EVALUATION OF USE OF SYNTHETIC LIGHTWEIGHT AGGREGATE (SLA) IN HOT MIX ASPHALT

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ABSTRACT

Successful use of Synthetic Lightweight Aggregates made from waste flyash and plastics can help in conserving mineral aggregates and reusing waste materials. The objective of this study was to evaluate the use of Synthetic Lightweight Aggregate made from waste fly ash and plastics in Hot Mix Asphalt. The scope of this laboratory study included preparation of aggregate blends and mixes with different percentages of Synthetic Lightweight Aggregates, compaction of samples, testing of samples and analysis of results. Mixes were made with 0, 5, 10, 15 and 20 percent Synthetic Lightweight Aggregates by weight of aggregates. Tests included bulk specific gravity, theoretical maximum density, resilient modulus and indirect tensile strength at 25^{o}C on unconditioned and conditioned samples, and rut testing with a wheel tracking equipment at 60^{o}C. Test results were analyzed statistically to determine the effect of Synthetic Lightweight Aggregates on Hot Mix Asphalt properties. The results indicate that the inclusion of Synthetic Lightweight Aggregates enhances stiffness, and resistance against rutting and moisture induced damage of Hot Mix Asphalt. A relatively high absorption was noted for mixes containing 20 percent Synthetic Lightweight Aggregates. The main conclusions are that Synthetic Lightweight Aggregate has excellent potential of being used as part of Hot Mix Asphalt, and that 15 percent by weight of aggregate seems to be an optimum amount for use. Further work should be carried on to determine the effect of Synthetic Lightweight Aggregate on low temperature properties of Hot Mix Asphalt.

INTRODUCTION

Coal fly ash and plastics are two of the major waste materials generated in the United States. While a significant amount of fly ash is generated from power plants, different types of waste plastics are produced as a result of discarding plastic containers and packaging materials. Only about 29 percent of the annually produced 63 million tones of coal fly ash and a minor percentage of the 40 million tons of plastics used for different packaging materials are recycled today in the United States (*1*). Without any reuse, these materials would eventually find their way to landfills across the country. One way of reusing these materials is by recycling them into usable construction materials. The feasibility of producing light weight aggregates (Synthetic Lightweight Aggregates, SLA) from fly ash and mixed waste plastics has been proven by researchers. Work has also been conducted on evaluation of the use of SLA in concrete and geotechnical fills (*2, 3, 4, 5, 6, 7, 8*).

The Hot Mix Asphalt (HMA) industry is a major user of mineral aggregates. In the recent past a number of different types of waste materials (in semi or fully processed form) and modifiers, such as granulated rubber and polymers, have been used for recycling of waste materials and enhancement of HMA properties. SLA has the potential of being used as partial replacement of mineral aggregates in HMA. If found to be suitable, the use of SLA can reduce the use of mineral aggregate and hence help in conservation of natural resources as well as in recycling waste products. A few percent replacement of mineral aggregate by SLA can result in the use of several hundred thousand tons of SLA, and hence a reuse of a significant amount of waste materials. Therefore, there is a need to evaluate the use of SLA in HMA.

OBJECTIVE

The objective of this study was to evaluate the use of Synthetic Lightweight Aggregate (SLA) made from waste fly ash and plastics in HMA.

SCOPE

The scope of this laboratory study included preparation of aggregate blends with different percentages of SLA, compaction of samples, testing of samples for different properties and analysis of results.

MATERIALS

Materials (granite aggregates and PG 64-28 asphalt binder) used for constructing surface HMA course were obtained from Aggregate Industries (Wrentham, MA quarry). This SLA was manufactured from high carbon coal fly ash and a mixed plastic dry blend – about 80 percent fly ash and 20 percent mixed plastic formulation. The fly ash was supplied by Pacific Gas and Electric's Brayton Point Coal Burning Power station, and has 20 percent carbon content. The mixed plastic was produced at University of Massachusetts-Lowell, using different types of plastic such as High Density Polyethylene (HDPE) and Polypropylene (PP) (Table 1). Note that this study used SLA produced from a previous project in which SLA production was demonstrated on a field-scale level.

TEST PLAN

Figure 1 shows the overall test plan. Aggregate blends were prepared with 0, 5, 10, 15 and 20 percent SLA, by weight of aggregates. Two blends with 0 and two blends with 10 percent SLA were compacted without asphalt, and the compacted blends were checked for gradation. This step was conducted to determine any significant breakdown of SLA aggregates during compaction, as compared to breakdown of mineral aggregate. Remaining batches were mixed with PG 64-28 asphalt binder at 5.6 percent asphalt content. Two mixes for each blend were tested for theoretical maximum density (TMD). Next, the remaining batches were mixed with asphalt binder, and samples were compacted to produce 6-8 percent air voids (voids in total mix, VTM, in order to simulate construction voids of approximately 7 percent), using a Superpave Gyratory Compactor (SGC). Note that the selected mix has a 12.5 mm nominal maximum aggregate size (NMAS), and an asphalt content of 5.6 percent. This mix is commonly referred to as "modified top" and is used by Massachusetts Highway Department (MHD) for paving surface courses. Four samples from each blend were tested for rutting with the Asphalt Pavement Analyzer (APA), using 8,000 cycles, 690 kPa pressure and 60^{o}C temperature. Three samples for each blend were tested for indirect tensile strength at 25^{o}C. Another three samples were tested for resilient modulus at 25^{o}C, and then conditioned according to the AASHTO T 283 procedure, for evaluation of moisture susceptibility. At the end of the conditioning period, the samples were tested for indirect tensile strength at 25^{o}C. The conditioned versus unconditioned strengths were compared to determine the retained tensile strengths. The data was analyzed to determine the effect of SLA on the different HMA properties.

RESULTS AND ANALYSIS

Detailed results are provided in Appendix A. The following paragraphs present the average test results and conclusions from statistical analyses.

Table 1 shows the specific gravities of the aggregate blends and the theoretical maximum densities. Note that because of the inclusion of light weight aggregate, SLA, the bulk and effective specific gravities, and the theoretical maximum density (TMD) of the aggregate blends and mixes with SLA are lower than those for the aggregate blends and mixes without SLA. Also, note that the calculated absorption values for all blends except that containing 20 percent SLA are below 1 percent (considered to be the limit for classifying aggregates as non-absorptive). It seems that an inclusion of SLA of upto 15 percent (of aggregate weight) does not result in significant increase in absorption values as compared to blends with mineral aggregates only.

To determine whether there is any significant breakdown of SLA during compaction, two samples of the mix without SLA and two samples of the mix with 10 percent SLA were compacted (dry, without adding asphalt), and gradations of pre compaction batches and post compaction samples were compared. The results shown in Table 2 do not provide any clear indication of any increased amount of fines in the case of the blend with SLA, as compared to the blend without SLA, and hence do not indicate any significantly higher break down of SLA particles.

During mixing and compaction, a HMA mix is subjected to a temperature exceeding 145^{o}C. While loose SLA pieces subjected to this high temperature did not indicate any apparent deformation, it is suspected that during mixing and compaction, the

SLA particles behaved at least partly as very high viscosity “binder”. This is probably due to the low shear modulus of the SLA particles at temperatures in excess of 100°C (6). This behavior was confirmed when “balls” of aggregate-SLA mixes were obtained when two batches of aggregates with 10 percent SLA were compacted without using any asphalt binder (Figure 2). The random “balling” effect of the SLA could have at least partially been responsible for the relatively high standard deviation of test results, as noted in the following paragraphs.

Resilient modulus tests were carried out for evaluation of stiffness properties of SLA modified mixes. Table 3 provides the results of resilient modulus testing of the samples of different mixes, along with results of statistical analysis. Note that the moduli increase significantly with an increase in percentage of SLA, and that the standard deviation of moduli for blends with SLA are very high compared to the standard deviation of modulus of the blend without any SLA. The significant increase in modulus with an increase in percentage of SLA is also shown in Figure 3.

Table 4 shows a comparison of indirect tensile strengths of unconditioned samples from blends with different percentages of SLA. Similar to modulus, a significant increase in strength is evident, as shown in Figure 4. Note that the strengths of the samples with 20 percent SLA could not be determined since the breaking load exceeded the maximum loading capacity of the equipment (22 kN). A breaking load of 22kN was assumed to calculate the indirect tensile strengths in this case. Hence, the actual strengths of the mixes with 20 percent SLA are greater than those shown in Table 4. Table 5 shows the results of indirect tensile strength tests on conditioned samples, and the calculated retained strengths (calculated as average strength of conditioned samples divided by average strength of unconditioned samples, expressed as a percentage). The statistical analysis shows a steady increase in conditioned strength with an increase in percentage of SLA (Figure 5). Figure 6 shows a steady increase in retained strength with an increase in percentage of SLA upto 15 percent. The retained strength shows a drop for the blend with 20 percent SLA. Since a high absorption (> 1 percent) was noted for mixes with 20 percent SLA, it is quite possible that the mix with a reduced amount of effective asphalt binder is more susceptible to moisture damage, and hence shows a reduced retained strength. However, it should be noted that the conditioned strength of mixes with 20 percent SLA are still higher than the conditioned strength of mixes with other percentages of SLA (Figure 5).

In order to evaluate the rutting potential of mixes with SLA, wheel-tracking tests were conducted with the Asphalt Pavement Analyzer (APA). Table 6 shows the results of rut testing, along with statistical analysis. There is a significant effect of SLA on rutting potential of HMA – the results show a clear decrease in rutting potential with an increase in SLA percentage (Figure 7). Note that the rut depths obtained for all of the mixes are lower than what is considered to be indicative of a mix with high rutting potential (<6 mm, 9).

CONCLUSIONS AND RECOMMENDATIONS

The results presented above were used to answer two questions 1. Is there any improvement in HMA properties with the addition of SLA? And 2. If there is, what is the optimum SLA percentage? The results obtained in this study seem to indicate an enhancement of both strength and stiffness with the addition of SLA. Of particular importance is the significant reduction in rutting potential with an increase in SLA content in HMA mix. The increased stiffness (as evident by the increased resilient modulus) for blends with higher SLA content would allow one to design relatively thinner pavement layers (10). Retained strengths, and more specifically conditioned strengths increase with an increase in SLA content, and hence mixes with SLA seem to have adequate resistance against moisture damage (all retained strengths exceed 90 percent). Therefore, from considerations of strength, stiffness and effect of moisture, mixes seem to improve significantly with the addition of SLA. Since a higher than 1 percent absorption is noted at 20 percent SLA content, from the results of this study it seems that 15 percent SLA would be the optimum percentage. While there is no indication that an addition of 20 percent SLA would actually reduce the quality of HMA, to obtain a specific effective asphalt content, one would probably end up using a slightly higher asphalt content to make up for the increased absorption at 20 percent SLA content.

One important thing that should be noted is that no low temperature testing has been done in this study. One potential effect of increased stiffness is increased potential of cracking at low temperature due to inability to accommodate strain. Hence testing should be done to evaluate properties at low temperature as well. Also, testing of leachate from HMA with SLA should be conducted to detect any undesirable materials, if any.

It should be noted that an use of 20% SLA in HMA results in a 13-percent decrease in weight (based on data provided in Table 1). Such reduction in weight would be beneficial for paving mixes used for bridge decks, parking garages and other structures where weight is an issue. Also, because of higher modulus values of SLA, its use can lead to reduction in required pavement thickness, and hence potential cost savings. These topics should be investigated.

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Disclaimer

The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views of the Chelsea Center for Recycling and Economic Development.

REFERENCES

1. Swan, Christopher, W, Daniel C. Jansen, M. G. Kashi and R. A Malloy. Synthetic Lightweight Aggregates from Fly Ash and Waste Plastics. In *Proceedings of the Beneficial Use of Waste Materials in Transportation*, November, 2001.
2. Kashi. M. G, C. Swan, O. Holmstrom and R. Malloy. Innovative, Lightweight Synthetic Aggregate Developed from Coal Fly Ash. In *Proceedings of the 13th International Symposium on Management and Use of Coal Combustion Products*. Vol. 1; 1999.
3. Holmstrom, O., C. Swan. Geotechnical Properties of Innovative, Synthetic Lightweight Aggregates. In *Proceedings of the 1999 International Ash Utilization Symposium*, 1999.

4. Kashi, M. G., R. Malloy, C. Swan. *Development of Synthetic Aggregate for Construction Materials*; Final Report for Chelsea Center for Recycling and Economic Development, Chelsea, MA, 2001.
5. Jansen, D. C., M. Kiggins, C, Swan, R. Malloy, M. Kashi, R. A. Chan, C. Javdekar, C. Siegel, J. Weingram. Lightweight Fly Ash/Plastic Aggregates in Concrete. In *Transportation Research Record 1775*, TRB, National Research Council, Washington DC, 2001.
6. Kashi, M. G., Robert A. Malloy, Christopher W. Swan, *Synthetic Lightweight Aggregate for Highway Construction*, Report submitted to The Recycled Material Resource Center, July 2001.
7. Malloy, R. N. Desai, C. Wilson, C. Swan, D. C. Jansen and M. Kashi. High Carbon Fly Ash/Mixed Thermoplastic Aggregate for Use in Lightweight Concrete. Presented at ANTEC 2001, Dallas, 2001.
8. Kiggins, M. Synthetic (Fly Ash/Plastic) Lightweight Aggregates in Concrete. Thesis submitted in partial fulfillment for a M. S. degree, Department of Civil and Environmental Engineering, Tufts University, Medford, MA, November 2001.
9. Kandhal, P. S. and R. B. Mallick. Use of Asphalt Pavement Analyzer (APA) to Evaluate Rutting in Hot Mix Asphalt (HMA), National Center for Asphalt Technology, Auburn University, 2001.
10. American Association of Highway and Transportation Officials (AASHTO) Pavement Design Guide, 1986.

LIST OF TABLES AND FIGURES

TABLE 1 Aggregate and mix properties

Components of Plastics:		
Plastic Type	**Grade**	**Percent**
Polyethylene Terephthalate (PET)	Bottle	16.2
High Density Polyethylene (HDPE)	Blow Molding	7.9
High Density Polyethylene (HDPE)	Injection Molding	22.1
High Impact Polystyrene (HIPS)	Injection Molding	8.7
General Purpose Polystyrene (GPPS)	Injection Molding	4.1
Low Density Polyethylene (LDPE)	Blown Film	14.2
Polypropylene (PP)	Injection Molding	25.3
Acrylonitrile Butadiene styrene (ABS)	Injection Molding	1.5

Property	Mineral Aggregate	SLA	Blends*				
			0%	5%	10%	15%	20%
Aggregate, Bulk specific gravity	2.640	1.500	2.640	2.543	2.454	2.369	2.292
Mix Theoretical Maximum Density	NA	NA	2.457	2.376	2.312	2.238	2.196
Aggregate Effective specific gravity	NA	NA	2.679	2.577	2.498	2.407	2.355
Aggregate Absorption	NA	NA	0.56	0.54	0.74	0.68	1.19

Notes: * Percent of SLA based on total mass of aggregate; Effective specific gravity and absorption calculated from theoretical maximum density, asphalt content and bulk specific gravity; NA – not applicable

TABLE 2 Pre and post compaction gradation

Sieve size, mm	Original Batch gradation, % passing	Average post compaction gradation, % passing, of dry batch (average of two samples)	
		Mix with no SLA	Mix with 10 % SLA
12.5	93	96	95
9.5	77	78	76
4.75	55	60	57
2.36	38	43	42
1.18	25	29	27
0.6	18	21	20
0.3	13	16	15
0.15	10	12	11
0.075	4	5.4	5.9

TABLE 3 Results of Resilient Modulus Tests (Unconditioned Samples)

Blend	Resilient Modulus, MPa	
	Average	Standard Deviation
Mix with No SLA	1,475	37.42
Mix with 5 % SLA	2,932	509.69
Mix with 10 % SLA	3,223	394.86
Mix with 15 % SLA	3,489	288.39
Mix with 20 % SLA	4,442	126.08

Results of statistical analysis

ANOVA table

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	1	1.7564387	1.7564387
Residuals	13	.4348892	.0334530
F = 52.50464		Pr > F = .0000	

TABLE 4 Results of indirect tensile strength tests (unconditioned samples)

Blend	Indirect tensile strength, kPa	
	Average	Standard Deviation
Mix with No SLA	89.4	3.61
Mix with 5 % SLA	155.7	6.77
Mix with 10 % SLA	121.5	34.06
Mix with 15 % SLA	173.2	24.95
Mix with 20 % SLA	252.4	46.54

Results of statistical analysis

ANOVA table

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	1	1.4336802	1.4336802
Residuals	13	.4370325	.0336179
F = 42.64635		Pr > F = .0000	

TABLE 5 Results of moisture susceptibility tests

Blend	Indirect Tensile strength, kPa	
	Average Conditioned, kPa	Retained, % (based on unconditioned strength, given in Table 4)
Mix with No SLA	83.4	93
Mix with 5 % SLA	160.4	103
Mix with 10 % SLA	120.8	99
Mix with 15 % SLA	180.4	104
Mix with 20 % SLA	219.7	87

Results of statistical analysis

ANOVA table

	Degrees of Freedom	Sum of Squares	Mean Square
Regression	1	1.2217400	1.2217400
Residuals	13	.7947218	.0611324
F = 19.98513		Pr > F = .0006	

TABLE 6 Results of rut tests

Blend	Rut Depth, mm (4 samples tested for each mix)	
	Average	Standard Deviation
Mix with No SLA	6.2	0.37
Mix with 5 % SLA	2.7	0.68
Mix with 10 % SLA	2.3	0.70
Mix with 15 % SLA	1.6	0.73
Mix with 20 % SLA	1.4	0.17

Results of statistical analysis

ANOVA table

	DF	Sum of Squares	Mean Square
Regression	1	5.2022593	5.2022593
Residuals	18	2.3654102	.1314117
F = 39.58750		Pr > F = .0000	

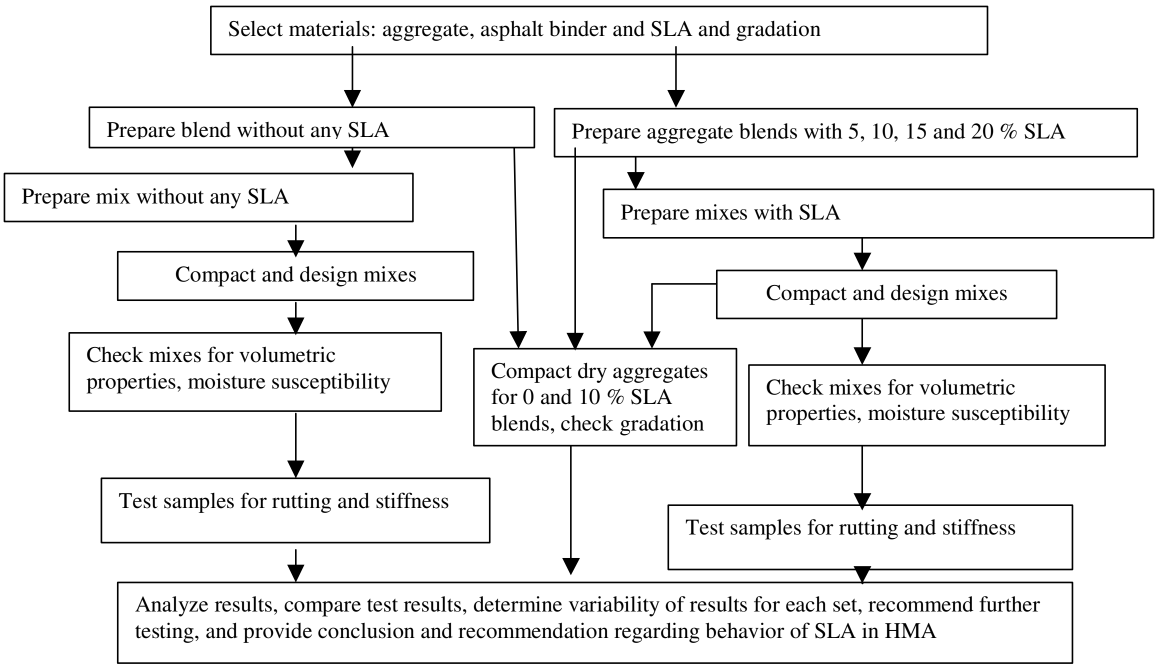

FIGURE 1 Overall test plan.

FIGURE 2 Ball of (dry) aggregate and SLA.

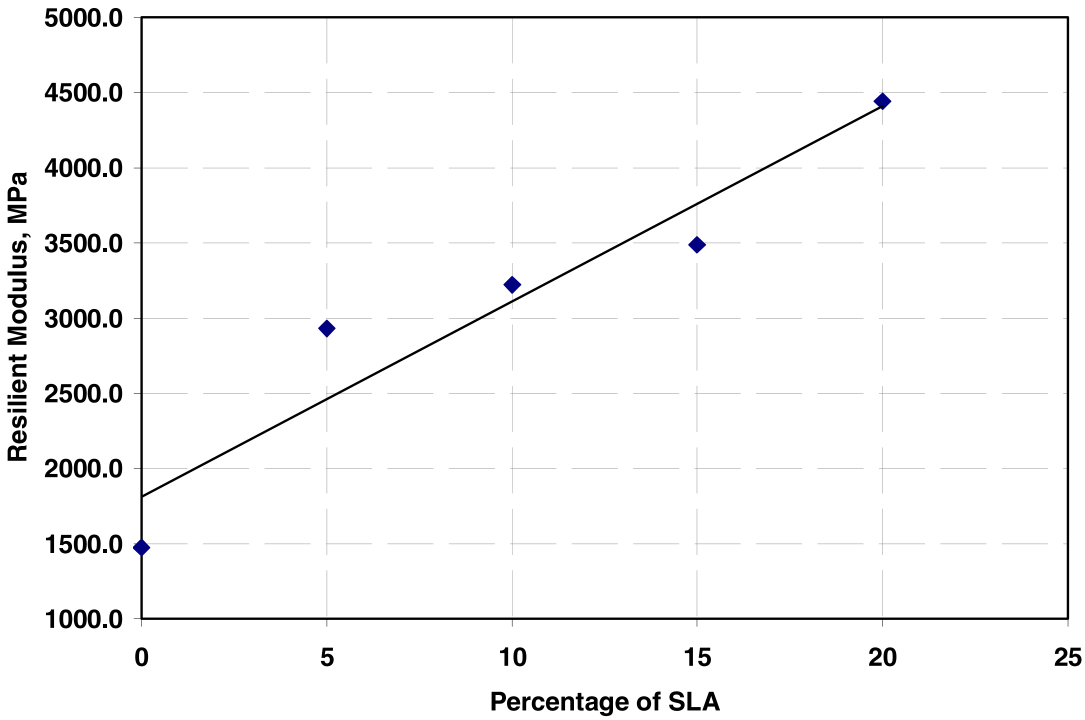

FIGURE 3 Plot of Resilient Modulus (Unconditioned Samples) Versus Percentage of SLA in Mix.

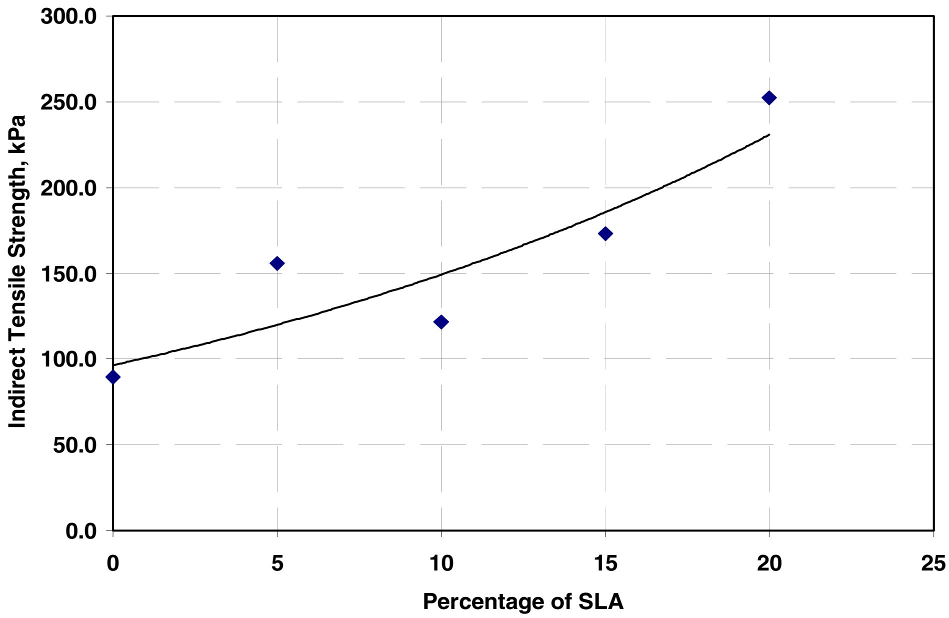

FIGURE 4 Plot of indirect tensile strength (of unconditioned samples) versus percentage of SLA in mix.

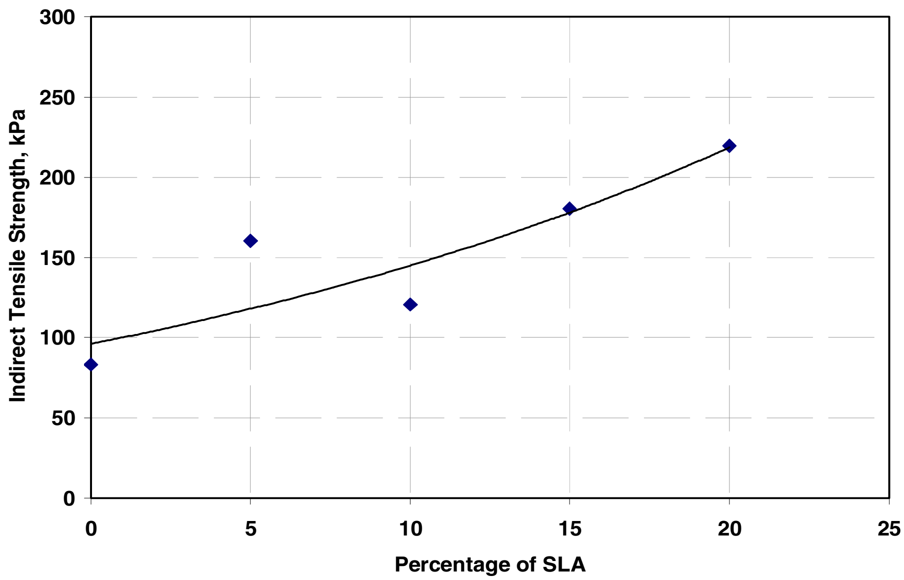

FIGURE 5 Plot of indirect tensile strength (for conditioned samples) versus percentage of SLA in mix.

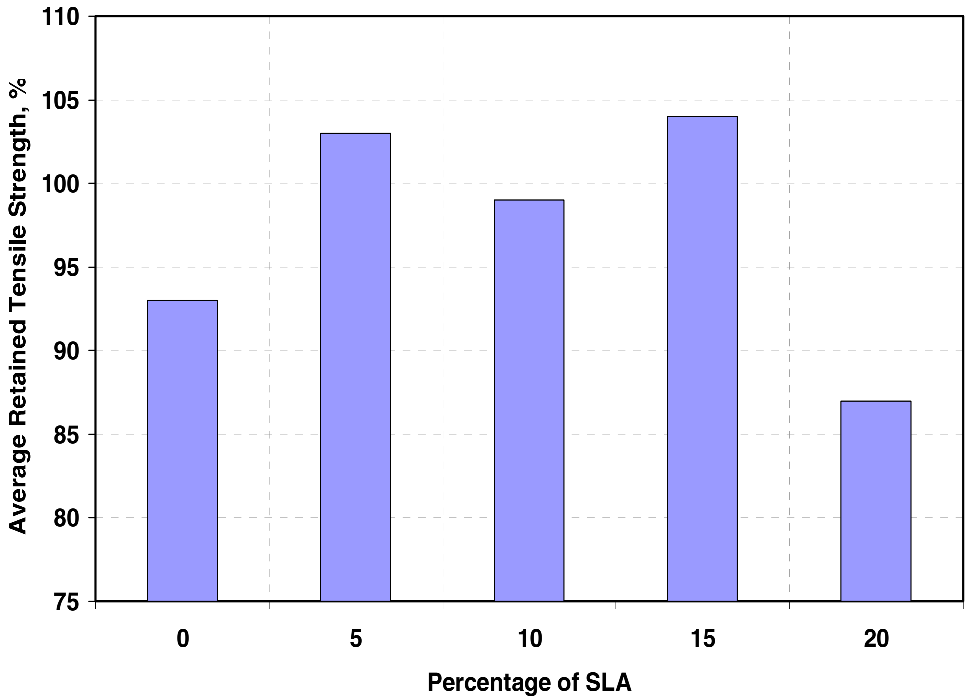

FIGURE 6 Plot of average retained strength versus percentage of SLA in mix.

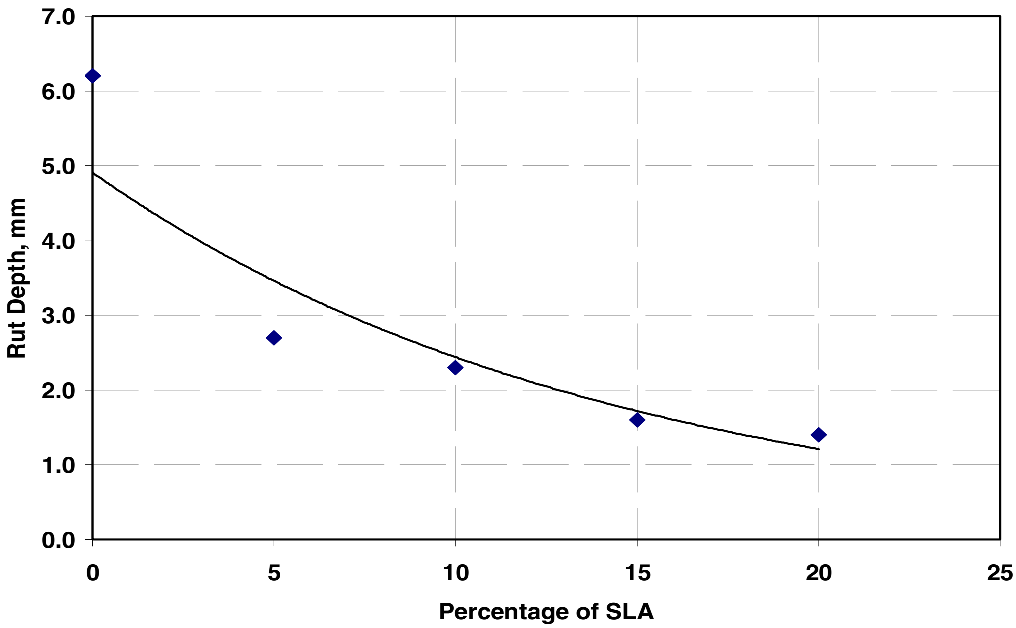

FIGURE 7 Plot of rut depth versus percentage of SLA.