new concrete pavement texture introduced in the last 20 to 30 years. It is also the quietest texture yet developed for non-porous concrete pavements. The texture can be constructed on newly constructed pavements as well as existing pavements. It uses conventional diamond grinding equipment and blades but in a somewhat different head configuration.

In the summer of 2003 when the Arizona Department of Transportation (ADOT) began covering up the freeway system of the fifth largest city in the United States, the concrete industry took notice. For the first time, local communities had banded together to force a governmental agency to improve the noise situation; and hence their quality of life.

The Federal Highway Administration (FHWA) subsequently approved ADOT's use of pavement as a noise mitigation strategy on an experimental basis. This was the first time that a state was allowed to use a pavement in conjunction with or in lieu of noise barriers for controlling freeway noise. Since noise walls are very expensive, any pavement surface that can reduce the required wall heights results in a significant competitive advantage from an overall project cost standpoint. This posed a serious threat to the concrete industry.

The Phoenix freeway system consisted of a concrete pavement with uniform transverse tining. The tining created a very objectionable tire whine for both passenger vehicles and for adjacent property owners. Not only did residents complain that they had difficulty hearing their radios on the drive home, but once they got there, the whine of tires was audible in their backyards.

With the realization that noise was becoming a quality of life issue for local communities, and that the predominant concrete texture in the United States (US) was transverse tining, the concrete industry mobilized in 2004. The American Concrete Pavement Association (ACPA) began developing a strategic effort to better understand the noise issues and to improve new and existing concrete textures. ACPA needed financial support to execute their plan and received generous support from the US cement industry starting in 2005.

With the financial support in place, ACPA created a three year effort to research tire-pavement interaction in 2005. The ACPA contracted with Purdue University to conduct research for both existing roadways (e.g. diamond ground textures) and newly constructed pavements (e.g. innovative new textures). In addition, the effect of transverse joints on tire-pavement noise level was investigated. To accomplish this, ACPA enlisted the aid of the International Grooving and Grinding Association (IGGA) and through that partnership the industry was able to study factors affecting diamond grinding and ultimately to develop a new diamond ground texture which is now called the Next Generation Concrete Surface (NGCS). The vision for the NGCS was to address the many miles of in-place concrete pavements with loud transverse tined textures.

The NGCS texture was developed through research on Purdue's Tire Pavement Test Apparatus (TPTA). The TPTA is unique in that it allows testing of multiple surfaces under controlled laboratory conditions. This allows more efficient and precise testing without the expense of test section construction and attendant traffic control and safety issues.

Once the NGCS surface had been verified on the Purdue TPTA, it became necessary to verify its performance on a real road when constructed with actual diamond grinding equipment. Therefore, an agency partner was necessary.

The Minnesota Department of Transportation (MnDOT) joined the effort and provided a location on their MnROAD low volume road test track. In the summer of 2007, the IGGA funded

Diamond Surfaces, Inc. to construct the Purdue NGCS surfaces at the MnROAD's facility. The single pass and double pass NGCS surfaces were successfully constructed and verified the efficacy of the TPTA to effectively predict the noise levels of field installations[1]. The Purdue research indicated the NGCS should be approximately 3 dBA lower than the conventional diamond ground textures evaluated and the MnROAD testing verified this finding.

With the success of the MnROAD experiment it became necessary to construct a full lane width test section on an in-service highway. That opportunity occurred in the fall of 2007 when Quality Saw and Seal, Inc. constructed a test section on I-355 near Tinley Park, Illinois. This section of highway was also previously used to construct 12 test sections as part of the National Cooperative Highway Research Program (NCHRP) project 10-67 on texturing concrete. To combine these two research opportunities took a partnership between the Illinois State Tollway and Highway Authority, Applied Research Associates, K-5 Construction, the Illinois Chapter of ACPA, the IGGA, and ACPA National. The partnership worked and the first NGCS was successfully constructed on a new roadway in October of 2007. The second NGCS was constructed on I-94 on the MnROAD mainline section in partnership with MnDOT and this was the first full-width roadway construction, and the first existing roadway NGCS placement.

In 2009 the Purdue research effort was completed. However, although the cement-industry funding for the strategic plan was no longer in place, ACPA and IGGA continued the NGCS development effort with the IGGA undertaking the lion's share of the effort. There is little doubt that none of this work could have been accomplished without the cement industry funding and the many partnerships involved. This framework created a solid footing for the IGGA to step up and continue funding the battle against noise. Today there has been 13 NGCS surfaces constructed in 9 states, with one located in Phoenix, Arizona right where it all began. In May of 2010, the Arizona DOT constructed a two lane wide NGCS test section to evaluate the noise levels against their Asphalt Rubber Friction Course which was used to cover up the transverse tined PCCP in the Phoenix area.

In the summer of 2010, the largest ever NGCS project was constructed in Duluth, Minnesota consisting of 104,000 sq. yd. of NGCS grinding. MnDOT constructed the project, which went right through downtown Duluth, as a noise mitigation effort.

It should also be noted that during the development of the NGCS texture between 2005 and 2009, significant improvements in tire-pavement noise measurement was occurring. The On Board Sound Intensity (OBSI) procedure, developed by General Motors, was gaining acceptance within the highway community. At the start of the NGCS development work, the de facto standard OBSI test tire was the Goodyear Aquatred 3 tire. By 2006 the ASTM Standard Reference Test Tire (SRTT) was beginning to replace the Goodyear tire as the tire of preference. With the development of the American Association of State Highway and Transportation Officials (AASHTO) TP76 OBSI Specification in 2008, the SRTT became the standard test tire in the US.

The majority of the Purdue diamond grinding research was conducted with the Goodyear Aquatred 3 (P205/70R15) and Uniroyal Tiger Paw (P205/70R15) tires. Near the end of the effort the SRTT (P225/60R16) was also used to conduct comparison testing on the surfaces.

Purdue Diamond Grinding Research Effort

Purdue University's diamond grinding research consisted of four test phases which evaluated 19 different combinations of diamond ground surfaces[2]. The four phases consisted of the following:

- Evaluation of Existing Diamond Grinding Configurations
- Evaluation of the Effects of Fin/land Polishing and Breakage

- Evaluation of New Types of Diamond Grinding Configurations and the Effects of Longitudinal Grooving
- Evaluation of the Effect of Acoustic Inserts in Grooves

The research was conducted at Purdue University's Herrick Laboratory using their Tire Pavement Test Apparatus (TPTA)[2]. The TPTA, shown in the right-hand side of Figure 1, consists of a 38,000-pound, 12-foot-diameter drum that makes it possible to test numerous types of pavement textures and compositions in combination with various tire designs. Six, curved test-pavement sections fit together to form a circle. Two tires, mounted on opposite ends of a beam, are then rolled over the test samples at varying speeds while microphones and other sensors record data. As indicated in Figure 1, two wheel tracks were constructed on each of the six curved test panels allowing 12 surface textures to be tested in one setup. Testing was conducted at speeds ranging from 0- 30 mph and temperatures ranging from 60-80o F.

Figure 1- Purdue Tire Pavement Test Apparatus and IGGA Diamond Grinding Head[2]

The left hand side of Figure 1 indicates the diamond grinding head that was designed by Diamond B, Inc. and constructed by Diamond Surfaces, Inc of the IGGA. This head was used to grind all the surfaces studied. It constructed an 8 inch wide diamond ground surface. Typical diamond grinding units grind 3 ft and 4 ft wide paths and use 50-60 blades per foot. To fully "stack" a head, it can take 6-8 hrs. The use of a small, 8 inch-wide head, tremendously reduces the blade cost and set-up time. When comparing different grinding blade/spacer configurations, this is a very important consideration. To attach the grinding unit, one of the wheel set ups is removed as indicated in Figure 1. Once the surfaces are diamond ground, the unit is removed, the test wheel apparatus re-installed, and testing is conducted.

Figure 2 indicates the OBSI equipment used to measure tire-pavement noise and the RoLine™ laser used to measure texture profiles. As indicated in the left-hand side of Figure 2, the OBSI equipment was mounted to the test tire support frame. Since two tires were used during testing, it was possible to test with two different tire types at the same time.

The right-hand side of Figure 2 indicates the texture measurement system. Texture measurement was accomplished by removing one of the tire support frames and installing an arm to support the RoLine™ sensor.

The panels that were cast for the TPTA were produced from transit mixed concrete with a 4,000 psi compressive strength requirement and placed at a 6 inch slump[2]. The aggregate consisted of siliceous gravels with a maximum aggregate size of one inch. Although the specimens were prepared over several years, the same mix design was used for all panels.

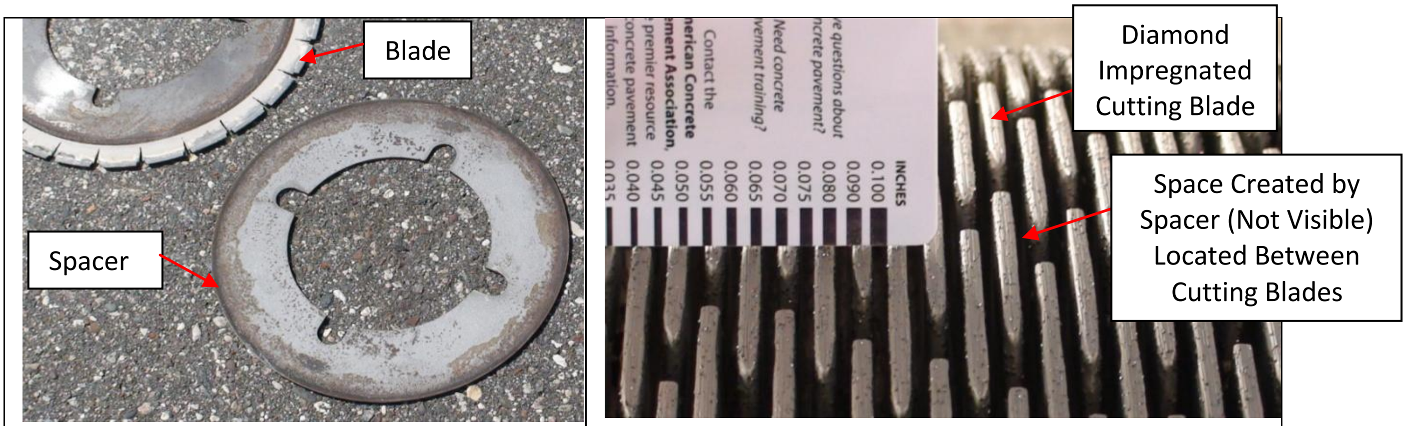
It was recognized that using only a single concrete mixture would provide limitations to the study; however, the belief was that any findings would be useful in understanding other mixes as well and that additional research could be pursued if necessary. Using only one mix design also significantly reduced the number of variables in the experiment.

It is important to note the Purdue testing was conducted at a maximum test speed of 30 mph which is only half the speed of field OBSI testing (e.g. 60 mph) so the reported results are lower than encountered in the field.

Figure 2- OBSI and RoLine^{TM} Test Equipment Mounted to TPTA[2]

Phase I Evaluation of Existing Diamond Grinding Configurations

A conventional diamond grinding head consists of diamond impregnated blades separated by spacers as indicated in Figure 3. While the function of the spacers is to promote debris removal and provide access for cooling with water, they also allow the ridge or land development. Traffic and maintenance operations subsequently reduce the fin height and smooth the fin/land profile resulting in the creation of the land area that forms the corduroy texture produced by diamond grinding.



Diamond Grinding Blade and Spacer	Diamond Grinding Blades Mounted on Grinding Head

Figure 3 Diamond Impregnated Blades Separated by Spacers (not visible) on Conventional Diamond Grinding Head

The first phase of the research consisted of identifying the possible blade and spacer widths available in the market place and testing various combinations to determine the effects of blade width, spacer width, and grinding depth on tire-pavement noise generation. To accomplish this, four blade widths, four spacer widths, and two grind depths were used as indicated in Table 1[2]. To conduct the OBSI testing, two tire types were used; an Aquatred 3 and a Uniroyal Tiger Paw.

Table 2 indicates the nine combinations of blades and spacers that were evaluated in Phase 1.

TABLE 1 DIAMOND GRINDING BLADE WIDTH, SPACER WIDTH, AND GRIND DEPTHS EVALUATED

Feature Evaluated	Range of Features (Blade/Spacer Widths in Thousands of an Inch)
Blade Width	90, 110, 125, 165, 125 with reduced diameter
Spacer Width	30, 90, 110, 130
Grind Depth	1/8” & 3/16”

TABLE 2 BLADE AND SPACER COMBINATIONS FOR PHASE 1 TESTING[2]

Sample Number	Repeating Blade(B)/Spacer(S) Configuration	Grind Depth (in)
1	B125 / S130	3/16
2	B125 / S130	1/8
3	B110 / S130	3/16
4	B110 / S130	1/8
5	B110 / S110	1/8
6	B125 / S110	1/8
7	B165 / S110	3/16
8	B125 / S130	3/16
9	B125 / S110	3/16

Overall Phase 1 Results

The results of the Phase 1 testing are indicated in Figure 4[2]. As indicated, the Aquatred tire results are consistently 1.5 - 3 dBA higher than the Uniroyal Tiger Paw results. Sample 6 (B125/S110) was the quietest texture for the Uniroyal tire and sample 9 (B125/110) for the Goodyear tire. For a given tire type, all the results of the Phase 1 testing were within 2.5 dBA of each other.

Effect of Grind Depth on OBSI Level

One of the parameters evaluated in the Phase 1 experiment was the effect of two different grind depths, 1/8” and 3/16”. The results of this testing are indicated in Figure 5. For four of the six instances the shallower grinding depths had lower OBSI levels. The shallower grinds are on average 0.5 dBA lower in level but no firm conclusions could be drawn.

Effect of Blade Width on OBSI Level

The effect of blade width was investigated by grinding samples with identical depths and spacer widths. The results of this testing is indicated in Figure 6. As indicated, the blade width does affect the overall level but it is neither consistent nor predictable. Half of the time wider blades were quieter and half the time narrower blades were quieter.

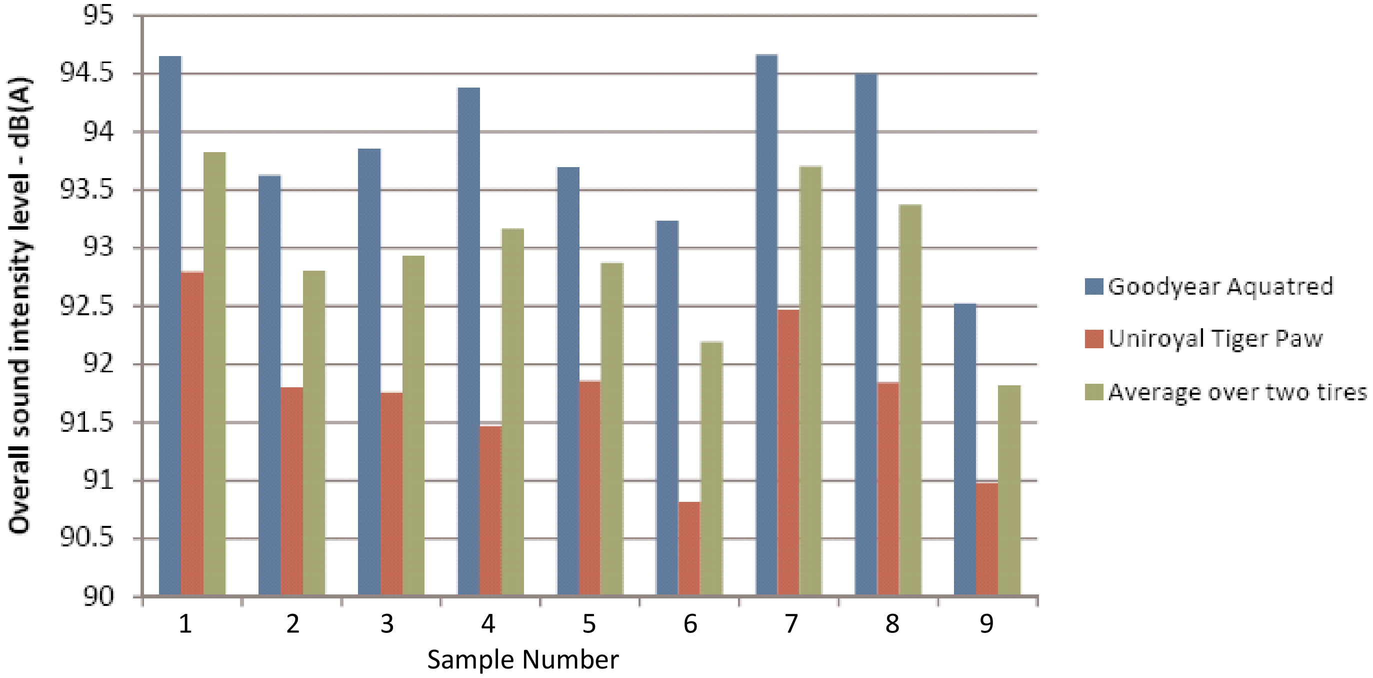


Figure 4 Results of TPTA Testing for Phase 1 Study[2]

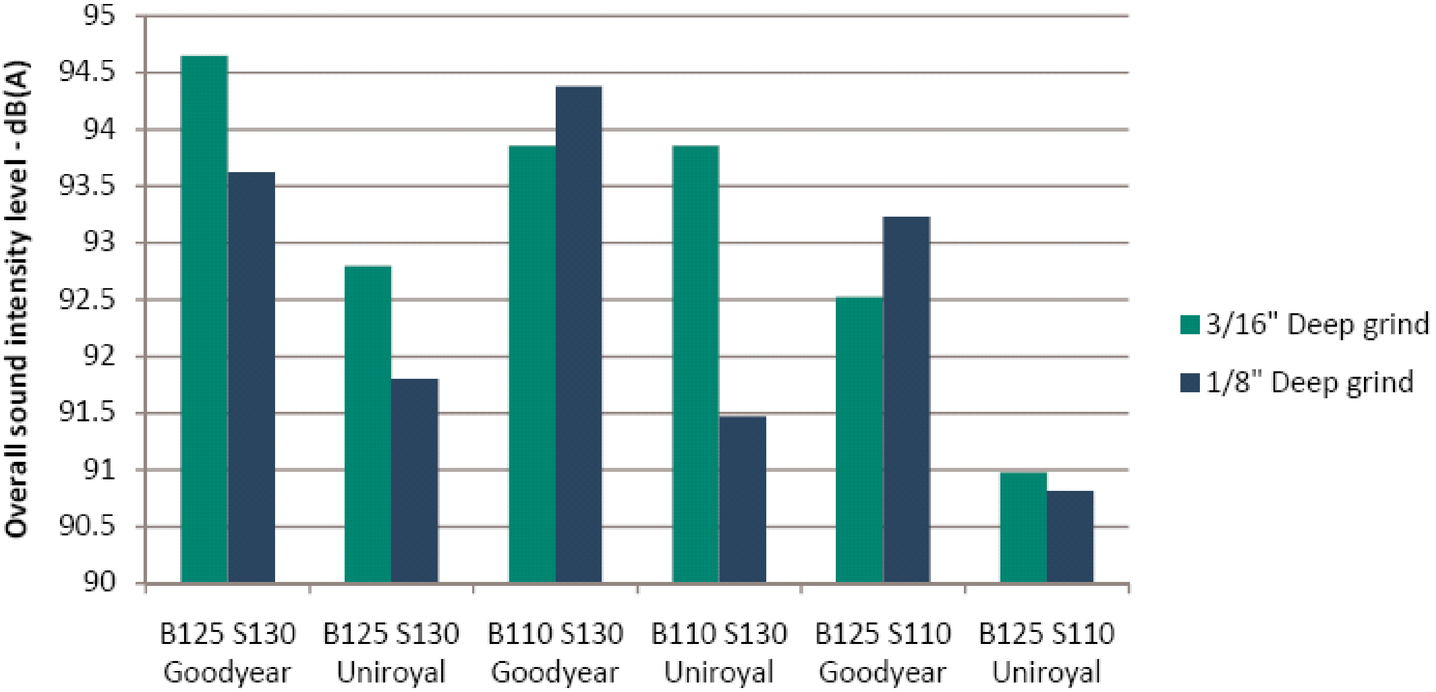


Figure 5 Effect of Grind Depth on OBSI Level[2]

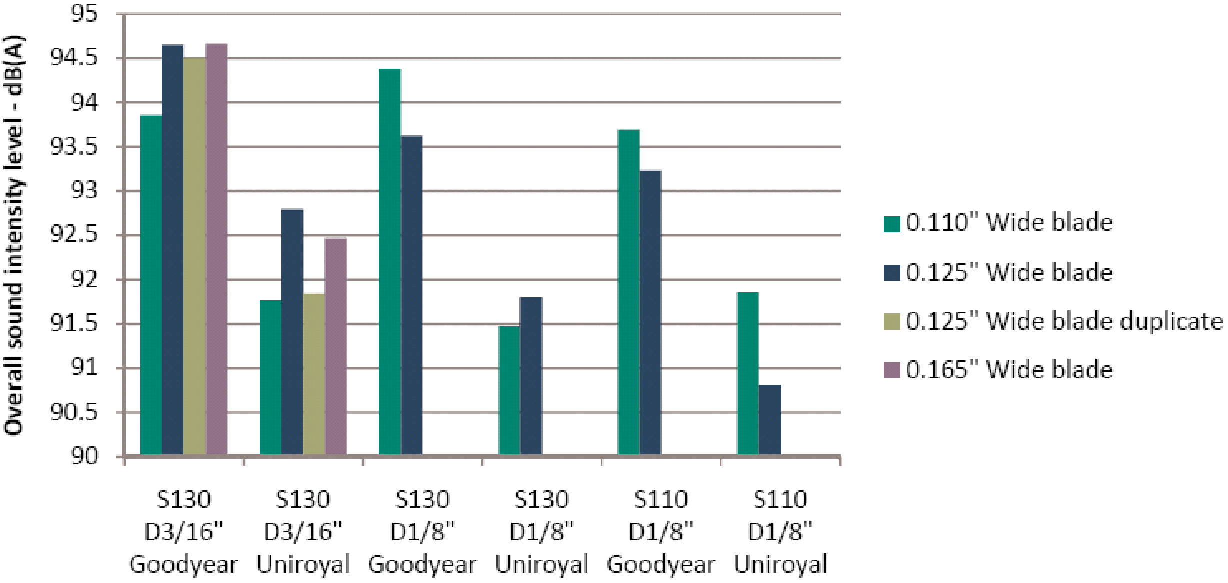


Figure 6 Effect of Blade Width on OBSI Level[2]

Effect of Spacer Width on OBSI Level

The effect of spacer width on overall noise level was investigated by grinding samples using the same blade widths and grinding depths and varying the spacer widths. Figure 7 indicates the results of that effort. As indicated the narrower spacer produced quieter results in 5 of the 6 cases with the difference being less than 1 dBA in most cases.

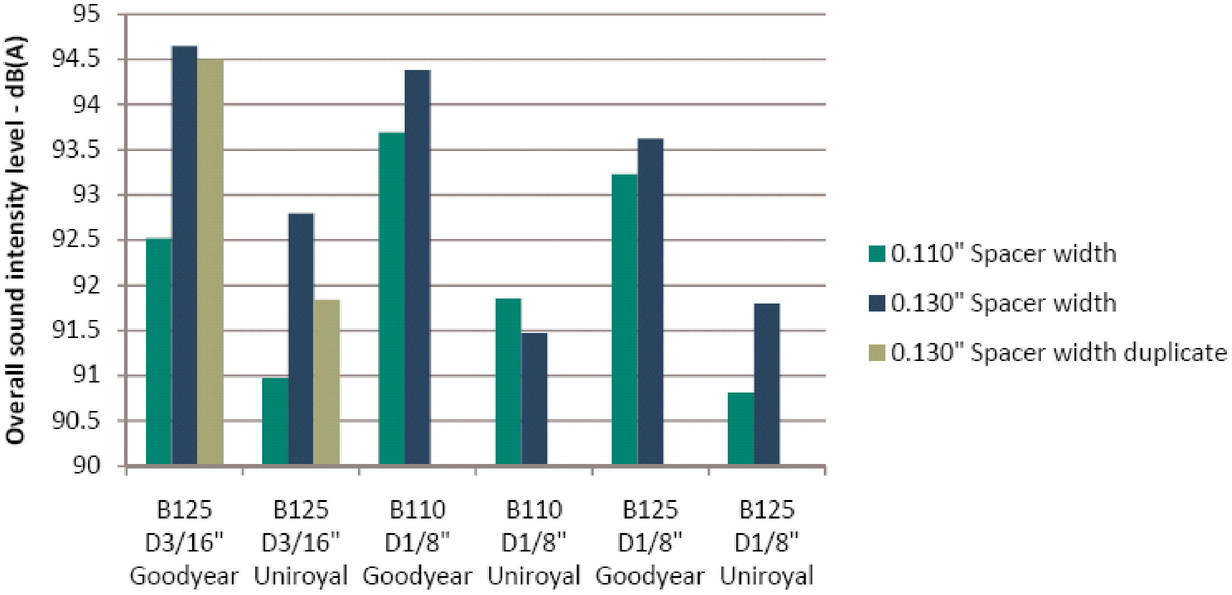


Figure 7 Effect of Spacer Width on OBSI Level[2]

After evaluating the range of blade and spacer widths requested by the industry, Purdue advised that no unique relationship could be found between spacer width, blade width, and spacer/blade configuration. Instead, it appeared that the controlling factor was the variability in the fin/land profile height resulting from the grinding process.

Figure 8 indicates a close up photo of the fin/land profile of one of the Purdue Grinds. The red circles indicate locations where the fin/land had broken off causing a variation in the profile. It was this observation that suggested to the researchers that this was causing increased noise levels[2].

Figure 8 Photo of Breakouts in Fins/Lands During Purdue Testing

Perhaps a better example of the random profile resulting from fin breakage is demonstrated by Figure 9. Figure 9 is a photo of an actual diamond ground pavement just after grinding, and before any fins are knocked down due to traffic and winter maintenance operations. As evident in the photo, the harder aggregate stand "proud" in relationship to adjacent areas. Purdue indicated that it was this fin profile variability that affected tire-pavement noise generation. Textures with low variability were quieter than textures with high variability. In conventional diamond grinding (CDG), the resulting fin variability is influenced by the blade/spacer configuration, the concrete mixture, aggregate type, pavement condition, equipment set up, operator skill, etc. This makes it very difficult to control from an experimental standpoint.

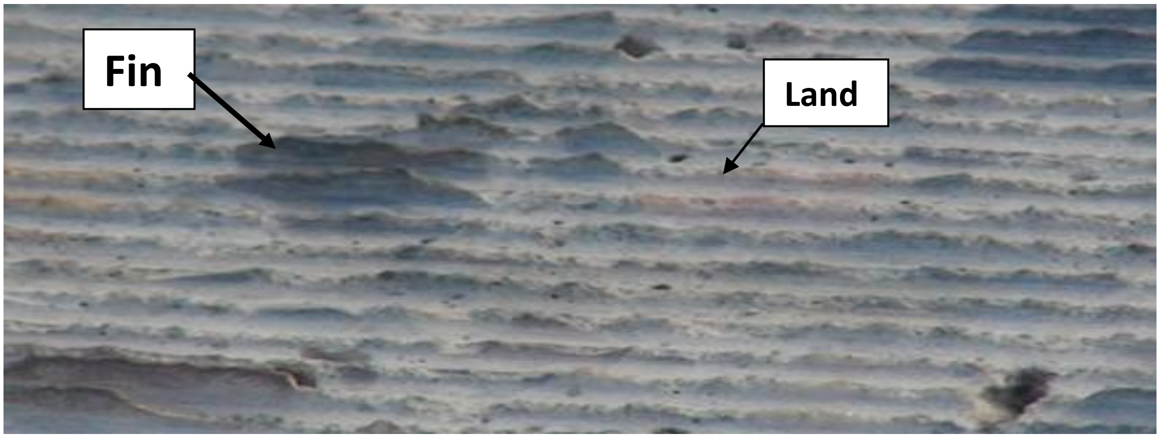


Figure 9- Variability of Fin/Land Profile on CDG Surface on MnROAD I-94

To evaluate this hypothesis, a texture with essentially no positive texture was conceived. That is, the surface would be diamond ground smooth and then additional texture imparted by grooving. In this manner, the exact land profile could be controlled/anticipated at the time of production, unlike conventional diamond ground (CDG) surfaces which are affected by many variables. Figure 10 indicates an actual field installation of one of these surfaces. It should be noted the that the CDG surface shown in Figure 9 produces texture in the upward or positive direction while the Purdue surface produces texture in the downward or negative direction. The Purdue texture, later called the Next Generation Concrete Surface (NGCS) was desirable from the standpoint that it was more of a "manufactured surface" and thus could be controlled as necessary from an experimental basis. To verify this hypothesis, a second round of testing was planned for Phase 2 and a small fin wear experiment pursued.

Figure 10- Photo of Purdue Negative Texture Profile (e.g. NGCS) and Land Area

Fin/Land Wear Study

Shortly after completing the Phase 1 testing and prior to completing the Phase 2 testing, a small fin wear study was initiated to evaluate the effects of micro texture and macro texture on the overall noise levels. To conduct the fin/land wear study, two samples used in the Phase 1 testing and two samples used in the early stages of the Phase 2 testing had the fins/lands artificially worn down using an abrasive, ceramic-sanding block. The four TPTA samples used were samples 7, & 8 from Phase 1 testing and samples 1 & 2 from the Phase 2 testing. The noise levels for each of the four TPTA samples were obtained for each of the following treatments[2]:

- **As Ground Condition**: Immediately after grinding the TPTA samples
- **Lightly Sanded**: Samples lighted sanded to remove micro texture from fins/lands
- **Fins/lands Broken Down**: Samples worked lightly with abrasive blocks to wear away the tops of the fins and reduce the macro texture
- **Final State**: Samples worked roughly with abrasive blocks to wear away the remainder of the fins to form a uniform height

The results of the fin wear study found that after the light sanding stage, all four pavements become louder with both tires. In the final two stages of "fins/lands broken" and "final state" the pavements became quieter. The conclusions of this effort indicated that removing the micro texture by polishing the surface increased the overall noise level. Reducing the macro texture to promote a uniform fin profile reduced the overall level. This supported the Phase 1 Purdue hypothesis and attempted to explain the associated mechanisms.

Phase 2 Development of the Quietest Diamond Ground Surface Possible

The Phase 2 test plan was based on lessons learned from the Phase 1 testing and also the fin/land wear study. The purpose of the Phase 2 testing was to develop the quietest diamond ground surface possible. A second goal was to investigate the effect of longitudinal grooving on OBSI level.

The rightmost column of Table 3 provides the purpose for each of the test configurations in Phase 2. As indicated, there were five separate purposes indicated. The first purpose was to provide additional testing on alternative grinding techniques that did not employ the controlled profile approach that were not evaluated in Phase 1 but may potentially be successful.

The second purpose was to include a duplicate that could be compared to the Phase 1 results. That is, the test result in Phase 2 on this sample should get the same answer as in the Phase 1 work. If it did not, then the amount of bias could be estimated.

The third purpose consisted of evaluating different techniques by which a controlled profile could be constructed. The objective was to develop little to no macro texture but good micro texture. Grooves were included to include negative macro texture.

The fourth and fifth purposes were to evaluate the effects of grooves when added to a flush ground surface, and also to have a baseline of an as cast texture as a reference to compare against.

Evaluation of New Grinding Configurations

Samples 1 thru 3 were intended to evaluate new grinding configurations not evaluated in Phase 1 which did not directly employ the negative texture concept.

Sample 1 used various widths of spacers randomly positioned within the grind pattern. Samples 2 and 3 were replicates of each other and explored the concept of using cutting blades as spacers. That is, where a spacer would normally go, a cutting blade (e.g. chopper) of slightly smaller diameter than the standard cutting blades was used. The purpose was to determine if the "chopper" blades could produce a more uniform fin profile at the top of the land resulting in a quieter texture while still using the conventional positive texture approach.

TABLE 3 BLADE AND SPACER COMBINATIONS FOR PHASE 2 TESTING[2]

Sample Number	Repeating Blade(B)/Spacer(S) Configuration	Grind Depth (in)	Test Purpose
1	B125 / Various Random Spacers Widths	3/16	To Evaluate New Grinding Techniques
2	B125/030/Chopper/S030	3/16	
3	B125/S030/Chopper/S030	3/16	
4	B165/S130	3/16	To Duplicate Phase 1 Study
5	First Pass: B090/S090 Second Pass: S090/B090	1/4	To Control Fin Profile
6	First Pass: B090/S090 Second Pass: S090/B090 Third Pass: B090 spaced on ½" c-c	1/8	
7	B165/S030/Chopper/S030/Chopper/ S030/Chopper/S030	1/8	
8	B165/S030/Chopper/S030/Chopper/S030	1/8	
9	Blank Specimen grooved with B090 Spaced on ½" c-c	1/8	To Determine Effect of Grooves
10	Blank Specimen-No Grinding or Grooving	None	Control Specimen

The results of sample 1 thru 4 testing are indicated in Figure 11. As evident, the random spaced blades had the lowest levels followed by the use of the chopper blades. However the replicate samples (e.g. 2&3) indicate the variability that exists when the fin profile cannot be controlled. Samples 1 thru 3 were only marginal improvements over sample 4 which was one of the Phase 1 CDG samples.

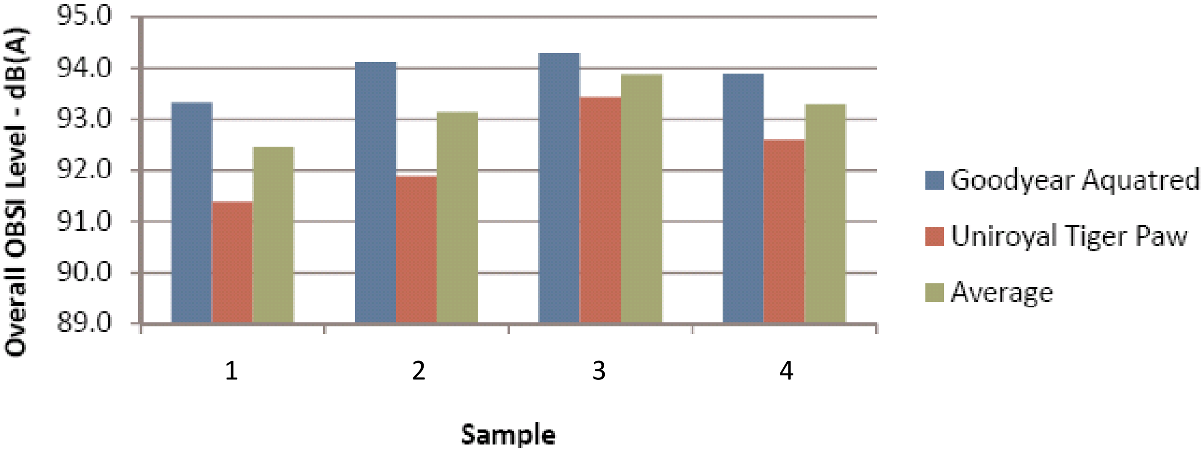


Figure 11 OBSI Results for Samples 1 thru 4[2]

Evaluation of Controlled Profile Approaches

Samples 5 thru 8 evaluated different techniques of minimizing and controlling the resultant macro texture profile while maintaining good micro texture. This was to be accomplished by flush grinding the texture to "manufacture" the profile. Sample 5 was produced by making two passes to flush grind the surface removing the positive texture and establishing good micro texture. This sample represents a flush grind surface with sandpaper like micro texture and almost no macro texture. Sample 6 was produced in the same manner with the exception that longitudinal grooves were installed after the flush grinding, creating a negative macro texture. Sample 6 was the precursor to what is now called the two pass NGCS texture. Sample 7 is the precursor to what is now called the single pass NGCS texture and was intended to produce a similar texture to Sample 6, except in one pass and with wider grooves. Sample 8 is similar to the single pass approach used in Sample 7 except one less chopper blade was used creating a closer groove spacing. The sample 8 texture produced some land breakage with the closer spacing of the grooves. Samples 9 and 10 had no grinding of the surface but maintained the micro texture resulting from the as cast condition. Sample 9 had grooves spaced on ½ centers while sample 10 had no grooves installed. Samples 9 and 10 had the least micro texture and almost no positive macro texture.

Figure 12 indicates the overall OBSI level for all of the Phase 2 test samples. As indicated in Figure 12, test sample 5 thru 7 exhibit the lowest OBSI levels of all surfaces. They are also quieter than any of the Phase 1 surfaces with sample 6 almost 3 dBA quieter than the Phase 1 results.

Sample 6 has the quietest "average tire" result. It should be noted, however, that the two tire types respond differently to these surfaces. Sample 5, which has no grooves, is the quietest for the Goodyear tire. It would appear that the wider the grooves, the higher the OBSI level for the Goodyear tire. The grooves appear to reduce the Uniroyal tire levels; with the narrower the groove the greater the reduction. Both tires appear to respond best to narrower grooves.

The major finding of the Phase 1 and 2 research was that the NGCS surfaces produced the lowest overall noise levels for the textures tested.

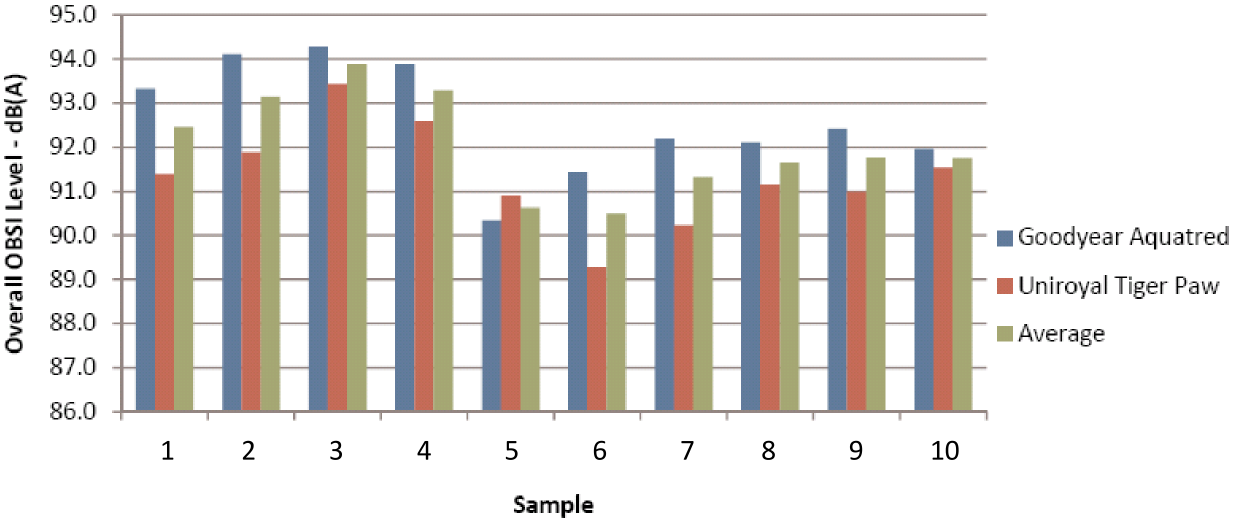


Figure 12 Overall OBSI Levels for Phase 2 Testing[2]

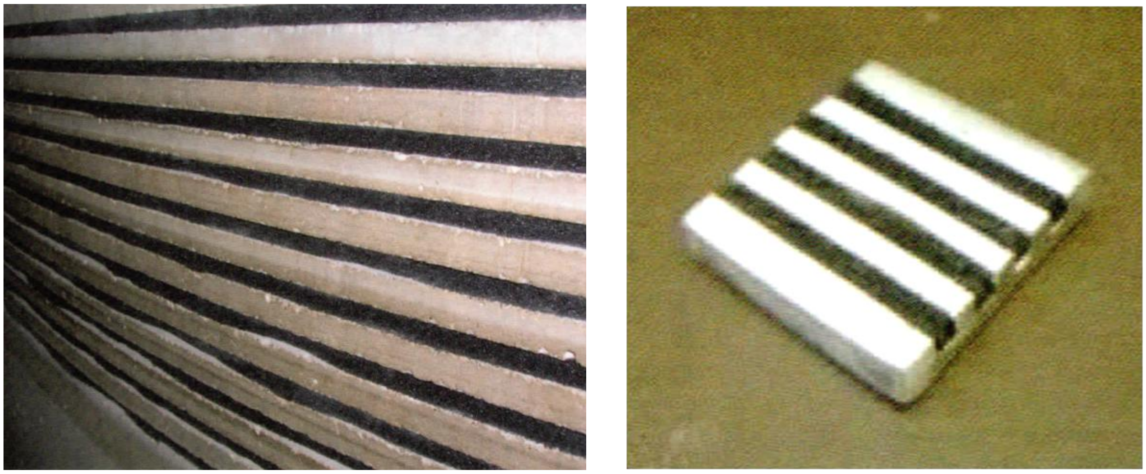
Evaluation of Longitudinal Grooving on OBSI Level

The effect of longitudinal grooving can be evaluated by comparing samples 5 and 6 and 9 and 10 to each other. Each of these paired samples are essentially identical except for the grooves. Comparing samples 5 and 6 suggests that grooving has a benefit while comparing samples 9 & 10 suggests there is no benefit. As previously mentioned, <u>the two tire types appear to respond quite differently to the grooving pattern and when one considers the multitude of tire types in the fleet, the effect of grooving may be insignificant.</u>

Evaluation of Foam Inserts in Longitudinal Pavement Grooves

Since the NGCS surface included 1/8” grooves on approximate ½” centers, considerable interest existed regarding the impact of the grooves on the overall tire-pavement noise and whether the grooves could be used to reduce the tire-pavement noise even further. To investigate this, a polyurethane open-cell backer rod material typically used in joint sealant installations was inserted into the NGCS grooves[3]. By increasing the amount of sound absorptive material as a function of the total surface area it was assumed some noise reduction benefit could be achieved. TPTA specimens were prepared with groove dimensions 1/8” by ¼” deep and ¼” wide by ¼” deep. All grooves were spaced on approximate ½” centers.

TPTA testing was conducted with three tire types: Goodyear Aquatred 3, Uniroyal Tiger Paw, and ASTM Standard Reference Tire (SRTT) at 30 mph. Figure 13 is a photo of the inserts installed in the grooves just prior to testing. The TPTA results indicated that the foam inserts reduced the overall noise for center band frequencies above 1000 Hz. Frequencies below 1000 Hz were not affected. The effect was most significant at center band frequencies between 1000 Hz and 1500 Hz where some center band frequencies were reduced between 3 - 5 dBA. The magnitude of the effect was dependent upon the tire type and texture type. It was also determined that the overall reduction could not be explained by sound absorption alone and that the foam may have affected the sound generation mechanism in some other way.



Foam Inserts Installed in Pavement

Foam Inserts installed in Aluminum Frame for Impedance Tube Testing

Figure 13- Photo of Open Cell Backer Rod (foam) Inserts Installed in Pavement Grooves and in Aluminum Frame Used for Impedance Tube Testing[3]

Figure 14 indicates the OBSI level as a function of percent of area of foam insert and tire type. As indicated in Figure 14, five of the six tire-pavement combinations resulted in reductions in OBSI level. In all cases where reductions occurred, the higher the percentage of area consisting of foam the greater the overall reduction. It should also be noted that the amount of reduction is a function of the tire-pavement interaction.

In addition to the TPTA testing, impedance tube testing was conducted to evaluate the absorptive characteristics of the foam used in the grooves. A grooved aluminum plate (see Figure 13) was used to install the foam inserts into. Impedance tube testing was conducted with and without the foam inserts in accordance with ASTM E10-50 for frequencies ranging between 500 Hz to 2600Hz. The absorption coefficients ranged between approximately 0.03 at 500 Hz. and 0.16 at 2600 Hz. While the absorption characteristics of the foam can explain some of the noise reduction at high frequencies, it does not explain the increase at low frequencies nor the higher noise mitigation seen between 1000 Hz to 1500 Hz. Further research is necessary to explain the insert mechanisms.

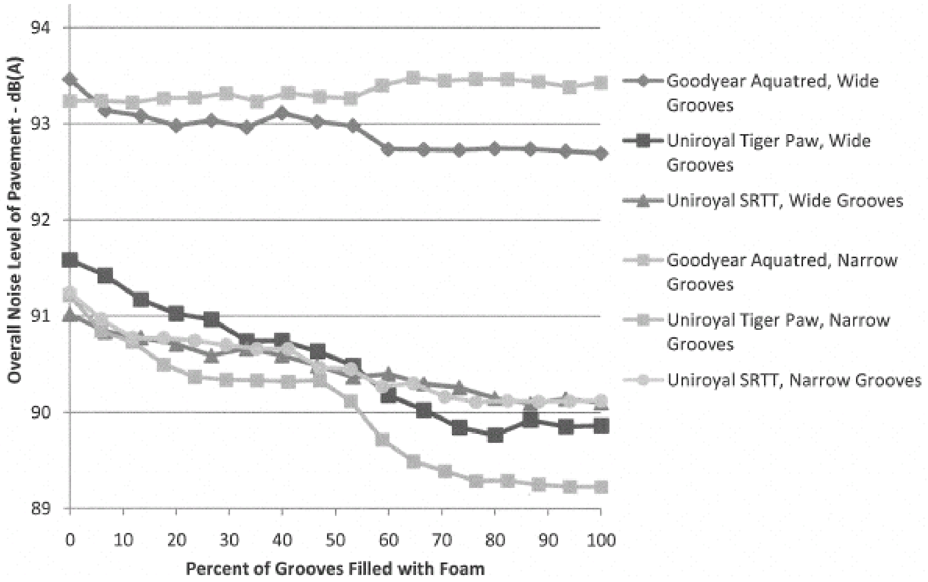


Figure 14 Effect of Inserts on OBSI Level for Different Percentages of Filled Area[3]

Proof of Concept Field Testing

When the new textures (NGCS) were tested on the TPTA they produced the quietest diamond ground surfaces. This was an epiphany in the research as it verified, for the first time, what the controlling factor was for tire-pavement noise generation of diamond ground surfaces; namely the fin or land profile.

The epiphany was soon confronted by reality, however. The Purdue grinding consisted of grinding an 8 inch wide wheelpath for 6 ft with a water hose cooling the head for each of the specimens. When grinding such small areas the heat generated by the blades/head is not excessive. However, when diamond grinding a pavement with a conventional machine, with a 3 ft or 4 ft head, this is not the case. The typical 1/8 inch opening provided by a spacer between the grinding blades allows water to circulate between them, cooling them and removing grinding debris. This is an important consideration in production grinding. In addition, flush grinding the surface prior to grooving requires approximately twice as many blades. For an 8 inch head such as Purdue's, this is not prohibitively expensive. To do it with a 3 or 4 ft grinding head would be expensive and a risky investment for an unproven strategy. The Purdue research indicated that the flush grind/grooved texture could produce a quieter texture, but it could not verify whether it could be constructed with conventional equipment in the field.

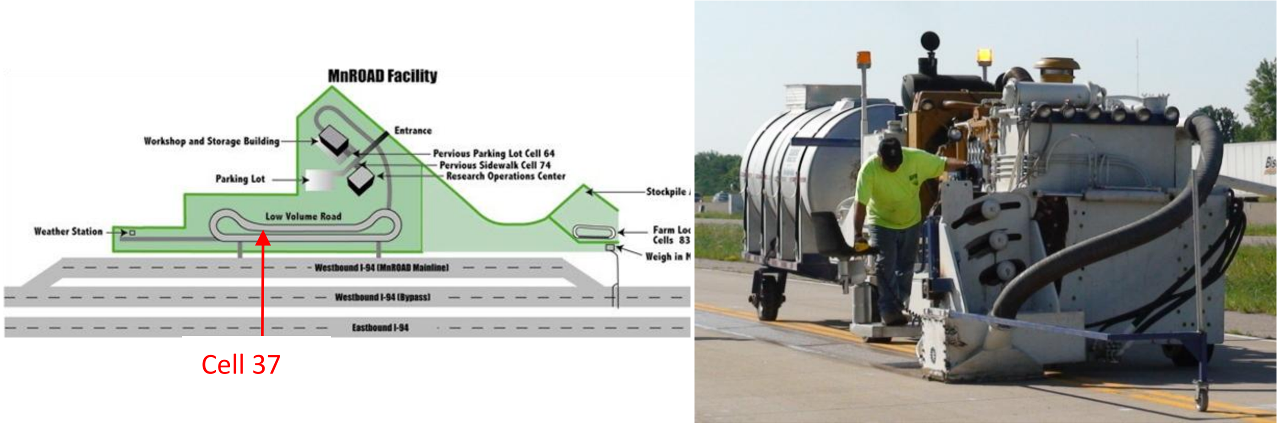
The Purdue testing was also limited to a maximum test speed of 30 mph. One concern that persisted was whether the TPTA results would be validated at higher test speeds such as 60 mph. So not only was constructability a question, but also the efficacy of the Purdue TPTA to predict in-service performance.

Prior to attempting field validation, two grinding/grooving configurations were developed and tested in the laboratory at Purdue. The first was a grinding configuration that used three smaller diameter blades stacked between two taller blades and the pattern repeated across the grinding head. The taller blades were approximately 0.08 inches larger in radius. This arrangement provided a single pass operation that could grind the surface smooth and also groove it on approximate ½ inch centers in one pass of the machine. The smaller blades were used to flush grind the specimen and provide micro texture while the taller blades were used to create grooves. The Purdue work had also demonstrated the advantage of micro texture in reducing noise levels.

The second grinding configuration used the same smaller blades to "flush" grind the pavement in the first pass over the surface. A second pass was then made using the same taller blades with spacers between them to create the approximate ½ inch on center spacing. This second pass provided grooves similar to what was constructed with the single pass configuration.

The purpose for the two different configurations, designed to achieve the same end result, was to allow consideration of either option by contractors during field construction. Some industry representatives did not consider the single pass operation as a viable option in a production environment due to excessive blade wear and the potential for ruining the head/blades. Many believed the two stage process would be required. So both options were pursued. Both surfaces produced similar results on the TPTA so field trials were pursued.

The opportunity to construct field test sections became a reality when the Minnesota DOT promoted construction of the test sections indicated in Figure 15 at the MnROAD Low Volume Road Test Cell Number 37[4]. At approximately this same location, Diamond Surfaces, Inc. had equipment uniquely designed to construct the proposed sections. The equipment consisted of a diamond grinding unit with a 2 ft head designed for curb cuts. This device not only allowed for fewer blades to be used but also was designed to allow quick blade changes. A head of blades could be changed in approximately 45 - 60 minutes versus 6 – 8 hrs. Figure 15 indicates the diamond grinding equipment.



Mn ROADs Test Center(Courtesy MnDOT)

Diamond Surfaces, Inc. Grinding Unit with 2 ft Head

Figure 15 MnROAD Research Test Facility and Diamond Grinding Equipment Used to Construct NGCS Proof of Concept Construction

The test strips represented a compromise between the ability to conduct OBSI testing at 60 mph and requiring as few blades to construct a test strip. It was estimated that an 18 inch wheel track was the narrowest that that could be tested at 60 mph and still ensure the test wheel was within the test strip. The use of 1/8 inch wide blades was selected because they represented the industry standard and therefore more economical than the 90 and 165 blades used in the Purdue work. It was also known that wider grooves had a greater potential for tracking issues so a narrower blade that can maintain production is more desirable. The industry standard 1/8 inch blade represented a good balance between production capability and groove width. The 90 thousands blade width used in the Purdue study was too thin for use in a production environment, and the 165 thousands width potentially prone to tracking issues.

Additionally, the two Purdue surfaces were to be compared to a conventional diamond grinding surface (e.g. CDG) to assist in determining the benefit achieved by controlling land profile. This resulted in the need to construct three diamond ground surfaces.

The purpose of the test strip construction was twofold: First, to verify the hypothesis that controlling the texture (e.g. fin) profile in contact with the tire could result in lower noise surfaces; and secondly, to verify that the results obtained using the TPTA could be reproduced in the field on real pavements using actual construction procedures.

The results of the OBSI testing for the test strips are indicated in Table 4[5]. Four repeat tests were conducted on each of the sections prior to constructing the sections and five repeat runs after. As evident in Table 4, the single pass and two pass strips (TS1 & TS2) provided similar results and were approximately 3 dBA lower than the CDG (TS3) test strip. This supported the original TPTA results. It should also be noted that the NGCS textures were approximately 5 dBA quieter than the transverse tined texture.

Upon review of the run to run variability indicated in Table 4, it was concluded that the 18 inch wide test strips were adequate to conduct the OBSI testing at 60 mph. However, a spotter was used to verify that the test vehicle maintained the correct wheelpath. Many more runs were conducted and the results discarded. So only the results that the test vehicle maintained the correct path are indicated in Table 4.

Table 4 OBSI Measurements for Each Track[5]

Track Number	Pre-Grind					Post Grind					
	1	2	3	4	Ave	1	2	3	4	5	Ave
TS1	**103.0**	**103.2**	**103.5**	**103.2**	**103.2**	**99.3**	**99.5**	**99.5**	**99.4**	**99.4**	**99.4**
TS2		**102.8**	**102.4**	**102.5**	**102.6**	**99.0**	**99.1**	**99.1**	**98.9**	**99.2**	**99.1**
TS3	**103.9**	**103.8**	**103.9**	**103.9**	**103.9**	**101.8**	**102.2**	**102.1**	**101.9**	**101.7**	**102.0**
TS4	**104.6**	**104.4**	**104.5**	**104.4**	**104.5**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

The test strip findings validated both that the Purdue Texture was quieter, at the time of construction than the conventional diamond grind texture, and that the Purdue TPTA results could be reproduced in the field using conventional equipment. With the validation of the TPTA results, the next step was to construct full-width test sections using a conventional diamond grinding machine on in-service pavements. This would allow trafficking of the test section as well as additional insight into the production side of the NGCS.

Field Test Section Construction

Since October of 2007, 13 in-service sections have been constructed in 9 states as indicated in Figure 17. The dark green color represents constructed NGCS sites, the light green color variations of constructed NGCS sites, and the blue color NGCS sites to be constructed in 2011. A number within a state indicates how many locations were constructed in that state.

The first in-service NGCS was constructed on the Chicago Tollway on I-355. At this site, both a conventional diamond ground (CDG) test section and a Purdue texture (NGCS) were successfully constructed in October of 2007. The sections were 1200 ft long and one lane-wide. This section of freeway was a newly constructed alignment which had not been open to traffic prior to constructing the test sections. The two pass process was used to construct the NGCS.

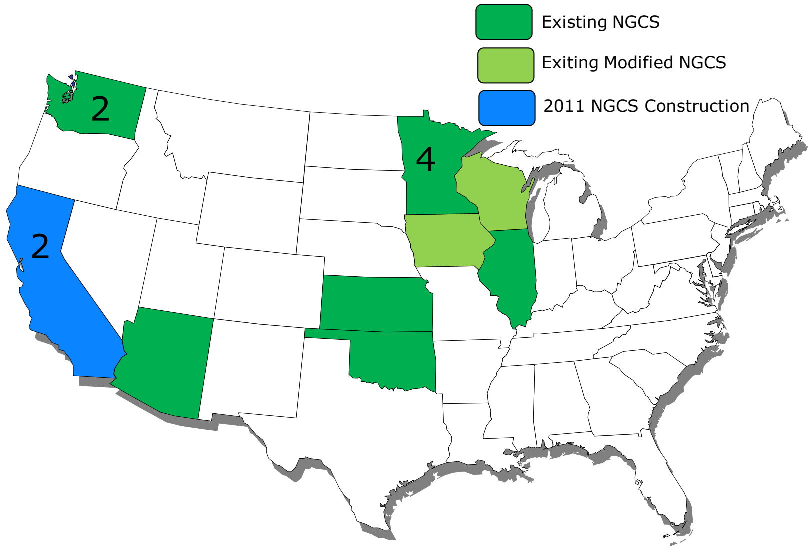


Figure 17 NGCS Test Section Locations

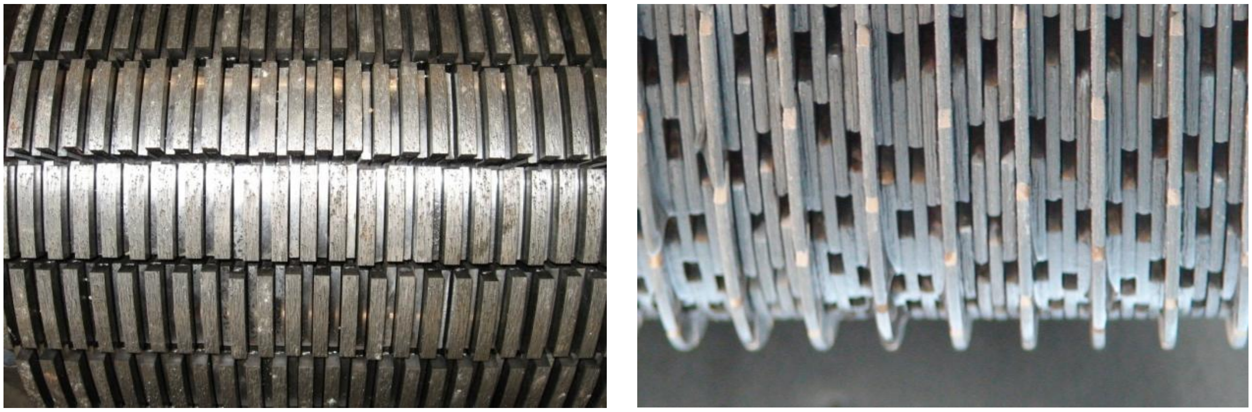
The next opportunity to construct test sections occurred at MnROAD on the I-94 WB section. A two-lane wide by 500 ft long section of NGCS was constructed in a single pass operation on a 14 year old random transverse tined pavement in October 2007. A two lane wide by 500 ft section of CDG was also constructed to compare to.

With the successful placement and performance of the two mainline sections, the ACPA officially named the Purdue texture as the "Next Generation Concrete Surface" (NGCS). This naming occurred to describe a category of texture(s) that evolved through research. The term may apply to several textures that evolve for both new construction and rehabilitation of existing surfaces. The desirable characteristics of such textures will be predominantly negative texture coupled with good micro texture and excellent macro texture.

In 2008, NGCS test sections were constructed in Kansas and Wisconsin and in 2009 in Oklahoma and Minnesota. It appears that 2010 was a tipping point for NGCS construction with four states (MN, AZ, WA, IA) constructing NGCS test sections.

The first NGCS construction that was bid as a conventional project occurred in Wisconsin on SR21 near Omro in 2008. The largest project constructed to date occurred in Duluth, Minnesota in the summer of 2010. The Duluth project constructed 104,000 sq. yds. of NGCS surface.

The Omro, Wisconsin project was unique in one aspect in that it used a different blade arrangement on the head than the other NGCS construction projects. Figure 16 indicates a photo of the head used for the first pass of the two pass construction alongside a more typical NGCS head which is from a single pass construction. Ignoring the taller blades used to construct the grooves on the single-pass head; it is obvious that the water flow around the blades on the conventional NGCS head is different than on the Wisconsin head. Although not obvious when viewing the texture, it is conceivable that the Wisconsin head could produce less micro texture since the blade segments overlap. The only other test section that deviated from the NGCS specifications is the Marshalltown, Iowa project that eliminated the spacers for the flush grind portion of the two pass operation.



Blade Arrangement Used at Omro, Wisconsin

Blade Arrangement Commonly Used for NGCS

Figure 16 Comparison of Wisconsin Head to Typical NGCS Grinding Head Arrangements

Noise Results to Date

The NGCS sites are reviewed periodically and OBSI testing conducted in general accordance with AASHTO TP76 except that the analysis is conducted from 500 to 5000 Hz instead of 400 to 5000 Hz. <u>No temperature corrections are applied to the data, so some temperature effect is occurring in the time series data at some locations</u>. Additionally, a tire change was made in 2009 when a new ASTM SRTT tire was acquired and used for testing during and after 2009. Prior to this, the ACPA 2006 SRTT tire was used for testing. The OBSI test results are indicated in Table 5.

TABLE 5 OBSI LEVEL FOR THE NGCS LOCATIONS BY YEAR

State	Route	OBSI Level (dBA)			
		2007	2008	2009	2010
Arizona[5]	I-10 EB				99.2
Illinois[6]	I-355 NB	100.5	100.9	101.2	100.7
Iowa[7]*	US 30				99.1
Kansas[8]	I-70 EB		99.4	100.5	100.9
Minnesota[9,10]	I-94 WB	100.1	99.0	101.1	99.8
	I-35				100.3
	I-94 Duluth NGCS LITE				99.6
Oklahoma				100.8	Not Tested
Wisconsin[11] ***	SR 21		102.8	Not Tested	Not Tested
Washington	I-82				Not Tested Yet
	Avondale Rd				Not Tested Yet

*Variation from NGCS Specification—No Spacers between cutting blades

**Grind Pass Feathered at Test Area

***Variation from NGCS Specification—Flush Grind with Over Lapping Segments— Very low temperatures during testing

Unfortunately only three sites, I-355, I-70, and I-94 have time series data available. The I-355 and I-94 sites indicate that the little to no change is occurring in the NGCS OBSI levels while the I-70 site is indicating a slight increase with time.

Noise Comparison to Other Pavement Textures

At several locations, the NGCS sections are co-located adjacent to non-diamond ground texture test sections. These sections are periodically tested for comparison at the same time the NGCS and CDG textures are tested. The results of these comparisons follow.

NCHRP 10-67 Test Sections

ARA, under contract to the National Cooperative Highway Research Program, constructed 12 test sections on I-355 in Chicago in 2007. An NGCS test section was co-located at this site so it could be evaluated against the other textures. Figure 18 indicates the 2010 test results for several of the NCHRP 10-67 sections in comparison to the NGCS site[9]. As indicated the transverse tined textures are generally the loudest of all the textures, followed by the longitudinal textures, then the drag textures and finally the diamond ground surfaces which are 4-5 dBA quieter than the transverse tined. This site is also unique in that the CDG surface is either equal to or 0.1 dBA less than the NGCS surface. This is the only location where the CDG has equaled or bettered the NGCS surface. It is also the only location where the NGCS section is located on an uphill grade while the corresponding CDG section is on level grade. The NGCS section was also constructed with ¾” groove spacing instead of the ½”to 5/8” currently specified.

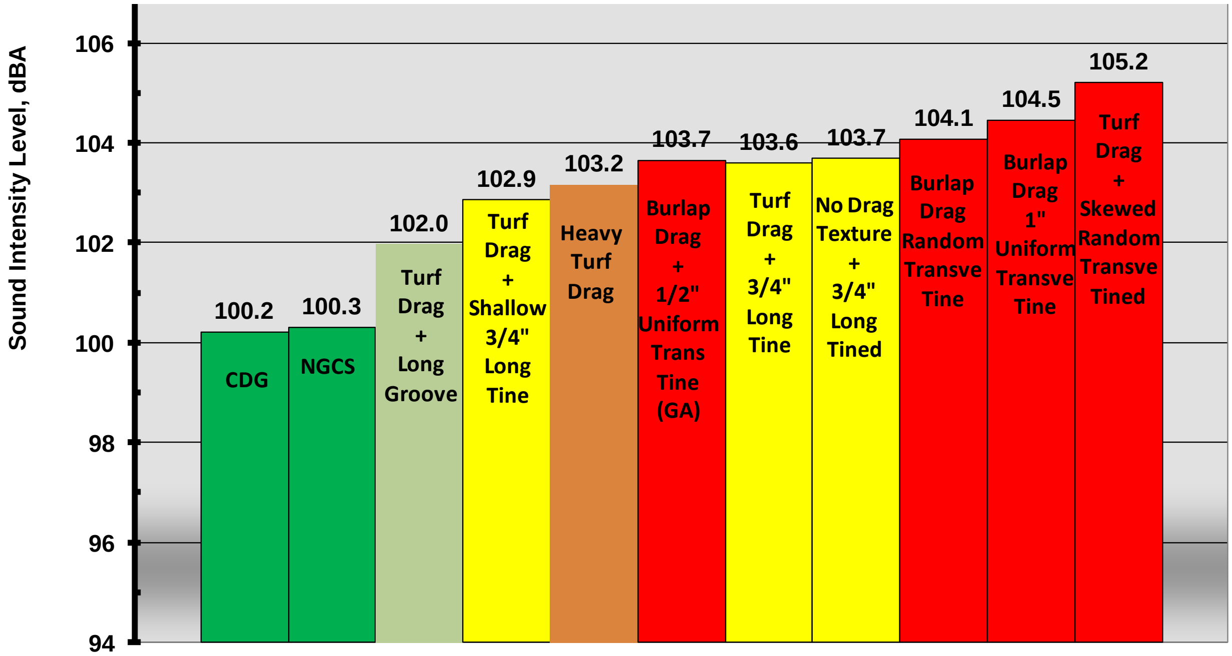


Figure 18 NCHRP 10-67 Textures Compared to NGCS Texture in 2010[9]

Kansas I-70 Test Sections

In 2008 Kansas constructed a two lift Portland Cement Concrete Pavement (PCCP) on I-70 near Abilene, Kansas to test the two lift construction process and to evaluate an exposed aggregate texture. In addition they constructed seven additional surface texture experiments including an NGCS Texture. Figure 19 indicates the 2010 OBSI results on several of these textures. The exposed aggregate has the loudest texture followed by longitudinal tining, CDG, drag texture and the NGCS which was the quietest texture.

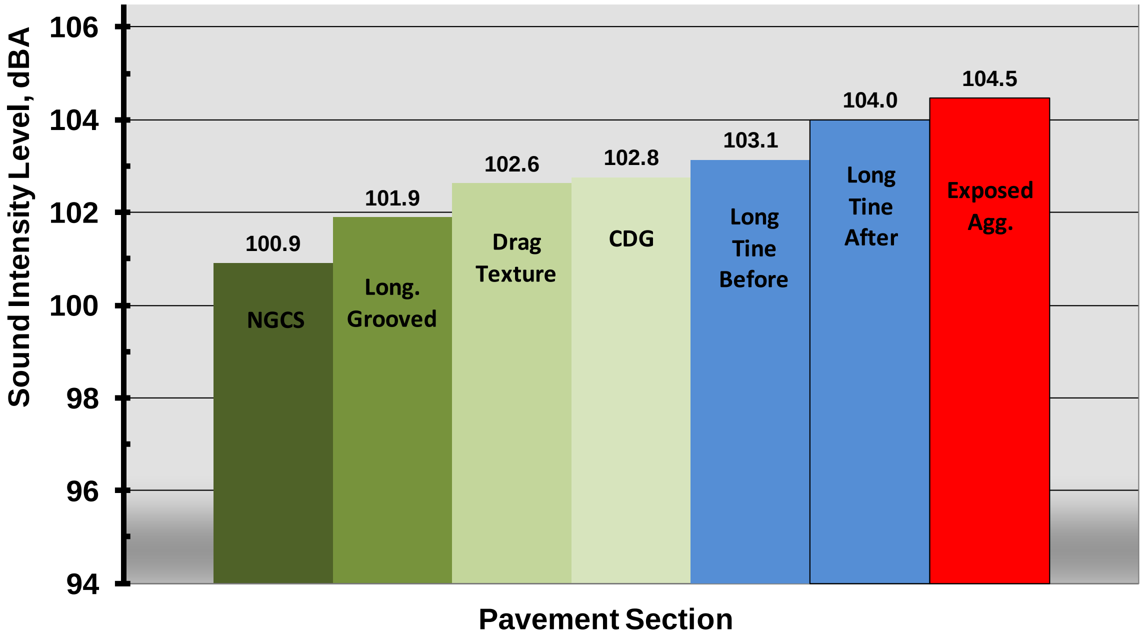


Figure 19 Kansas I-70 EB Surface Texture Test Sections Compared to NGCS in 2010

MnROAD Test Sections

The Minnesota DOT has a pavement test track facility for conducting research as indicated in Figure 15[12]. Three different NGCS textures have been constructed at this location as well as many other textures, including the world's only exposed aggregate texture with an NGCS ground into it. Figure 20 indicates the 2010 OBSI levels of several of these test sections in comparison to the NGCS sections.

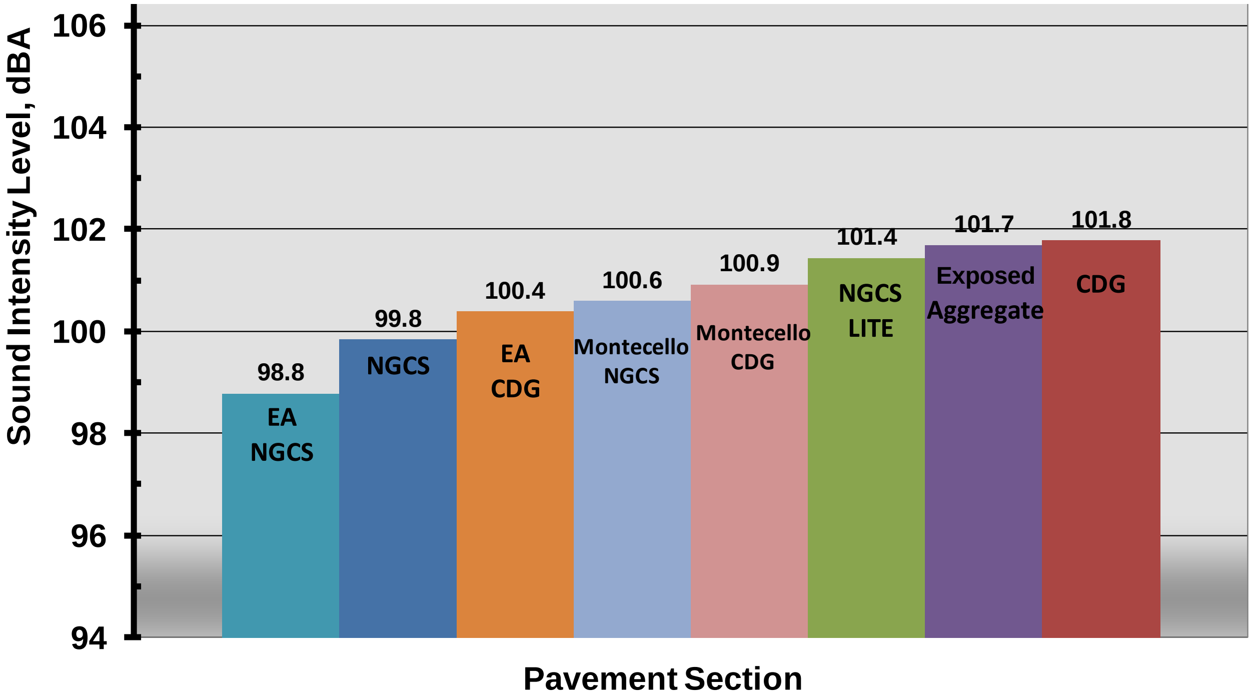


Figure 20 Comparison of Several MnROAD Test Sections to NGCS Test Sections in 2010

As evident in Figure 20, the exposed aggregate texture with the NGCS surface is the quietest texture. This is also the lowest measurement ever obtained by the author on a concrete pavement. The next quietest texture is the NGCS followed by the CDG on the exposed aggregate. The loudest texture is the CDG texture. It should be noted that all of the NGCS sections were quieter than the exposed aggregate surface. This is also the quietest exposed aggregate texture the author is aware of.

Conventional Diamond Grinding Test Sections

At each of the NGCS test section locations, CDG textures are also constructed so that the two textures can be compared over time. This provides a direct comparison on the same projects, traffic, and environment. Table 6 indicates the difference between the NGCS and CDG surfaces at each of the locations right after construction and in 2010. The number in parenthesis after the 2010 difference is the years since construction. As evident in Table 6, the NGCS surface has been quieter than the CDG in all cases at the time of construction with an average difference of 2.1 dBA lower. After 2 -3 years the difference is 1.3 dBA lower. However the 2010 average may not be accurate since there are only three data points to average and the Chicago I-355 site is anomalous in comparison to the other sites for both the as-constructed levels and at 3 yrs. If the Chicago site is ignored for the as-constructed condition, the average difference for the other 5 sites would be 2.5 dBA lower than the CDG texture which is only slightly lower than the original Purdue estimate of a 3 dBA reduction.

TABLE 6 COMPARISON OF NGCS AND CDG OBSI LEVELS AT EACH LOCATION

State	OBSI Difference at Time of Construction (dBA)	OBSI Difference in 2010 (dBA)
Arizona[4]	-2.9	NA
Illinois[5]	-0.2	0 (3 yrs)
Iowa[6]	-1.3	NA
Kansas[7]	-2.3	-1.9 (2 yrs)
Minnesota[8]	-4.2	-2 (3 yrs)
Oklahoma	-1.6	NA
Average Difference	**-2.1**	**-1.3**

NGCS LITE Development

During NGCS development at Purdue University, it was observed that by improving micro texture it was possible to increase the noise reduction[2]. Although not proven at the time, it would follow that the improved micro texture would also improve frictional properties of the NGCS surface. Soon after the proof of concept work was completed discussions were held to evaluate means by which the micro texture on the land could be improved. If this were possible it would provide a major benefit for the NGCS texture.

At the time of the discussions it was believed that custom blades would be necessary to accomplish this task. However, the custom blades would be expensive and the time to construct them would prevent test section construction in 2008. Instead, Diamond Surfaces, Inc. proposed to attempt to simulate this approach by using worn blades of varying diameters and changing the spacers to 0.05" instead of the 0.03" spacers specified for NGCS. In October/November of 2008, the test section was constructed on I-94 WB at MnROAD. The texture was later called NGCS LITE.

The NGCS LITE surface was developed to provide additional micro-texture on existing NGCS surfaces should it become necessary to do so. With the large land size of the NGCS surface, the texture wear was assumed to be less than occurs on CDG surfaces. As such it should have extended life in comparison to CDG. With the advent of the NGCS LITE surface, it would provide an easily renewable surface that could be "touched up" in less time and cost than a CDG surface. Very little material is removed to create this surface, providing a significantly faster operation.

Unfortunately the first attempt at constructing the NGCS LITE surface was not successful. The noise was higher than the NGCS surface. At that time further development of the NGCS LITE surface ceased with the realization that special blades would probably be required. In the summer of 2009 Husqvarna Construction Products indicated they had an architectural blade that could produce the desired texture. In June of 2010, Interstate Improvement, Inc. ground a two foot wide test strip into cell 37 at MnROAD (see Figure 21) to demonstrate that the Husqvarna blades could indeed produce the desired texture. Figure 22 indicates the texture as constructed. The OBSI results were 99.8 dBA which indicated a success[13]. The test strip used ¾" groove spacing instead of the ½" to 5/8" spacing specified for NGCS to accommodate the blade widths of the specialty blades.

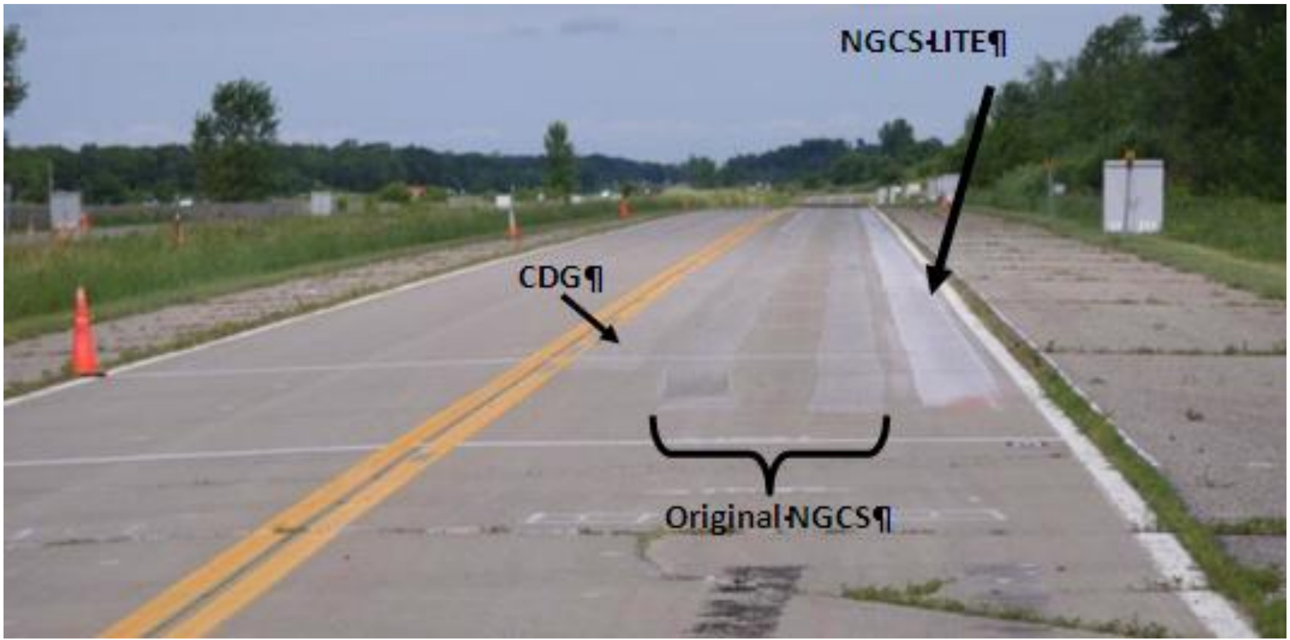


Figure 21 NGCS LITE Test Strip on Cell 37 at MnROAD[13]

However, a 2 ft. wide test strip did not prove it could be constructed on a production job. So in September 2011, Interstate Improvement, Inc. constructed a 1000 ft long by one lane wide test strip on I-35 in Duluth Minnesota. The OBSI level of the NGCS LITE texture prior to installing grooves was 99.6 dBA[14].

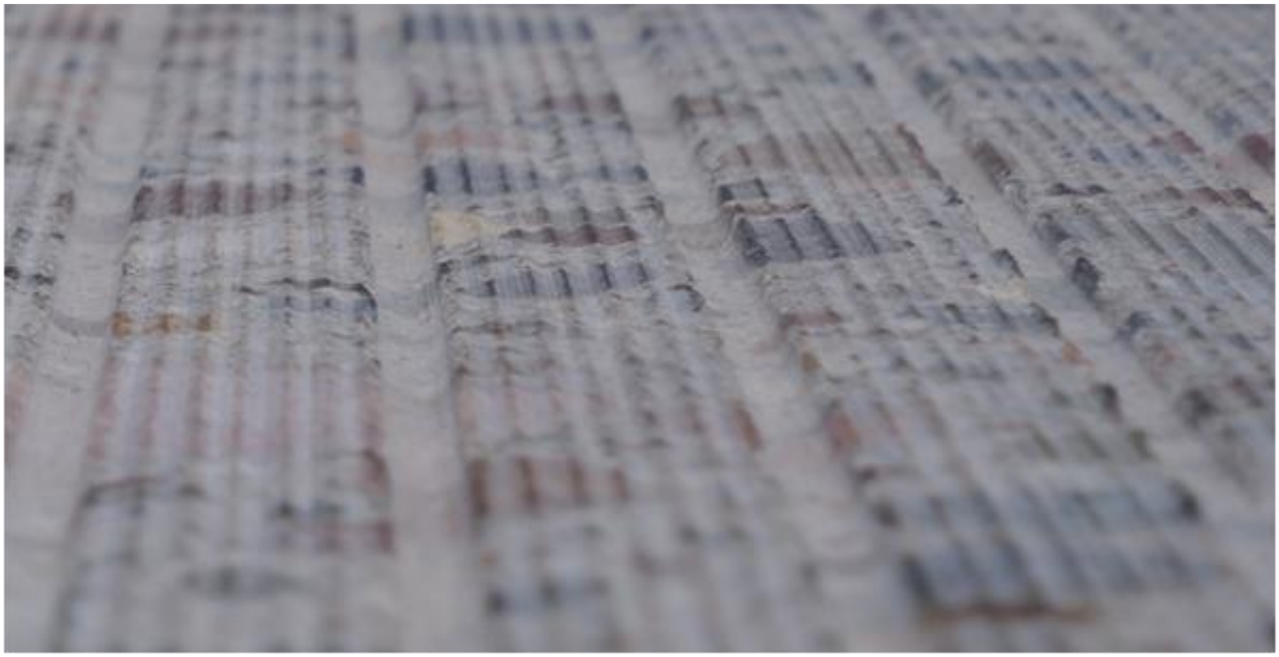


Figure 22 NGCS LITE Test Strip at MnROAD Cell 37[13]

Friction Results to Date

The original Purdue workplan included both friction and rolling resistance testing for each of the TPTA textures evaluated. However, concerns existed with the TPTA's ability to safely conduct skid testing. There also existed a need to further develop the newly created NGCS surface. As a result of this, the OBSI test plan was expanded and the friction and rolling resistance components were eliminated.

In the US, the ASTM E274 locked-wheel skid trailer is the predominant friction test device with only Arizona using an alternative device. Figure 23 is a photo of MnDOT's E274 device along with the two types of ASTM test tires; the smooth and ribbed tires. Most states use the ribbed tire for network level management. As indicated in Figure 23, water is sprayed from a nozzle just in front of the tire. The water film developed is 0.5 mm in thickness which is approximately half the thickness of a dime.

Currently the industry has no direct way of measuring friction on the NGCS test sections except for obtaining data from the agencies. The ability to obtain this data and the frequency at which it is obtained is controlled by each individual agency. As such, friction data is not currently available for all sites and years and only the data which the industry is allowed to present is provided.

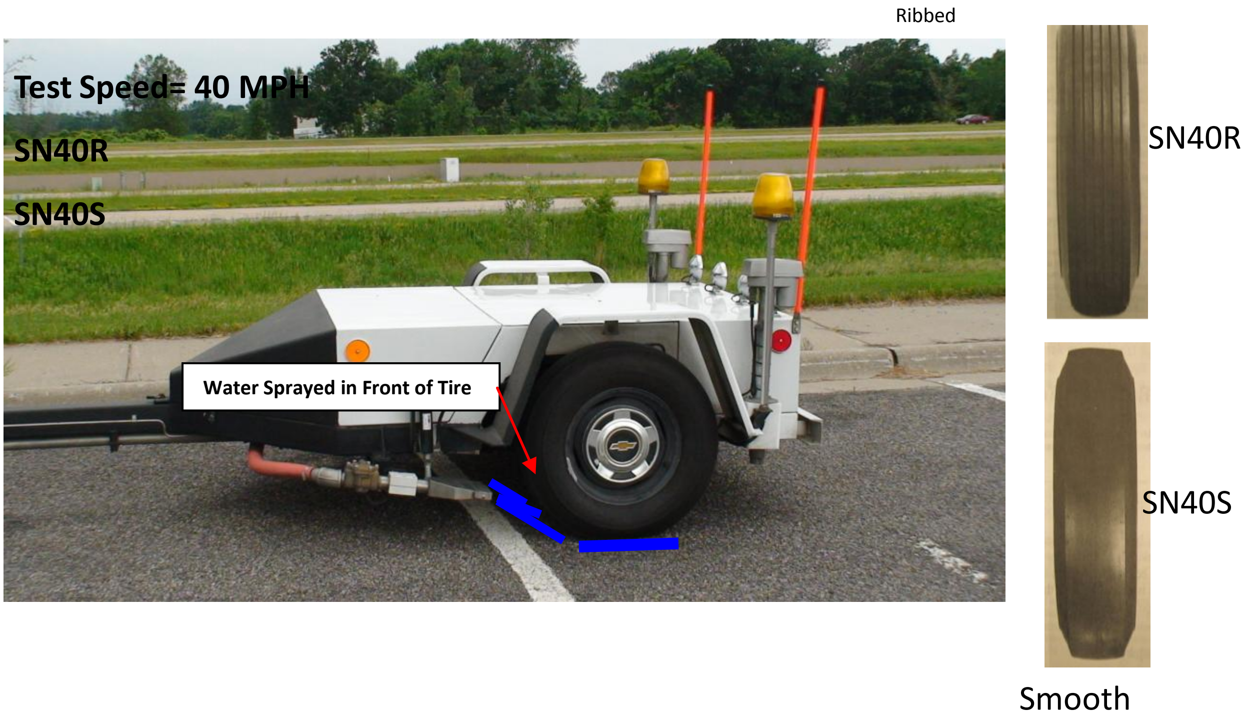


Figure 23 MnDOT ASTM E274 Skid Trailer with ASTM Smooth and Ribbed Tires

Table 7 indicates the friction data for each of the sites and the year it was obtained. The yellow colored cells in the Table indicated the year the test sections were constructed. The MnDOT data is the only time series data available and it indicates a stable friction levels in the short term.

Friction Comparison to Other Textures

MnROAD's Friction Test Results

The friction performance of the MnROAD I-94 test sections has been monitored by MnDOT since the construction of the test sections. Figure 24 indicates the time series behavior of the sections for both the ASTM ribbed (E501) and smooth (E524) tires. The 07 data reflect the friction of the NGCS just after original diamond grinding and just prior to opening to traffic. The test sections were constructed on a random transverse tined section which was 14 yrs old at the time and exhibited a ribbed and smooth tire friction of 51 and 36, respectively.

TABLE 7 FRICTION DATA (SN40) FOR NGCS LOCATIONS BY YEAR

State	Route	Friction (SN40R)			
		2007	2008	2009	2010
Arizona[4]	I-10 EB				NA
Illinois[5]	I-355 NB	35.1	41.9	NA	NA
Iowa[6]*	US 30				48
Kansas[7]	I-70 EB		NA	42.2	47.0
Minnesota[8,9]	I-94 WB MnROAD	51.3	45.1	42.4	44.3
	I-35 Duluth				53.6
	I-35 Duluth NGCS LITE				53.6
Oklahoma				51.8	39.8
Wisconsin[10] ***	SR 21		NA	NA	NA
Washington	I-82				47.1
	Avondale Rd				NA

One of the more remarkable aspects of data presented in Figure 24 is that the smooth tire results are higher than the ribbed tire results for the diamond ground surfaces. This is not the case for the random transverse tining which the test sections were constructed upon.

Since the NGCS has large lands (see Figure 10), it would not be expected to change much over time and it is evident the NGCS smooth and ribbed tire results have remained relatively consistent over the three years since construction.

Kansas I-70 Friction Results

The Kansas Department of Transportation constructed seven texture experiments on I-70 WB near Abilene, Kansas in 2008. The seven textures were exposed aggregate, longitudinal tining, astro turf, astro turf with grooving, burlap drag with grooving, conventional diamond grinding, and NGCS. The friction results of KDOT's testing are indicated in Figure 25 for six of the textures. As indicated there was an overall increase in Friction for the 2010 year, particularly the ribbed tire. It should also be noted that the two textures with grooves have the smallest difference between the ribbed and smooth tire results. The turf drag and longitudinal tined surfaces have very dramatic differences between the ribbed and smooth tire results. Surprisingly the turf drag section has the highest ribbed tire results.

Anti Lock Brake Testing

Conventional roadway friction measurement is accomplished by skidding an under inflated 15" tall, bias-ply tire at discrete locations while traveling 40 mph in the direction of travel. This is the technique used by most all transportation agencies in the US. These results are then used to evaluate the driving conditions for passenger cars (and trucks) driving at 45 to 75 mph, on 15" to 18" radial ply tires, equipped with ABS braking systems and driving around curves and tangent sections.

In recent times there has been increased interest in the use of smooth tires for friction measurement as they better represent the macro texture conditions of roadways and many believe they better relate to wet weather accidents. However, the ribbed test tire is still the industry standard.

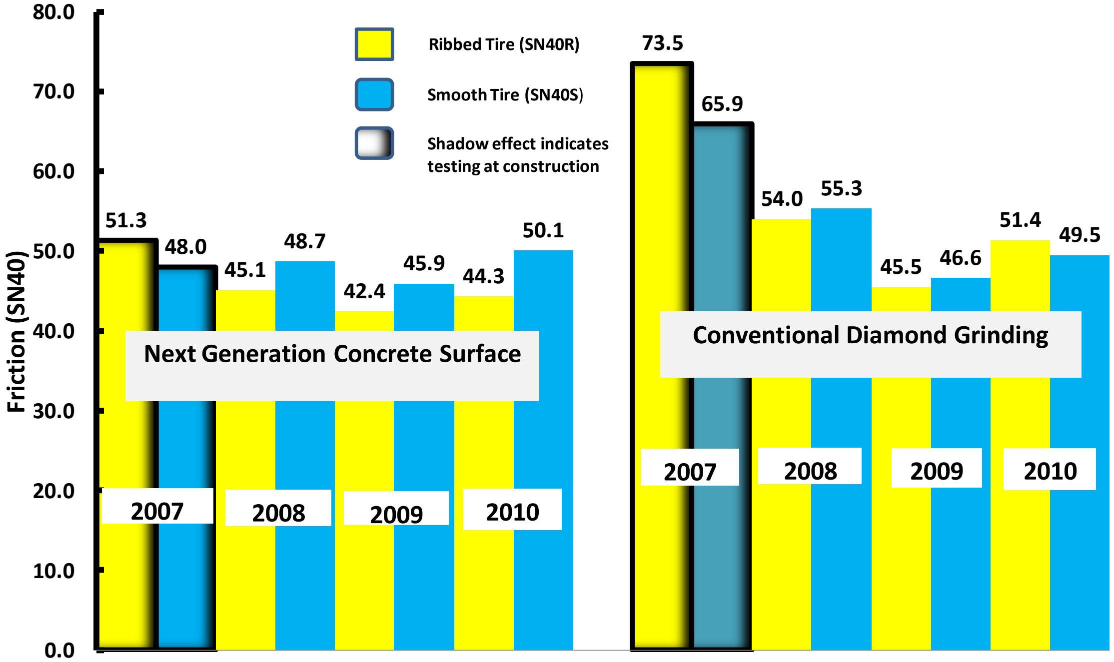


Figure 24 Friction (SN40) as a Function of Surface Texture and Time at MnROAD I-94 WB

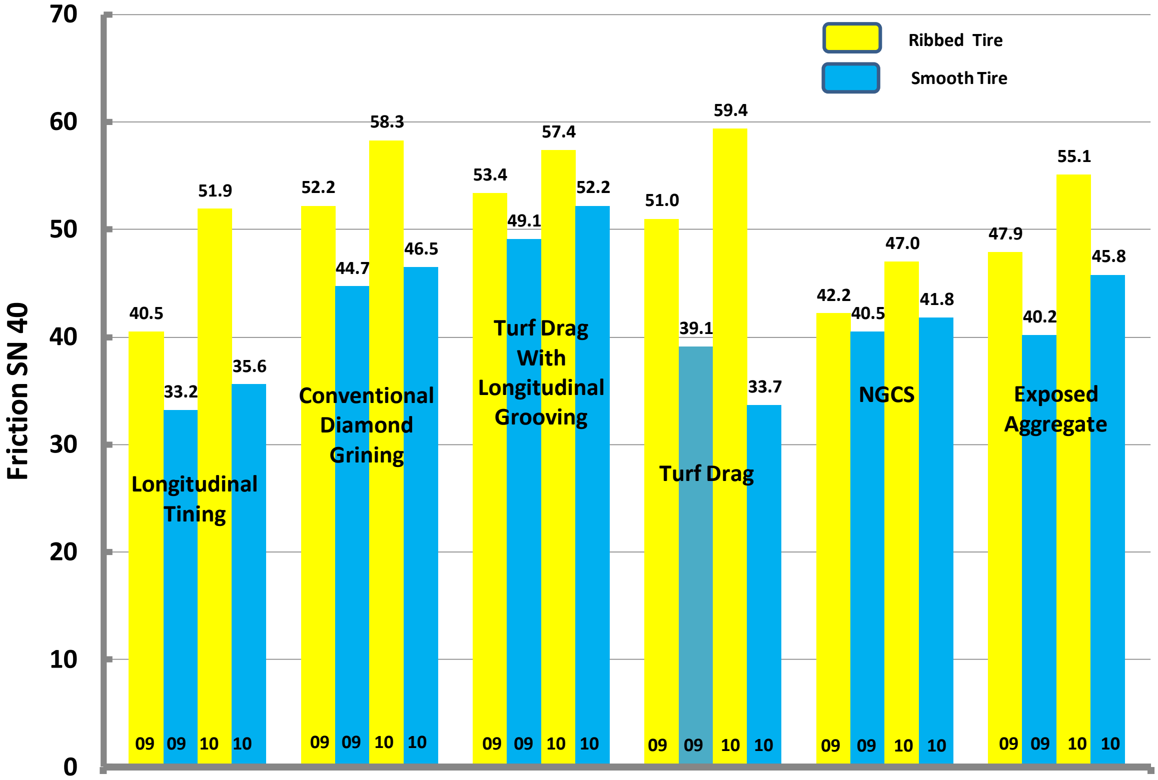


Figure 25 Friction (SN40) as a Function of Surface Texture and Time at KDOT I-70 EB

To evaluate the impact of the grooved NGCS surface on ABS braking, stopping distance testing was conducted by the University of Michigan Transportation Research Institute (UMTRI). UMTRI conducted the testing with an instrumented SUV vehicle at the Chicago I-355 site while the roadway was still closed during construction. Figure 26 is a photo of the testing conducted on the CDG section.

Since the roadway had not been opened to anything but construction traffic, the CDG and Random Transverse Tined (RTT) textures had not experienced any "wear in" as typically occurs with newly constructed textures. The NGCS, due to its construction process, was already "worn" in.

A water truck, provided by Quality Saw and Seal, Inc., was used to flood the surface just prior to SUV brake testing. The water truck is evident in the background of Figure 26. The water application rate could not be accurately controlled so this was more of a qualitative test than a quantitative test.

Stopping distance testing was conducted in the direction of traffic for the CDG surface which was located on a level grade. Since the RTT and NGCS surfaces were located on a slight grade, testing was conducted in the downhill direction as this was considered a more conservative approach[15]. This resulted in the testing occurring in the opposite direction of travel. No adjustments were made to the data to account for the grade effect. Stopping distance testing was conducted at 60 MPH for both the dry and wet pavement conditions.

Figure 26 SUV Stopping Distance Testing on I-355

At the time of the instrumented SUV testing, a Pontiac G6 rental car was also used to conduct similar braking tests. However, after several series of tests brake fade became the controlling factor and the rental car testing was discontinued.

The results of the Chicago I-355 braking testing are indicated in Figure 27. As indicated, the wet tests resulted in longer stopping distances than the dry tests. The NGCS surface had the longest wet and dry stopping results, while the CDG surface the shortest wet and dry test results.

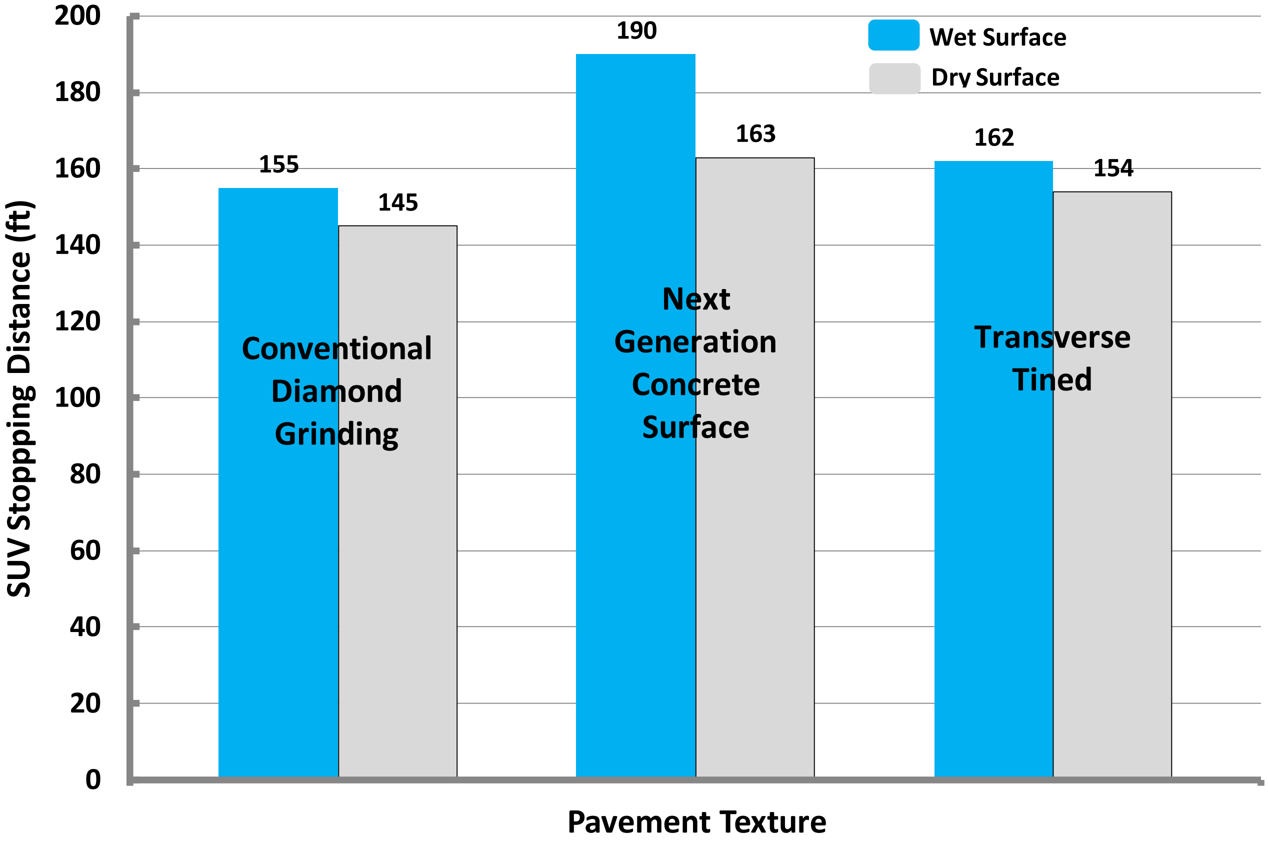


Figure 27 SUV ABS Brake Stopping Distance Testing at Chicago I-355

Anisotropic Friction

During the 1960s, the California Highway Department developed longitudinal grooving as a wet weather accident reduction strategy with significant success: wet weather accident reductions as high as 90% were reported [16]. Although the longitudinal grooving provided a significant reduction in wet weather accidents, little or no friction improvement was measured using the lock-wheel skid trailer with a ribbed tire. At the time it was felt that the safety improvement occurred as a result of increased lateral stability provided by the grooves during cornering and during accidents when vehicles lose control.

In 2008, the IGGA contracted with MACTEC, Inc. to bring a California CT-342 test device to MnROAD to evaluate the NGCS and other surfaces. Since the NGCS surface uses longitudinal grooves it was felt that additional benefits were obtained with this surface that were not presently being measured.

The California CT-342 device was developed in the 1960s and is unique in that it has the ability to measure friction at any angle on a roadway surface between 0 and 90 degrees if properly ballasted. Figure 28 is a photo of this device being used at the MnROAD facility[17].

The results of this testing are indicated in Figure 29 for the surfaces tested. It should be noted that only data up to 30 degrees is shown since, at 90 degrees, the device bumped up and down while crossing the grooves due to insufficient ballast.

Figure 28 CT-342 Measuring Friction at Various Angles at MnROAD[17]

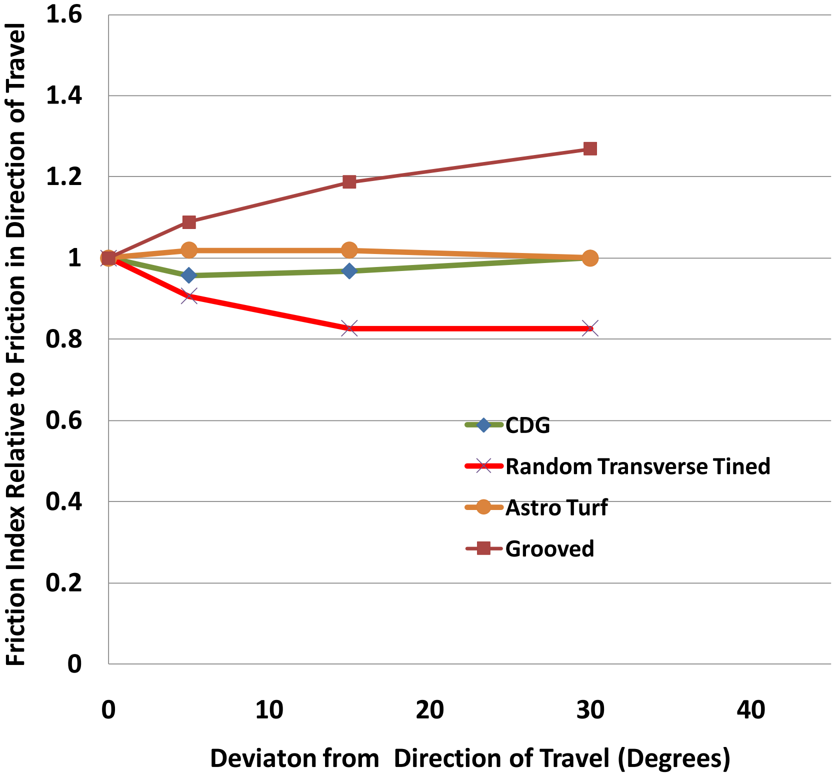


Figure 29 Anisotropic Friction Behavior On Various Concrete Surfaces

The Friction Index results indicated in Figure 29 are obtained by dividing the friction measured at some angle to the direction of travel by the friction obtained in the direction of travel. Therefore, if the friction is the same in all directions, the Friction Index would equal 1. If the friction at some angle to the direction of travel is less, than the index will be less than 1.

As indicated in Figure 29, the Friction Index of the grooved NGCS surface increases as the angle away from the direction of travel increases. This may very well explain why grooved surfaces provide increased wet weather accident reductions. As vehicles begin to get out of control the friction may be increasing in the direction of the “new” travel.

Hydroplaning Potential

Although friction and hydroplaning are part of a surface texture continuum, they must be considered as separate design elements. For example, Figure 30 indicates the mean texture depths determined by KDOT on the I-70 texture experiment previously described. Plotted along with this data is the 0.5 mm water film thickness for the ASTM E-274 skid trailer. Note that the only surface that is challenged by this film thickness is the burlap drag texture (which also had the largest difference between ribbed and smooth tire results).

Since hydroplaning planning is a function of mean texture depth, if all other parameters are held constant, it is obvious that the hydroplaning resistance of these textures ranked differently than the friction plot in Figure 25. This is why safety cannot be described by friction alone, but must consider hydroplaning resistance and lateral stability.

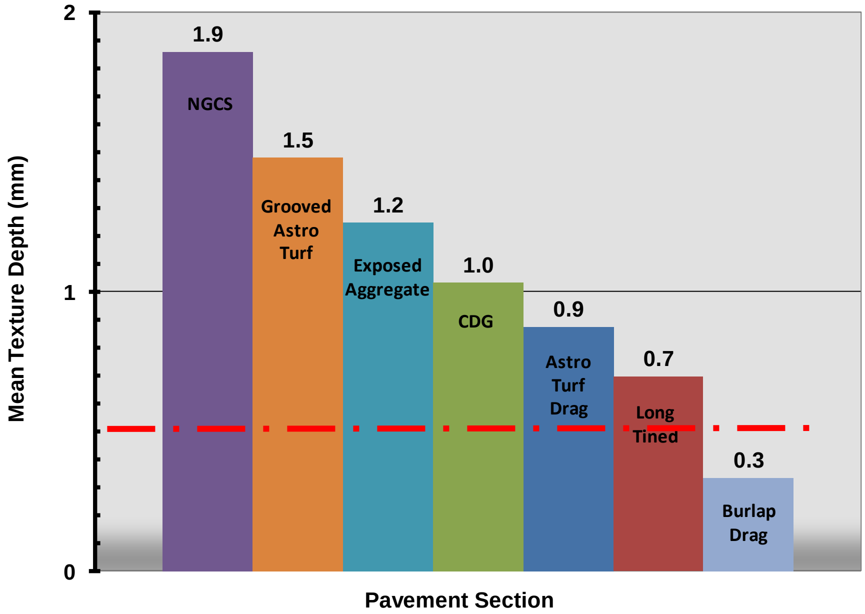


Figure 30 Mean Texture Depths on Kansas I-70 Texture Experiment

Summary

The NGCS surface is the first new non- porous concrete texture to be introduced in the last 20 to 30 years. It took three years to research and develop, but less than one year to get field test sections constructed. Today, there are 13 surfaces in 9 states in which evaluation of its performance is ongoing; from the deserts to the wet freeze environments utilizing pavements built with a wide array of aggregates and mix designs. With only three years of experience with this texture, the journey is a long way from over.

The NGCS was conceived as a “manufactured surface” which would result in consistent and predictable properties at the time of construction and throughout its life. Figure 31 indicates typical

OBSI levels associated with the various textures and to date the NGCS surface has met the low noise goals and demonstrated the lowest variability in as-constructed results.

With the improved lateral stability and hydroplaning resistance afforded by the NGCS texture, there are additional benefits than just noise reduction. Currently there are four specifications for construction of NGCS. The four specifications are listed below and are available at the IGGA website @ http://www.igga.net/specs/dot-specification.cfm

- NGCS Test Section Construction on New Roadways (February 2011)
- NGCS Test Construction on Existing Roadways (February 2011)
- NGCS Construction on Newly Constructed Roadways (February 2011)
- NGCS Construction on Existing Roadways (February 2011)

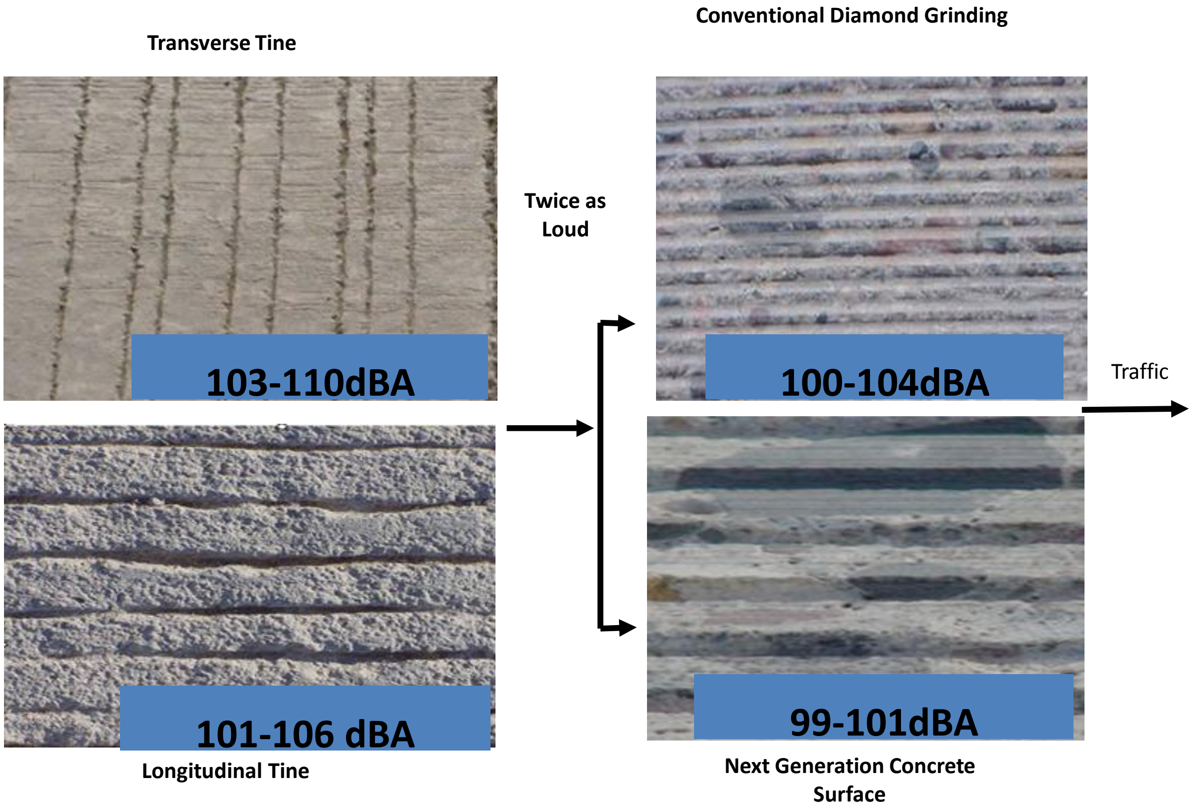


Figure 31 Typical OBSI Levels Measured on Each of the Pavement Textures

Acknowledgements

The author would like to acknowledge the contribution of several individuals who are primarily responsible for the development and implementation of the NGCS texture. First is Mr. Jerry Voigt (ACPA) who developed the concrete industry's noise workplan in 2004 by which the Purdue work was undertaken. Second is Dr. Robert Bernhard formerly of Purdue University who, with the assistance of Mr. Will Thornton, determined that fin profile was the controlling factor in noise generation. Next is Mr. Terry Kraemer who was steadfast in the belief that the NGCS could be constructed; and proved it against many dissenting opinions. And finally, Mr. Scott Eilken who constructed the first NGCS texture on a highway.

In addition to the individuals, three organizations should be recognized for their contributions: First, the cement industry for funding the work that developed the NGCS surface. Second, the IGGA whose technical contributions and assistance proved invaluable to Purdue. The IGGA also provided the proof of concept testing. Thirdly, the Minnesota Department of Transportation for their willingness to construct the proof of concept sections and the many subsequent NGCS sections. Without the actual field trials, the Purdue work would no doubt have just been another research report.

References

References are available on line @ www.NGCS.info

1. Scofield, L, "MnROAD Validation of Purdue TPTA Results- Construction Report" , American Concrete Pavement Association, August 2, 2007.
2. Dare, T., Thornton, W., Wulf, T., Bernhard, R., "Purdue Final Report Acoustical Effects of Grinding and Grooving on Portland Cement Concrete Pavements HL 2009-1", Purdue University's Institute of Safe, Quiet, and Durable Highways, 2009
3. Dare, T., Wulf, T., Bernhard, R., "Acoustical Performance of Open Cell Foam in Longitudinal Grooves on Concrete Roadways," Purdue University's Institute of Safe, Quiet, and Durable Highways, November 2008.
4. Scofield, L, "MnROADs Low Volume Road Testing to Validate the Purdue TPTA Textures and Predictive Joint Effects", American Concrete Pavement Association, June 2007
5. Scofield, L., "Arizona I-10 EB NGCS and CDG Test Section Draft Construction Report", American Concrete Pavement Association, June 2010
6. Scofield, L., "Chicago I-355 NB OBSI Test Results", American Concrete Pavement Association, June 2010
7. Scofield, L., "OBSI Testing of Iowa US 30 Diamond Ground Surfaces," American Concrete Pavement Association, October 2010
8. Scofield, L., "Kansas I-70 EB Surface Texture Test Section OBSI Evaluation," American Concrete Pavement Association, June 2010
9. Scofield, L., "OBSI Testing of MnROAD I-94 WB Exposed Aggregate and Diamond Ground Test Sections," American Concrete Pavement Association, June 2010
10. Scofield, L., "Chicago I-355 Testing of NCHRP 10-67 Site Locations," American Concrete Pavement Association, June 2010
11. Scofield, L., "MnROAD I-94 NGCS, NGCS LITE, and OBSI Test Results," American Concrete Pavement Association, July 2009
12. Wilde, W. J., Izevbekhai, B., "Innovative Diamond Grinding on MnROAD Cells 7,8,9, and 37" Minnesota Department of Transportation, Final Report 2011-05, December 2010
13. Scofield, L., "MnROAD NGCS LITE Test Strip Evaluation," American Concrete Pavement Association, January, 2011
14. Scofield, L, "Duluth I-35 NGCS Open House Testing", American Concrete Pavement Association, January 2011.
15. Scofield, L., "Chicago I-355 Validation of Purdue TPTA Results", American Concrete Pavement Association, October 16, 2007.
16. Beaton, J., "Slippery Pavements," Paper Presented at the 39th Annual Meeting of the Institute of Traffic Engineers in Los Angles by California Highway Department, August 25-28, 1969.
17. Scofield, L., "California Friction Testing at MnROAD (CA-342)," American Concrete Pavement Association, Powerpoint Presentation, November 2008.