Applicability of Use of Fly Ash in Hot Mix Asphalt Concrete

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Abstract - *Rapid development generates waste and open dumping of waste with related environmental effects has become one of the major problems in Sri Lanka. Fly ash is an industrial waste at the Norochcholai coal power plant. With more power generation by coal, the production of fly ash will increase. Therefore identifying alternative uses of fly ash is very important. Quarry dust which is a byproduct in rock quarries is generally used as the mineral filler in hot mixed asphalt concrete. It is a necessity to safeguard our natural resources by minimizing the excavation of rock formations, sand deposits etc. Therefore, this study investigates the feasibility of using fly ash as a partial substitute to mineral filler in hot mixed asphalt concrete to reduce the consumption of natural resources and minimize environmental hazards that occur through disposal of fly ash.*

Major percentages of pavements in Sri Lanka constructed are asphalt pavements which consist of coarse aggregate, fine aggregate, mineral filler and a bituminous binder. The coarse aggregate is crushed stone with particle size ranging from 2.36mm to 19mm and the fine aggregate is sand or quarry dust, which the size ranges between 0.15mm and 2.36mm. The mineral filler normally used is quarry dust, 85 percent of which passes the 0.075mm sieve. The aggregate mixture is bound together with bitumen. To replace quarry dust with fly ash firstly, the physical properties were examined, to check samples for conformity. Secondly, the Marshall Test method, which is a widely used test recommended by Asphalt institute and presently used by Road Development Authority of Sri Lanka, is adopted for optimizing the proportioning of the asphaltic concrete mix components and the Marshall properties of the samples are checked for conformity. Marshall Test method on three sets of tests were conducted by replacing mineral filler with fly ash in the percentages of 100%, 58% 42% (12%, 7% and 5% respectively from the total weight of aggregates). Results were checked for conformity with specifications of the Institution for Construction Training & Development (ICTAD). ICTAD specifications were fulfilled only for the replacement of 42% of mineral filler with fly ash (5% from total weight of aggregates).

It can be concluded from the results of this investigation that fly ash could be utilized as a partial substitute to mineral filler in hot mixed asphalt concrete. The results of this study will help reduce the consumption of depleting resources such as rock and minimize environmental hazards that occur through disposal of fly ash.

Keywords: *fly ash, mineral filler, hot mix, asphalt concrete*

1 INTRODUCTION

For the construction of roads two main methods are available. They are concrete paving and asphalt paving. In Sri Lanka the most popular method for all types of roads is asphalt paving method, due to its durability and good finish. Because of the popularity of asphalt paving in Sri Lanka, asphalt has become one of the most important materials for road construction. Aggregates used for asphalt mixtures could be crushed rock, sand and gravel. Aggregates that are used for asphalt paving are mostly extracted from natural resources existing in the country. All these materials are considered as depletion resources. To generate these materials it requires thousands of years.

With the rapid development of the country the generation of waste is also rapidly increased. Under this another new industrial solid waste which is available in Sri Lanka is Fly ash, due to the Norochcholai coal power plant in Puttalam. Approximately about 70000 tons (Source: www.environmentlanka.com/blog/2010) of fly ash generates annually. The people have to face another major problem with disposal of industrial solid wastes. It is therefore pertinent to investigate methods of making use of the solid waste in a profitable manner and mitigate adverse impacts on the environment due to pollution caused by the disposal of fly ash.

Hence it is good to consider how this fly ash can be made use of in the road and highway industry. The study seeks to evaluate the suitability of utilization of fly ash in Hot Mix asphalt and assess the optimum amount of fly ash that can be replaced with quarry dust while retaining the properties of the final product so that the results of this study will help to reduce the consumption of depleting natural resources (rocks) and minimize environmental hazards that occur through disposal of fly ash.

2 GENERAL

Nearly all main highways and road pavements in Sri Lanka are constructed using asphalt mixes which consist of coarse aggregate, fine aggregate, mineral filler and a bituminous binder. The coarse aggregate is crushed stone with particle size ranging from 2.36mm to 19mm and the fine aggregate is sand or quarry dust, in which the size ranges between 0.15mm and 2.36mm. The mineral filler normally used is quarry dust, 85 percent of which passes the 0.075mm sieve.

Asphalt paving has become a popular alternative to concrete due to its durability and flexibility. It can withstand abuse from the weather and punishment from heavy objects. Among the reasons for the popularity of asphalt paving includes elasticity, durability, absorption, decorativeness and affordability. Since it has cooked liquid, it can expand and contract with the weather, making it less prone to frost heaves. Also, it is less likely to crack or lift. Due to its resilience it can withstand heavy weights, such as vehicle traffic. Its dark surface can absorb additional heat in dry weather seasons. Normally asphalt paving has a good finish. It can be stamped like concrete to imitate brick, pavers or cobblestones in any colour and it can form different designs or mosaics. The price of asphalt is less compared to concrete, and it's quicker to install, reducing labour costs.

An average asphalt pavement consists of the road structure above the formation level which includes unbound and bituminous bound materials. This gives the pavement, the ability to distribute the loads of the traffic before it arrives at the formation level. Normally, pavements are made of different layers. The Fig.1 below depicts the typical layers of a pavement. It is the topmost asphalt layer which is being considered for this research by replacing quarry dust with fly ash.

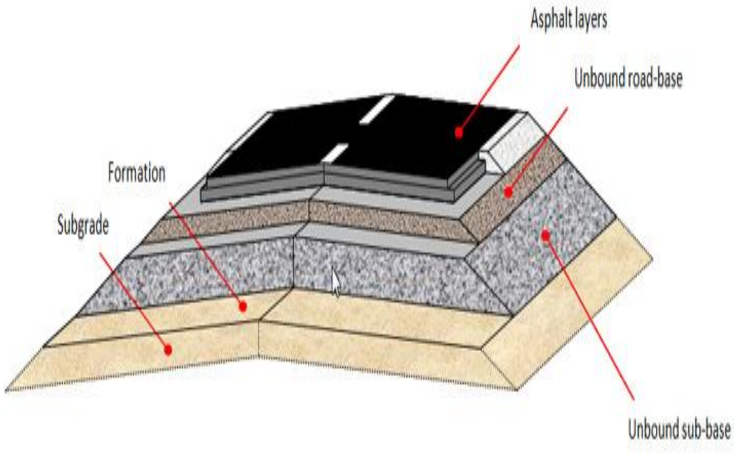

Fig. 1 Different layers of a pavement

To replace quarry dust with fly ash firstly, the physical properties are examined to check samples for conformity. Secondly, the Marshall Test method recommended by the Asphalt Institute of America and presently used by Road Development Authority of Sri Lanka, is adopted for optimizing the proportioning of the asphaltic concrete mix components. The Marshall parameters of the samples are checked for conformity. The parameters evaluated were the compacted density mix (CDM), the percentage of air voids in the mix (VIM), the percentage of voids in the mineral aggregates (VMA), the percentage of voids filled with bitumen (VFB), Marshall Stability and flow. Samples were tested at standard temperature in order to assess the acceptability of the mixes for use in Sri Lanka. The results were compared with standards as per the specifications published by the Institute of Construction Training and Development as shown in Table 1.

Table 1 Marshall Parameters as per ICTAD specifications

Marshall parameter	ICTAD Specification limit
Marshall Stability in kN	Not less than 8
Marshall Flow in (0.25 mm)	8 to 16
Air voids in Mix (%)	3 to 7
Voids in Mineral Aggregates (%)	Not less than 13
Voids Filled with bitumen (%)	70 to 85

3 METHODOLOGY

Following tests were carried out concerning the properties of fly ash to identify how the fly ash could be used in hot mix asphalt concrete.

Sieve analysis was carried out according to Standard Specifications for Hot Mixed and Hot Laid Bituminous Paving mixtures(ASTM D 3515), on a representative sample of the fly ash.

For the determination of specific gravity of fly ash and quarry dust ASTM D 854 was used.

Fineness of fly ash and quarry dust were compared using ASTM C 204. Blaine air permeability test was performed for specific surface test. For Blaine air permeability test a bed of Fly ash and quarry dust was prepared in special permeability cell which have an exact porosity of e = 0.500. The weight of the relevant material (m) is calculated from the following equation,

$$m \;=\; 0.500 \;\rho\, V$$

Where

P - is the density of the material (g. cm^{-3})

V - volume of the cement bed (cm^3)

Specific surface s is expressed as

$$s = \left(\frac{K}{\rho}\right)\left(\frac{\sqrt{e^2}}{1-e}\right)\frac{\sqrt{t}}{\sqrt{0.1\eta}}$$

Where

K - the apparatus constant
e - porosity of bed
t - the measured time (s)
ρ- Density of cement (gcm^{-3})
η - the viscosity of air at the test temperature (Pas)

The results of above tests are given in Tables 2, 3 and 4.

Table 2 Sieve analysis test results for fly ash

Sieve size	Weight retained / (g)	Total weight retained / (g)	% retained	% Passing
2.36 mm	0.64	0.64	0.062	99.938
1.18 mm	4.13	4.77	0.461	99.539
600 μm	10.84	15.61	1.508	98.492
300 μm	25.48	41.09	3.970	96.030
150 μm	414.57	455.66	44.027	55.973
75 μm	363.80	819.46	79.179	20.821
Pan	204.66	1024.12	98.954	1.046

Table 3 Specific gravity of fly ash and quarry dust

Sample No.	Specific gravity	
	Fly ash	Quarry dust
01	2.068	2.429
02	2.044	2.330
03	2.077	2.500
Average	2.063	2.420

Table 4 Specific surface (fineness) of fly ash and quarry dust

Trial	Specific surface	
	Fly ash x K	Quarry dust x K
01	0.463	0.404
02	0.426	0.416
03	0.474	0.442
Average	0.454	0.421

The mineral filler in asphalt concrete consists of 12% from the total weight of aggregates. Marshall tests were conducted on three trial mixes, by replacing mineral filler with fly ash in the percentages of 100%, 58% 42% (12%, 7% and 5% respectively from the total weight of aggregates). Due to time constraints and each replacement needs 36 tests, only these three replacements were considered. The mineral filler was added to 57.5% and 30.5% of coarse and fine aggregates, respectively (Asphalt Institute, 1997). These aggregate proportions are typical of wearing course mixes normally used for main roads in Sri Lanka. Standard Marshall Specimens (63.5 mm height and 101.6 mm diameter) were prepared in the following manner. Weight of bitumen was varied from 3.5% to 6% in steps of 0.5%, resulting in six percentages by weight of bitumen content, and three samples were prepared for each bitumen percentage. The grading and proportions were kept constant for all the mixes by sieving the aggregates to individual sizes and then recombining them in a continuous grading required by the local standards.

The same quantity of materials was used for each sample in an effort to obtain approximately the same height of the specimens. The mix was first partially compacted using a heated standard rod, fifteen times around the perimeter and five times in the center. The whole mould was then fixed in the Marshall Compaction machine which consists of a 4.5 kg hammer falling from a distance of 457 mm. Both sides of the samples were compacted 75 times. The compacted samples were allowed to cure overnight at room temperature. The density of the samples was then determined by obtaining the submerged weight in water and weighing the samples in air.

Samples were then tested at standard temperature (60^{0}C) in the Marshall machine and the deformation stability (in kN) and the flow of the samples (in mm) were recorded. The Marshall parameters of the samples were also checked for conformity.

The same procedure was repeated for all samples.

4 TEST RESULTS OF MARSHALL TEST

4.1 Replacing 100% of mineral filler with fly ash

The average Marshall Stability and flow values for replacing 100% of mineral filler by fly ash are given in Table 5.

Table 5 Average Marshall Stability and flow values for replacing 100% of mineral filler by fly ash

% of bitumen by weight	Marshall stability (kN)	Flow (mm)
3.5	5.37	5.07
4	7.15	6.15
4.5	7.03	5.88
5	9.02	5.57
5.5	10.39	6.36
6	8.29	6.18

4.2 Replacing 58% of mineral filler with fly ash

The average Marshall Stability and flow values are given in Table 6 for replacing 100% of mineral filler by fly ash.

Table 6 Average Marshall Stability and flow values for replacing 58% of mineral filler by fly ash

% of bitumen by weight	Marshall Stability (kN)	Marshall flow (mm)
3.5	2.02	6.37
4	5.43	5.81
4.5	6.21	6.34
5	8.08	8.79
5.5	1.05	12.02
6	-	7.957

4.3 Replacing 42% of mineral filler with fly ash

Table 7 indicates the average Marshall Stability and flow values for replacing 42% of mineral filler by fly ash.

Table 7 Average Marshall Stability and flow values for replacing 42% of mineral filler by fly ash

% of bitumen by weight	Marshall Stability (kN)	Marshall flow (mm)
3.5	7.509	4.531
4	8.328	4.876
4.5	9.143	4.230
5	7.968	4.209
5.5	8.594	3.627
6	10.230	5.007

According to the test results of Table 5 and 6 it can be seen that the two most important parameters namely Marshal stability and Marshal flow do not conform with the ICTAD specifications. However, the results of Table 7 indicate that both the Marshal Stability and flow values are in agreement with the ICTAD specifications for the bitumen content of 5.5%. Therefore, the rest of the Marshall parameters for the 42% of replacement of the mineral filler with the fly ash were determined for conformity and the results are given in Table 8. Fig. 2 indicates the acceptability of the specimen by replacing 42% of mineral filler with fly ash.

Table 8 Average Marshall Test results for replacing 42% of mineral filler by fly ash

% of bitumen by weight	Average CDM (g/cc)	Average VIM (%)	Average VMA (%)	Average VFB (%)
3.5	2.290	5.340	13.198	61.9
4	2.245	6.546	15.350	58.2
4.5	2.340	1.904	12.227	84.8
5	2.301	2.862	14.142	81.3
5.5	2.248	4.439	16.561	73.4
6	2.272	2.752	16.116	83.0

Fig. 2 represents the acceptability of the specimen by replacing 42% of mineral filler with fly ash

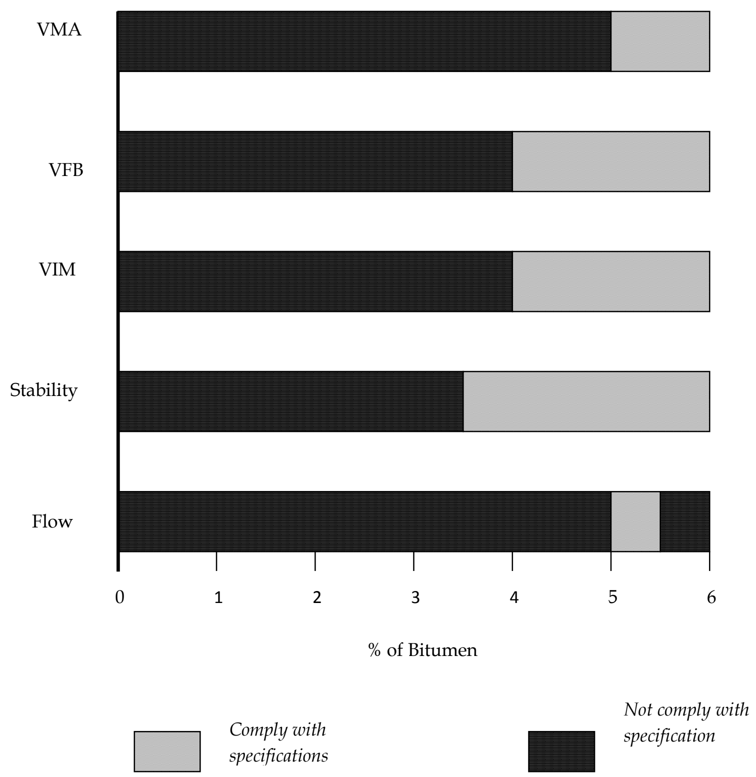

Fig. 2 Acceptability of the specimen by replacing 42% of mineral filler with fly ash

Finally the test results were compared with the ICTAD specifications and the final comparison is given in Table 9.

Table 9 Marshall Properties of asphaltic mix at bitumen content of 5.5% compared with ICTAD specifications

Marshall parameter	Value at 5.5% bitumen content	ICTAD Specification limit
Marshall Stability in kN	8.6	Not less than 8
Marshall Flow in (0.25 mm)	14.51	8 to 16
Air voids in Mix (%)	4.44	3 to 7
Voids in Mineral Aggregates (%)	16.56	Not less than 13
Voids Filled with bitumen (%)	73.4	70 to 85

5 CONCLUSIONS

From the results, the following can be concluded:

- According to the sieve analysis test results, it is proved that the fly ash from Norochcholai coal power plant meets the ASTM requirements for mineral filler.

- Fly ash from Norochcholai coal power plant has a specific gravity of 2.063, closer to that of quarry dust which has the specific gravity of 2.420. So it is considered that it could be used as the mineral filler in Hot Mix Asphalt, because most conventional mineral fillers have a specific gravity in the 2.6 to 2.8 range.

- Fineness of the fly ash when compared with the quarry dust was found to have a slightly higher value. Theoretically higher fineness may indicate more effective mineral filler, although the higher fineness also means a greater surface area of particles that must be coated, resulting in an increase in asphalt content of the mix.

- Results conforming to specifications were obtained only for replacement of 5% of mineral filler from the total weight of aggregates with fly ash (42% of mineral filler)

- The stability value of replacing 5% of mineral filler from total weight of aggregates with fly ash was well above the minimum (8 kN) criteria in ICTAD specification.

- For this replacement of 5% of mineral filler from total weight of aggregates with fly ash, the optimum bitumen content by weight of the aggregates was 5.5% which satisfied the ICTAD specifications.

Hence it can be concluded that, fly ash can be utilized as a partial replacement for the mineral filler in hot mix asphalt concrete wearing courses used in Sri Lanka.

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