EVALUATION OF COARSE AND FINE GRADED SUPERPAVE MIXTURES UNDER ACCELERATED PAVEMENT TESTING

Bouzid Choubane[1], Salil Gokhale[2], Gregory Sholar[1] & Howard Moseley[1]

(1) Florida Dept. of Transportation, Materials Research Park
5007 N.E. 39th Avenue, Gainesville, FL 32609
Phone: (352) 955-6302
Fax: (352) 955-6345
E-mail: bouzid.choubane@dot.state.fl.us
Email: greg.sholar@dot.state.fl.us
Email: howard.moseley@dot.state.fl.us

(2) Applied Research Associates, Inc., Transportation Sector,
5007 N.E. 39th Avenue, Gainesville, FL 32609
Phone: (352) 955-6312
Fax: (352) 955-6345
E-mail: sgokhale@ara.com

Word Count: 5659

Body Text	= 2954
Abstract	= 205
Tables 4 x 250	= 1000
Figures 6 x 250	= 1500

ABSTRACT

Initial Superpave implementation guidelines encouraged mix designers to develop coarse gradations for higher traffic level mixtures, as this was thought to produce a more robust aggregate structure. Consequently, many agencies have specified the use of a coarse-graded asphalt mixture on high volume facilities. However, target density can be difficult to obtain while compacting coarse-graded mixtures and control of volumetric properties is harder to maintain than for fine-graded mixtures. The Florida Department of Transportation (FDOT) conducted an experiment to assess the rutting performance of coarse and fine-graded Superpave mixtures under Accelerated Pavement Testing (APT). Both mixtures consisted of aggregate from the same source, and were made with virgin binder meeting the requirements of PG 67-22. Both mixtures contained the same effective binder content and were designed for 10-30 million ESALs, using the standard Superpave mix design methodology. During placement of these mixtures, all standard FDOT density requirements and acceptance criteria were applicable.

The subsequent investigation showed that, under similarly controlled conditions, the fine graded mixture performed slightly better than the coarse-graded mixture in terms of rutting resistance.

This paper presents a description of the testing program, data collection efforts and subsequent analysis and findings focusing primarily on rutting as generated and observed under accelerated pavement testing.

INTRODUCTION

The aggregate gradation specifications in the Superpave mix design procedure (MP2-03) include a primary control sieve (PCS) point that lies along the maximum density line. Gradations that pass above the PCS point are commonly called fine-graded mixtures, whereas those passing below are called coarse-graded mixtures. As part of the initial field implementation of Superpave, it was thought that coarse-graded mixtures would provide a more robust aggregate structure and therefore better rutting performance (*1*). Thus, State transportation agencies, including Florida, started specifying coarse-graded mixtures on all high volume roads (those that have a 20-year design traffic level equal or higher than 10 million Equivalent Single Axle Loads (ESALs) (*2*, *3*). However, there have been significant challenges regarding the use of coarse-graded mixtures both in Florida and nationally. For instance, obtaining density on the roadway proved to be a consistent problem for coarse-graded mixtures. These mixes required a higher level of density to reduce the water permeability to an acceptable level. To achieve such a level of in-place density, a combination of static and vibratory compaction are usually used. It has recently reported that the compaction in vibratory mode has induced, in some instances, damages to pavement supporting layers and/or buried infrastructures particularly in or near urban areas. Another problem that has been observed is the excessive breakdown of aggregate due to the high number of passes required with a vibratory compactor. This breakdown of aggregate can result in significant loss in pavement life. Many contractors, therefore, prefer the use of fine-graded mixtures as they are relatively easier to construct, produce and manage from a quality control standpoint. Many states have also historically observed good performance from some of their fine-graded mixtures. Furthermore, full-scale experiments at WesTrack showed that coarse-graded Superpave mixtures rutted significantly more than the fine-graded mixtures (*4*). Other research also suggests that fine-graded mixtures perform at least as well as coarse-graded mixtures in terms of rutting performance (*5, 6, 7, 8*).

WesTrack Experiment

The Federal Highway Administration (FHWA) and National Cooperative Highway Research Program (NCHRP)-sponsored WesTrack was a full scale test track originally constructed in 1994. The main objectives were to provide early field verification of the Superpave system and also to develop performance related specifications for HMA pavements. The original 26 test sections included both fine- and coarse-graded mix designs. All of the mixtures were 19 mm nominal maximum size, with a performance grade (PG) 64-22 binder (*4*). By June 1998, this test facility had been trafficked for more than two years with more than 4.5 million (ESALs) applied by four driverless tractor-triple-trailer combinations. Test results at WesTrack showed that the coarse-graded mixtures had the most severe distresses. These test sections were replaced with a similar coarse-graded mixture. However, some of the replacement sections rutted even more rapidly than the original sections, and exhibited significant deformation within the first five days of trafficking.

OBJECTIVE:

The primary objective of this study was to evaluate the appropriateness of the recommendation that only coarse-graded mixtures be used in heavy traffic conditions. A comparative rutting performance of coarse- and fine-graded Superpave mixtures was thus investigated under APT.

FLORIDA'S APT PROGRAM

FDOT initiated an Accelerated Pavement Testing (APT) program in early 2000. The APT and research program is based within the new State Materials Research Park in Gainesville. The testing site consist of eight linear test tracks with each test track measuring approximately 150 ft long (45 m) by 12 ft wide (3.6 m). There are an additional two test tracks designed with water-table control capabilities within the supporting base layers. The accelerated loading is performed using a Heavy Vehicle Simulator (HVS), Mark IV model. The HVS is electrically powered (using an external electric power source or electricity from an on-board diesel generator), fully automated, and mobile. Wheel loads were applied on all test sections through a Goodyear G165 (12 in wide) super-single tire loaded to 9,000 lbs (40 kN) at a speed of 8 mph (12 km/h). The load was applied in a uni-directional mode with a 4 in (100 mm) wheel wander, in 1 in (25 mm) increments, with the tire pressure maintained at approximately 115 Psi (790 kPa). All tests were conducted at a controlled temperature of 50° C, at a depth of 2 in (50 mm) from the pavement surface. A complete description of the test facility and the initial experiment has been presented elsewhere (*9*).

Results from Florida's Initial Experiments

The first experiment in Florida's APT program was designed to address the effects of a styrene butadiene styrene (SBS) polymer modifier on the performance of fine-graded Superpave mixtures. One mixture included a PG 67-22 virgin binder, while the other mixture contained a PG 76-22 polymer-modified binder. Both mixtures contained the same effective binder content, aggregate components and gradation. The aggregates used for both mixtures were a combination of Florida limestones and local sand. The respective Superpave mixtures were placed in two, 2 in (50 mm) lifts to construct seven distinct test tracks (or lanes) while complying with all the standard FDOT construction, materials, and in-place (as constructed) specifications and methods. Each of the test lanes was further divided into three distinct pavement test sections. For all pavement test sections, the supporting layers consisted of a 10.5 in (265 mm) limerock base over a 12 in (300 mm) limerock stabilized subgrade. Three different pavement structures were tested:

1. Two layers of asphalt mixture with virgin PG 67-22 binder (fully unmodified).
2. One layer of polymer modified mixture over one layer of unmodified PG 67-22 mixture (hybrid).
3. Two layers of asphalt mixture with polymer modified binder (fully modified).

All of the volumetric properties of the mixtures and the pavement structure were essentially the same, with the only difference between the mixtures being the asphalt binder type used. All testing was conducted at a controlled temperature of 50° C at 50 mm (2 in) depth from the pavement surface. The results of this round of research indicated the superior performance of the polymer modified mixtures with respect to rutting and have been described elsewhere (*9*).

The second experiment in Florida's APT program was designed with the primary objective to validate the results from the first experiment using, this time, coarse-graded mixtures. These coarse-graded mixtures were designed containing limestone aggregates from the same source. Testing conditions were essentially the same as the first experiment, including the pavement structure. Target aggregate gradations for both experiments are shown in tabular form in Table 1, and graphical form in Figure 1. Rutting data from the second experiment showed that, similarly to the findings from the first experiment, the polymer modified mixtures exhibited significantly better rutting resistance compared to the unmodified mixtures,. Furthermore, it was observed that the fine-graded mixtures tested in the first experiment performed equally, if not better, than the coarse-graded mixtures tested in the second experiment. A comparison of the rutting performance is shown in Figures 2 through 4 for the fully unmodified, hybrid and fully modified mixtures respectively. Table 2 also shows the final rut depths for each of the pavement test sections tested.

The results obtained from the first two experiments raised some concern regarding Florida's specifications about using only coarse-graded mixtures on high traffic level facilities. However, since a "head-to-head" comparison and interpretation of the results in terms of performance of coarse vs. fine-graded mixtures from the two experiments may not have been as conclusive. The two experiments were conducted at different times and the binders were obtained from different producers. Consequently, a third experiment was designed with the express objective of comparing the rutting performance of coarse and fine-graded Superpave mixtures.

EXPERIMENT DESIGN

The first two experiments had shown the superior performance of polymer modified binders with respect to rutting resistance. The HVS testing time was also significantly greater for the polymer modified mixtures as compared to the unmodified mixtures. The research team felt that the results obtained with unmodified binders would be reciprocated with polymer modified binders. Therefore, for more practicality and ease of production/construction, mixtures for the current (third) experiment were designed only with unmodified binder conforming to PG 67-22, for both the coarse and fine-graded mixtures.

Prior to construction, most of the existing asphalt layers from the second experiment were removed by milling, leaving approximately 1 in (25 mm) of asphalt remaining on top of the limerock base course. The limerock base course and subgrade layers were not disturbed during the construction process. A total of five test lanes (numbered 1 through 5), were constructed as part of this experiment. Three test lanes were constructed with a fine-graded mixture, while the remaining two lanes were constructed with a coarse-graded mixture. Each test lane was further divided into three pavement sections (called A, B and C), with each pavement section being approximately 44 ft (14 m) in length and 12 ft (3.6 m) in width. Both mixtures were laid in two lifts of 2 in (50 mm) each, therefore conforming to the original pavement structure of a total of 4 in (100 mm) of asphalt. It should be noted that the new mixtures were placed on an existing 1 in (25 mm) of coarse-graded mixture. As mentioned earlier, aggregates used for the earlier experiments were a combination of Florida limestones and local sand. Because one of the sources of limestone was no longer available, the coarse and the fine-graded mixtures tested in this study utilized a combination of granite aggregate from Georgia and local sand. The mixture designs are shown in Table 3 and the target gradation plot is shown in Figure 5.

During construction, samples were taken from each truck delivering the mix to the HVS test track, and were tested in the laboratory for density requirements. The target laboratory air void content was 4.0% for both mixtures at N_{des} 100 gyrations. The laboratory air void content during production for the fine-graded mix averaged 3.9% for the top layer and 4.0% for the bottom layer, whereas the air void content averaged 4.0% for both layers for the coarse-graded mix. The in-place density of the compacted pavement was measured by nuclear density gauges and also by recovering cores from the pavement after construction. The target density was 93% for the fine-graded mix and 94.5% for the coarse-graded mix. Standard laboratory density tests on recovered cores showed that the average density for the top and bottom layers of the fine-graded mix was 92.5% and 92.6% respectively. Similarly, the average measured density for the top and bottom layers of the coarse-graded mix was 92.9% and 93.3% respectively. Individual laboratory air void and density measurements for each test section are shown in Table 4. In general, in-place densities were adequately uniform over the entire test track.

As with previous experiments, all testing was performed at a controlled temperature of 50° C at a depth of 2 in (50 mm) from the pavement surface. The load was applied through a Goodyear G165 (12 in wide) super-single tire loaded to 9,000 lbs (40 kN) at a speed of 8 mph (12 km/h), with a 4 in (100 mm) lateral wheel wander. A total of 90,000 HVS loaded wheel passes were applied on each of the test sections.

Rutting measurements were obtained periodically, using a laser-based profiling device mounted on the underside of the wheel carriage of the HVS. The working of this system has been described elsewhere (*10*). At the beginning of each test, rutting measurements were obtained after every 100 HVS passes up to a total of 2,000 HVS passes. Thereafter, rut data collection interval was successively increased with increasing number of HVS passes. The rut measurements thus obtained are show in Figure 6. In this experiment, it was observed that the fine-graded mixtures performed as well or slightly better than the coarse-graded mixtures in terms of rutting performance.

Laboratory Test Results

Rutting performance of the coarse and fine-graded mixtures was also analyzed in the laboratory with the Asphalt Pavement Analyzer (APA). During construction, extra mix was sampled from trucks transporting the coarse and fine-graded mixes to the HVS test track. Two sizes of APA specimens, 3 in (75 mm) and 4.5 in (115 mm) tall, were tested as part of this experiment, each type with a 6 in (150 mm) diameter. Test specimens for the APA were then compacted in the laboratory using a Superpave Gyratory Compactor (SGC). While the 3 in (75 mm) specimens were compacted to a target air void level of 7±0.5%, the 4.5 in (115 mm) specimens were compacted to the N_{design} level of gyrations, which was 100 gyrations for both the coarse and fine-graded mixtures. On average, 4 to 6 specimens were prepared and tested for each test section.

The results of APA testing are shown in Table 4, and indicate that the amount of rutting in either type of mixture is nearly the same. The average APA rut depths were slightly higher for the coarse-graded mixture, but not at a level that would indicate significantly inferior rutting performance compared to the fine-graded mixture. The APA results thus correlated well with the HVS results in terms of rutting performance.

Experience at NCAT

The National Center for Asphalt Technology (NCAT), located in Auburn, AL, operates a full scale test track utilizing multiple heavily loaded tractor-trailers that apply ten million ESAL's of loading over a two year time period. The FDOT purchased two test sections in the year 2000 to study the performance of coarse-graded and fine-graded mixtures. Limestone aggregates and reclaimed asphalt pavement were shipped from southeast Florida to the test track for construction of the two test sections. The two mixtures utilized the same aggregate components but in slightly different percentages to obtain the coarse and fine-gradations. Each mixture was designed to meet Superpave criteria for a 12.5 mm traffic level D mixture (10 – 30 million ESAL's). The two sections were trafficked for two years and then left in-place to be trafficked again for two more years as part of NCAT's second experiment. The second experiment is scheduled to be completed in December 2005. As of this writing, 17 million of the scheduled 20 million ESAL's have been applied to the two sections. The fine-graded mixture has rutted 3.8 mm and the coarse-graded mixture has rutted 5.2 mm, further demonstrating that fine-graded mixtures can perform as well as or better than coarse-graded mixtures with respect to rutting.

CONCLUSIONS

The present study was performed with the primary objective of evaluating the rutting performance of coarse and fine-graded mixtures. The results of this research and experience at the NCAT test track have shown that fine-graded mixtures can perform at least as well as coarse-graded mixtures with respect to rutting. In response to these results and observing similar trends elsewhere in the United States, the FDOT has made several changes to the July 2005 edition of the Superpave specification. The FDOT will now allow fine-graded mixtures for traffic level D and E mixtures and will require PG76-22 modified binder in the top structural layer of traffic level D mixtures and in both structural layers for traffic level E mixtures. The adoption of these changes should improve the quality of hot-mix asphalt and reduce production and constructability issues associated with coarse-graded mixtures.

In conclusion, the subject experiment provided, within a short time period, information on the performance of asphalt mixtures under realistic loading conditions. Such information is critical to support informed highway planning, policy and decision-making both at the local and State levels. It also shows that APT can produce cost-effectively early, reliable, and beneficial/practical results while improving pavement technology and understanding/ prediction of pavement systems performance.

ACKNOWLEDGEMENTS

The work represented herein was the result of a team effort. The authors would like to acknowledge Tom Byron, Pat Upshaw, Steve Ross, Shawn English, and Kyle Younger for their diligent efforts and contributing knowledge.

REFERENCES

1. Kandhal P. S. and L. A. Cooley. *The Restricted Zone in the Superpave Aggregate Gradation Specification.* National Cooperative Highway Research Program, NCHRP Report 464, 2001.
2. J. A. Musselman, B. Choubane, G. C. Page, and P. B. Upshaw. Superpave Field Implementation: Florida's Early Experience. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1609*, TRB, National Research Council, Washington, D.C., 1998, pp. 51-60.
3. B. Choubane, G. C. Page, and J. A. Musselman. *Investigation of Water Permeability of Coarse Graded Superpave Pavements*. Proceedings, Vol. 67, Association of Asphalt Paving Technologists (AAPT), 1998.
4. *Performance of Coarse-Graded Mixes at WesTrack: Premature Rutting.* FHWA-RD-99-134, FHWA, U. S. Department of Transportation, June 1998.
5. Kandhal P. S and Rajib Mallick. Effect of Mix Gradation on Rutting Potential of Dense-Graded Asphalt Mixtures. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1767,* TRB, National Research Council, Washington D.C., 2001, pp. 146-151.
6. Kandhal P. S. and L. A. Cooley. *Coarse Versus Fine-Graded Superpave Mixtures: Comparative Evaluation of Resistance to Rutting.* NCAT Report 02-02, National Center for Asphalt Technology, Auburn University, Alabama, February 2002.
7. Hand A., Stiady J., White T., Noureldin A. and Khaled Galal. Gradation Effects on Hot-mix Asphalt Performance. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1767,* TRB, National Research Council, Washington D.C., 2001, pp. 152-157.
8. Hand A. J. and Amy L. Epps. Impact of Gradation Relative to Superpave Restricted Zone on Hot-Mix Asphalt Performance. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1767,* TRB, National Research Council, Washington D. C., 2001, pp. 158-165.
9. Byron T, Choubane B, and M. Tia. *Assessing Appropriate Loading Configuration In Accelerated Pavement Testing*. Proceedings, 2nd International Conference on Accelerated Pavement Testing, Minneapolis, MN, 2004.
10. T. Byron, S. Gokhale and Bouzid Choubane. Laser Based Technology for Automated Rut Measurement in Accelerated Pavement Testing. Presented at the 84th Annual Meeting of the Transportation Research Board, Washington D.C., January 2005, CDROM 05-1685.

LIST OF TABLES

LIST OF FIGURES

TABLE 1 Mix Design Job Mix Formulas and Target Volumetric Properties of Asphalt Mixtures in Experiments 1 and 2

Percentage by Weight of Total Aggregate Passing Sieves					
Type Material		Fine Graded Mix	Coarse Graded Mix	Control Points	Restricted Zone
Sieve Size	19.0 mm (3/4in)	100	100	100	
	12.5 mm (1/2 in)	93	94	90-100	
	9.5mm (3/8 in)	89	89	-90	
	4.75mm (No.4)	71	56		
	2.36mm (No. 8)	53	30	28-58	39.1-39.1
	1.18mm (No. 1.16)	42	20		25.6-31.6
	600µm (No. 30)	35	15		19.1-23.1
	300µm (No. 50)	22	10		
	150µm (No. 100)	9	6		
	75µm (No. 200)	4.5	4.3	2-10	
G_{sb}		2.346	2.311		

Volumetric Properties							
Mix Type	Asphalt Binder	% Binder	V_a @ N_{des}	VMA	VFA	P_{be}	G_{mm}
Fine Graded	PG 67-22	8.2	4.0	14.5	72	4.97	2.276
Coarse Graded	PG 67-22	8.2	4.0	14.1	72	4.80	2.253

TABLE 2 Summary of Rutting Measurements from Experiments 1 and 2

Pavement Structure	Pavement Section	Test Temperature (° C)	Number of HVS Passes	Final Rut Depth (mm)
Both Layers Unmodified	Fine 1-4A	50	95,478	16.5
	Fine 1-4B	50	65,000	17.0
	Fine 1-5A	50	113,945	15.6
	Fine 1-5B	50	62,935	20.7
	Coarse 2-5A	50	70,000	23.0
	Coarse 2-5B	50	68,978	20.7
	Coarse 2-5C	50	71,591	21.1
Hybrid (Top layer modified, bottom layer unmodified)	Fine 1-3A	50	275,000	11.3
	Fine 1-3B	50	280,032	12.0
	Coarse 2-3A	50	140,000	12.8
	Coarse 2-3B	50	150,000	22.3
	Coarse 2-4A	50	213,036	21.5
	Coarse 2-4B	50	60,000	14.6
	Coarse 2-4C	50	8,000[a]	5.5[a]
Both Layers Modified	Fine 1-1B	50	140,060	7.8
	Fine 1-2B	50	240,000	9.2
	Coarse 2-1A	50	200,000	8.0
	Coarse 2-1B	50	215,032	11.1
	Coarse 2-1C	50	201,175	10.9
	Coarse 2-2A	50	200,000	9.2

[a] Test not fully completed.

TABLE 3 Mix Design Job Mix Formulas and Target Volumetric Properties of Asphalt Mixtures in Experiment 3

Percentage by Weight of Total Aggregate Passing Sieves					
Type Material		Fine Graded Mix	Coarse Graded Mix	Control Points	Restricted Zone
Sieve Size	19.0 mm (3/4in)	100.0	100.0	100	
	12.5 mm (1/2 in)	98.0	98.0	90-100	
	9.5mm (3/8 in)	90.0	90.0	-90	
	4.75mm (No.4)	68.0	54.0		
	2.36mm (No. 8)	48.0	32.0	28-58	39.1-39.1
	1.18mm (No. 1.16)	34.0	23.0		25.6-31.6
	600µm (No. 30)	25.0	17.0		19.1-23.1
	300µm (No. 50)	16.0	11.0		
	150µm (No. 100)	8.0	5.0		
	75µm (No. 200)	4.9	4.5	2-10	
G_{sb}					

Volumetric Properties							
Mix Type	Asphalt Binder	% Binder	V_a @ N_{des}	VMA	VFA	P_{be}	G_{mm}
Fine Graded	PG 67-22	4.6	4.0	14.6	73	4.5	2.579
Coarse Graded	PG 67-22	4.5	4.0	14.6	73	4.4	2.589

TABLE 4 Comparison of Laboratory and Test Track Results for Experiment 3

Layer	Mix Type	Test Section	Air Voids (%)	Density (% Gmm)	APA Rut Depth (mm), 8000 Cycles		HVS Rut Depth (mm)
					75 mm Specimens	115 mm Specimens	
Top Layer	Fine Graded	3-2C	3.6	93.0	3.5	3.4	14.8
		3-3A	4.3	92.6	3.3	3.5	12.2
		3-3B	4.3	92.1	3.3	3.5	12.7
		3-3C	3.3	92.1	4.0	3.6	16.9
	Coarse Graded	3-4A	4.3	93.7	3.1	3.3	13.6
		3-5A	4.5	92.6	2.3	3.3	17.1
		3-5B	4.5	92.6	2.3	3.3	14.2
		3-5C	4.3	92.6	3.1	3.3	16.2
Bottom Layer	Fine Graded	3-2C	3.3	92.8	3.8	3.0	--
		3-3A	4.0	92.4	2.5	2.9	--
		3-3B	4.0	92.5	2.5	2.9	--
		3-3C	4.8	92.5	Not tested	3.0	--
	Coarse Graded	3-4A	4.3	92.6	2.8	2.9	--
		3-5A	4.5	93.6	2.8	2.6	--
		3-5B	4.5	93.7	2.8	2.6	--
		3-5C	4.3	93.3	3.2	2.9	--

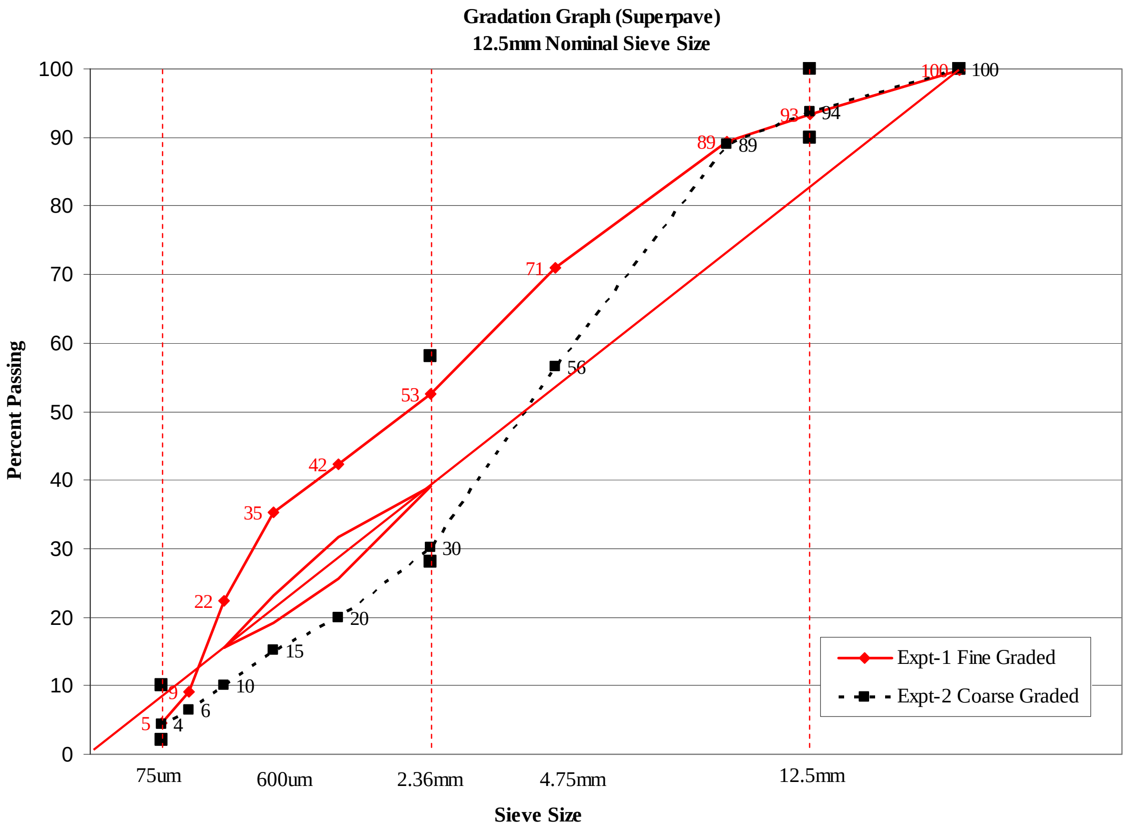

FIGURE 1 Gradation plot of coarse and fine graded mixtures from experiments 1 and 2.

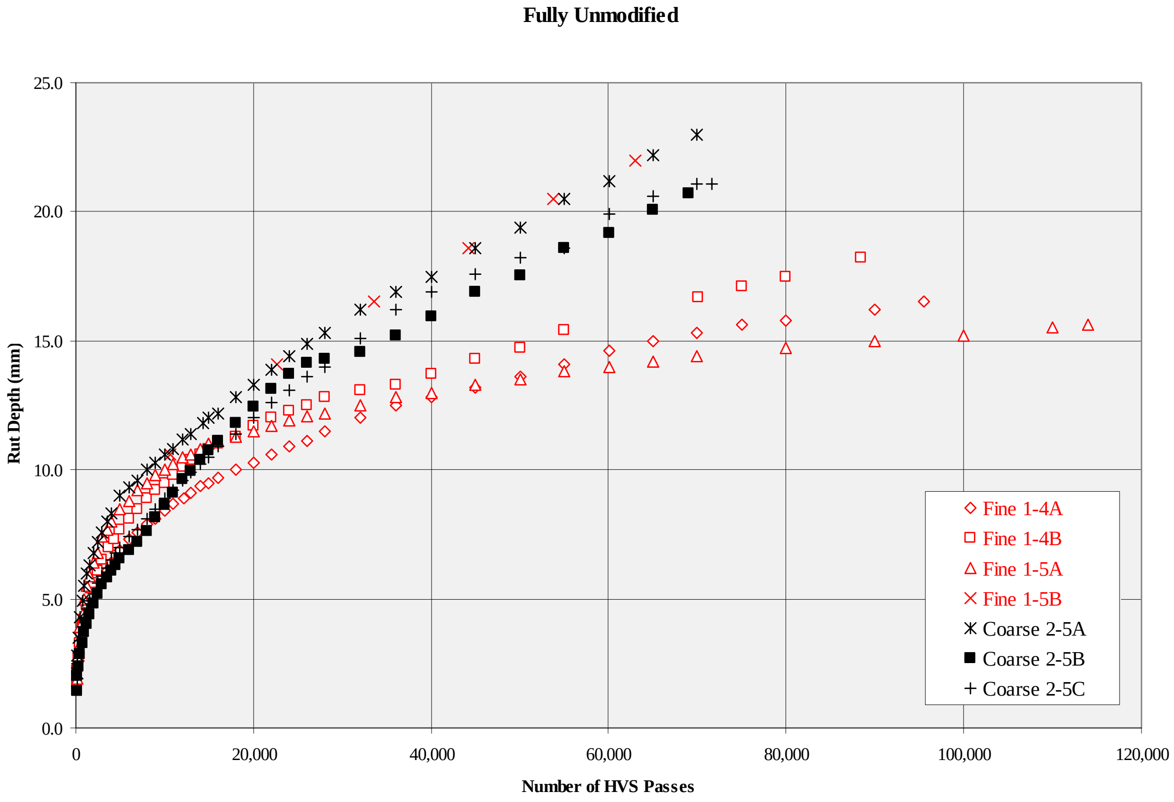

FIGURE 2 Rutting performance of fully unmodified mixtures.

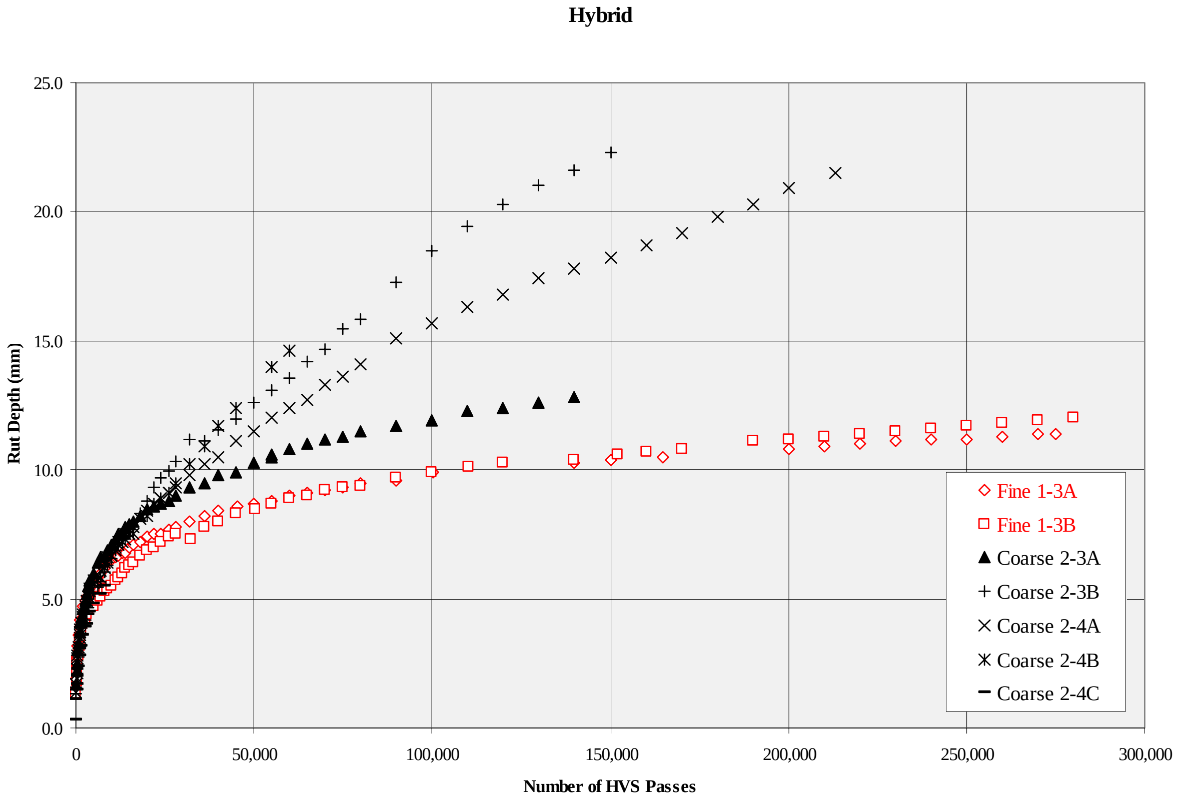

FIGURE 3 Rutting performance of hybrid mixtures.

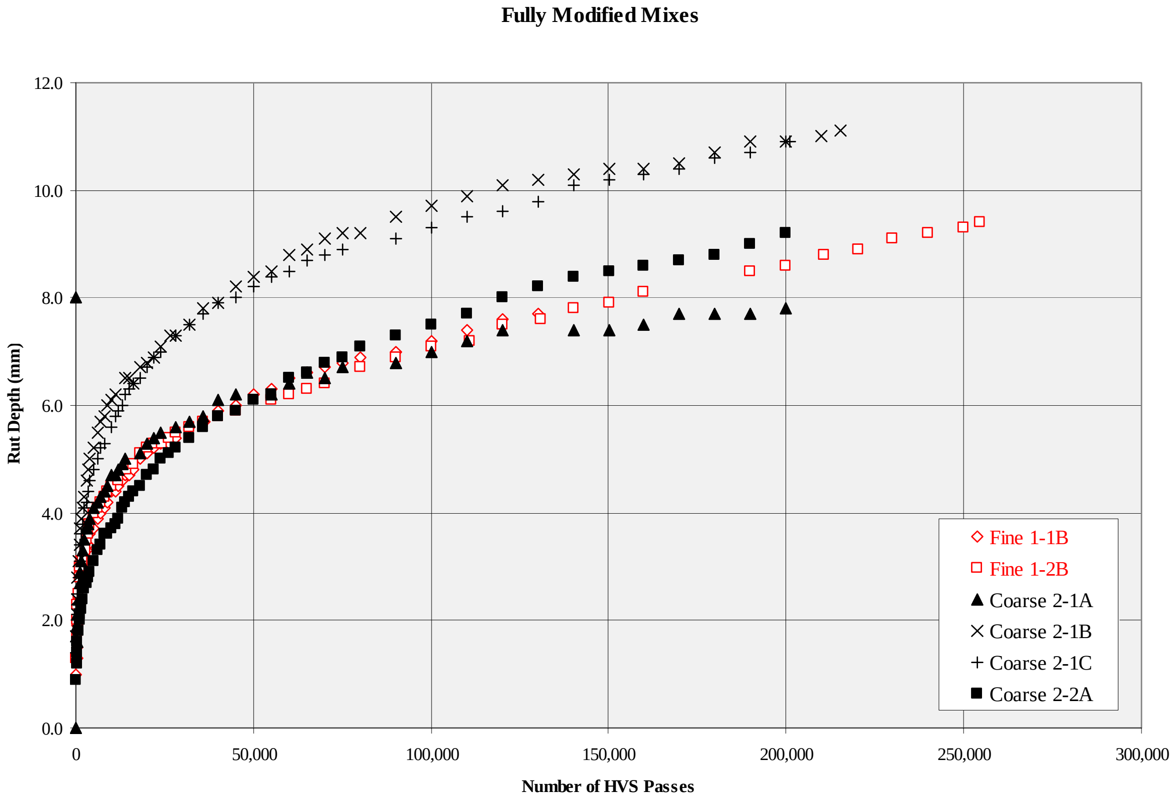

FIGURE 4 Rutting performance of fully modified mixtures.

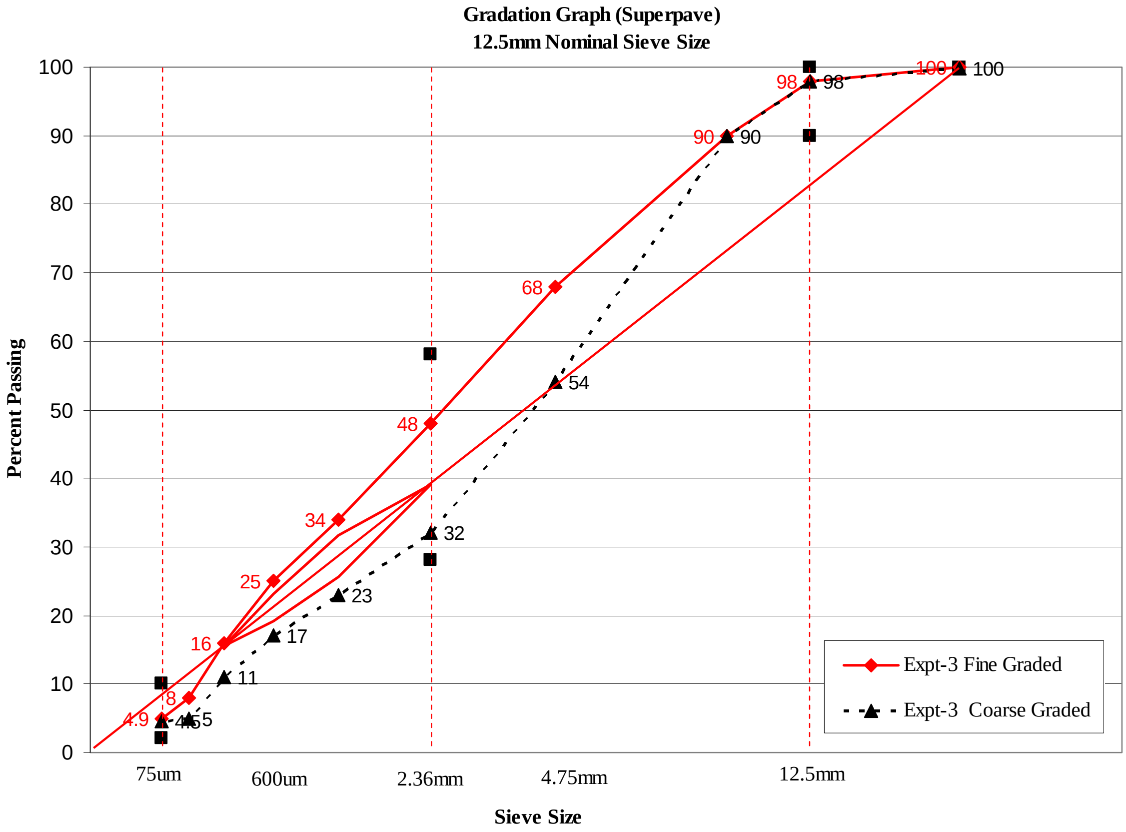

FIGURE 5 Gradation plot of coarse and fine graded mixtures from experiment 3.

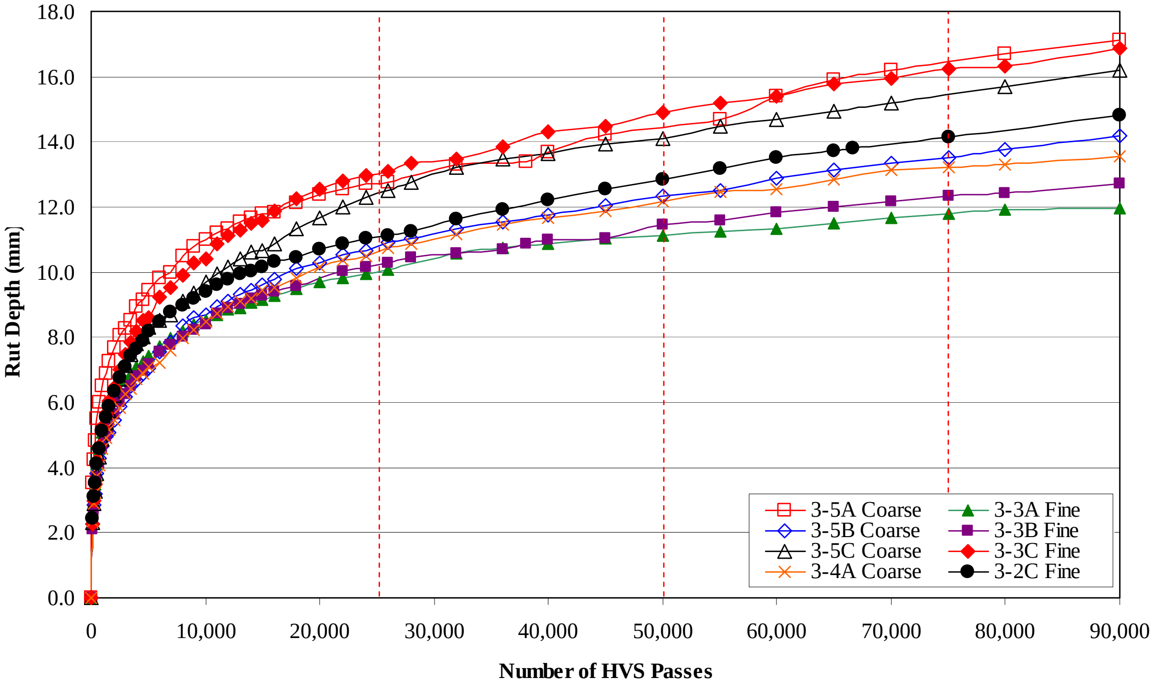

FIGURE 6 Comparison of rutting performance of coarse and fine-graded mixtures in experiment 3.