U.S. Department of Transportation
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GEORGIA USE of SMA, OGFC, AND MICRO-MILLING RESULTS IN IMPROVED SUSTAINABLE PAVEMENT PERFORMANCE

FHWA-HIF-19-084

A successful and proactive preservation scheme (featuring the combined use of SMA, OGFC, and micro-milling) has proven itself as a cost-effective pavement strategy for the Georgia DOT in providing safety and longevity on many of its interstate roadways.

WHAT WAS THE MOTIVATION?

Since the 1990s on many of its heavily trafficked roadways, the Georgia Department of Transportation (GDOT) has been using stone matrix asphalt (SMA) topped with an open-graded friction course (OGFC) or a porous European mix (PEM) (see figure 1 [data source: Wu and Tsai 2016]). SMA is a gap-graded mixture offering increased stone-on-stone contact and serves as an intermediate and wearing course that is more resistant to rutting while the porous surfaces increase safety by removing water and reducing vehicle splash and spray.

In rehabilitating these designs, GDOT's practice was to mill off the porous surface layer and about 1.5 inches of the immediate underlying SMA layer using conventional milling methods (Lai et al. 2012); however, this operation was wasteful, particularly since the underlying SMA was in excellent condition and still capable of carrying traffic. In looking for more cost-effective resurfacing methods, GDOT investigated the use of micro-milling equipment to precisely remove only the deteriorated OGFC while leaving the underlying SMA intact (Tsai et al. 2012). Micro-milling uses additional teeth on the milling drum affixed in a tighter pattern that allows more precise removal and produces a smoother pavement texture than conventional milling, making it a more cost-effective resurfacing method.

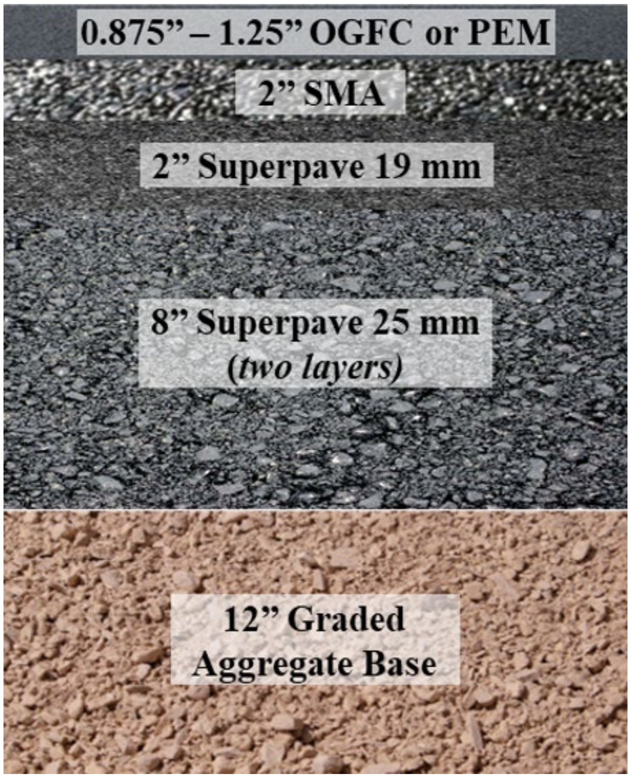
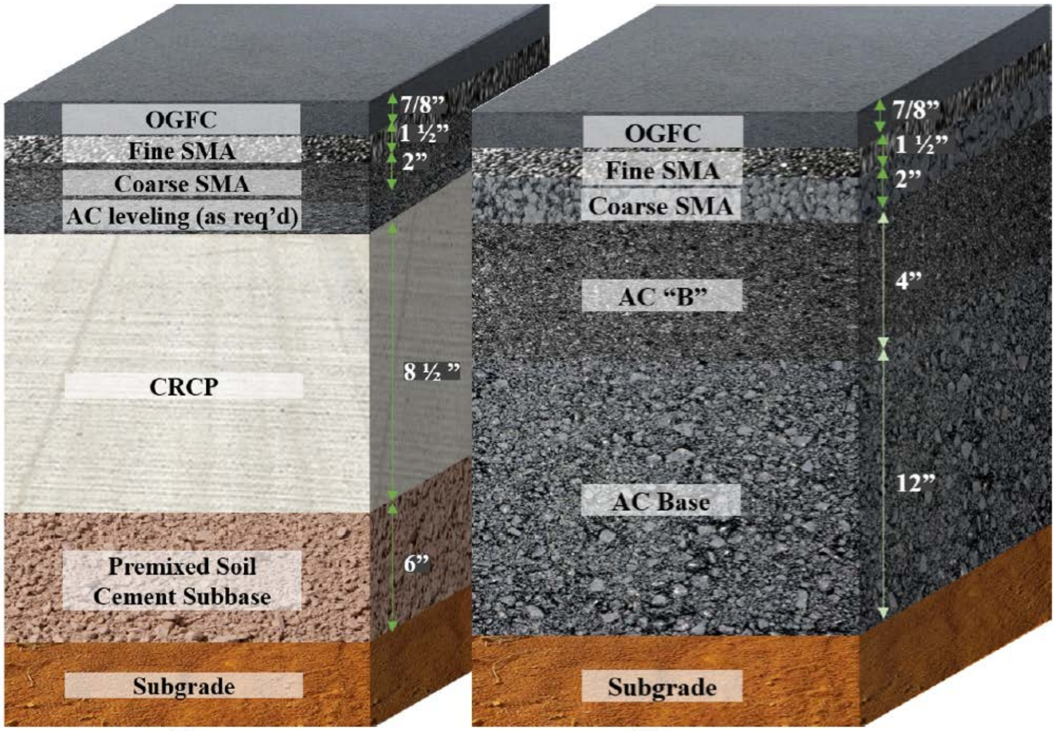


Figure 1. Typical pavement design on Georgia's interstate highways.

WHAT WAS DONE?

The section of interest for this case study was originally constructed in the 1970s on Interstate 95 near Savannah. For the initial construction, an 8.5-inch continuously reinforced concrete pavement (CRCP) was placed over a 6-inch premixed soil cement subbase (Brown et al. 1998; Lai et al. 2012). That concrete pavement structure was later overlaid with an SMA and OGFC combination in 1992.

In 1995, records from the Department's computerized pavement condition evaluation system (COPACES) revealed that the asphalt surface on the I-95 section exhibited low-severity rutting, block cracking, patching, and potholes; and medium-severity raveling. To address those issues, the 6.6-mi section was widened and resurfaced that year, wherein all existing asphalt concrete (AC) layers on the CRCP were milled to expose the concrete (see figure 2). In doing so, it became evident that the majority of the distresses were confined within the surface, while the underlying SMA layers had maintained good structural integrity. Consequently, in the next rehabilitation performed in 2009, GDOT implemented micro-milling on the OGFC surface layer only and resurfaced with a 0.88-inch thick OGFC.



(a) (b)

Figure 2. I-95 resurfacing plan over existing CRCP (a) and inner lane widening plan (b).

Note: Most of the existing pavement section (along the traveling direction) primarily includes the original CRCP structure, while a short section (less than 1 mi) is composed of a full-depth AC.

WHAT BENEFITS WERE ACHIEVED?

PERFORMANCE

As part of the GDOT protocol, an annual distress monitoring is completed using COPACES. Typically, projects that receive a rating of 75 or below are reviewed to determine an appropriate treatment, while the pavement condition rating below 70 typically triggers resurfacing (milling and overlay).

Since the 2009 surface layer resurfacing (micro-milling removal of the original OGFC layer and replacement with a new OGFC), the I-95 section has performed quite well. Exposed to a traffic volume of 71,970 vehicles per day (vpd) and 28.5 percent trucks, the I-95 section has maintained a COPACES rating above 91 for nearly a decade (see figure 3) and the deterioration rate is lower relative to the rate before the 2009 preservation scheme—all indicative of good performance. The distresses currently exhibited by the asphalt pavement surface include rutting, load-associated cracking, and raveling, all of which are at low-severity level. Moreover, figure 3 suggests that these distresses did not initiate for about 6 years after placement. Hence, well-maintained SMA layers (coupled with an OGFC surface layer), resulted in maximizing pavement service life and offer the potential for additional service life extensions by incorporating micro-milling, provided that the SMA layers are kept in good condition.

In the presented case study, the full benefits of SMA—namely, reduced rutting and enhanced durability—can be maintained over the life of the pavement through the combination of SMA, OGFC, and micro-milling for resurfacing.

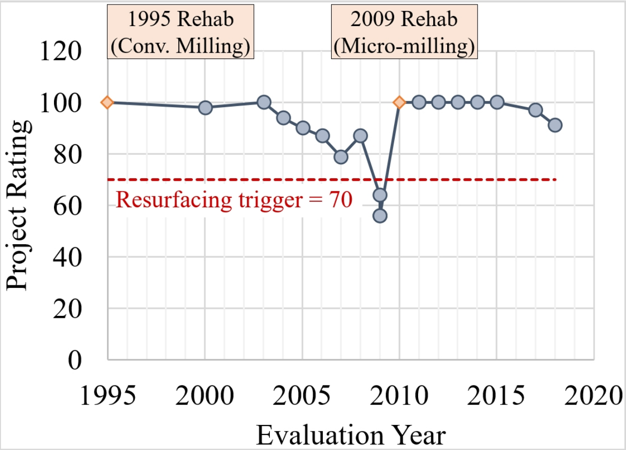


Figure 3. Performance of I-95 sections over time.

ENVIRONMENTAL PERFORMANCE

Chatham County, Georgia, where the I-95 section is located, has a sustainability road map to reduce energy consumption and greenhouse gas emissions (Chatham 2009). Although a life-cycle assessment (LCA) was not originally completed to identify the environmental benefits of GDOT's decision to use SMA and micro-milling, such an assessment was performed later to evaluate the broad environmental performance of the rehabilitation strategy using an LCA tool (Al-Qadi et al. 2015; Yang et al. 2017).

In the LCA comparison, the SMA option was compared to a hypothetical AC option with four different maintenance and rehabilitation schedules: resurfacing periods of 8, 10, 12, and 14 years. Additional assumptions in the analysis include the following:

- The maintenance and rehabilitation (M&R) schedule was milling and inlay of the top 0.88 inches, as implemented in the 2009 resurfacing for I-95.
- The supporting layers, including the CRCP, remain intact.

- The International Roughness Index (IRI) of the newly resurfaced pavement was estimated to be 40 inches/mi. GDOT provided smoothness data from 2000 to 2015, where were utilized to update the progression coefficients implemented in the use stage. The same triggering value of 70 inches/mi was assumed at each rehabilitation activity (corresponding to the IRI at year 2009 for the I-95 section). It is worth noting that to achieve the same triggering value for resurfacing, the IRI progression changes between the four resurfacing periods, i.e., 8-year resurfacing cycle will have a higher IRI progression than the 14-year resurfacing cycle.
- The materials and construction (M&C), M&R, use, and end-of-life (EOL) stages of the pavements were considered in the life-cycle assessment. The use stage refers to the in-service period during which the pavement carries traffic, and a prominent parameter during this stage is vehicle fuel consumption that is directly related to road surface roughness (i.e., the rougher the road, the more fuel consumed).
- An analysis period of 45 years was used to include the appropriate number of rehabilitation cycles per scenario.

Figure 4 illustrates the comparative analysis of the total primary energy (TPE), smog, and eutrophication for the four full-depth AC cases relative to the I-95 SMA option. The first series of columns in the figure is for the I-95 section (a combination of OGFC, SMA, and micro-milling), while the next four series of columns indicate the conventional full-depth AC pavements with the rehabilitation interval indicated within the parenthesis (e.g., "(8yr)" means that the resurfacing is triggered every 8 years). The figures present ratios of the four different M&R scenarios relative to the SMA pavement (thus, the SMA + Micro-milling column is equal to 1.0).

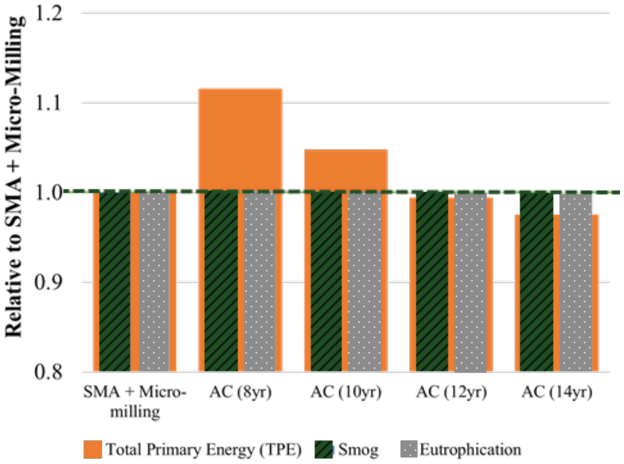


Figure 4. Comparative environmental performance analysis for the entire life cycle of the I-95 section and the hypothetical AC sections.

Focusing first on TPE, in comparing the I-95 section to the hypothetical full-depth AC section with an 8-year interval for resurfacing, the AC section produced 12.5 percent more TPE when considering the entire life cycle of the project. Breaking down the composition of the TPE results for the I-95 SMA section, the use stage was noted to account for 73.2 percent of the total TPE. On the other hand, the M&C, M&R, and EOL stages resulted in 12.3, 14.3, and 0.2 percent of the TPE. The general trends for the hypothetical AC scenarios are similar, but it is worth noting that as the interval for resurfacing increases from 8 to 14 years, the percent contribution of the use stage increases while the contribution of the M&R stage decreases. These relationships are anticipated as longer intervals between resurfacings leads to a rougher pavement surface and the reduced number of triggered M&R activities would provide less contribution to the overall environmental performance. As illustrated in figure 4, the TPE values for the entire project (considering all life cycle stages) were highest for the AC (8yr) scenario and decline as the rehabilitation activity interval increases to 14 years; this behavior was mainly driven by the use stage and roughness progression.

In contrast to the TPE, figure 4 illustrates a minimal difference between the five scenarios for smog and eutrophication. It is noteworthy that the presented smog and eutrophication values accounted for the total life cycle (material to end-of-life stages). This observation can be attributed to the fact that the use stage contributed to nearly 99 percent of the total smog and eutrophication values. Given that the cumulative contribution of the use stage is similar for the scenarios, this trend is then reflected in the potential smog and eutrophication environmental performance.

ECONOMIC SAVINGS

The costs of SMA layers are higher than the costs of conventional AC. GDOT cost data from 2012 indicates an SMA cost of $106.13 per ton compared to $83.63 per ton for AC; these values were used as the basis for a cost analysis and updated to 2019 values using consumer price indices. A sensitivity analysis of the relative costs of various scenarios is presented in figure 5, using pay items obtained from GDOT records. In the considered cases, GDOT pursued an investment for long-lasting flexible pavements using the combination of OGFC, SMA, and micro-milling.

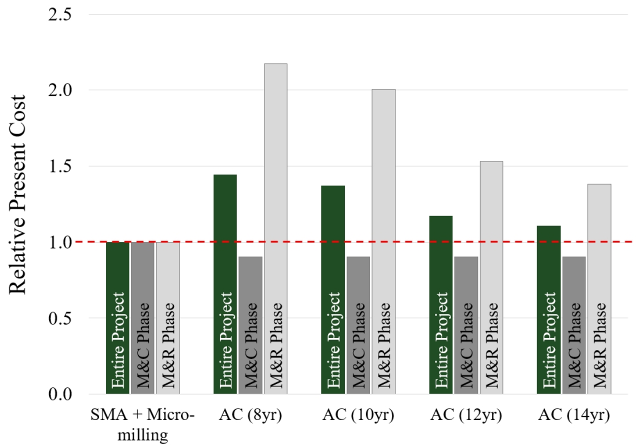


Figure 5. Relative cost of the entire project life cycle and M&R stage.

Given the increase in triggered resurfacing intervals within the analysis period, the cost of the full-depth AC pavement case with an 8-year interval may result in more than twice the M&R costs compared to those of the I-95 section with SMA and micro-milling. Moreover, as would be expected, if the resurfacing interval increases up to 14 years, the cost difference decreases although still greater than the SMA pavement structure. The higher initial costs associated with the SMA as a new pavement layer or part of a rehabilitation design were offset by the pavement's longevity and the reduced need for major rehabilitation. It is also worth noting that the relative cost for the M&C stage resulted in a decreased initial cost by 10 percent for the full-depth AC pavement compared to the pavement with SMA layers; this is attributed to the lower unit cost of the AC surface course pay item.

Typically, GDOT implements one cycle of micro-milling (removing 0.25 to 0.50 inches of the existing SMA layer) prior to placing 2-inch lifts of SMA, followed by the application of the thin OGFC surface layer. Given this rehabilitation scheme, GDOT expects to reap significant cost savings (on the order of $60,000 per lane-mi) (Tsai et al. 2012).

WHAT WERE THE KEY OUTCOMES AND LESSONS LEARNED?

The Georgia DOT has employed a combination of OGFC and SMA layers on its interstate highways for more than two decades. A preservation program of micro-milling allows for the removal of the OGFC layer while maintaining the SMA layer, thus exploiting its structural integrity and reducing costs. A review of GDOT's experience and an assessment of a project on I-95 near Savannah reveals the following key outcomes:

- After the major rehabilitation of the I-95 section in 1995 (the first time incorporating the SMA and OGFC layers) only functional distresses resulted, which corresponded to a good condition rating after 9 years of service.
- GDOT has identified that incorporating micro-milling into its resurfacing protocols facilitates the precise removal of the OGFC surface layer and improves the adherence of a new OGFC inlay to the existing SMA layers. This preserves and prolongs the structural integrity of the SMA layers, which results in significant environmental and economic savings.
- Four resurfacing cycles for conventional full-depth AC pavements were considered to compare with the I-95 section. To achieve the same level of pavement performance as the SMA and micro-milling section, a full-depth AC resulted in a TPE increase of up to 1.4 times. This suggests that the combination of SMA and micro-milling significantly reduces the M&R effort compared to conventional full-depth AC.
- The relative cost for the M&C stage is 10 percent less for the full-depth AC pavement compared to that for the SMA pavement, but the SMA material cost is offset when considering overall life-cycle costs. In particular, the M&R stage revealed a twofold cost increase in full-depth AC compared to SMA over the pavement life because of the later relative improved structural performance and a delay in future rehabilitation.
- The combination of micro-milling with OGFC and SMA layers led to a performance period of at least 24 to 28 years, as the structural integrity of the SMA layer was effectively maintained.

> *SMA mixtures, placed underneath open-graded mix types, have shown durable and exceedingly superior performance on Georgia interstate roadways. These mixtures, when used in conjunction with micro-milling of the aged and deteriorating open-graded surface layer, have displayed good field performance for more than 25 years.*
>
> –Sheila Hines, (retired) GDOT
> State Bituminous Construction Engineer

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KEY WORDS

asphalt pavement, sustainability, stone matrix asphalt, open-graded friction course, micro-milling, performance, environmental performance, life cycle costs

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