Grains of gain

Study takes another look at manufactured-sand use

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The International Center for Aggregates Research (ICAR) has been performing research on the use of aggregates in asphalt and portland cement concrete (PCC) for more than 15 years.

A study was initiated at the University of Texas to investigate the use of manufactured sands in PCC pavements. The research project was funded by the Texas Department of Transportation (TxDOT) and had the objective of finding better methods to evaluate and design PCC pavement mixtures containing manufactured fine aggregates (MFA) while maintaining performance.

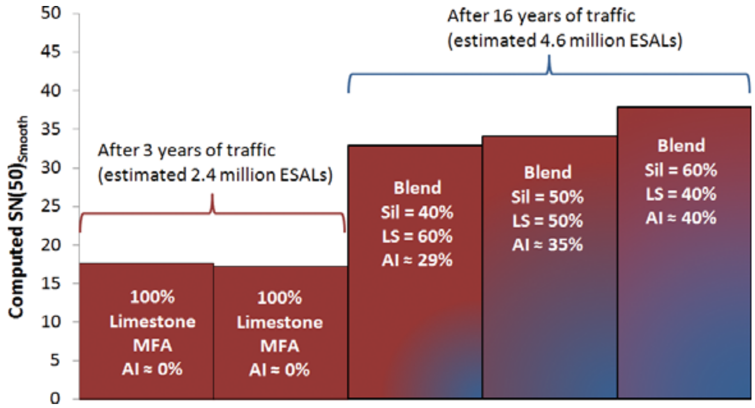
The abundance of manufactured fine aggregates, their low cost, and the lack of natural sands in some areas are some of the reasons why new methods of testing and proportioning MFA were investigated. While crushed stone has been extensively used by the concrete industry, manufactured sand has not. The two main problems that have hampered the use of MFA in PCC pavements are related to (1) poor skid performance and (2) difficulties in proportioning MFA due to their poor shape and gradation. This article discusses a new method for evaluating concrete surfaces for skid resistance and an improved method for proportioning pavement concrete.

Stopping the skid

The need for skid-resistant pavements was recognized at the First International Skid Prevention Conference in 1958. State agencies started developing equipment to test skid resistance both in the laboratory and in the field. While pavement skid-testing equipment was used to measure skid on existing pavements, materials tests were needed to identify good-performing aggregates. In PCC pavements, the mineralogy of the fine aggregate

Figure 1. A section containing 100% MFA.

Figure 2. MPD vs. Measured SN(50)$_{smooth}$.



is important for obtaining good friction, because the surface of concrete exposed to traffic mostly consists of mortar (fine aggregate and cement paste). Unlike asphalt concrete, coarse aggregate only becomes an influencing factor in cases where the top surface of the pavement has been severely abraded or when coarse aggregate is intentionally exposed (i.e., diamond grinding).

In 1958, Shupe and Lounsbury showed a correlation between calcium carbonate content of aggregates and skidding susceptibility on PCC pavements. In 1965 the contribution of siliceous sand particles in skid resistance was recognized by Gray and Renninger, who pioneered the acid insoluble residue test (AI). The AI test consists of mixing a sample of fine aggregate with a concentrated solution of hydrochloric acid. After the reaction between the aggregate and the acid stops, the aggregate is washed, oven-dried, and then the weight change is used to compute the acid-insoluble residue. Since hydrochloric acid dissolves carbonates, the AI test is capable of measuring the noncarbonate content of aggregate. In 1966, Balmer and Colley performed a laboratory concrete skid-performance test and correlated those results with the acid-insoluble residue of the aggregates they evaluated. Aggregates containing a higher percentage of siliceous sand or a lower percentage of carbonates were found to result in better skid performance. Moreover, they concluded that 25% siliceous fine-aggregate content was satisfactory for skid performance with most aggregates. Studies done after 1966 had similar conclusions as the study by Balmer and Colley.

Many states have either banned the usage of carbonate fine aggregates or have required blending those aggregates with harder aggregates to meet certain limits. Most specifications base their limits on the study done by Balmer and Colley. Some specifications require a minimum of 25% siliceous sand content in pavement concrete, while other specifications have set limits based on AI values. TxDOT originally required fine aggregates to meet an AI limit of 28%, which would have required about 25% siliceous sand content and excluded the usage of 100% carbonate sands. After skid problems were reported, the AI limit was raised to 60%. Under the 60% AI specifications, the maximum amount of carbonate sand that can be used in a PCC pavement is less than 40% of the total sand volume.

The adoption of the 60% AI limit by TxDOT has affected districts that have limited local sources of natural siliceous sands and thus requires transporting natural sands from distant sources to be blended with local sources of manufactured carbonate sands to meet the 60% AI limit. The goal of the research project was to evaluate the polish resistance of manufactured fine aggregates, identify aggregate tests that best relate to concrete performance and investigate the possibility of using more manufactured sands in PCC pavement.

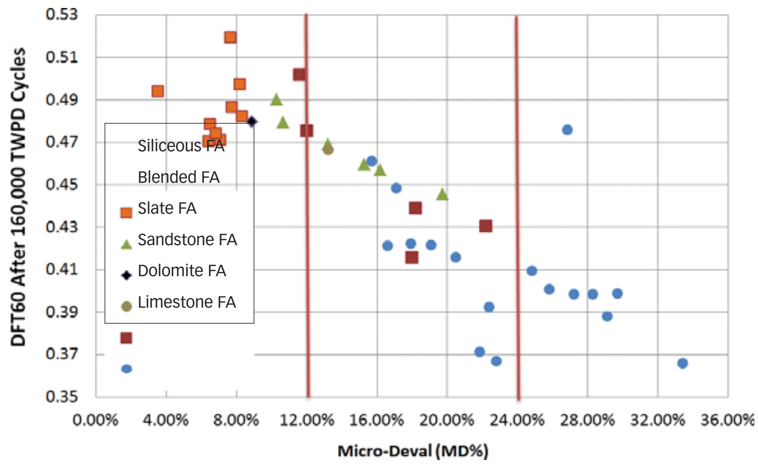
Five field sections in two different locations were evaluated. Those sections were chosen because they were the only known sections in Texas that were made with materials that did not meet the TxDOT AI limit of 60%. The first location had two sections that were constructed with 100% limestone MFA, while the second location contained three sections made from three different blends of siliceous sand and limestone MFA. The difference between the two sections made with 100% MFA (AI ≈ 0%) was in gradation, not source. The other three sections were constructed using blends of sands that do not meet the 60% AI limit (AI of 29, 35 and 40%). After being in service for only two years, sections that contained 100% MFA were found to be highly polished (Figure 1).

Most state agencies in the U.S. use the locked-wheel skid-trailer test (ASTM E 274) to evaluate skid resistance. The method consists of measuring the locked-wheel friction (100% slip condition) of a trailer towed behind a truck at a speed of 40 mph (TxDOT uses 50 mph). The trailer administers a water spray to the pavement in front of the tire to simulate wet conditions. The resulting friction force acting between the test tire and the pavement surface is used to determine the skid resistance, which is reported as a skid number (SN). Higher SN values signify higher skid resistance. A smooth tire (ASTM E 524) or a ribbed tire (ASTM E 501) can be used on the skid trailer.

Results shown in Figure 2 were found using a dynamic-friction tester (DFT) that was converted to an equivalent SN value. The DFT (ASTM E 1911) is a laboratory and field apparatus that measures the torque needed to stop three small spring-loaded standard rubber pads rotating in a circular path on a wet pavement. The torque measured is then converted

Figure 3. A modified polishing device.

Figure 4. DFT60 after 160,000 TWPD cycles.



to a friction value. Although the estimated equivalent single-axle load (ESAL) count for the blended sections is twice that of the 100% MFA sections, the skid values obtained for the 100% manufactured limestone sections were about half those of the blended sand sections. The blended sand section with the highest siliceous sand content (or highest AI content) had the highest skid value. Moreover, Figure 2 shows that even when only 40% siliceous sand was used (AI ≈ 29%), good skid resistance was achieved.

To complement the field testing, laboratory tests on aggregates and concrete also were performed. To be able to evaluate the polish resistance of concrete in the laboratory, a method of simulating abrasion due to traffic was needed. A three-wheel polishing device (TWPD) developed by the National Center for Asphalt Technology (NCAT) to test asphalt concrete was purchased and modified (Figure 3). The TWPD was developed to be used with a circular track meter (CTM) (ASTM E 2157) and a DFT. It polishes a circular path on a laboratory specimen that has the same diameter as the path evaluated by the CTM and DFT. The NCAT polisher is composed of three wheels that rotate on a laboratory specimen for a specified number of cycles. Iron plates can be placed on the turntable to increase the weight on the TWPD and, hence, the stress on the concrete. The TWPD also has a water-spray system that sprays water on the surface being polished. NCAT added the water-spray system to wash away the abraded particles, simulate wet weather conditions and extend the life of the wheels.

Results obtained from this research show that higher carbonate contents might indicate the presence of softer sands, but that is not always true. The AI test, which is used by state agencies, is a surrogate test that measures the carbonate content of fine aggregates. The AI does not directly measure the hardness of the aggregate. As part of the project, other aggregate tests were investigated: the micro-deval test (ASTM D 7428) for fine aggregates was found to be a more reliable test for predicting the performance of concrete tested in the laboratory. The test consists of placing a presoaked aggregate sample (washed and graded) in a jar with a fixed volume of water and a fixed quantity of steel ball bearings. The unit is then put into rotation for a specified period of time or number of cycles. After the sample is run in the device, it is washed over a No. 200 sieve, and the retained sample is oven-dried. The percent loss in mass is computed from the oven-dried sample. Aggregates with a low percent loss are considered to be more durable than the aggregates with a higher percent loss.

Figure 4 compares the results obtained from the micro-Deval test to the DFT friction values at 40 mph (DFT60) after 160,000 polishing cycles. Results in Figure 4 show that as the percent micro-Deval loss increases, the friction value measured by the DFT decreases. The main difference between AI and micro-Deval is that micro-Deval can more accurately differentiate between softer and harder carbonate fine aggregates.

Furthermore, data obtained from both laboratory and field testing indicate that while a 100% limestone MFA might cause a loss in skid, blending a small percentage of siliceous sand with MFA significantly increases skid performance. For blended sands skid resistance increases as the percentage of siliceous sand increases.

They came up with five

Methods commonly used for proportioning concrete such as ACI 211 select the cement content of a mixture based on slump, strength and durability requirements. These methods, however, do not provide guidance on minimizing cement. Various research projects performed by ICAR have shown that cement can be reduced in concrete while maintaining the strength and improving the durability. ICAR research also has shown that the minimum cement content is a function of the desired workability, which is dependent on the type and combination of aggregate being used. Aggregates with poor shape and grading typically have a lower packing density than well-shaped and well-graded aggregates, resulting in more paste (cementitous material and water) being required to fill the voids between aggregates. The proper selection of aggregates can minimize the increased water and cementitious-materials contents needed to ensure adequate workability while also reducing the overall cost of the mixture.

Considerable research has been performed in several of the ICAR studies to develop improved methods of mixture proportioning for concrete containing MFA including high levels of fines passing the No. 200 sieve. More than 60 concrete mixtures containing 11 different blends of aggregates made with natural and manufactured sands having different shape, texture and gradation were evaluated. The results

Figure 5. An example of a combined DRUW.

from this testing were used along with previous ICAR research to develop a mixture proportioning method for slipform paving concrete. This method is summarized in five steps:

1. Evaluate aggregate properties, including sieve analysis, specific gravity, absorption and presence of deleterious material in fines passing the No. 200 sieve;
2. Determine the optimum combination of aggregates. Various methods are available, but it is recommended to use a 0.45 power chart to obtain a dense-combined aggregate gradation;
3. Determine the void content for the aggregate combination obtained in step two using a combined dry-rodded unit weight test (Figure 5). The void content (percent void) is equal to the paste content required for the mixture;
4. Choose paste quality: water-to-cementitous ratio, percent air, supplementary cementious material, admixture, etc.; and
5. Perform trial batches and adjust mixture proportions accordingly; if the workability is not achieved, paste can be added to the mixture. On the other hand if the trial batch shows that paste can be further reduced, then reduce the paste content.

Sand success

The results of this research project were used to provide TxDOT with the following:

- A new method for evaluating manufactured sands for PCC pavement based on a mechanical test that evaluates aggregate resistance to abrasion rather than aggregate chemical composition. Using this test instead of the AI test allows for more manufactured sands to be used in PCC pavements without affecting performance; and
- A simple proportioning mixture design method specifically tailored to optimize slipform pavement concrete mixtures containing any combination of aggregate. CP

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