International Journal of Scientific & Engineering Research, Volume 4, Issue 9, September-2013 72
ISSN 2229-5518

Evaluation of Cost Effective Material for Maintenance of Flexible Pavement

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Abstract— Pavements represent an important infrastructure facility in all countries. Two important parameters for good pavements are pavement design and materials. A good design of bituminous mix is expected to result in a mix which is adequately strong, durable and at the same time environment friendly and economical in order to maintain the pavement.

This work is undertaken to prepare cost effective material for maintenance of flexible pavement. By using industrial wastes steel slag and foundry sand as a replacement material for fine aggregate in bituminous mix and ground granulated blast furnace slag as a replacement material for fillers in bituminous mix. Fillers play an important role in engineering properties of bituminous paving mixes. Conventionally stone dust, cement and lime are used as fillers.

Index Terms— steel slag, ground granulated blast furnace slag, foundry sand

1 Introduction

Roads are very important national investment and require maintenance to keep them in a satisfactory condition and ensure safe passage at an appropriate speed and with low road user cost. Late or insufficient maintenance will increase the ultimate repair costs, inconvenience and reduce safety. Pavement maintenance is therefore an essential function and should be carried out on a timely basis. From the budget allocation plan of India the amount for maintenance and repairs of highways is Rs. 1089.49 crores in 2010-2011 and Rs. 1272.49 in 2011-2012 for a length of 33,20,596 km. Hence amount of maintenance per kilometre in 2010-2011 is Rs. 3281 and in 2011-2012 is Rs.3832. is it sufficient for pavement maintenance? It is necessary to develop cost effective material for pavement maintenance.

Generally a bituminous mixture is a mixture of coarse aggregate, fine aggregate, filler and binder. Two things are of major considerations in flexible pavement engineering– pavement design and the mix design. A good design of bituminous mix is expected to result in a mix which is adequately (i) Strong (ii) Durable (iii) Resistive to fatigue and permanent deformation (iv) Environment friendly (v) Economical. A mix designer tries to achieve these requirements through a number of tests on the mix with varied proportions and finalizes with the best one.

Objective of Bituminous Mix Design:

Bituminous concrete consists of a mixture of aggregate continuously graded from maximum size , typically less than 25 mm, through the fine filler that is smaller than 0.075 mm. Sufficient bitumen is added to the mix so that the compacted mix will have acceptable elastic properties. The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregate, and coarse aggregate to produce a mix which is workable, strong, durable and economical. The objective of the mix design is to produce a bituminous mix by proportioning various components so as to have-

1. Sufficient bitumen to ensure a durable pavement
2. Sufficient strength to resist shear deformation under traffic at higher temperature
3. Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic
4. Sufficient durability
5. Should be economical.

2 Introduction to Flexible Pavement Maintainance:

2.1 Meaning of Flexible Pavements:

Flexible pavements are constructed of several layers of natural granular material covered with one or more waterproof bituminous surface layers, and as the name imply, are considered to be flexible. A flexible pavement will flex (bend) under the load of a tyre. In flexible pavements, the load distribution pattern changes from one layer to another, because the strength of each layer is different. The strongest material (least flexible) is in the top layer and the weakest material (most flexible) is in the lowest layer.

2.2 Pavement deterioration and its types:

Pavement deterioration is the process by which distress (defects) develop in the pavement under the combined effects of traffic loading and environmental conditions. Distresses in flexible pavement are as follows:

1. Fatigue (Alligator) Cracking
2. Polished Aggregate
3. Bleeding
4. Potholes
5. Block Cracking
6. Ravelling
7. Corrugation and Shoving
8. Rutting
9. Depression
10. Stripping
11. Longitudinal Cracking
12. Transverse (Thermal) Cracking

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13. Patching

14. Polished Aggregate

15. Water bleeding and pumping

2.3 Main Causes of Distresses In Pavement:

1) Traffic
2) Environmental condition
3) Method of construction and quality of construction material
4) Moisture infiltration.

Pavements fail prematurely because of many factors, there are four primary reasons pavements fail prematurely:

- Failure in design
- Failure in construction
- Failure in material
- Failure in maintenance

2.4 Conventional Material used for Maintenance of Flexible Pavement:

1. Slurry Seal Coat:

Slurry seal consists of a mixture of sand, Portland cement, water, and emulsified asphalt mixed to a rich consistency. It is spread in a thin layer over the pavement. Portland cement is added for stabilizing and setting the slurry. Slurry seal coats are normally used to fill cracks and minor depressions in older AC pavement.

2. Emulsified asphalt:

Emulsified asphalt is a mixture of asphalt cement and water. This asphalt/water ratio is about 60/40. The bitumen content in the emulsion is around 60% and the remaining is water. Sometimes a special type of emulsified asphalt is specified in the Special Provisions. The special type of emulsified asphalt is 50/50 mixture of water and emulsified asphalt. An asphalt emulsion consists of three basic ingredients: asphalt, water, and an emulsifying agent.

3. Final seal (Rubber crumb slurry):

A slurry seal, using rubber crumbs instead of aggregate can be used to fill the wider active cracks. Hand tools are used to mix and apply this slurry seal.

The slurry consisted of the following mix by volume:

- Rubber crumbs 60%
- Stable grade bitumen emulsion 35%
- Cement 5%.

4. Micro surfacing:

Micro surfacing is a mix of polymer-modified emulsion, well-graded crushed mineral aggregate, mineral filler (normally Portland cement), water, and chemical additives. The aggregate, mineral filler, emulsion, and water are mixed in a truck-mounted travelling plant, which is deposited into a spreader box. No compaction is needed, traffic may be allowed over the application within an hour after placement.

5. Pothole repair material:

The four components of a typical mix are:

- Coarse aggregate (retained on 2.36mm sieve)
- Fine aggregate (passing 2.36mm sieve but retained on 75μ)
- Filler (passing 75μ), may be cement.
- Binder: Bitumen etc.

6. Stone Mastic Asphalt (SMA) Mortar:

Mixture of asphalt cement (and any additives), filler (all material passing through 75 μ sieve) and fibres blended by volume.

3. EXPERIMENTAL STUDY

3.1 Material Used:

1. Steel Slag:

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces.

2. Ground granulated blast furnace slag:

Blast Furnace Slag is a by product obtained in the manufacturing of Pig iron in the Blast furnace and is formed by the combination of earthy constituents of iron ore with lime stone flux. Quenching process of molten slag by water is converting it into a fine, granulated slag of whitish colour.

3. Foundry sand:

Sand is used in the foundry industry mainly for making moulds for the casting. This sand is generally recycled. After a repeated use, they lose their characteristics and thereby becoming unsuitable for further use in manufacturing process. This sand is usually discarded and dumped in the landfill as a waste.

4. Course aggregate:

The mineral aggregate most widely used in bitumen mixes are crushed stone, crushed or uncrushed gravel. Since mineral aggregate constitutes of approximately 88% to 96% by weight and approximately 80% by volume of the total mix. Their influence upon the final characteristics of bituminous mixes is very great

5. Fine aggregate:

It shall be fraction passing 2.36 mm and retained on 75 μ sieve consisting of crushed stone or natural sand. Its function is to fill up the voids of the coarse aggregate. Here in this work natural sand is used as fine aggregate. It should be clean, hard, strong, free of organic impurities and free of silt and clay.

6. Cement:

It is the filler material used in bituminous mix which passes through 75 μ sieve. The fillers should be inert material. The cement should be fresh, have uniform consistency and free of lumps and foreign matter.

7. Bitumen:

Bitumen is the residue or by-product when the crude petroleum is refined. Bitumen is act as a binder in bituminous mix. Different grade of bitumen are used in different mix. Here we used 60/70 bitumen for preparation of bituminous mix.

3.2 Test Results:
1. Coarse Aggregate:
   1. Water Absorption= 0.406%
   2. Specific Gravity= 2.96
   3. Fineness modulus = 7.49
2. Fine Aggregate:
   1. Water Absorption= 1 %
   2. Specific Gravity= 2.66
   3. Fineness modulus = 2.57
3. Cement:
   1. Fineness Test = 7%
   2. Specific gravity= 3.15
4. Steel slag:
   1. Water Absorption= 0.95%
   2. Specific Gravity= 2.89
   3. Fineness modulus = 3.29
5. Foundry sand:
   1. Specific Gravity= 2.43
   2. Fineness modulus = 3.091
6. Ground granulated blast furnace slag:
   1. Specific Gravity= 2.94
   2. Fineness Test = 6.5%

4. TESTING OF BITUMINOUS MIX AND RESULTS:

4.1: Brief Procedure of Marshall Test:
1. 1200gm aggregate are weighted and heated up to 154-160 degree C.
2. Bitumen is heated 175 -190 degree C.
3. Aggregate & Bitumen are mixed thoroughly until a uniform grey colour is obtained.
4. Marshall Mould diameter 100mm & 64mm ht compacted with 75 blows on each face.
5. Mould is taken out kept under normal laboratory temp for 12 hours.
6. It is immersed in water bath kept at a constant temp 60 degrees for 30 minutes.
7. Load is applied vertically at the rate of 50mm per minute.
8. The maximum load at sample fails is recorded as the Marshall Stability value.
9. Corresponding vertical strain is termed as the flow value.

4.2: Test Procedure:
A specimen from the Water bath is removed and placed in the lower segment of the testing head. The upper segment of the testing head on the specimen is placed, and the complete assembly is paced in position in the loading machine. The dial gauge is placed in position over one of the guide rods. Readings of dial gauge and proving ring are recorded.

4.3: Parameters used:
1. Theoretical Maximum Specific Gravity of Mix:

$$Gt = 100/ (W1/G1+W2/G2+W3/G3+W4/G4)$$

Where,
W1 = Percentage by weight of coarse aggregate in total mix
W2 = Percentage by weight of fine aggregate in total mix
W3 = Percentage by weight of filler in total mix
W4 = Percentage by weight of bitumen in total mix
G1 = Specific gravity of coarse aggregate
G2= Specific gravity of fine aggregate
G3= Specific gravity of filler
G4= Specific gravity of bitumen.

2 Bulk Density of mix:

$$Gm = \text{weight in Air} / (\text{weight in air} - \text{weight in water}) * 1\ gm/cm^3$$

3 Volume of air voids:

$$Vv = ((Gt - Gm) / Gt) * 100$$

4 Voids in Mineral Aggregate (VMA):

$$VMA = Vv + Vb$$

Where,
Vv = Volume of air voids, Vb = Volume of bitumen.

5 Voids Filled With Bitumen (VFB):

$$Vb= Gm*(W4/G4)$$

Where,
Gm = Bulk Density
W4 = Percent by weight of bitumen in total mix
G4= Specific gravity of bitumen.

4.4: Marshall Test Results:
The results of the Marshall test of samples and average Marshall Properties of Samples prepared with conventional mix for varying bitumen contents have been presented below:

TABLE 5.1 RESULTS OF MARSHALL TEST FOR CONVENTIONAL MIX

Bitu-tu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6	1	1172	703	4.2	350	2.57	2.48	4.12	18.55	14.49	78.12
	2	1170	700	4	352	2.55	2.46	4.15	18.60	14.45	78
	3	1172	703	4.5	352	2.57	2.48	4.13	18.54	14.50	78.12
6.5	1	1184	605	3.8	365	2.58	2.44	5.05	20.44	15.39	75.29
	2	1184	606	3.8	364	2.57	2.44	5	20.30	15.37	75
	3	1182	605	4	360	2.55	2.43	5.05	20.40	15.39	75.10
7	1	1194	700	4	352	2.55	2.41	5.49	21.87	16.38	74.89
	2	1194	700	5	354	2.57	2.44	5.57	21.68	16.57	74.80
	3	1192	700	4	353	2.55	2.44	5.50	21.75	16.50	74.85

From the test results optimum binder content selected as 6.5%.

TABLE 5.2 RESULTS OF MARSHALL TEST FOR
REPLACEMENT OF FINE AGGREGATE AND FILLER MATERIAL BY 50%

Bitu-men (%)	Sample no:	Wt. in Air gm	Wt in Water gm	Flow value (mm	Stability Value (kg)	Gt	Unit wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1182	702	5	479	2.57	2.45	4.66	20.12	15.46	76.12
	2	1181	700	5	475	2.57	2.44	4.65	20.11	15.45	76.82
	3	1182	700	5	474	2.57	2.45	4.66	20.12	15.46	76.12
6.5	1	1184	705	4	500	2.53	2.44	3.55	18.94	15.39	77.29
	2	1184	700	4	480	2.53	2.44	3.55	18.94	15.39	80.25
	3	1184	700	5	482	2.53	2.45	3.56	18.90	15.20	80.15
6.5	1	1195	700	4	472	2.55	2.44	4.31	19.7	15.39	78.12
	2	1185	700	5	470	2.55	2.44	4.31	19.7	15.39	78.12
	3	1184	700	4	472	2.55	2.45	3.92	19.38	15.46	79.77

TABLE 5.3 RESULTS OF MARSHALL TEST FOR 60%
REPLACEMENT OF FINE AGGREGATE AND FILLER MATERIAL (STEEL SLAG AS A FINE AGGREGATE AND GGBFS AS A FILLER MATERIAL)

Bitu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1180	700	4	495	2.56	2.45	4.65	19.72	15.44	75.22
	2	1182	700	5	492	2.57	2.44	4.69	20.10	15.45	76.12
	3	1180	700	5	492	2.57	2.44	4.66	20.00	15.45	76.14

ISSN 2229-5518

TABLE 5.4 RESULTS OF MARSHALL TEST FOR 70%
REPLACEMENT OF FINE AGGREGATE AND FILLER MATERIAL (STEEL SLAG AS A FINE AGGREGATE AND GGBFS AS A FILLER MATERIAL)

Bitu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1182	702	5	490	2.50	2.45	4.76	20.30	15.46	76.72
	2	1181	700	5	485	2.51	2.44	4.85	20.11	15.47	76.77
	3	1182	700	6	484	2.55	2.45	4.66	20.10	15.46	76.10

TABLE 5.5 RESULTS OF MARSHALL TEST FOR 80%
REPLACEMENT OF FINE AGGREGATE AND FILLER MATERIAL (STEEL SLAG AS A FINE AGGREGATE AND GGBFS AS A FILLER MATERIAL)

Bitu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1180	700	5	480	2.57	2.45	4.80	21.17	15.45	76.22
	2	1180	700	6	475	2.57	2.45	4.75	20.17	15.45	76.85
	3	1180	700	6	478	2.56	2.45	4.86	20.15	15.46	76.17

TABLE 5.6 RESULTS OF MARSHALL TEST FOR 60%
REPLACEMENT OF FINE AGGREGATE AND FILLER MATERIAL (FOUNDRY SAND AS A FINE AGGREGATE AND GGBFS AS A FILLER MATERIAL)

Bitu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1180	700	5	468	2.55	2.45	4.70	21.15	15.40	78.25
	2	1181	700	6	465	2.55	2.45	4.75	20.80	15.45	78.45
	3	1181	700	6	465	2.53	2.44	4.68	20.75	15.41	78.34

TABLE 5.7 RESULTS OF MARSHALL TEST
70% REPLACEMENT OF FINE AGGREGATE AND FILLER MATERIAL (FOUNDRY SAND AS A FINE AGGREGATE AND GGBFS AS A FILLER MATERIAL)

Bitu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1182	700	6	460	2.53	2.43	4.66	19.82	15.46	78.20
	2	1181	700	6	454	2.53	2.44	4.65	20.10	15.47	78.44
	3	1180	700	6	458	2.52	2.45	4.76	21.00	15.46	78.32

TABLE 5.8 RESULTS OF MARSHALL TEST
80% REPLACEMENT OF FINE AGGREGATE AND FILLER MATERIAL (FOUNDRY SAND AS A FINE AGGREGATE AND GGBFS AS A FILLER MATERIAL)

Bitu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1181	700	6	450	2.48	2.44	4.64	21.13	15.42	78.12
	2	1181	700	6	447	2.50	2.44	4.62	21.10	15.41	78.14
	3	1180	700	6	445	2.46	2.45	4.67	20.89	15.42	78.13

TABLE 5.9 RESULTS OF MARSHALL TEST
REDUCTION OF COARSE AGGREGATE BY 20% AND REPLACING ALL FINE AGGREGATE WITH 50% STEEL SLAG AND 50% FOUNDRY SAND (USING CEMENT AS FILLER)

Bitu-tu-men (%)	Sample no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1182	704	5	470	2.50	2.42	4.12	20.08	15.40	78.18
	2	1184	700	5	463	2.57	2.44	4.15	20.40	15.32	77.20
	3	1184	700	6	465	2.49	2.42	4.00	20.24	15.37	78.45

TABLE 5.10 RESULTS OF MARSHALL TEST
REDUCTION OF COARSE AGGREGATE BY 20% AND REPLACING ALL FINE AGGREGATE WITH 70% STEEL SLAG AND 30% FOUNDRY SAND (USING CEMENT AS FILLER)

Bitu-tu-men (%)	Sam-ple no:	Wt in Air gm	Wt in Water gm	Flow value (mm)	Stability Value (kg)	Gt	Unit Wt (g/cc)	% air Voids Vv	VMA %	Vb %	VFB %
6.5	1	1183	700	4	475	2.57	2.45	4.10	20.00	15.40	78.10
	2	1185	700	4	469	2.57	2.43	3.45	18.40	15.39	77.25
	3	1182	700	5	470	2.55	2.45	3.00	17.39	15.39	77.55

1. The results for Marshall Stability with 60% replacement of fine aggregates using steel slag are more as compare to other trials; the stability values obtained are 495 kg, 492 kg, and 492 kg.
2. The results for Marshall Stability with 50% replacement of fine aggregates using foundry sand are more as compare to other trials made with foundry sand, the stability values obtained are 472 kg, 470 kg, and 472 kg.
3. Therefore optimum percentage replacement obtained from Marshall Test results for steel slag is 60% and for foundry sand is 50%.

5. COST COMPARISON OF MATERIAL

5.1: For Conventional Mix:

Considering for 10 m^2 area:
Quantities of aggregate for 10 m^2 area is 0.27 m^3,
56 kg bitumen used per m^3, for 0.27 m^3 of

Aggregate= 15.12 kg bitumen is required,
Volume of aggregate= 0.27m^3

1. 10 mm-4.75mm 80%	= 0.21 m^3*1050
	= Rs. 220.50
2. 4.75 mm-75 µ 15%	= 0.04 m^3*1120
	= Rs.44.80
3. Filler @ 5%	= 0.020 m^3*925

	= Rs. 18.50
Total cost of aggregate	= 0.27 m^3
	= Rs. 283.80
Cost of bitumen	= 15.12 kg
	= 0.0151 tonnes*42000
	= Rs.635.04
Total cost of mix	= Rs. 918.84

It is the cost for normal mix.

5.2: Cost for Mix made with Steel Slag and Foundry Sand:

Volume of aggregate		= 0.27m^3
1.	10 mm- 4.75mm 60%	= 0.162 m^3*1050
		= Rs.170.10
2.	4.75mm-75 μ (50-50%)	
	Steel slag	= 0.054*200
		= Rs. 10.80
	Foundry sand	= 0.054*150
		= Rs. 8.10
3.	Filler @ 5%	= 0.020 m^3*925
		= Rs. 18.50
	Total =0.27 m^3	= Rs.207.5
	Cost of bitumen	=15.12 kg
		= 0.0151 tonnes*42000
		= Rs.635.04
Total cost of Mix		= Rs.842.5

Therefore saving in cost per10 m^2 is Rs.94.39 by using steel slag and foundry sand replacement for fine aggregates in bituminous mix by reducing 20% of coarse aggregates. Hence saving in cost for 1 m^2 is Rs.9.43.

6.0 CONCLUSIONS:

1. From the result and analysis of various properties of steel slag and foundry sand it is found that these materials can be used as fine aggregates as replacement for natural sand and ground granulated blast furnace slag can be used as filler material as replacement for cement in bituminous mix.
2. Bituminous mixes prepared using conventional mix at different bitumen content gives the optimum bitumen content as 6.5%.
3. Bituminous mixes prepared with 50% replacement of fine aggregates with steel slag and 50% replacement of cement with GGBFS gives the Marshall Stability value as 500 kg which is 30 kg more as compare to the other mixes.
4. Bituminous mixes prepared with 60% replacement of fine aggregates with steel slag gives the Marshall Stability value as 495 kg, 492 kg, 492 kg which are high as compare to the other trials.
5. Saving in cost per 1 m^2 is Rs.9.43 by using steel slag and foundry sand replacement for fine aggregates in bituminous mix by reducing 20% of coarse aggregates.
6. By using steel slag and foundry sand in bituminous mix an environmental effects from wastes and disposal problems of waste can be reduced.

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