U.S. Department of Transportation
Federal Highway Administration

SUSTAINABLE PAVEMENTS PROGRAM

SUPERPAVE5: POTENTIAL ASPHALT SURFACE MIX

FHWA-HIF-19-083

The Indiana Department of Transportation (INDOT) has adopted Superpave5 as a standard specification on pavement construction projects. Superpave5 is an asphalt mix-design method that targets 5 percent air voids during laboratory design and field placement. Starting in 2013, INDOT demonstrated that layers containing the Superpave5 mixes are constructible without additional equipment or effort. In the short term, these layers exhibit similar environmental impacts as previous Superpave designed mixes and INDOT will continue to monitor to assess long-term performance.

WHAT WAS THE MOTIVATION?

Cracks resulting from asphalt binder aging is the primary failure mechanism for most asphalt-concrete (AC) pavements in Indiana. Asphalt mixtures designed using the conventional Superpave approach last for 15 to 20 years, and INDOT sought to extend the service life of AC pavements by delaying asphalt-binder aging. Increasing the in-place density was identified as one way of decreasing asphalt-binder aging and was conservatively estimated to provide an additional 2 to 3 years of pavement life (Hekmatfar et al. 2015). However, the compaction of conventional Superpave mixes to an increased density would mean a significantly higher compactive effort that could damage the aggregates and significantly increase costs. Research conducted at Purdue University illustrated that the key to achieving a high in-place density is to modify the AC mix design and use the same air void criterion for both laboratory and field compaction (Hekmatfar et al. 2015). This approach also maintains the binder content and rut resistance of AC mixes designed using the conventional Superpave procedure.

WHAT WAS DONE?

The current Superpave mix-design approach (AASHTO M323) includes laboratory compaction of AC mixes at 4 percent air voids. INDOT compaction specifications require field placement of the asphalt mixtures at 7 percent air voids, which assumes that traffic will densify the pavement to the 4 percent air-void design level. However, even after several years of service, the design air void level may not be achieved, which allows increased AC oxidation that reduces pavement durability from aging, brittleness, and permeability.

Inspired by work completed by the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR) a target value of 5 percent air voids AC was selected for design and construction, with the resultant approach termed Superpave5. The compaction of AC mixes to 5 percent air voids increases the in-place density of the pavement. This in turn improves the pavement's durability in terms of enhancing resistance to cracking, rutting, and moisture damage while reducing aging potential (Aschenbrener et al. 2017).

INDOT constructed three demonstration projects to compare the construction and performance of AC mixes produced using the Superpave5 and the conventional Superpave approaches. Two projects in Indiana were selected for this case study—one on State Route (SR) 13, near Middlebury and the other on U.S. 40 in Richmond. Each project includes pavements designed using both mix design approaches. SR 13 represents the first Superpave5 project in the U.S. with its construction in 2013 on the southbound direction. U.S. 40, with two lanes in each direction and a center turn lane, was constructed in 2016 on the westbound passing lane and eastbound driving lane. General details for both projects are presented in table 1 (data sources: Montoya, Pouranian, and Haddock 2016; Huber et al. 2019).

Both projects include a 1.5-inch surface course built using the Superpave5 and traditional Superpave approaches, with the volumetric properties of the AC mix designs presented in table 2 (data sources: Montoya, Pouranian, and Haddock 2016; Huber et al. 2019). A PG 70-22 binder was used in both pavements, and the binder content for both projects was kept approximately the same.

Table 1. General project details.

Project Characteristic	SR 13	U.S. 40
Year built	2013	2016
Two-way annual average daily traffic	13,400 vpd (2012)	17,790 vpd (2016)
Trucks (%)	19	5
Directional distribution (%)	49.0 (Northbound)	49.6 (Eastbound)
Superpave5 section length (mi)	2.2	1.8
Entire project length (mi)	6.1	1.8

Table 2. Properties of AC mix designs used at the SR 13 and U.S. 40 projects.

Property	SR 13 Superpave5	SR 13 Control	U.S. 40 Superpave5	U.S. 40 Control
Design gyrations	30	100	50	100
Binder content (%)	5.4	5.1	7.1	6.7
Voids in mineral aggregate (VMA) (%)	17.0	15.5	16.7	15.6
Air voids (%)	5.0	4.0	5.0	4.0

The use of higher air voids in the Superpave5 mixes, compared to the conventional Superpave mixes, calls for a similar increase in the voids in mineral aggregate (VMA) if the binder content is to be maintained. The initial selection of 30 gyrations was based on a modulus (E*) and rutting resistance (Flow Number) of mix designs done at different gyration levels and compacted to 5 percent air voids for the performance tests. These mixtures were compared to the regular Superpave design (4 percent design air voids) compacted to 7 percent air voids for the performance test specimens. For the three different designs studied, the research indicated that designs done with 30 gyrations would provide the equivalent mixture properties. After constructing two trial sections using mixtures designed with 30 gyrations, a decision was made to increase the design gyrations to 50. These designs had a slightly different aggregate gradation, an example of which is shown in figure 1 (data source: Montoya, Pouranian, and Haddock 2016). Table 3 shows the properties of the plant-produced AC mixes for both projects as well as the in-place air voids (data sources: Montoya, Pouranian, and Haddock 2016; Huber et al. 2019).

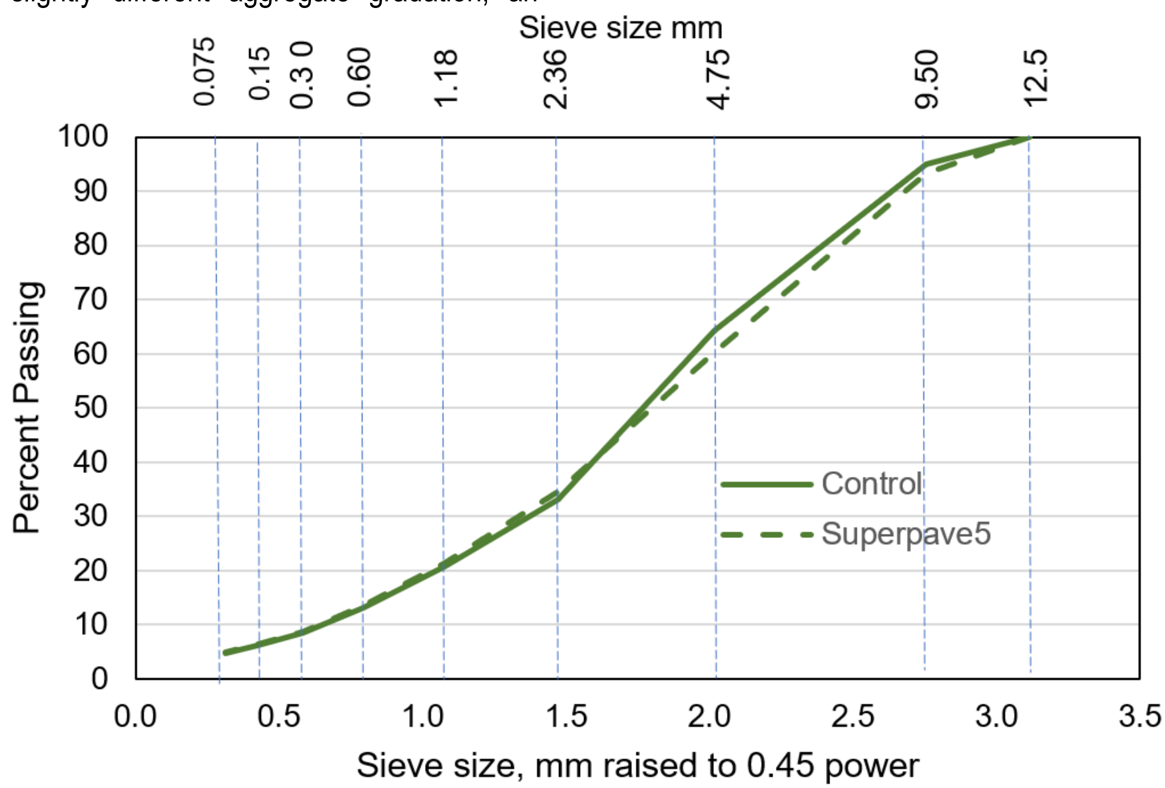

Figure 1. Asphalt-concrete aggregate gradations for control and Superpave5 used at the U.S. 40 project.

Table 3. Properties of plant-produced AC mixes.

Property	SR 13 Superpave5	SR 13 Control	U.S. 40 Superpave5	U.S. 40 Control
Number of gyrations	30	100	50	100
Binder content (%)	5.3	5.2	6.7	6.5
Air voids at design gyrations (%)	4.3	2.7	5.6	4.7
In-place air voids (%)	4.7	7.3	4.7	6.7

In the construction of each project, the same plant was used to produce both AC mixes. In addition, the rolling train, passes, and patterns were the same for both sections. This confirms that Superpave5 mixes could be produced and constructed without additional equipment or construction efforts.

WHAT BENEFITS WERE ACHIEVED?

PERFORMANCE

Table 4 summarizes the rut depths and the International Roughness Index (IRI) for both projects; SR 13 data were collected in 2018 (Huber et al. 2019) while the U.S. 40 data were collected in 2019 and provided by INDOT. To date, the Superpave5 and control sections on SR 13 exhibit similar smoothness and rutting performance after approximately 5 years of service. Similarly, in the driving lanes of U.S. 40, the Superpave5 and control sections show comparable similar smoothness and rutting performance after 3 years of service. However, in the passing lanes of U.S. 40, the control section exhibits greater IRI values, which could be attributed to the presence of several manholes and utility access points along this portion of roadway.

COST

The SR 13 and U.S. 40 sections were demonstration projects that were bid using change orders, so a direct examination of actual construction costs may not be meaningful. Therefore, additional pairs of projects featuring Superpave5 and control mix designs were selected for initial cost comparison (that is, the projects were bid separately from the SR 13 and U.S. 40 projects). Those costs are summarized in figure 2.

All groups represent the price per ton of a 9.5-mm surface mix. The Group 1 projects were in neighboring counties, and the bid prices are by the same contractor. The Group 2 projects, however, reflect bids by different contractors for projects in different counties. The Group 3 projects represent prices by a single contractor for projects in different counties. In general, it appears that the two AC mix-design approaches have a similar average bid price at this time. However, as differences in the performance of the sections become apparent, a life-cycle cost analysis may be used to better evaluate the cost-effectiveness of the Superpave5 approach.

Table 4. Field performance data for SR 13 and U.S. 40 projects.

Roadway		SR 13 (2018 data)		U.S. 40 (2019 data)	
Lane	Performance Indicator	Superpave5 Section	Control Section	Superpave5 Section	Control Section
Driving	Rut depth, inches	0.14	0.13	0.08	0.08
	IRI, inches/mi	53	47	60	48
Passing	Rut depth, inches	Not Applicable	Not Applicable	0.08	0.08
	IRI, inches/mi	Not Applicable	Not Applicable	50	110

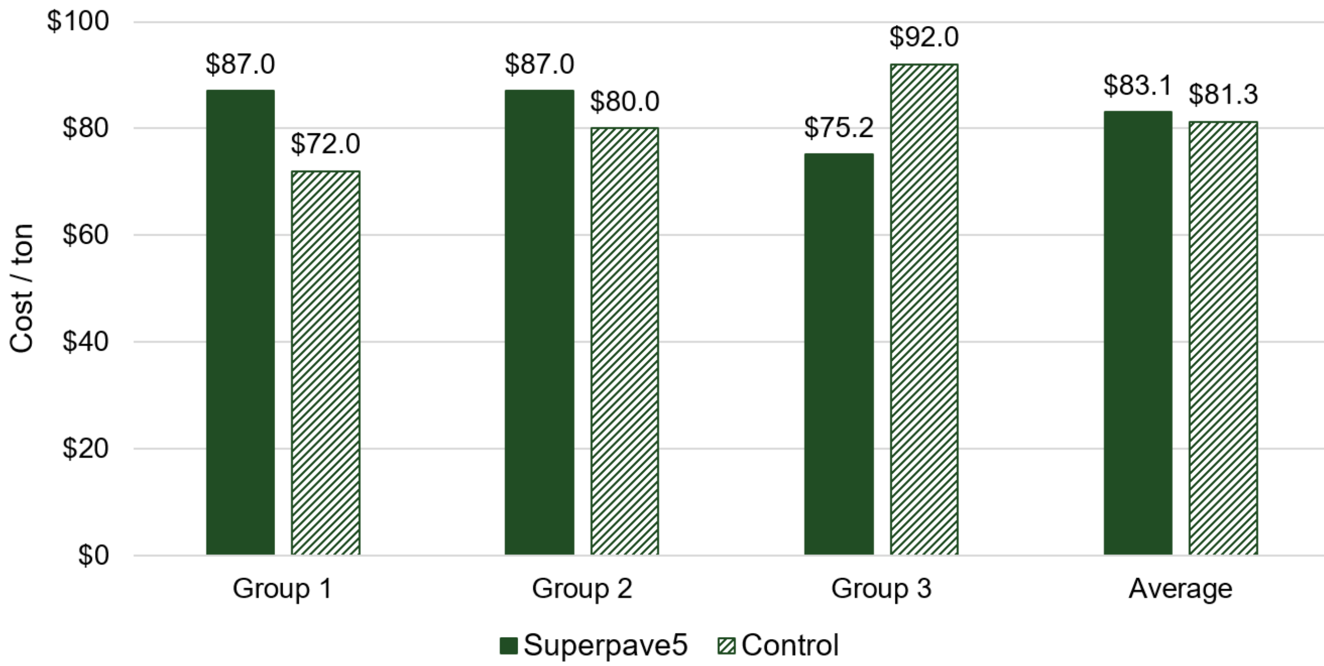

Figure 2. Cost comparison of the production of Superpave5 and control mixes.

ENVIRONMENTAL PERFORMANCE

In addition to economic benefits, INDOT, through its Green Initiatives, is dedicated to improving pollution prevention, energy efficiency, and air quality efforts as well as decreasing the demand on natural resources (INDOT 2019). To assess the broader environmental performance of the two AC mix-design approaches, researchers contracted by FHWA performed a limited life-cycle assessment (LCA) in 2019 on the SR 13 and U.S. 40 projects. Because the same plant was used to produce all AC mixes and the same construction processes were followed for both projects, the analysis is greatly simplified.

To reflect INDOT's Green Initiatives, the environmental areas selected for this case study included total primary energy (TPE) and smog. The limited LCA focused on differences in these indicators associated with the two mixes, which included the constituent materials used and field performance to date.

Figure 3 presents the environmental performance of the materials used for both the SR 13 and U.S. 40 projects. The control exhibits slightly less environmental performance for TPE than Superpave5, but smog is virtually the same for both mixtures. The U.S. 40 project used more absorptive aggregates, which resulted in higher binder contents than SR 13 and thus slightly affected the TPE results. These results were generated using environmental inventory data developed by Al-Qadi et al. (2015).

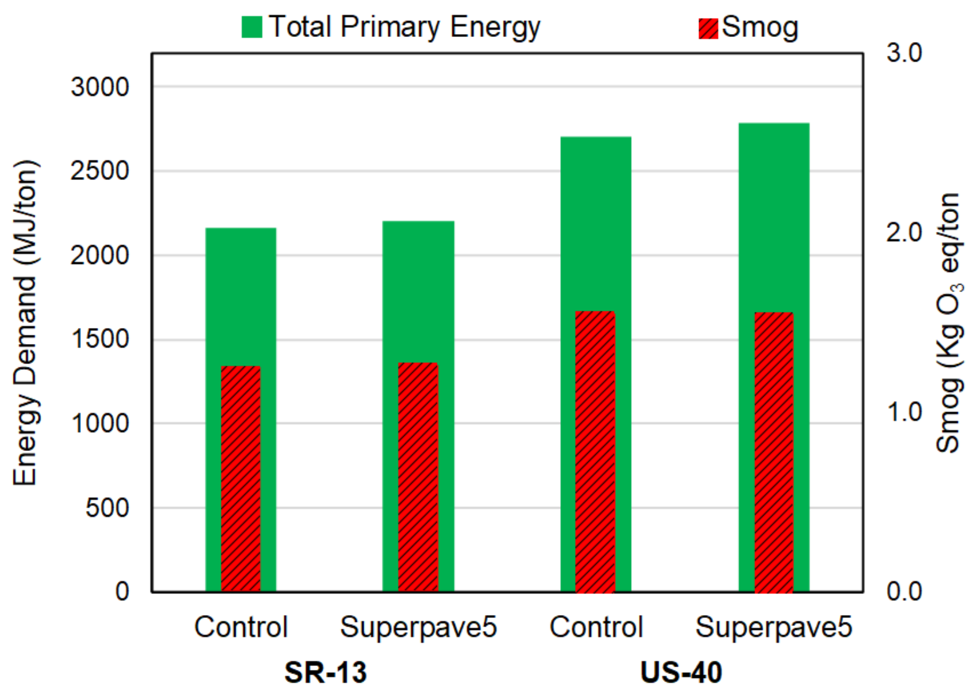

Figure 3. Environmental performance of materials used on SR 13 and U.S. 40.

Figure 4 shows a limited analysis of the two environmental performance per year associated with pavement roughness for both roadways. The two SR 13 sections had similar TPE (less than 0.5 percent difference) while the Superpave5 segment had about 2 percent higher potential smog levels. The same general trends for the control and Superpave5 sections are observed for the driving lanes of U.S. 40, although the values are lower compared to SR 13. This resulted from fewer trucks using U.S. 40. In contrast, the Superpave5 section in the U.S. 40 passing lanes had considerably lower TPE and potential smog levels when compared to the control segment. This is due to the high IRI values of the control section in the passing lane, which is caused by factors other than the mix type. A traveling speed of 55 mi/hr was used in the analysis. The environmental performance were computed using a roughness-speed impact model (Mojtaba et al. 2018) and an LCA tool (Yang, Ozer, and Al-Qadi 2017; Ozer, Yang, and Al-Qadi 2017). These potential environmental benefits are based on the performance of the projects to date and additional future analysis using long-term performance data will provide a more accurate assessment of the environmental benefits of the Superpave5 approach.

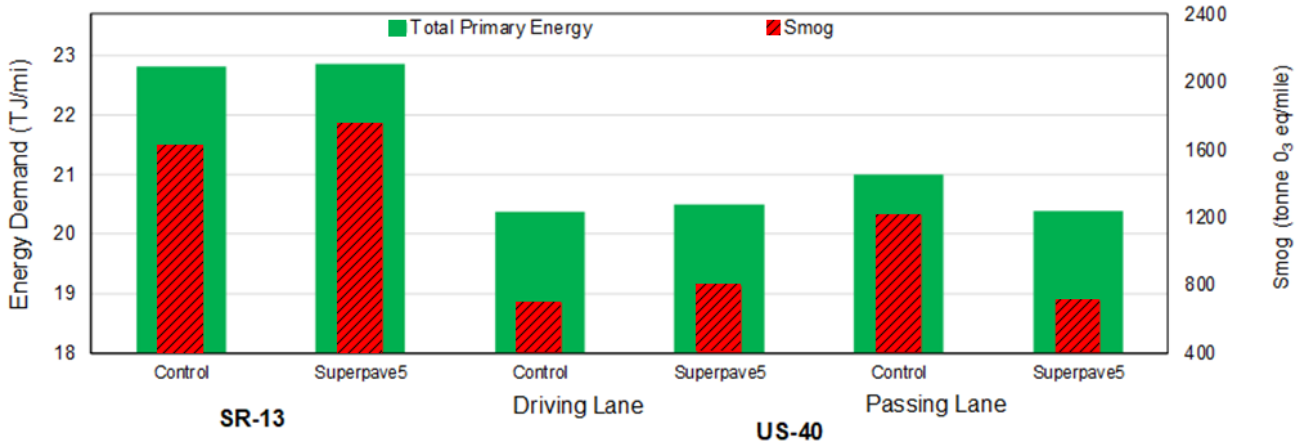

Figure 4. Environmental impacts associated with roughness on the SR 13 and U.S. 40 projects.

WHAT WERE THE KEY OUTCOMES AND LESSONS LEARNED?

Two field demonstration projects using the Superpave5 mix design approach were constructed in Indiana to highlight the ease of attaining higher in-place density without additional equipment or effort. The demonstration projects showed that this new AC mix design approach has the potential to increase long-term durability and achieve INDOT goals of cost savings and reduced environmental impacts.

As part of this case study, the following key outcomes were identified:

- Superpave5 mixes were produced using the same production procedures and plant as the conventional Superpave mixes.
- The early performance of the Superpave5 sections constructed on U.S. 40 and SR 13 show IRI and rut depth measurements comparable to their conventional counterparts after 3 and 5 years of service, respectively.
- The initial construction costs of the Superpave5 sections were relatively similar to that of their conventional counterparts. The long-term performance of the Superpave5 sections is expected to be better as they will be less susceptible to aging-related defects due to the high in-place density.
- The life-cycle costs of the Superpave5 sections are anticipated to be lower than the conventional Superpave due to improved long-term durability and performance resulting from the increased in-place density.

A general rule of thumb is a 1 percent increase in density will extend the pavement life by 10 percent. Adoption of Superpave5 has increased the average density of 2019 projects by at least 1.5 percent. This no-cost specification change will greatly extend pavement service life, offer monetary benefits to the Department and taxpayers, as well as facilitate more efficient use of available resources.

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- The Superpave5 sections and their control counterparts exhibited similar TPE and potential smog levels resulting from the used constituent materials and field performance to date. With improved long-term durability, Superpave5 sections are expected to exhibit lower TPE and potential smog levels associated with reduced maintenance activities and better field performance.

This case study illustrates the baseline performance and sustainability impacts associated with the use of Superpave5. INDOT will continue to monitor the aforementioned pavement sections to determine the long-term effects.

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