Civil Engineering Dimension, Vol. 15, No. 1, March 2013, 36-42
ISSN 1410-9530 print / ISSN 1979-570X online

CED 2013, 15(1), DOI: 10.9744/CED.15.1.36-42

Experimental Investigations of Effect of Sulphur on Beach Sand–Fly Ash–Asphalt (S-F-A) Paving Mixes

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Abstract: The main components of the flexible pavements are asphalt and aggregates. But in most of the places in India there is shortage of the good quality aggregates (especially coarse aggregates), at the same time beach sand is available in plenty in many regions. Due to relative abundance of beach sand, the studies on the utilities of the beach sand in paving mixes are worth taking up. But beach Sand-Asphalt mix alone is not suitable for pavement construction, because of its low stability and high air voids. In the present study, Sand-Fly ash-Asphalt-Sulphur (S-F-A-S) mixes are being made in different proportions and tested for their properties. Fatigue strength, stability, water sensitivity, stiffness modulus and dynamic modulus tests are carried out at standard test conditions and the results are analyzed for drawing conclusions. This study investigates the potential use of abundant ingredients, which may replace the ones which are scarce in nature.

Keywords: Fly ash, sulphur gyratory compactor, indirect stiffness modulus, dynamic modulus, fatigue.

Introduction

Asphalt pavement is a crucial part of India's strategy for building a high performance transportation network for the future. Asphalt construction is fast and relatively simple; it is economical, and the materials to make it are widely available [1]. In flexible pavement, asphalt is an expensive constituent and aggregates are costly and scarce. Kerala is a state in the southern part of India having a vast coastal area with abundance of the fine beach sand. This can be used as an alternative to the stone aggregates in order to cater lack of good quality aggregate [2]. Fly ash is another by-product of thermal power stations which are also pettily available. Fly ash, when added as filler, seems to improve performance of mix in multiple ways to create high performance asphalt pavements [3]. Over the last several years, evidence has begun to compound that fly ash as modifier improves the rheology of the mastic and produces multifunctional and synergistic benefits in the mixture [3,4]. Works in the United States and Europe have proven that this modifier can substantially improve the resistance of the Hot Mix Asphalt (HMA) to permanent deformation (creep) damage at high temperatures [5].

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Note: Discussion is expected before June, 1st 2013, and will be published in the "Civil Engineering Dimension" volume 15, number 2, September 2013.

Received 10 July 2011; revised 12 July 2012; accepted 27 August 2012

It also substantially improves low temperature fracture toughness without reducing the ability of the mastic to dissipate energy through relaxation [6]. Extensive researches were done by various researchers throughout the world regarding the addition of fly ash to bituminous mixes [3,4,7,8]. Buttlar et al. [6] used micromechanics to assess the mechanical properties of mineral fillers such as hydrated lime and fly ash, combined with asphalt to form mastics. They concluded that a rigid layer adsorbed to the filler explains the ability of the filler to result in stiffening ratios that are greater than would be predicted based on volumetric concentrations alone. Based on the equivalent rigid layer analysis, physicochemical reinforcement effects play a dominant role throughout the range of filler-to-asphalt ratios encountered in practice. Fly ash, hydrated lime and lime slurry added to reclaimed asphalt has been shown to improve the ageing kinetics and general rheological properties of reclaimed and recycled asphalt [9]. Furthermore, the addition of lime slurry and fly ash in the cold milling and cold in-place recycling process has proved to be very beneficial [10].

Investigators have found out that the properties of Sand-Asphalt mixes can be improved significantly using sulphur and have also indicated various tests of fly ash on Sand-Asphalt-Sulphur mixes and given encouraging result. Possibility of incorporation of beach sand and fly ash with sulphur in bituminous blends is the aim of this research work. S-F-A-S mix can be used as an overlay mix to any concrete mix which may act as a base course [7].

To objectives of the study are; to study the fatigue characteristics of the S-F-A-S mix, to study and to compare the indirect stiffness characteristics and the dynamic modulus of the mixes with varying proportions of Asphalt and Sulphur, and to find out the extent of Sulphur which can replace the asphalt content in the above mix.

The study is limited to stress strain characteristics of S-F-A-S mix. The fatigue, stiffness modulus and dynamic modulus tests were carried out using Nottingham Asphalt Tester (NAT) with a temperature level of 30 ± 1^{o} C. The dynamic modulus tests were conducted at a stress level of 0.2 MPa.

Experimental Investigation

Materials

Beach sand used for the study was collected from Shankumugham beach in Trivandrum district of Kerala state in India. This sand was very fine, its gradation is shown in Figure 1. The physical properties of the materials used for the present investigations are shown in Table 1.

Table 1. Physical Properties of the Materials Used

Material	Physical Properties	
Sand (Sankumugham Beach) Trivandrum, Kerala.	Specific Gravity	2.63
Asphalt (Cochin Refineries Kerala)	Grade	60-70
	Specific Gravity	1.01
	Softening Point (R&B)	42^{0}C
	Ductility	96 cm
Sulphur	Specific Gravity (Local Market)	1.96
Fly Ash (Hindustan News Print, Kottayam, Kerala)	Specific gravity	2.05
	Plasticity	Non Plastic

Figure 1. Grain Size Distribution of Shankumugham Beach Sand

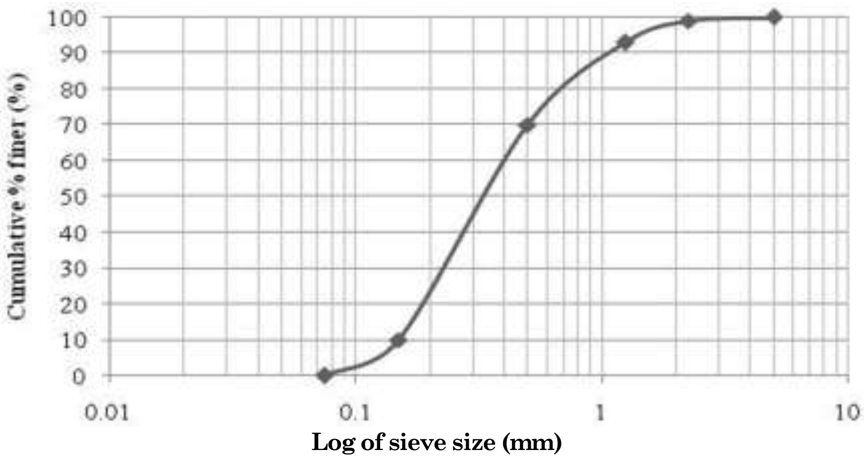

Figure 2. Gain Size Distribution of Fly Ash

The asphalt was tested to find out the basic properties such as viscosity, specific gravity, softening point etc. Sieve analysis was conducted on beach sand for finding out the gradation. The sand was found to be uniformly graded, having a gradation in the range of the 300-600 μ. The filler material used for the preparation of specimen was fly ash. Grain size distribution of fly ash used for the study is shown in Figure 2.

Details of Proportioning of Mixes

For studying the effect of varying proportion of constituent, 1200 gm of mixes with various percenttages, by mass, of ingredients were considered. In all these mixes, asphalt was decreased from 7 to 3% with a decrement of 1%, by mass, of total mix, while sulphur was increased from 9 to 13% with an increment of 1%, by mass, of total mix, and the rest was aggregate (i.e. beach sand and fly ash). Different trial mixes were prepared and tested for determining the proportion of beach sand, and fly ash. From this trial mixes, it was observed that equal proportion of fly ash and beach sand, i.e. 42 g each, and the remaining with sulphur and asphalt, produces a dense, homogenous mix in the case of S-F-A-S mixes. For mix preparation, beach sand and fly ash were heated to 150° C, required quantity of asphalt and sulphur heated separately to 140° C and mixed thoroughly with the heated sand-fly ash mix by keeping mixing temperature as 160±2° C. The sample was allowed to cool at room temperature and Marshall stability test was carried out according to procedure for asphalt mixes as specified in ASTM D: 1559 [4]. Obtained result is shown in Table 2.

From Table 2, it was observed that, the 42-42-4-12 (42% beach sand, 42% fly ash, 4% asphalt, 12% sulphur) mix is the superior mix since it shows maximum Marshall properties. The air voids obtained was much more than the standard value which is due to the gradation of aggregates and additives used in the mix preparation. The fine content of the total mix is more in sand asphalt mix compared to the other mixes.

Preparation of Sample using Superpave Gyratory Compactor

Five sets of mix combinations, each set having three cylindrical specimens of diameter 100 mm, were prepared for fatigue and stiffness modulus tests. The different combinations of constituents for the preparation of the mixes are as shown in Table 2. The specimens were compacted by using gyratory compactor and the gyrations are applied at the rate of 30 gyrations per minute with a consolidation pressure of 600 kPa. After 80 gyrations the mould is taken out from the machine and the sample is extracted. The sample is allowed to cool at room temperature and the stiffness and fatigue tests are done after 24 hours, by using Nottingham Asphalt Tester (NAT), CRT-NU14.

Indirect Tensile Stiffness Modulus Test

The indirect tensile stiffness modulus test was done using the NAT by applying a horizontal stress of 200 kPa. The Linear Variable Differential Transducers (LVDT) measures the deformations of the specimen. A total of five pulses were applied and the stiffness modulus was directly obtained from the equipment. The setup of indirect tensile stiffness modulus test is shown in the Figure 2.

Figure 2. Configuration of Indirect Tensile Stiffness Modulus (ITSM) Test

Indirect Tensile Fatigue Test Results

For determining the fatigue life, indirect tensile fatigue test was carried out. Five combinations of mixes as per the blend shown in Table 2 were used for the fatigue study. Horizontal stress was varied from 100 to 400 kPa initially and 200 kPa was then selected for the experiments so as to get a reasonnable number of load cycles to failure. Stiffness

Table 2. Marshall Properties of S-F-A-S Mixes

Beach Sand (% by mass)	Fly Ash (%)	Asphalt (%)	Sulphur (%)	Stability (KN)	Air voids (%)	Flow Value (mm)	Unit wt (kN/m^3)
42	42	3	13	7.5	10.5	3.80	15.50
42	42	4	12	14.2	16.2	2.90	15.46
42	42	5	11	12.1	15.8	3.12	15.50
42	42	6	10	11.5	14.6	3.40	15.63
42	42	7	9	10.2	11.6	3.90	15.62

modulus of each test specimen was determined at the target stress level to which fatigue test was to be conducted.

Dynamic Modulus Test

The dynamic modulus tests were conducted in accordance with AASHTO Designation: TP 62-03 [11], at different frequencies and number of cycles using NAT. The frequency and number of cycles applied are shown in Table 3. The tests were carried out in room temperature i.e. 30±1° C, by applying axial stress amplitude of 200 kPa.

Water Sensitivity Study

The samples, which were found to be satisfying the Marshall criteria was further selected for the accelerated curing, in order to find out its water sensitivity. This was done by conducting the Marshall tests on the samples, which were immersed in water at 60°C for a period of 24 hours. The test was done according to ASTM D1075 standards [12]

Results and Discussion

As seen in Table 2, when there is no sulphur in the mix, the asphalt containing sand particles have very little inter locking between them, resulting in low stability. When sulphur is added to the mix, the solidified sulphur in the voids interlocks the asphalt coated particles together, thereby increasing stability.

Table 3. Number of Cycles for the Test Sequence

Frequency (Hz)	Number of Cycles
25	200
10	100
5	50
1	20
0.5	6
0.1	1

In a bituminous mix, a high air void content is considered objectionable, because in such cases the bituminous mix becomes highly permeable and hence more susceptible to weathering action, thereby reducing its durability. The air voids content specified for a base course by Asphalt Institute is 3%-8%. The equivalent air voids content for this range of Sulphur-Asphalt mixes, comes to about 10%-30%. The air voids of all the mixes tested fall within this range.

The low flow values in general reflect that the mixes are stiffer than conventional asphalt concrete mixes. Beach Sand–Fly ash–Asphalt–Sulphur mix (S-F-A-S) shows good Marshall properties, the presence of calcium in the fly ash increases the bond between the aggregate and asphalt, but the polar bonds are not so strong as that of the bond formed during hydrated lime addition.

Indirect Stiffness Modulus Test

The indirect stiffness modulus values were directly obtained from the test and are tabulated in Table 4 and graphically depicted in Figure 3.

The indirect tensile stiffness value was maximum for the blend with 4% asphalt and 12% sulphur. Further addition or reduction of asphalt and sulphur in the mix reduces the stiffness modulus significantly.

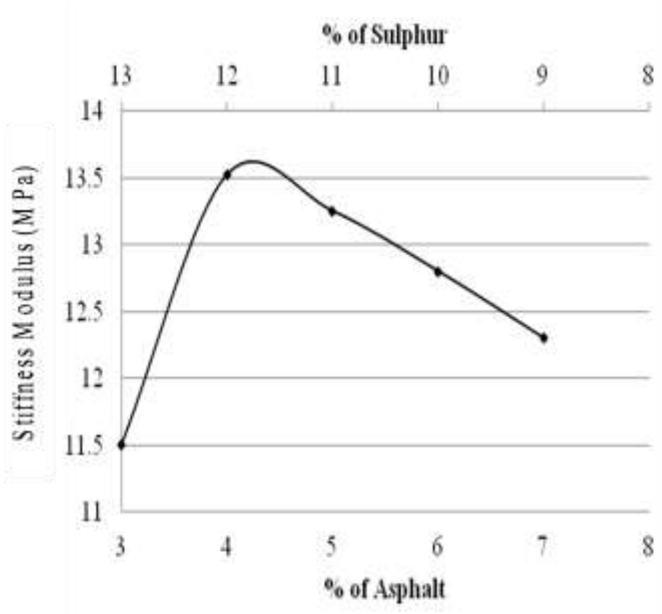

Figure 3. Graphical Representation of Stiffness Modulus Test Results

Table 4. Indirect Stiffness Modulus Result

Details of mix	Horizontal Stress (KPa)	Stiffness Modulus (MPa)
42-42-3-13	200	11.50
42-42-4-12	200	13.52
42-42-5-11	200	13.25
42-42-6-10	200	12.80
42-42-7-9	200	12.30

Dynamic Modulus Test

The dynamic modulus tests were conducted at frequencies of 25, 10, 5, 1, 0.5, and 0.1 Hz and at a stress level of 0.25 MPa. The application of first frequency phase is considered as the preconditioning phase, the average dynamic modulus corresponding to 10 Hz is considered as the dynamic modulus. The results obtained from the dynamic modulus test were shown in Figure 4 and tabulated in Table 5.

From the figure, it is clear that the dynamic modulus was highest for 4% asphalt and 12% Sulphur blended mix. Further reduction and addition of asphalt and sulphur reduces the dynamic modulus.

Table 5. Indirect Fatigue Test Results

Details of the mix	Dynamic Modulus (MPa)
42-42-3-13	1873
42-42-4-12	2008
42-42-5-11	1992
42-42-6-10	1900
42-42-7-9	1895

Indirect Tensile Fatigue Test

The load repetition to failure for varying percentages of asphalt and sulphur content is depicted in the Table 6. The graphical representation of indirect fatigue test results is shown in Figure 5.

It was observed that 4% asphalt and 12% sulphur was the optimum content of sulphur in the blend, for good fatigue life of S-F-A-S mix.

Water Sensitivity Test Results

The water sensitivity test results are as depicted in Table 7 and the same is graphically represented in figure 6. The water sensitivity studies proved that all the selected samples were found to be having a stability value ratio of more than 0.78, which is greater than as specified in MoRTH (Ministry of Road Transport and Highways), as 0.75 [7]. The sample with 4% asphalt and 12% sulphur content had a maximum value of 0.9 and was least sensitive, which again proves the superior quality of this mix over the others. By suitably proportioning the various constituent the fly ash can be put to maximum use thus can control pollution and disposal problem to a certain limit [13].

Table 6. Indirect Fatigue Test Results

Details of the mix	Number of Load Repetitions
42-42-3-13	281
42-42-4-12	492
42-42-5-11	428
42-42-6-10	398
42-42-7-9	385

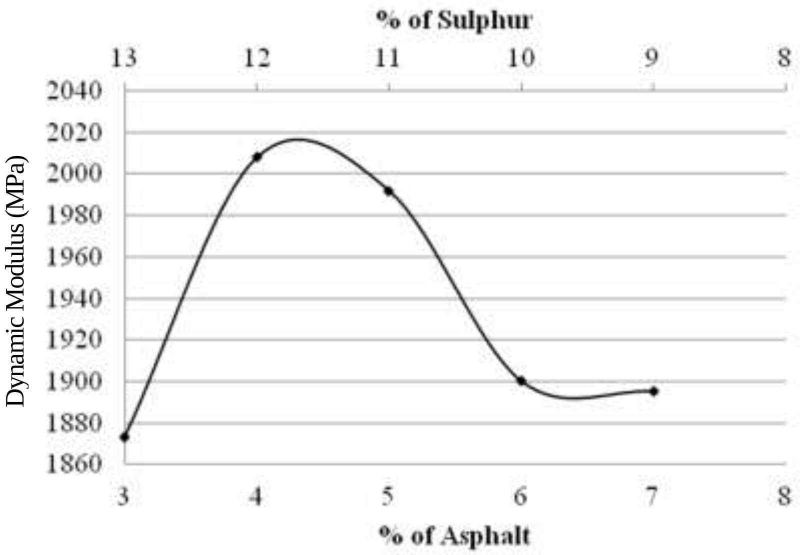

Figure 4. Graphical Representation of Dynamic Modulus Test Results

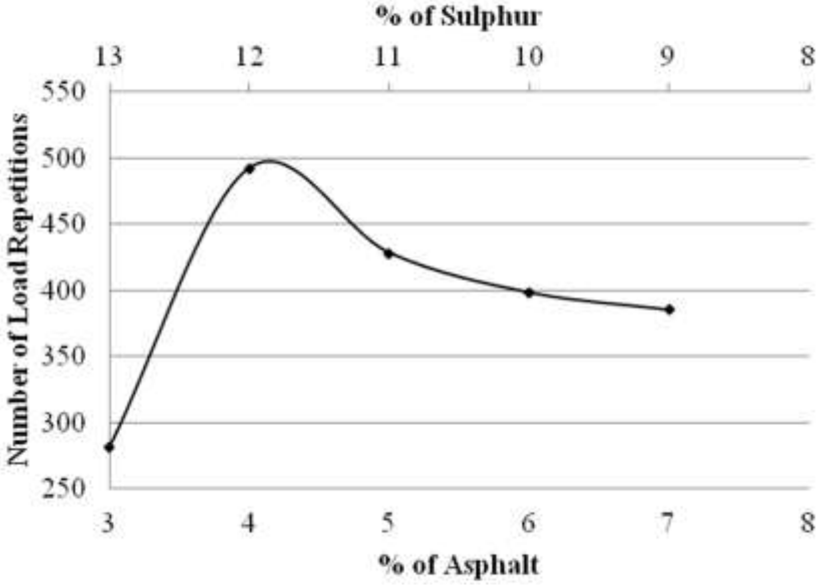

Figure 5. Graphical Representation of Indirect Fatigue Test Results

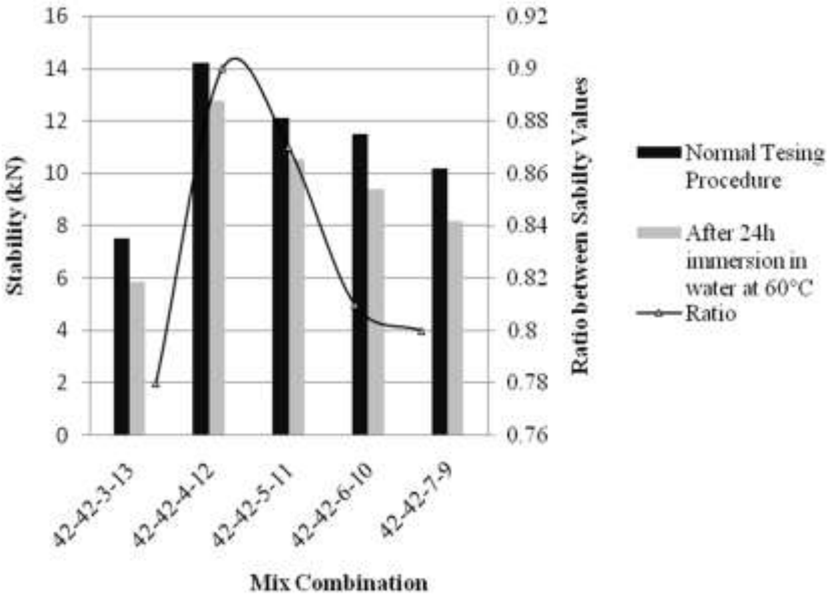

Figure 6. Water Sensitivity Test Result

From the above mentioned test results, it is observed that, by addition of sulphur, the properties of S-F-A mix is enhanced and the variation of sulphur and asphalt in the mix greatly affects properties of the S-F-A-S mix. From the indirect fatigue, dynamic modulus and indirect stiffness tests, it was observed that 4% content of asphalt combined with 12% sulphur was the optimum content of sulphur in the blend for high modulus, stiffness and for good fatigue life of S-F-A-S mix.

Table 7. Water Sensitivity Test Results

Details of mix	Marshall Stability (kN)	Stability after 24 h immersion in 60°C (kN)	Ratio
42-42-3-13	7.5	5.85	0.78
42-42-4-12	14.2	12.78	0.90
42-42-5-11	12.1	10.52	0.87
42-42-6-10	11.5	9.40	0.81
42-42-7-9	10.2	8.16	0.80

Conclusions

Conclusions drawn from this investigation are as follows:

- The flow values, in general, reflect that the mixes are stiffer than conventional asphalt concrete mixes.
- From sensitivity water test, it was seen that the S-F-A-S mix was least sensitive to water, as its Marshall stability ratio more than 0.75. The S-F-A-S 42-42-4-12 mix have the minimum water sensitivity as its Marshall stability ratio was 0.90.
- S-F-A-S mix has good fatigue life and stiffness modulus and hence the mix can be considered as an alternative in the areas with shortage of quality aggregate but abundant in beach sand.
- The variation of sulphur and asphalt in the S-F-A-S mix, significantly affects the properties of Sand – Fly ash - Asphalt mixes.
- For the optimum Asphalt-Sulphur proportion of 16% in the mix, all the properties of the mix were showing a parabolic trend; the properties increased with sulphur content up to 12% and 4% asphalt and thereafter showing a decrease trend.

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