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Utilization of Fly Ash in Asphaltic Concrete Mixtures

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Abstract □ Dwindling supplies and increasing costs of conventional highway materials used in road construction as well as concerns over shrinking landfill spaces prompt researchers to investigate the use of waste products, such as fly ash, as substitute materials in highway construction. The highway industry is capable of utilizing waste materials in large quantities if their effect on pavement performance proves to be technically, economically and environmentally satisfactory.

This research examines the effects of fly ash when used as partial replacement of aggregate in asphaltic concrete mixtures.

And measuring the effect of fly ash on bulk specific gravity, air void, indirect tensile strength (ITS) under dry and wet conditioning as well as the tensile strength ratio (TSR) of asphaltic concrete mixture.

The results indicated that asphaltic concrete mixtures containing 2% and 5% fly ash produced about the same TSR value as control mixture. And all of the mixtures met the minimum ITS and TSR requirements established by the South Carolina Department of Transportation (SC DOT) for Type 1A surface courses.

At this point and with this limited study, these asphaltic concrete mixtures is recommended in several applications such as parking lots, secondary roads and driveways.

Keywords □ waste materials, fly ash, bulk specific gravity, air void, indirect tensile strength (ITS), tensile strength ratio (TSR)

I. Introduction

The highway industry in the United States is one of the largest industries. The United States has built and maintains a system of approximately 3.2million kilometers of hard surfaced roads of which 93% are asphalt mixes. Each year approximately 350million tons of materials are used to maintain the system. Two major components of an asphalt mix are aggregates (i.e., rocks) and asphalt cement.

However, due to many reasons(e.g., geology), in some parts of the country(e.g., Charleston, South Carolina), a quality aggregate source cannot be found. The aggregate must be imported from other locations and this increases the cost of the asphalt mix.

One of the major worldwide problems in waste management today is the vast amount of waste material produced daily. Environmental concerns and a decreasing number of landfill sites are forcing nations to look for better ways to recycle waste materials.

Dumping away these by-products represents a waste of the material and causes environmental pollution problems. With proper quality control, large amounts of many industrial by-products can be incorporated into construction materials, this results in significant energy and cost savings.

Therefore, it is important, in such cases, for engineers and researchers to determine an alternative solution to the problem. The utilization of by-products or waste materials, if found to be effective, is one solution to this type of problem.

Fly ash, a by-product of coal-fired power generation, is of interest to scientists and engineers. Researchers have been investigating the use of fly ash in construction materials in order to better manage as well as to improve properties of construction materials.

One of the largest privately owned fabric producers in the United States is located in South Carolina. This company uses coal for generating energy for operating their plants. However, they produce several thousand tons of waste materials (i.e., ash) every year.

The cost of landfilling these materials has been increasing every year. Therefore the company decided to find alternative selections to this problem. The research group in Clemson University was contacted to initiate a research project to determine the feasibility of the use of these materials in asphaltic concrete pavements.

The main objective of this research was to evaluate the utilization of fly ash in asphaltic concrete mixtures. This evaluation involved test data from specimens containing virgin aggregate that were compared to the test results for those mixtures containing fly ash.

II. Materials and Testing Procedures

1. Materials

The asphalt cement was obtained form the Inman Fuel Oil Company in Inman, South Carolina. The Inman asphalt is a Canadian crude in origin. Results of tests performed on this asphalt supplied by the manufacture is displayed in Table 1.

Table 1. Physical properties of asphalt cement

Properties of asphalt cement	Inman PG 64-22	Spec.
Viscosity, @ 135°C	0.38	Max. 3.0
Flash point (°C)	316	
Specific gravity @ 60°F	1.033	
G^*/Sin delta (Kpa) Temp. 64°C unaged binder	1.32	Min. 1.0
G^*/Sin delta (Kpa) Temp. 64°C RTFO residue	2.68	Min. 2.2
$G^* \times$ Sin delta (Kpa) PAV Aged, Temp. 25°C	4,551	Max. 5,000
Creep stiff (Mpa) Temp. -12°C	223	Max. 300
M value, Temp. -12°C	0.319	Min. 0.300

The aggregate blend was designed to meet

Table 2. Chemical compositions of aggregate from Liberty (%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	SO_3	Sr	Zr	Loss on Ignition
65.35	16.35	3.64	2.53	1.40	3.79	5.34	0.50	0.10	0.10	0.18	0.03	0.03	0.66

superpave requirements for a 19.5mm asphaltic concrete mix. The aggregate was obtained from quarries in Liberty, South Carolina which are owned and operated by Vulcan Materials Co. The chemical composition and physical properties of the aggregate supplied by aggregate quarry is listed in Table 2 and 3.

Table 3. Physical properties of aggregate from Liberty

Specific gravity	Absorption (%)	Unit weight (kgf/m^3)	F.M	Abrasion ratio (%)
2.69	0.6	1,642	6.8	15.4

Sieve analysis was performed in accordance with ASTM C-136 to verify that the aggregate gradation conformed to the South Carolina Department of Transportation (SC DOT) gradation specifications for Type 1A surface course,

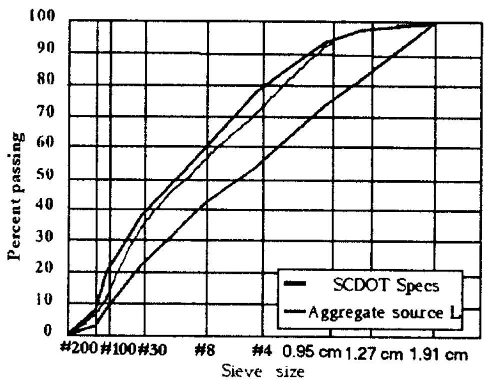

Fig. 1. SC DOT Type 1A surface course specifications and aggregate source Liverty gradations

and Fig. 1 illustrates the gradation curves of aggregate.

Fly ash used during this study obtained from power generating plants owned by the textile manufacturer, and the chemical compositions of the fly ash is listed in Table 4.

Table 4. Chemical compositions of fly ash

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	TiO_2	C
58.7	24.1	7.3	3.2	1.2	0.7	0.8	1.6	1.2	1.2

2. Testing Procedures

The virgin aggregate was placed in pans in an oven (340°F±20°F) for 24 hour. The aggregate was sieved and placed in appropriately marked containers according (6M, 789, dry and washed screens) and size fractions [19mm, 6.3mm, 4.76mm, 1.18mm and pan (3/4 in., 1/4 in., No. 4, No. 16 and pan)].

The asphalt cement was heated for 2 hour in an oven (280°F). The aggregate pans were placed in an oven (340°F±20°F) for 24 hour prior to mixing. The mixing pans were heated for approximately 30min. prior to use.

The hot aggregate was placed in a stainless steel bowl and hand stirred. The necessary hot asphalt cement was then mixed with the aggregate using a mechanical mixer for 1.5min. The mixture was then placed in Marshall molds (4in diameter) and compacted. The samples were cooled under fans for 2 hour and then removed from the molds using a mechanical hand jack.

Fly ash was used in asphalt mixes to determine their effects on the performance of the asphalt mixtures. Initially, several specimens with different percentages of fly ash were made and tested. This iinitial testing was necessary to determine the effect of these materials on the strength of asphalt specimens.

After initial testing was completed, the Marshall method of mix design described in the Asphalt Institute Series 2 and SC DOT specifications were used to determine the optimum asphalt cement of control mixtures as well as mixtures containing fly ash. All samples were compacted with 50 blows per side effort. This level of compaction is used for most roads and pavements in the state(excluding the interstate system). For this phase of the research program, five mix designs were conducted. A total 75 Marshall specimens (5 mix designs × 15 specimens per design) were made and tested. Each specimen is 4 inches in diameter and approximately 2.5 inches in height weighting approximately 1,200 grams.

The Marshell method of mix design is conducted by making and testing several samples with various asphalt contents (e.g., 4.5%, 5%, 5.5%, 6% and 6.5%), by total weight of the mixture.

Several properties of each sample were obtained or calculated during the mix design testing procedures. Some of these properties included : unit weight, percent air voids, percent voids in the mineral aggregate, stability and flow. The results of the mix design for all mixtures are shown in Table 5.

Table 5. Physical properties of control mixture

Property	4.5 % AC	5.0 % AC	5.5 % AC	6.0 % AC	6.5 % AC
Unit weight, pcf	139.7	139.6	142.1	141.9	143.9
Stability, lbs	1977	1819	2074	1704	2213
Flow 1/100 in.	11.8	11.5	13.3	12.3	12.5
% AV	10.1	9.5	7.2	6.6	4.6
% VMA	19.8	20.3	19.3	19.9	19.1
% VFA	49.3	53.5	62.9	66.8	76.0

* AV : Air void
VMA : Voids in the mineral aggregate
VFA : Voids filled with aggregate

The moisture susceptibility of all mixtures (control and mixtures containing fly ash) was studied using the testing procedures described in ASTM 4867. Marshall samples used for this phase of laboratory work were compacted at 20 blows per side compaction effort due to the requirements of the testing procedures, which include two major requirements. The first requirement is that the samples used for wet testing to be saturated at minimum 55% saturation level and up to maximum of 80%.

The testing program was divided into two phases : dry and wet testing. One half of the specimens were designs designated as dry and the other half as wet. The samples chosen for the dry testing were stored for 24 hours at room temperature.

The samples designated as wet were saturated using a vacuum (20″ Hg) until they reached the minimum saturation level (55%). However, if the samples were saturated to higher than 80%, they were discarded and another sample was made and tested. After achieving the required percent saturation, the sample was then placed in a water bath for 24 hours (140 ±1.8°F). After 24 hours of saturation, the sample was placed in another water bath (77± 1.8°F) for approximately 2 hours. Then the indirect tensile strength (ITS) of all mixtures (dry and wet samples) were measured.

After obtaining the ITS values, the tensile strength ratio (TSR) of each mixture was calculated. The TSR value is the ratio of wet ITS to dry ITS (i.e., % TSR=(wet ITS / dry ITS)×100).

All testing performed on asphalt mixtures were performed according to ASTM, TAI (The Asphalt Institute) and/or SC DOT testing procedures. A listing of these tests is shown in Appendix A.

Ⅲ. Test Results and Analysis

The results of testing is shown in Table 6.

Table 6. Test results of asphaltic concrete mixtures containing fly ash

Type	Bulk specific gravity	Air void (%)	Dry tensile strength (psi)	Wet tensile strength (psi)	Flow(×0.01in)	
					Dry	Wet
M0	2.232	5.40	164.34	152.53	9.74	10.44
M2	2.117	8.57	129.57	119.94	12.84	10.80
M5	2.082	9.66	127.30	117.34	10.70	10.60

※ M0, M2, M5 : 0%, 2%, 5% containing fly ash

The effects of the fly ash content on the bulk specific gravity and percent air void value, the control samples, in general, had the highest bulk specific gravity and the lowest percent air void value. The specimens containing 2% and 5% fly ash had a slightly lower bulk specific gravity than control specimens, but these differences were not significant at the 5~7% level, and most bulk specific gravities of the mixtures were within acceptable range.

Table 6 shows that the samples containing 2% and 5% fly ash had dry and wet ITS(Indirect tensile strength) that were lower than the control sample. It means that the ITS decreased with the increase of the content of fly ash. And the ITS values of samples of containing 2% and 5% fly ash were little difference.

The flow values of all samples were showed about the same regardless of containing or not containing fly ash and under dry and wet conditioning.

The tensile strength ratio (TSR) values of mixtures tested in this study were shown in Fig. 2.

Fig. 2 shows that the control sample produced higher TSR than that of samples containing fly ash, but there were no major differences between specimens containing fly ash and those not containing fly ash.

In most cases, the tensile strength ratio values of mixtures were greater than 85%

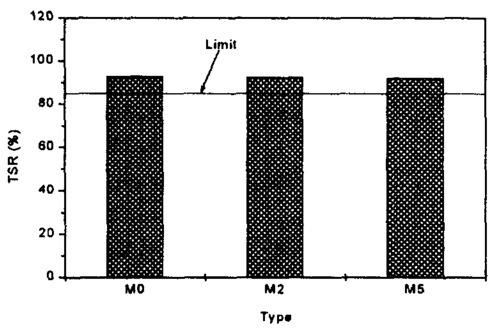

Fig. 2. Tensile strength ratio

that is the minimum required by the SCDOT.

From the limited experimental data obtained during this research it was determined that the use of fly ash as aggregate in asphaltic concrete mixture is technically feasible ; however, utilization of fly ash in asphalt specimens decreased 24 hour tensile strengths. One factor that might have influenced this trend is the low unit weight of samples containing fly ash as compared to control sample. Nevertheless, a number of asphalt mixtures containing 2% and 5% fly ash exhibited higher ITS and TSR values than the minimum required by the SCDOT for type 1A surface course. Additional experimental work is needed to establish the feasibility of using asphalt mixtures containing fly ash for high traffic volume highways.

IV. Conclusions

This study was performed to evaluate the utilization of fly ash in asphaltic concrete mixtures. The following conclusions are drawn ;

1. Bulk specific gravity of specimens containing 2% and 5% fly ash is lower than the control mixture, but these values are within reasonable range.

2. Percent air void value of specimens containing fly ash is higher than that of the control sample above of about 60% and 80% each of 2% and 5% containing fly ash.

3. The dry and wet ITS of the samples containing 2% and 5% fly ash are lower than the control samples. And these values met the minimum ITSwet(65psi) requirement for type 1A surface course.

4. The samples of containing 2% and 5% fly ash produced lower TSR than that of the control sample, but these values are satisfied the minimum required by SC DOT.

5. The asphaltic concrete mixtures containing fly ash are recommended for use in several applications such as secondary roads, with low traffic volumes, parking lots and driveways.

Appendix A

ASTM Standards for Asphalt Concrete Mixtures

D	1073	Specifications for Fine Aggregate for Bituminous Mixtures
D	1075	Effect of Water on Cohesion of Compacted Bituminous Mixtures
D	1559	Test Methods for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
D	2041	Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
D	2726	Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
D	3549	Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
D	4469	Test Method for Calculating Percent Asphalt Absorption by the Aggregate in an Asphalt Pavement Mixture

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