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# Assessing the Relative Rutting Susceptibility of HMA in the Laboratory with the Asphalt Pavement Analyzer

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The Strategic Highway Research Program (SHRP) identified rutting as a major cause of distress for Hot Mix Asphalt (HMA) pavements. The resulting Superior Performing Asphalt Pavements (Superpave™) mix design system specifically addressed the aggregate and asphalt binder properties that contribute to permanent deformation. However, the Superpave™ system does not currently include a laboratory proof-test to quickly assess the rutting susceptibility of HMA.

In the early 1980's, the Georgia Department of Transportation funded research to develop and refine a laboratory wheel-tracking device. Based on the results of this research, Pavement Technology, Inc. (PTI) developed the Asphalt Pavement Analyzer (APA). Various laboratory studies have been conducted since the development of the APA to assess the suitability of this device as a proof-test for HMA.

In 1998, the Tennessee Department of Transportation (TDOT) initiated a study with the University of Tennessee to further evaluate the merits of the APA. In this study, over 30 mixes from various locations across the state of Tennessee were tested in the APA. The results of this study indicate that the APA is sensitive to critical material properties that have been documented to contribute to rutting of HMA on the roadway.

*Keywords:* HMA, Asphalt Pavement Analyzer (APA), rutting, proof-test

## INTRODUCTION

Permanent deformation, physically visible as rutting at the pavement surface, is a primary concern for asphalt mix designers, materials engineers, contractors, and federal, state, and local highway agencies. Pavement rutting in excess of about 6 mm (¼-inch) is generally considered a hydroplaning safety hazard. Excessive rutting often results in premature maintenance and rehabilitation activities, reducing the service life of the pavement. Over $15 Billion is spent each year on Hot Mix Asphalt (HMA). In 1997, the Tennessee Department of Transportation (TDOT) spent approximately $250 million on HMA construction. TDOT typically designs flexible pavements for a 20-year service life. It has been estimated that cost savings of around $2 million per year could be realized by increasing the life of all pavements by only one percent (Avera 1998). Eliminating the occurrence of excessive rutting in HMA would go a long way

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toward reducing the life-cycle-cost of flexible pavements.

In the early 1990's, $50 million of asphalt related research was conducted as part of the Strategic Highway Research Program (SHRP). The SHRP researchers identified rutting as a major cause of distress for HMA. This mode of distress is the result of consolidation of the mix after construction and plastic flow of the HMA in the wheel path over time (Roberts, et al. 1996). From this extensive research effort, the Superior Performing Asphalt Pavements (Superpave™) mixture design and analysis system was conceived. Superpave™ introduced a new system for specifying component materials, design, and analysis of asphalt mixtures (McGennis, et al. 1995). However, the Superpave™ mixture design and analysis system does not currently include a proof-test to assess the relative rutting susceptibility of HMA. Such a test would be very useful in the design and evaluation of HMA (Petros 1999).

The objective of this study was to evaluate the merits of the Pavement Technology, Inc. (PTI) Asphalt Pavement Analyzer (APA) as a proof-test to predict the relative rutting susceptibility of HMA in Tennessee. The primary objective of this phase of the study was to evaluate the sensitivity of the APA to critical material properties that have been documented to contribute to rutting of HMA on the roadway. It should be noted that the mixes evaluated in this study will be continuously monitored over the life of the respective pavements, and the results of this laboratory test program will be compared with field rutting when long-term performance data becomes available. The results of this field validation phase will be documented in a subsequent publication.

## BACKGROUND

### Material Properties that Affect Rutting of HMA

The Superpave™ mix design system specifies asphalt binder and aggregate properties, including aggregate quality and gradation. These specifications were developed to address specific pavement distress issues. As noted, one major concern in the design of HMA is rutting. Excessive asphalt binder content, excessive amounts of fine grained aggregate, and high percentages of natural, rounded aggregate particles have been documented to be common causes of rutting (Button, et al. 1990).

As noted, the amount of asphalt contained in a given mix is known to affect the mix's performance. HMA surface mixes are typically designed with an asphalt content of about 6 percent. Too much, or even too little asphalt cement can be a contributing cause of rutting. One way to improve the high-temperature performance of asphalt cement is to modify the asphalt with polymers or other additives. Latex, ethylene vinyl acetate, and styrene-butadiene-styrene, are some examples of additives that have been blended with neat asphalt cement to improve the high temperature performance (Button, et al. 1996). Modifying the asphalt binder may decrease a mix's propensity to rut, but other properties of HMA have equal importance in controlling rutting potential.

Mix gradation and aggregate selection have been reported to have tremendous impacts on rutting. It has been documented that gradation can be even more important in minimizing rutting than asphalt binder and additive properties (Hughes 1990). Experimentation has also shown that the rutting susceptibility of HMA increases dramatically when natural fine aggregate particles replace crushed particles in a given gradation (Button, et al. 1990). The amount of dust contained in HMA can also impact rutting potential because the dust tends to "extend" the asphalt (Roberts, et al. 1996).

The Superpave™ system attempts to control these factors by limiting the amount of dust in a mix to 6 % passing the 0.075 mm (# 200) sieve. Superpave™ specifications attempt to control the amount of natural, rounded sand contained in the HMA by specifying a restricted zone on the gradation curve between the 4.75 mm (# 4) and 0.30 mm (# 50) sieves. Figure 1 shows typical gradation control limits and the Superpave™ restricted zone for a 19-mm Superpave™ mix. These limits are dependent upon the nominal maximum aggregate size (Asphalt Institute

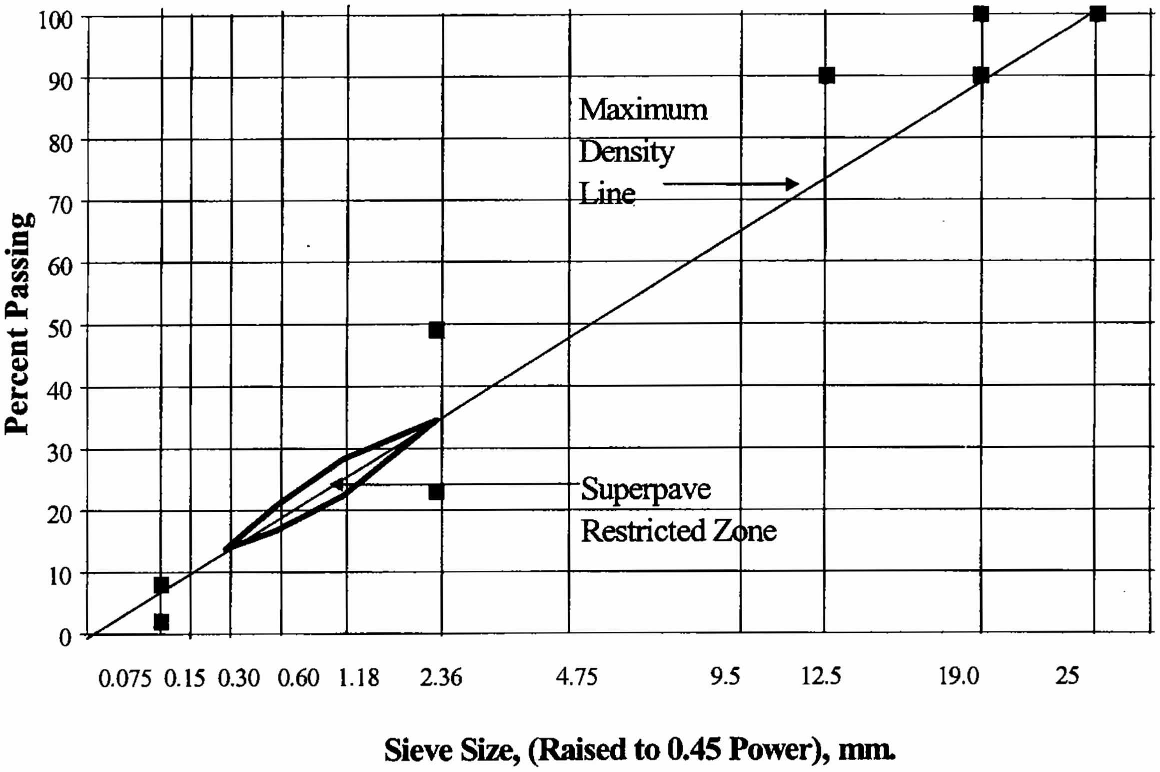

FIGURE 1 Example Superpave Gradation Requirements and Restricted Zone for a 19 mm Nominal Maximum Aggregate Blend

1996). It should be noted that historically, many Tennessee surface (TDOT 411D) mixes have been designed with gradations passing through the restricted zone and many of these mixes have performed adequately. Over half of the mixes tested in this study were designed with gradations passing through the restricted zone.

The quality of local aggregate also has an impact on HMA rutting susceptibility. Regions with quality crushed stone and angular natural sand have been observed to exhibit a higher resistance to rutting (Parker and Brown 1994). Further, it has been reported that medium graded mixtures provide significantly better resistance to rutting than coarse graded mixtures (Matthews and Monismith 1993). Coarse graded mixes tend to be more difficult to work with; thus achieving maximum compacted density is often a problem. When density is not achieved, the mix will often compact excessively under traffic, leaving large ruts in the wheel path.

In summary, rutting in HMA is affected by a combination of material properties. Asphalt binder type and grade, asphalt binder content, aggregate gradation, and particle shape contribute to this mode of distress. The affects of these properties on the performance of HMA, either alone or in combination, have been well documented in the literature (Parker and Brown 1994).

## Wheel-Tracking Devices

Since the implementation phase of Superpave™, wheel-tracking devices have gained a great deal of attention as candidates for proof-testing the ability of

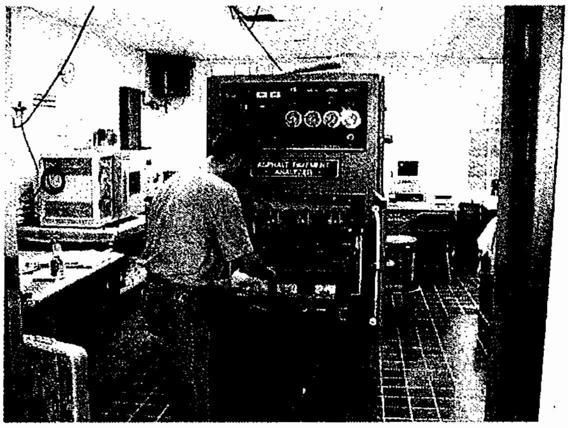

**Photo 1**

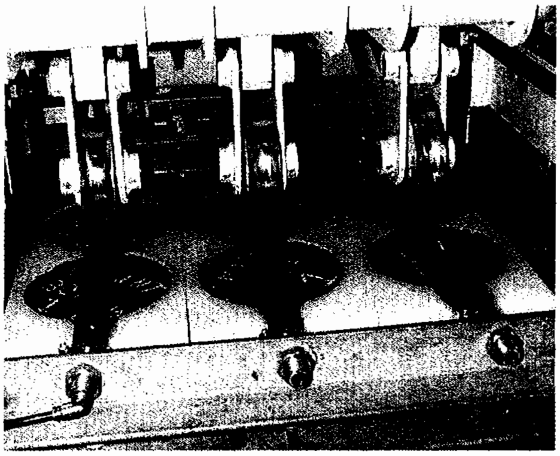

**Photo 2**

**Photo 3**

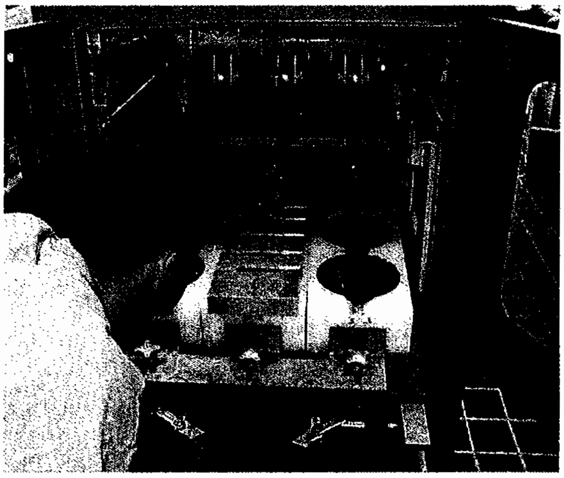

**Photo 4**

FIGURE 2 Several Different Views of the Asphalt Pavement Analyzer. Photographs 1 and 2 Exhibit the APA with Specimens Being Loaded and Tested, While Photographs 3 and 4 Exhibit Specimens After Testing, and With Rut Depth Measurements Being Taken

HMA to resist rutting. Currently, there are a number of different commercially available wheel-tracking devices. These include the French Pavement Rutting Tester (PRT), the Hamburg Wheel Tracking Device (WTD), the Georgia Loaded Wheel Tester (LWT), the APA, and various other versions of these basic designs. These devices are somewhat similar in concept with slight differences in design and operation. Table I summarizes the similarities and differences between some of these devices. The APA is currently being considered for use in the State of Tennessee by TDOT and is the focus of this study.

In 1985, researchers at the Georgia Institute of Technology, under contract with the Georgia Department of Transportation (GDOT), designed the LWT. The LWT was developed to allow the HMA designer to accurately predict the asphalt mix design's rutting potential, and make adjustments in the laboratory before failure occurs on the roadway (Collins, et al. 1995).

TABLE I Testing Parameters for Several Different HMA Wheel-Tracking Devices (Williams, 1998)

| | Typical Testing Parameters for Each Device | | | |
|---|---|---|---|---|
| Device | French | Hamburg | Georgia LWT | APA |
| Temperature, C | 60 | 50 | 40 | 5 to 80 |
| Environmental Condition | Hot/Dry | Hot/Wet | Hot/Dry | Hot/Dry, Hot/Wet |
| Specimen Size, Length, Width, Thickness, mm | 500×180×100 | 320×260×80 | 300×125×75 | 300×125×75 |
| Wheel Type | Pnuematic (500 kPa) | Solid Steel | Aluminum Wheel on Pressurized Hose (700 kPa) | Aluminum Wheel on Pressurized Hose (700 kPa) |
| Wheel Size | 400 mm Diameter, 90 mm Width | 203.5 mm Diameter, 47 mm Width | Hose Diameter 29 mm | Hose Diameter 29 mm |
| Load, N | Up to 5000 | Up to 697 | Up to 700 | Up to 1200 |
| Wheel Speed | 1.6 m/s | Sinusoidal 0.33 m/s Max at Center | 0.6 m/s | 0.6 m/s |
| Maximum Cycles (1 Cycle = 2 Wheel Passes) | 30,000 | 20,000 | 8,000 | 8,000 |
| Maximum Rut Depth, mm | 10 | 4 | 7.6 | 5 to 7 |

The LWT uses an articulating arm with a weight applying constant load to an aluminum wheel that cycles back and forth across a pressurized hose resting on an asphalt concrete test specimen (USDOT 1991). The LWT concept is based upon similar wheel tracking devices used to study rutting and other modes of asphalt distress (Lai 1986). The work performed on the LWT in Georgia during the late 1980's and early 1990's ultimately led to the development of the APA. After 10 years of use, GDOT indicates that the LWT, and its modified version, the APA, can predict the rutting susceptibility of specific asphalt mixes at relatively low cost per test (Collins, et al. 1995). Several different views of the APA are presented in Figure 2.

## Previous Research Using Wheel-Tracking Devices to Evaluate Rutting

There have been a number of studies conducted on HMA using the various laboratory wheel-tracking devices. One study compared the rheometric properties of five asphalt binders with the rutting observed in several wheel-tracking devices. At constant stress, work dissipated per loading cycle is controlled by the complex shear modulus divided by the phase angle ($G^*/\text{Sin }\delta$). Therefore, SHRP researchers chose this parameter as part of the high temperature Superpave™ asphalt binder specification. It was reported that the LWT provided a very good relationship between the asphalt binder property of $G^*/\text{Sin }\delta$ and rutting susceptibility. It was also reported that the French and Hamburg devices provided reasonably good relationships with this asphalt binder property (Stuart and Izzo 1995).

A different study was conducted by the Florida DOT to determine the ability of the LWT to accurately rank three mixes with known historical performance. The researchers fabricated beam samples and obtained rut depth measurements. The LWT ranked the HMA mixes from poor to good in the same order as their actual field performance. Marshall stability data failed to accurately rank the HMA mixes. This study indicated that the LWT is a more accurate tool for evaluating HMA rutting susceptibility than Marshall stability alone (West, et al. 1991).

A FHWA sponsored round-robin test program was conducted between six states to evaluate repeatability and variability of the LWT. All sample preparation was performed by the GDOT. Each laboratory used the same procedures to compact the test specimens. Results from the study indicated that within-laboratory rut depth repeatability was very good, however, the between laboratory variability was not good. The

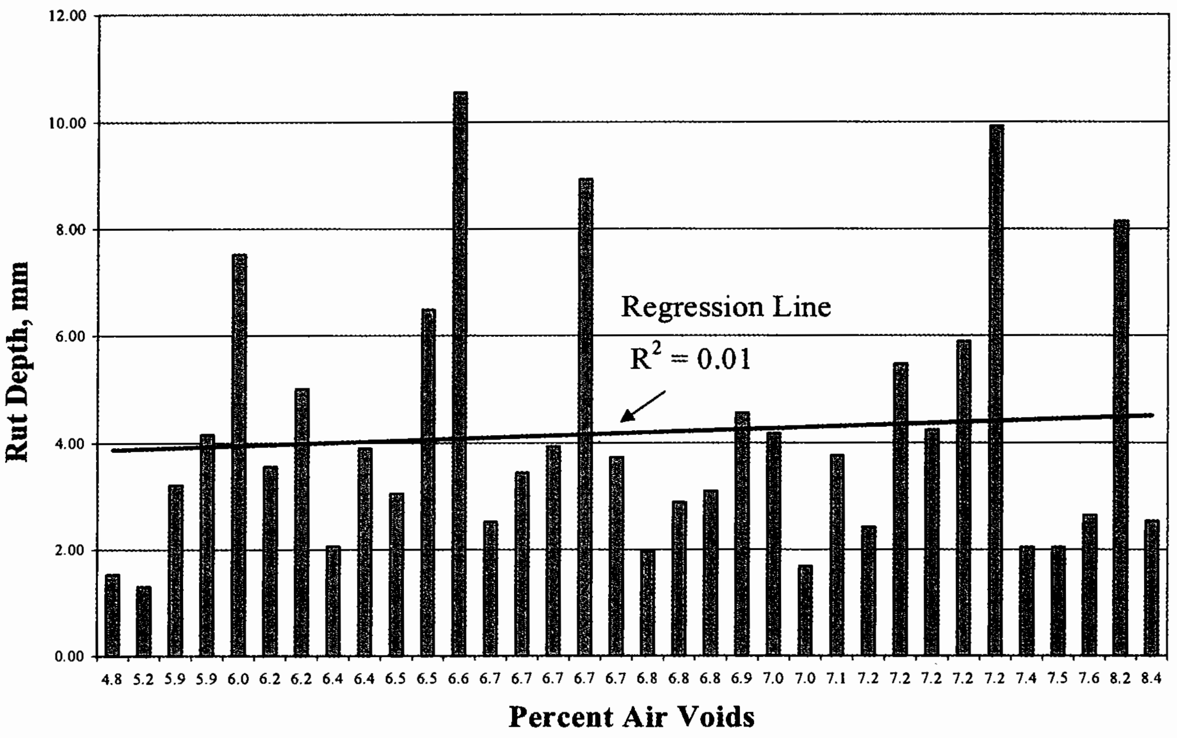

FIGURE 3 APA Rut Depth After 8000 Cycles vs. Percent Air Voids

high variability between labs was attributed to densification variability during sample compaction (Lai 1993).

Researchers from the Stone Matrix Asphalt Technical Working Group (SMA TWG) conducted a study using the LWT and the French and Hamburg devices to evaluate the rutting effects of limiting draindown. All three devices showed a change in rutting propensity based on what polymers were used to control draindown (Mogawer and Stuart 1995).

The use of the LWT to predict rutting susceptible hot mix asphalt has been demonstrated by the GDOT to be an effective practice. The LWT has evolved into the APA, which can use multiple, user-defined environmental and loading parameters for the evaluation of HMA samples. The repeatability of the APA has been shown to be good within labs, but a high variability between labs still exists (West 1998). Sample fabrication and rut-depth measurement procedures seem to be the roots of this variability. With automatic data collection currently available, this variability is expected to decrease.

The APA and the French and Hamburg devices were evaluated with respect to their ability to accurately predict the observed performance of HMA at WesTrack. The conclusions of the study indicated that each device provided a good correlation with actual rut depths measured on the test track. The devices did not rank the mixes in the exact order of failure observed in the field. However, they did exhibit a higher variability in average rut depths in the poor performing mixes (Williams and Prowell 1999). This study concluded that the testing temperature and method of laboratory compaction of HMA need to reflect actual field conditions in order for the laboratory testing devices to be comparable to field performance.

TABLE II Critical Material Properties of the HMA Mixes Tested in This Study

| *TDOT Mix Type* | *Mix ID* | *Asphalt Binder Grade* | *Asphalt Binder Content, (%)* | *Dust Content, % Passing 0.075 mm (# 200) Seive* | *Dust-to-Asphalt Ratio* | *Gradation Passing Through Restricted Zone* | *Rut Depth, mm. @ Cycles* | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | *500* | *8000* |
| 307 BM/2 | 1MB | PMAC-20 | 4.6 | 5.4 | 1.2 | YES | 0.70 | 3.21 |
| 411 D | 1MS | PMAC-20 | 6.5 | 6.0 | 0.9 | YES | 0.67 | 2.64 |
| 307 S- Fibers | 1SBF | PG 76–22 | 5.1 | 5.2 | 1.0 | YES | 0.85 | 2.53 |
| 307 S – No Fibers | 1SBNF | PG 76–22 | 4.4 | 5.2 | 1.2 | YES | 0.73 | 2.04 |
| 411 S – Fibers | 1SSF | PG 76–22 | 6.1 | 5.4 | 0.9 | NO | 0.73 | 1.68 |
| 411 S – No Fibers | 1SSNF | PG 76–22 | 6.0 | 5.4 | 0.9 | NO | 0.59 | 1.96 |
| 307 BM/2 | 2MB | AC 20 | 4.5 | 4.8 | 1.1 | YES | 0.66 | 2.88 |
| 307 BM/2 | 3MB | PG 64–22 | 4.2 | 5.0 | 1.2 | YES | 0.46 | 1.30 |
| 411 D | 2MS | PG 76–22 | 6.2 | 3.9 | 0.6 | NO | 0.72 | 2.04 |
| 411 S | 2SS | PG 76–22 | 5.5 | 4.7 | 0.8 | NO | 0.72 | 2.06 |
| 307 BM | 4MB | MG 20–40 | 4.4 | 4.9 | 1.2 | NO | 0.44 | 1.53 |
| 411 D | 3MS | MG 20–40 | 5.0 | 3.0 | 0.6 | NO | 0.88 | 3.89 |
| 411 D | 4MS | PG 76–22 | 5.3 | 4.9 | 0.9 | YES | 0.93 | 3.44 |
| 411 D Latex | 5MS | PG 64–22 | 5.7 | 4.3 | 0.8 | YES | 1.94 | 7.52 |
| 307 BM | 5MB | AC-20 | 4.2 | 5.8 | 1.4 | YES | 0.78 | 3.05 |
| 307 BM | 6MB | PG 64–22 | 5.0 | 5.4 | 1.1 | YES | 0.81 | 3.73 |
| 411 D | 6MS | PG 64–22 | 5.9 | 5.2 | 0.9 | YES | 1.15 | 4.55 |
| 307 BM/2 | 7MB | PG 64–22 | 5.2 | 4.9 | 0.9 | YES | 1.13 | 4.15 |
| 307 BM | 8MB | PG 64–22 | 4.3 | 4.1 | 1.0 | YES | 1.22 | 3.93 |
| 411 D | 7MS | PG 64–22 | 6.6 | 5.4 | 0.8 | YES | 1.82 | 5.89 |
| 411 D | 8MS | AC – 20 | 6.8 | 5.2 | 0.8 | YES | 3.01 | 8.93 |
| 307 BM | 9MB | PG 64–22 | 4.5 | 3.9 | 0.8 | YES | 1.23 | 5.00 |
| 411 D | 9MS | PG 64–22 | 5.4 | 3.7 | 0.7 | YES | 3.82 | 9.92 |
| 411 D | 10MS | PG 64–22 | 6.9 | 4.2 | 0.6 | YES | 2.69 | 8.14 |
| 411 S | 3SS | PG 64–22 | 5.8 | 6.1 | 1.1 | NO | 1.08 | 3.76 |
| 307 S | 2SB | PG 64–22 | 4.8 | 3.0 | 0.4 | NO | 0.87 | 2.52 |
| 411 S | 4SS | PG 64–22 | 4.9 | 3.2 | 0.7 | YES | 1.14 | 4.17 |
| 411 D | 11MS | PG 64–22 | 6.3 | 3.5 | 0.6 | YES | 4.15 | 10.55 |
| 411 S | 5SS | PG 64–22 | 4.9 | 4.8 | 1.1 | YES | 2.16 | 6.48 |
| 307 BM/2 | 10MB | AC – 20 | 4.2 | 4.6 | 1.1 | YES | 0.92 | 3.55 |
| 411 D | 12MS | PG 64–22 | 6.6 | 5.4 | 0.8 | YES | 1.90 | 5.47 |
| 307 S | 3SB | PG 64–22 | 5.0 | 4.4 | 0.9 | NO | 1.41 | 4.24 |
| 411 S | 6SS | PG 64–22 | 5.4 | 4.6 | 0.9 | NO | 0.88 | 3.09 |
| 411 S | 7SS | PG 76–22 | 6.1 | 6.3 | 1.2 | NO | 0.67 | 2.42 |

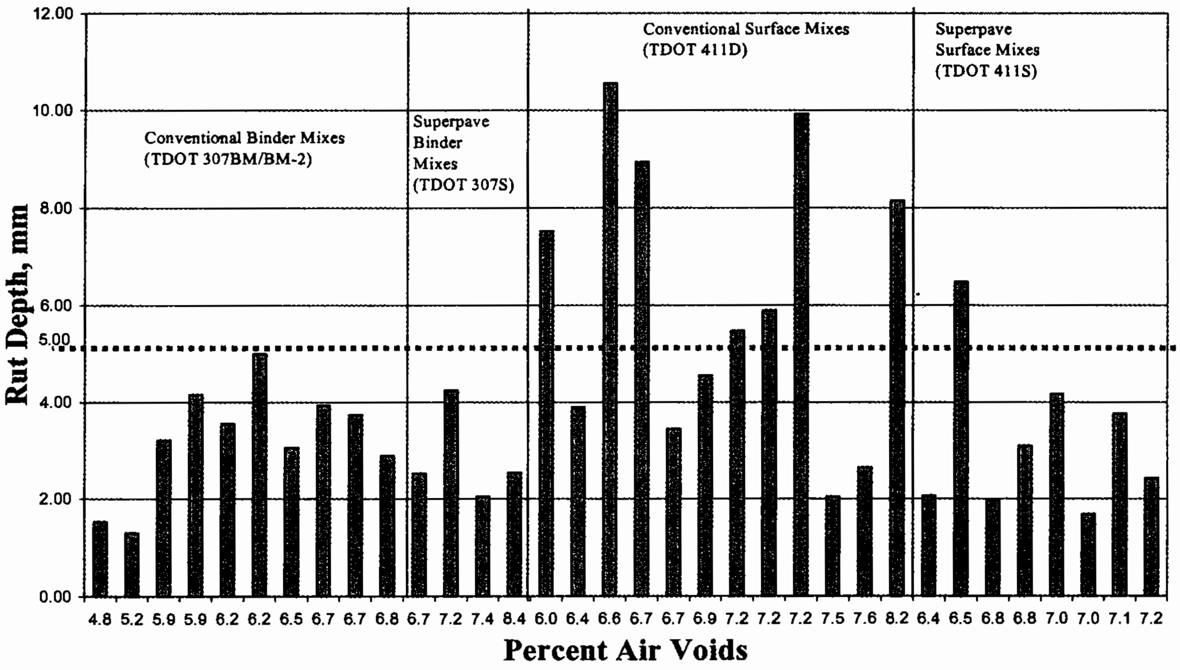

FIGURE 4 APA Rut Depth After 8000 Cycles vs. Percent Air Voids, Grouped According to Mix Type

In summary, previous research suggests that the APA is a suitable laboratory tool for the evaluation of rutting susceptibility of HMA. Laboratory tests have shown that the APA can predict a good or poor performing asphalt mixture at various environmental testing conditions (Brock, et al. 1998). Further, the within-lab repeatability of the APA has been documented to be good.

## TEST PROGRAM

### Test Specimen Preparation

Loose HMA samples from thirty-four projects across Tennessee were obtained at the time of paving and transported to the asphalt laboratory at the University of Tennessee for testing and evaluation. The loose HMA samples were re-heated in the laboratory, split, and tested for theoretical maximum (Rice) specific gravity in accordance with ASTM and AASHTO procedures. Cylindrical test specimens were compacted in the Superpave™ Gyratory Compactor (SGC) to achieve 7 +/- 1 percent air voids. According to previous research, this is the typical range of compaction in percent air voids achieved for flexible pavements in Tennessee roads immediately after construction (Jackson and Ownby 1998). Bulk specific gravities were determined for the compacted specimens in accordance with ASTM procedures.

### Compaction of Test Specimens

As previously stated, cylindrical test specimens were compacted with the SGC to achieve the desired air void range of 7 +/- 1 percent. Time in the oven and compaction temperature was held constant for all mixes tested. The HMA was allowed a maximum of two hours to come up to the compaction temperature of 150 °C (300 °F). All molds and accessories were

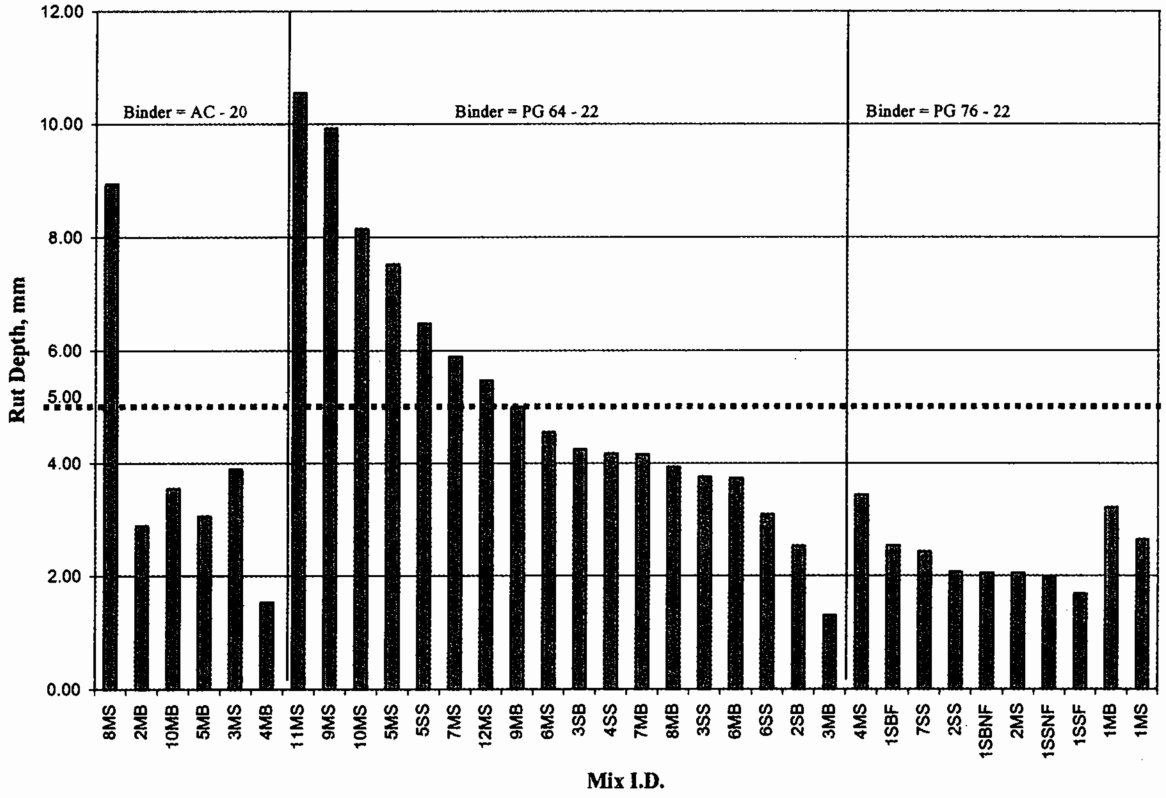

FIGURE 5 APA Rut Depth After 8000 Cycles vs. Mix I.D., Grouped According to Binder Type

heated in the oven for 1 hour at the compaction temperature. The SGC compacts specimens to either a given height or a specific number of gyrations. For this study, compaction was held to a specific height of 75 mm (3.0 in.) in order to achieve the estimated volume for the desired air-void range. Pressure was maintained at 600 kPa (90 psi). Two SGC pills were compacted for each mix tested in this study.

### APA Rut Testing

The APA chamber temperature was set at 50 °C (120 °F) and the compacted test specimens were soaked for four (4) hours at the testing temperature. The wheel loading conditions were held constant at 445 N (100 lbs.) downward force and a hose pressure of 690 kPa (100 psi). The compacted samples were subjected to 8000 cycles in the APA. Rut depth measurements were obtained at a seating load of 10 cycles, and at intervals of 500, 1000, 4000, and 8000 cycles. These criteria were selected based on prevailing industry practices (Watson 1998).

## TEST RESULTS

Some of the critical material properties of the mixes tested in this study are summarized in Table II. These include: asphalt binder type; asphalt binder content; dust content; dust to asphalt ratio; and whether or not the aggregate gradation passes through the Superpave™ restricted zone. The APA average rut depths

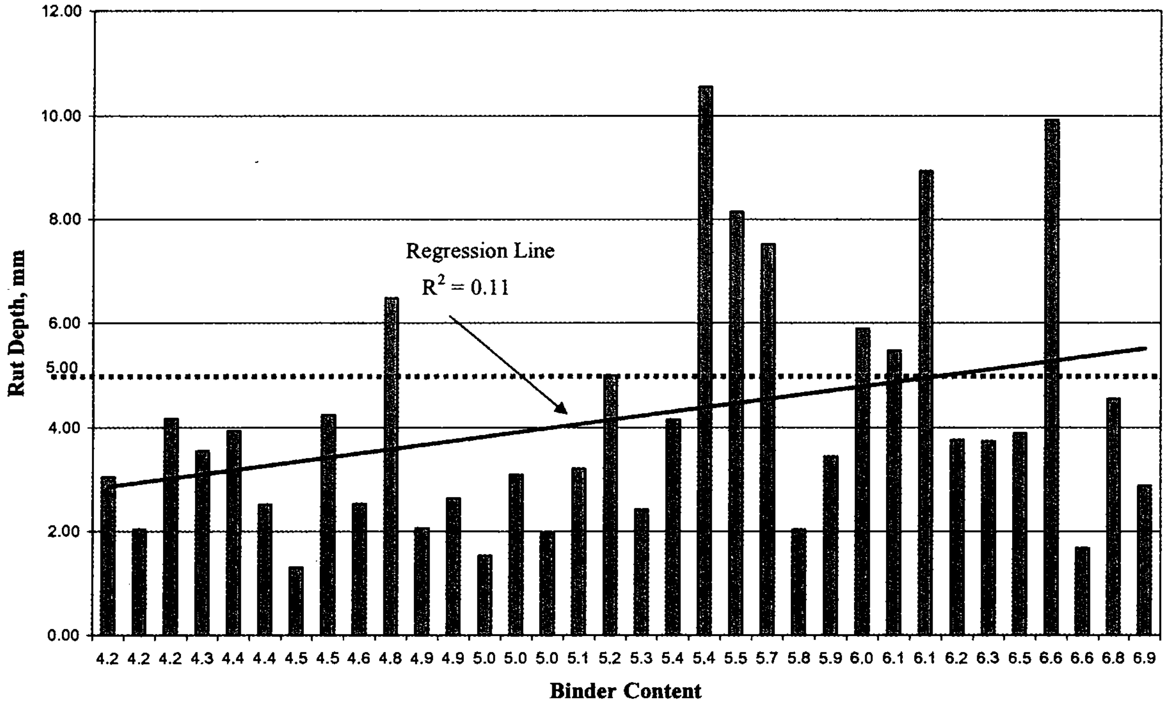

FIGURE 6 APA Rut Depth After 8000 Cycles vs. Binder Content

for each mix after 500 and 8000 cycles are also summarized in Table II. Comparisons of the observed APA rut depths versus the above-referenced material properties are presented in the following paragraphs.

## Compacted Test Specimen Air Voids

The APA rut depth after 8000 cycles is plotted versus percent air voids in Figure 3. Figure 3 illustrates that there is no apparent pattern in the APA rut depth data with respect to air voids, within the established range. This comparison of data exhibits a very weak correlation, as evidenced by the nearly flat regression line and extremely low coefficient of determination ($R^2$) value. This suggests that for the mixes evaluated in this study, air voids ranging from 6 to 8 percent (the typical air void range observed on the roadway immediately after construction) have very little effect on the observed rut depths in the APA, or the effect is small when compared to the effect of other material or mix properties.

## HMA Mix Type

The mixes evaluated in this study are identified as binder and surface mixes in accordance with Sections 307 and 411, respectively, of the TDOT Standard Specifications for Road and Bridge Construction. The mixes are further classified as conventional or Superpave™ with respect to the method of design used in developing the Job Mix Formula (JMF). The conventional TDOT mixes (411D and 307BM/BM-2 designations) were designed by the 75-blow Marshall method, whereas the Superpave™ mixes (411S and 307S designations) were designed in accordance with the Superpave™ volumetric mix design criteria.

Figure 4 presents the APA rut depth after 8000 cycles, grouped according to the above-

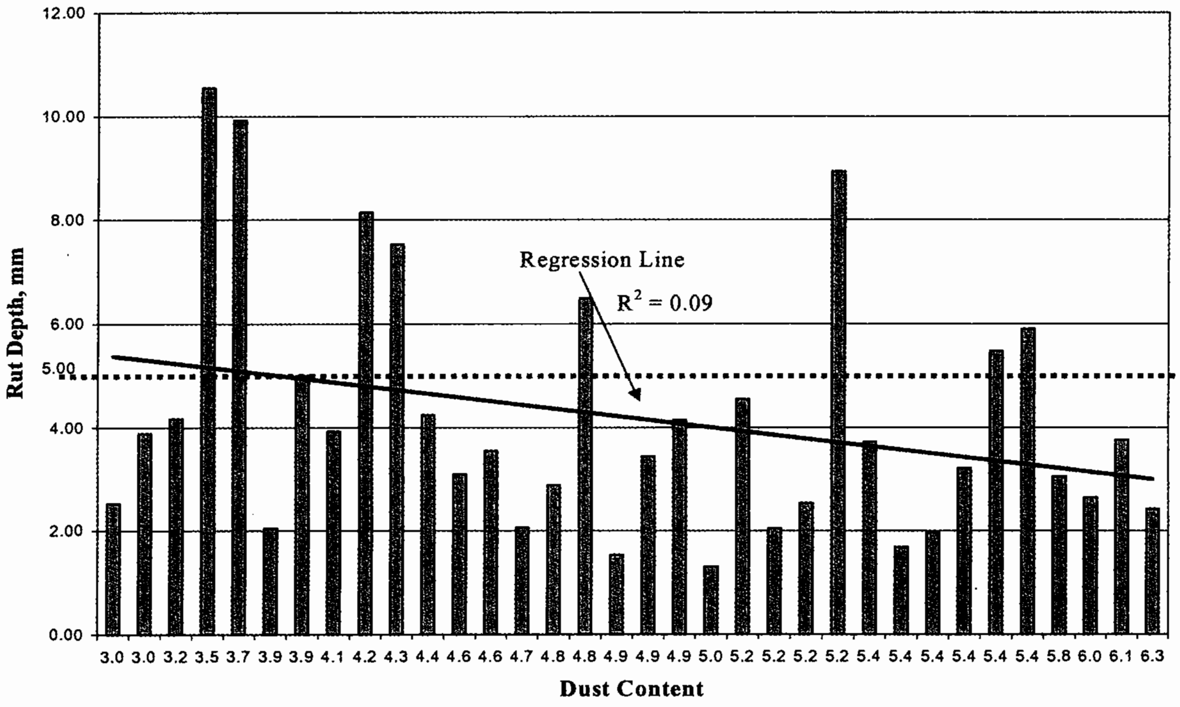

FIGURE 7 APA Rut Depth After 8000 Cycles vs. Dust Content

described mix types. This figure indicates that there is a higher occurrence of rutting in excess of 5 mm (0.20 in.) for the conventional 75-blow Marshall surface mixes (TDOT 411D) as opposed to the other mix types tested in the study. Only one Superpave™-designed mix experienced this magnitude of rutting. Further, based on this data, it appears that the TDOT binder mixes (307 BM/BM-2 and 307S) exhibit less rutting in the APA than the surface mixes (411D and 411S).

## Asphalt Binder Type

Figure 5 presents a plot of APA rut depth after 8000 cycles, grouped according to the Superpave™ binder grade. According to Superpave™, asphalt binders are performance graded to reduce rutting susceptibility up to a specific performance temperature. This figure illustrates that every mix that exhibited greater than 5 mm (0.20 in.) of rutting in the APA, whether designed by the Marshall or Superpave™ mix design methods, contained a PG 64–22 asphalt binder. This indicates that the APA is sensitive to the grade of asphalt binder used in HMA. It should be noted that over half of the mixes containing a PG 64–22 asphalt binder did not exhibit excessive rutting in the APA. However, none of the mixes with a modified PG 76–22 asphalt binder exhibited high amounts of rutting at the testing temperature.

It should also be noted that the testing temperature of 50 °C (120 °F) is well below the design performance temperature for either the PG 64–22 or PG 76–22. These asphalt binders have a maximum performance temperature of 64 and 76 °C, respectively. As previously noted, the testing temperature was chosen based on current industry practices (Watson 1998).

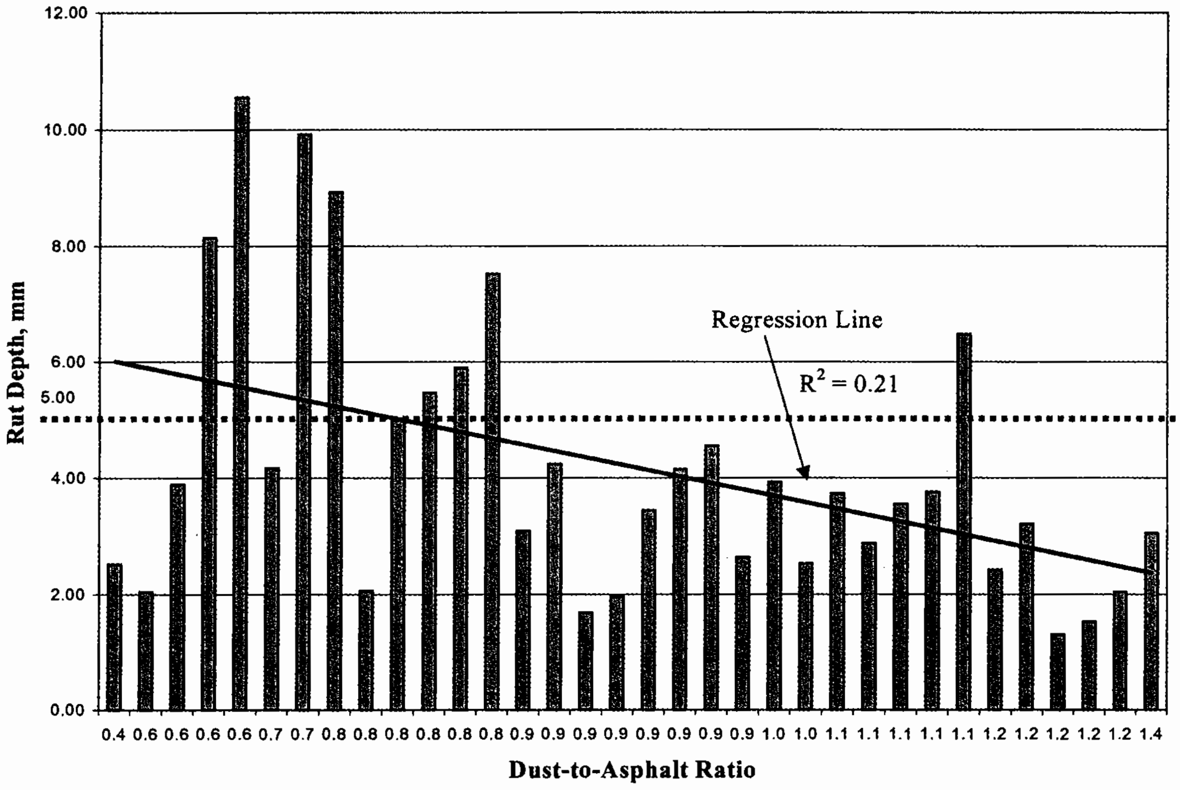

FIGURE 8 APA Rut Depth After 8000 Cycles vs. Dust-to-Asphalt Ratio

## Asphalt Binder Content

Figure 6 is a plot of APA rut depth after 8000 cycles versus asphalt binder content. This plot suggests that there is a slight tendency for increased rutting with increased asphalt binder content. However, the regression line and very low $R^2$ value presented in Figure 6 indicate that this correlation is very weak. For the mixes tested in this study, it appears that other factors are masking the effect of binder content on rutting susceptibility or the effect of binder content is small relative to other material or mix properties.

## Dust Content

Figure 7 is a plot of APA rut depth after 8000 cycles versus dust content (percent passing the 0.075 mm (# 200) sieve). This figure indicates that dust content alone, within reasonable limits, does not correlate well with APA rut depth. As with the previous observations, it is suspected that other, more significant material or mix properties are masking the effect of dust content on the mixes evaluated in this study. The relatively flat regression line and extremely low $R^2$ value presented in Figure 7 support this observation. The combined effect of dust and binder content, or dust-to-asphalt ratio is typically considered a better indicator of rutting susceptibility of HMA.

## Dust-to-Asphalt Ratio

A plot of APA rut depth after 8000 cycles versus dust-to-asphalt ratio is presented in Figure 8. The improved correlation shown in Figure 8 versus those shown in Figures 6 and 7 suggests that the APA is

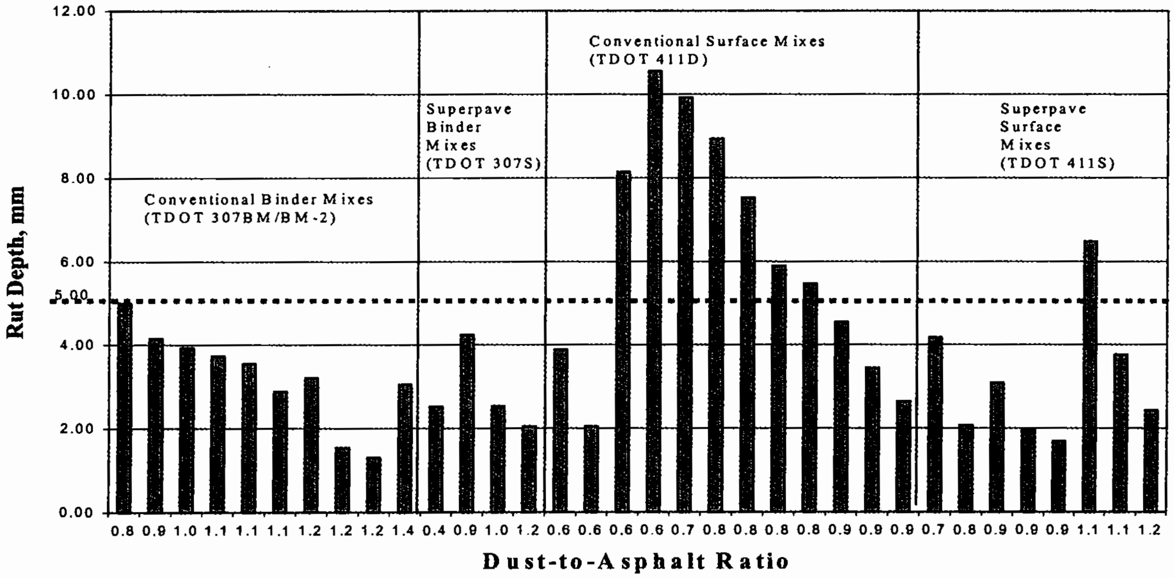

FIGURE 9 APA Rut Depth After 8000 Cycles vs. Dust-to-Asphalt Ratio, Grouped According to Mix Type.

more sensitive to the effects of dust-to-asphalt ratio than either asphalt binder content or dust content alone. It should be noted that this correlation is still relatively weak as evidenced by a relatively low $R^2$ value. The current Superpave™ specification limits this property from 0.6 to 1.2. According to Figure 8, the mixes exhibiting the most rutting in the APA had values on the low end of the current Superpave™ specification, between 0.6 and 0.8.

Figure 9 presents a plot of rut depth versus dust-to-asphalt ratio, re-grouped according to mix type. This figure more clearly illustrates that, for the conventional 75-blow Marshall surface mixes (TDOT 411D), the APA appears to be sensitive to dust-to-asphalt ratios approaching the lower limit of the Superpave™ specification.

### Superpave™ Restricted Zone

Figure 10 presents a plot of APA rut depth after 8000 cycles with respect to whether or not the aggregate gradation passes through the Superpave™ restricted zone. As noted earlier, SHRP researchers determined that HMA with gradations passing through the restricted zone have a relatively high propensity for rutting. This figure illustrates that every mix that experienced greater than 5 mm (0.20 in.) of rutting in the APA, whether designed by the Marshall or Superpave™ criteria, had a gradation that passed through the restricted zone. This suggests that the APA is quite sensitive to the gradation of the HMA, especially on the fine sieves. It should be noted that over half of the mixes with gradations passing through the Superpave™ restricted zone did not rut excessively in the APA. None of the mixes with gradations falling outside of the Superpave™ M restricted zone exhibited high amounts of rutting in the APA

## CONCLUSIONS

The Superpave™ mix design and analysis system provides a good means of specifying asphalt binders and aggregates based on performance. However, Superpave™ does not currently include a proof-test to assess the relative rutting susceptibility of HMA. The

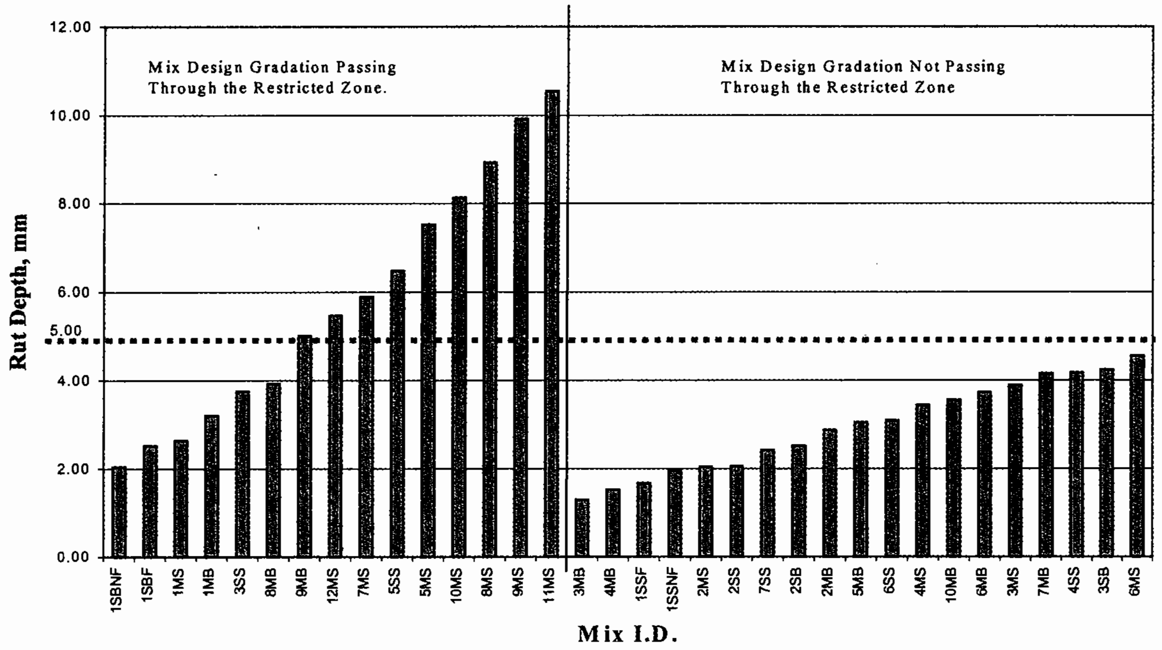

FIGURE 10 APA Rut Depth After 8000 Cycles With Respect to Whether or Not Aggregate Gradation Passes Through the Superpave Restricted Zone

objective of this study was to evaluate the merits of the APA as a proof-test to predict the relative rutting susceptibility of HMA. Thirty-four mixes from various locations within the state of Tennessee were tested in the APA. Based on the test results presented herein, the APA appears to be sensitive to the critical material properties that have been documented to contribute to rutting of HMA. It should be noted that the mixes evaluated in this study will be continuously monitored over the life of the respective pavements, and the results of this laboratory test program will be compared with field rutting when long-term performance data becomes available. The results of this field validation phase will be documented in a subsequent publication.

The APA, as an empirical laboratory test, is unlikely to provide a complete measure of the anticipated performance of a given HMA. It is recommended that the APA always be used as a tool in conjunction with well-established mix design and analysis methods.

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