An Experimental Study on Effect of Fillers on Bituminous Paving Mixes

Alamanda Laxmana Rao [1], P Sanyasi Naidu[2], Dr. NC Anil[3]

[1]PG Student, [2]Assistant Professor, [3]Associate Professor
Civil Engineering & Sanketika Institute of Technology and Management

***Abstract*: Construction of highway involves huge outlay of investment. A precise engineering design may save considerable investment; as well as reliable performance of the in-service highway can be achieved. Two things are of major considerations in this regard – pavement design and the mix design. Our project emphasizes on the mix design considerations. A good design of bituminous mix is expected to result in a mix which is adequately strong, durable and resistive to fatigue and permanent deformation and at the same time environment friendly and economical. A mix designer tries to achieve these requirements through a number of tests on the mix with varied proportions of material combinations and finalizes the best one. This often involves a balance between mutually conflicting parameters. Bitumen mix design is a delicate balancing act among the proportions of various aggregate sizes and bitumen content. For a given aggregate gradation, the optimum bitumen content is estimated by satisfying a number of mix design parameters.**

Fillers play an important role in engineering properties of bituminous paving mixes. Conventionally stone dust, cement and lime are used as fillers. An attempt has been made in this investigation to assess the influence of non-conventional and cheap fillers such as brick dust and fly ash in bitumen paving mixes. It has been observed as a result of this project that bituminous mixes with these non-conventional fillers result in satisfactory Marshall Properties though requiring a bit higher bitumen content, thus substantiating the need for its use. The fillers used in this investigation are likely to partly solve the solid waste disposal of the environment.

***Keywords*: Steel slag, Brick dust, Marshall Stability test**

I. INTRODUCTION

A. General

Highway construction activities have taken a big leap in the developing countries since last decade. Construction of highway involves huge outlay of investment. Basically, highway pavements can be categorized into two groups, flexible and rigid. Flexible pavements are those which are surfaced with bituminous (or asphalt) materials. These can be either in the form of pavement surface treatments (such as a bituminous surface treatment (BST) generally found on lower volume roads) or, HMA surface courses (generally used on higher volume roads such as the Interstate highway network). These types of pavements are called "flexible" since the total pavement structure "bends" or "deflects" due to traffic loads. A flexible pavement structure is generally composed of several layers of materials which can accommodate this "flexing". On the other hand, rigid pavements are composed of a PCC surface course. Such pavements are substantially "stiffer" than flexible pavements due to the high modulus of elasticity of the PCC material. Flexible pavements being economical are extensively used as far as possible. A precise engineering design of a flexible pavement may save considerable investment; as well as reliable performance of the in-service highway pavement can be achieved. In recent years, many countries have experienced an increase in truck tire pressures, axle loads, and traffic volumes. Tire pressure and axle load increases mean that the bituminous layer near the pavement surface is exposed to higher stresses. High density of traffic in terms of commercial vehicles, overloading of trucks and significant variations in daily and seasonal temperature of pavements have been responsible for development of distress symptoms like raveling, undulations, rutting, cracking, bleeding, shoving and potholing of bituminous surfaces. Suitable material combinations and modified bituminous binders have been found to result longer life for wearing courses depending upon the percentage of filler and type of fillers used

B. Objectives of bituminous paving mix design

The overall objective of the design of bitumen pavement mixtures is to determine an economical blend of stone aggregate, sand and fillers such as fly ash and brick dust that yields a mix having

- Sufficient bitumen to ensure a durable pavement.
- Sufficient mix stability to satisfy the demands of traffic without distortion or displacement.
- Sufficient void in total compaction mix to allow for a slight amount of additional compaction and traffic loading without flushing bleeding and lost of stability yet low enough to keep out harmful air and moisture.

Sufficient workability to permit sufficient placement of the mix without segregation.

C. Scope of Project:

In order to achieve the desirable engineering properties of bituminous paving mixes mainly in form of Marshall test results it has been planned to carry out the project in the following phased manner.

- IRC grading 2 with stone aggregates from 19 mm to 600 micron, granulated blast furnace slag from 600 micron to 75 micron and fly ash/ brick dust constitute the aggregate grading.
- Bitumen 80/100 has been used as an alternative to 60/70 as used in case of normal paving mixes.
- Bitumen content has been varied depending on the type of filler till changes in the trend of Marshall Properties are observed.

- Mixing and Compaction temperature of bitumen has been decided based on viscosity tests on 80/100 bitumen at various temperatures.
- Marshall Properties of the resulting mixes are compared with the minimum requirements suggested by IRC.

II. LITERATURE REVIEW

A. Evolution of mix design concepts

During 1900's, the bituminous paving technique was first used on rural roads – so as to handle rapid removal of fine particles in the form of dust, from Water Bound Macadam, which was caused due to rapid growth of automobiles [Roberts et al. 2002]. At initial stage, heavy oils were used as dust palliative. An eye estimation process, called pat test, was used to estimate the requisite quantity of the heavy oil in the mix. By this process, the mixture was patted like a pancake shape, and pressed against a brown paper. Depending on the extent of stain it made on the paper, the appropriateness of the quantity was adjudged [Roberts et al. 2002]. The first formal mix design method was Hubbard field method, which was originally developed on sand-bitumen mixture. Mixes with large aggregates could not be handled in Hubbard field method. This was one of the limitations of this procedure. Fransis Hveem, a project engineer of California Department of Highways, developed the Hveem stabilometer (1927). Hveem did not have any prior experience on judging the just right mix from its colour, and therefore decided to measure various mix parameters to find out the optimum quantity of bitumen .Hveem used the surface area calculation concept (which already existed at that time for cement concrete mix design), to estimate the quantity of bitumen required [Hveem 1942]. Moisture susceptibility and sand equivalent tests were added to the Hveem test in 1946 and 1954 respectively [Roberts et al. 2002]. Bruce Marshall developed the Marshall testing machine just before the World War-II. It was adopted in the US Army Corps of Engineers in 1930's and subsequently modified in 1940's and 50's.

B. Role of mix volumetric parameters

Bitumen holds the aggregates in position, and the load is taken by the aggregate mass through the contact points. If all the voids are filled by bitumen, then the load is rather transmitted by hydrostatic pressure through bitumen, and strength of the mix therefore reduces. That is why stability of the mix starts reducing when bitumen content is increased further beyond certain value During summer season, bitumen melts and occupies the void space between the aggregates and if void is unavailable, bleeding is caused. Thus, some amount of void is necessary to provide by design in a bituminous mix, even after the final stage of compaction. However excess void will make the mix weak from its elastic modulus and fatigue life considerations. The chances of oxidative hardening of bitumen are more, where, the mix has more voids. Evaluation and selection of aggregate gradation to achieve minimum VMA is the most difficult and time-consuming step in the mix design process .VMA specification has always been a big issue in mix design specifications. The recommendation of minimum VMA is sometimes questioned by the researchers, and is said not to be equitable across different gradations. It is seen that the bitumen film thickness, rather than the VMA, may be related to durability of the mix.

C. Various mix design approaches

There is no unified approach towards bituminous mix design, rather there are a number of approaches, and each has some merits are demerits. Table-1 summarizes [RILEM 17 1998] some of the important bituminous mix design approaches. **Clifford Richardson** was probably the first to describe the importance of filler. He believed that particles smaller than 0.05 mm were the most valuable particles, and suggested that good filler should contain at least **60** percent by weight particles smaller than this size. He also proposed the dual function of filler as: **(a.)** Rendering the mixes higher density, and **(b.)** stiffen the asphalt cement. His view was shared by Spaulding and others. Satisfactory fillers recommended by Richardson included Portland cement, ground limestone, ground shale and ground clay.

Tillson (1990):

In his book, "Street Pavements and Paving Materials" in brought up the object of the powdered mineral matter as to fill the voids in the sand so as to make the total voids as small as possible and thus the exact quantity to be used in an bitumen wearing surface mixture should be determined by the gradation of the sand.

Richardson (1913):

Extended the function of filler to include making the bitumen cement less susceptible to changes in consistency caused by heat. Filler was defined as a part of the mineral filler with at least 75 percent passing # 200 sieve and at least 66 percent remaining suspended in water for 15 seconds. Acceptable fillers were extended to include ground trap rock, marl and volcanic ash.

Richardson (1915)

He is presented "The Theory of the Perfect Sheet Bitumen Surface", in which he stressed the importance of fine particle size and surface area of the filler saying, We now understand the fact that an extended surface area in addition to providing for the use of a. larger amount of bitumen exercises a still more important function, due to the greater surface energy developed by the larger surface area of a fine mixture over that of a coarse one and that, aside from the greater surface presented by a fine sand as compared to a -coarse one,

The presence of highly dispersed colloids with their extensive surface is necessary for the production of the most satisfactory surface.

This concept was shared later by many others with regard to the function of the filler.

Spielmann AndbHughes agreed with Richardson's conception that the filler forms a colloidal suspension in bitumen and together fills the voids in the aggregate. In addition, they specified that the immediate effect of the admixture of filler to bitumen was to increase its adhesive powers, and raise its softening point and its general stability.
Warden et al. (1952): Fly ash was a suitable filler material in terms of mixing, placing and composition, stability, resistance to water damage, and flexibility.

III. EXPERIMENTAL INVESTIGATIONS

A. Bitumen

Penetration is the consistency test used to designate grades of bitumen. It is the distance in tenths of millimeter that a standard needle will penetrate the sample under specified conditions of time, temperature and load on the needle. The test was performed by taking bitumen in a container and softened then the temperature was maintained at 250C the dial was set so that the needle was just in contact with the surface of the bitumen. The initial reading was taken. Then the needle was released for 5 seconds and the final reading was taken the difference between the two readings gave the penetration value.
The conducted test was as follows:

Table No 1 Results of penetration test of Bitumen 80/100

Sample	Reading-1	Reading -2	Reading-3	Average	Final Averaged
1	104	84	81	89.67	
2	89	84	70	81.60	85.33

Softening point test may be classed as a consistency test in that it measures the temperature at which the bituminous materials reach a given consistency as determined by the test conditions while it is applicable to semi-solid materials and is useful in characterizing bitumen.
The test was performed by forming a sample in a brass ring, cooling it in a melting ice bath and then placing the sample within the ring in a 50C water bath. After placing a steel ball on a sample surface, the water bath temperature was raised at the rate of 50C per minute. The temperature at which the sample sagged under the weight of the steel ball and touches the bottom of the container surface 2.5 cm below the

Table No 2 Results of Softening Point test

Specimen no(80/100)	Softening point(0C)	Average
1	48	
2	46	47

- **Specific gravity** of bitumen is defined as the ratio of mass of a given volume of substance to the mass of an equal volume of water temperature of both being 270C. The bitumen was taken in a pycnometer having weight 25gm the water raised in pycnometer was observed 24.27 gm from which the specific gravity of bitumen was found. Grade 80/100 = 1.03.
- Viscosity test was conducted in BROOKFIELD VISCOMETER. The test is conducted mainly for determination of mixing and compaction temperature for bitumen with fly- ash and brick-dust dust as fillers. The following readings we got in the laboratory.

BITUMEN 80/100

Table No 3 Viscosity test results for bitumen 80/100

Temperature 0c	Speed(rpm)	Torque (%)	Viscosity(cp)
120	2	10.3	2575
	2.5	7.5	1575
	3	9.7	1617
	4	9.5	1188
	5	12.1	1210
	6	13	1083
130	2	5.8	1450
	2.5	4.2	840
	3	5.3	883.3
	4	5.2	650
	5	5.8	580
	6	7	583.3
	10	11.5	575
	12	13.6	566.7
140	2	3.7	925
	2.5	3.5	700
	3	2.6	433.3
	4	3.9	487.5
	5	3.7	370
	6	4.4	366.7
	10	7	350
	12	8.5	358.3

	20	13.7	342.5
150	2	2.6	650
	2.5	1.9	380
	3	2.0	333.3
	4	3.1	387.5
	5	8.3	330
	6	3.1	258.3
	10	5.3	265
	12	5.2	216.7
	20	9.1	227.5
	30	12.8	215
160	2	2	500
	2.5	2.1	420
	3	2.5	416.7
	4	2.5	312.5
	5	2.4	240
	6	2.7	225
	10	3.7	185
	12	4.4	183.3
	20	5.9	147.5
	30	8.7	145
	50	14.6	146
	60	17.2	143.3
170	2	1.6	400
	2.5	2	400
	3	2.1	350
	4	2	250
	5	2.2	220
	6	2.3	191.7
	10	2.9	145
	12	3	135
	20	4.4	110
	30	6.1	101.7
	40	8.1	101.3
	50	9.8	98
	60	11.7	97.5
180	2	2.2	225
	2.5	2.7	440
	3	3.9	416.7
	4	1.7	212.5
	5	2.2	220
	6	2.1	175
	10	2.5	125
	12	2.9	120.8
	20	4.4	110
	30	4.4	76.7
	50	7.5	74
	60	8.5	70.8
	100	14.1	70.5

B. Aggregates

Elongation index of an aggregate is percentage by weight of particles whose greatest dimension of length is greater than one and four fifth or 1.8 times than mean dimension. The elongation test is not applicable for sizes smaller than 6.3mm.Taking 200 sample of each sieve range as specified below, the result of our computed elongation index are as follows. If 'm' g of aggregates retained out of total amount of 'M' then elongation=(m/M)x100

Table No: 4 Elongation test results

Sieve size(mm)	Passing(gm)	Retained(gm)
6.3-9.5	165.2	169.2
9.5-13.2	670.4	13.2
13.2-19	382.8	540
>19	1194	456.4
Total	Passing = 2412.40g	Retained = 1308.8g

Elongation = T. retained x 100/T.weight=1308.8 x 100/3721.2 = 35.17%

- Flakiness index of aggregates is the percentage by weight of aggregates whose least dimension is less than three fourth or 0.6 times than mean dimensions. The test is applicable to size greater than 6.3mm.The results are as follows:

If 'm' g of aggregates passed out of M g of total aggregates then Flakiness index = (m-M) x 100

Table No: 5 Flakiness test results

Sieve size(mm)	Passing(gm)	Retained(gm)
6.3-9.5	30	284.4
9.5-13.2	184.4	635.6
13.2-19	177.2	725.2
Total	Passing = 909.6	Retained = 2697.6g

Flakiness index = 909.6 x 100/ 3607.2 = 25.21%

- Specific gravity of an aggregate is to measure the quality or strength of the material. Stone having low specific gravity values are generally weaker than those having higher values

The sample was weighed in water and the buoyant weight was found kg

Specific Gravity = 2.64

Table No:6 Aggregate test results

Parameters	Value
Specific gravity	2.64
Impact Strength (%)	20.2
Abrasion Strength (%)	19.5
Water Absorption (%)	3.06
Crushing strength (%)	19.12

The specific gravities of GBFS, fly ash and brick dust were found to be 2.3, 2.63, and 2.72

C. Bitumen Concrete Mix Design

Marshall method of mix design has been adopted in this project. Accordingly aggregates with the grading 2 of IRC and bitumen 80/100 having properties as described in the preceding paragraphs have been used.

The objective of bituminous paving mix design is to develop an economical blend of aggregates and bitumen. In the developing of this blend the designer needs to consider both the first cost and the life cycle cost of the project. Considering only the first cost may result in a higher life cycle cost.

Historically bitumen mix design has been accomplished using either the Marshall or the Hveem design method. The most common method was the Marshall. It had been used in about 75% of the DOTs throughout the US and by the FAA for the design of airfields. In 1995 the Superpave mix design procedure was introduced into use. It builds on the knowledge from Marshall and Hveem procedures. The primary differences between the three procedures are the machine used to compact the specimens and strength tests used to evaluate the mixes. The current plan is to implement the Superpave procedures throughout the US for the design and quality control of HMA highway projects early in the next century. It appears that the Marshall method will continue to be used for airfield design for many years and that the Hveem procedure will continue to be used in California.

The HMA mixture that is placed on the roadway must meet certain requirements.

- The mix must have sufficient bitumen to ensure a durable, compacted pavement by thoroughly coating, bonding and waterproofing the aggregate.
- Enough stability to satisfy the demands of traffic without displacement or distortion (rutting).
- Sufficient voids to allow a slight amount of added compaction under traffic loading without bleeding and loss of stability. However, the volume of voids should be low enough to keep out harmful air and moisture. To accomplish this mixes are usually designed by 4% VTM in the lab and compacted to less than 7% VTM in the field.
- Enough workability to permit placement and proper compaction without segregation

Fig 3.3.1 shows a setup of the Marshall test apparatus where it is designed to apply loads to test specimens through semicircular testing heads at a constant rate of 50mm per minute. It is equipped with a calibrated proving ring for determining the applied testing load, a Marshall stability testing head for use in testing specimen, and a Marshall flow meter for determining the amount of strain at maximum load for test.

Fig No: 3.3.1 Marshall Apparatus Setup

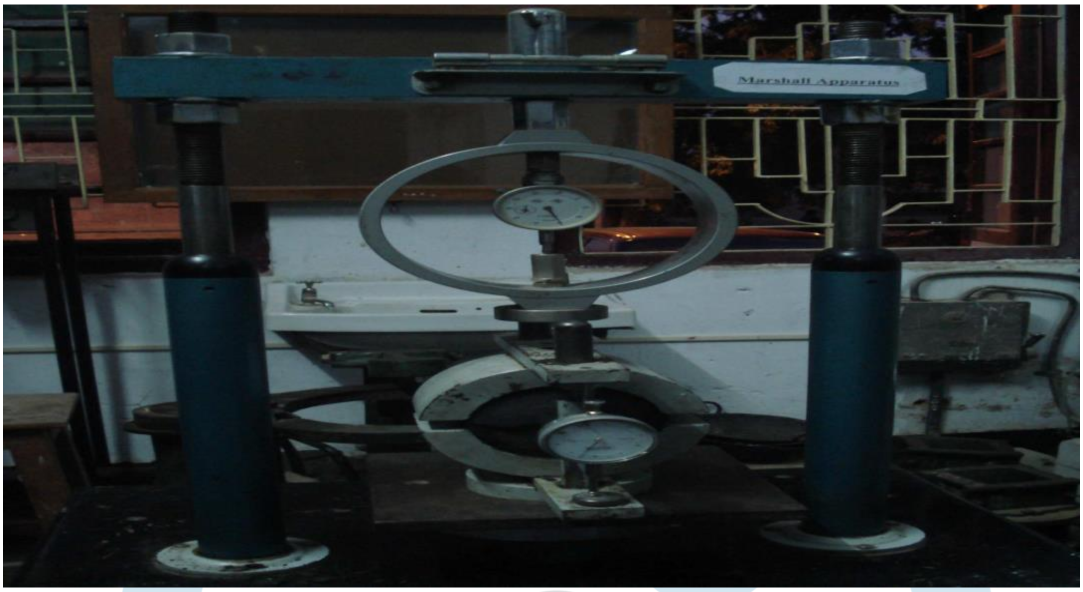

Fig No: 3.3.2 shows a water bath where Marshall Specimens are kept immersed for about 30 minutes at 60 degree centigrade just before the conduct of the test.

The tank has a perforated false bottom or equipped with a shelf for suspending specimens at least 5cms above the bottom of both.

IV. TEST RESULTS AND DISCUSSION

A. Brief Procedure of Marshall Test

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

B. Calculation of Air Voids And VMA

After completion of stability and flow test a density and void analysis was made for each series of test specimen.

1. Bulk specific gravity values corresponding to given bitumen content was determined. The erroneous results were not entered.
2. The unit weight for bitumen content was determined by multiplying the bulk specific gravity value by 1gm/cm3.

3. The percentage of air voids was calculated for Vv = ((Gt – Gm) / Gm) * 100
Gm = Bulk Density
Gt = Theoretical specific gravity of mixture Gt = 1000/ (W1/G1+W2/G2+W3/G3+W4/G4)
Where
W1 = Percentage by weight of coarse aggregates in total mix W2 = Percentage by weight of fine aggregates in total mix W3 = Percentage by weight of filler in total mix
W4 = Percentage by weight of bitumen in total mix G1 = Apparent specific gravity of coarse aggregate G2= Apparent specific gravity of fine aggregate G3= Apparent specific gravity of filler
G4= Apparent specific gravity of bitumen
The percent voids in mineral aggregate (VMA) corresponding to given % of bitumen and various fillers was determined using formula given below.
VMA = Vv + Vb
Vv = Volume of air voids;
Vb = Volume of bitumen = Gm*(W4/G4) Gm = Bulk Density
W4 = Percent by weight of bitumen in total mix

C. Marshall Test Results:

The results of the Marshall test of individual specimens and average Marshall properties of specimens prepared with fly ash as filler for varying bitumen contents have been presented in table 7.

Table No 7 Results of Marshall test (specimens with fly ash)

Bitumen (80/10 0) (%)	Sample no:	Wt in air	Wt in water	Flow value (mm)	Stability Value(kg)	Gt	Unit wt(g/cc)	% air voids	VMA
5	1	1176	608.2	1.7	2080	2.25	2.07	8.69	18.74
	2	1182	618.1	1.9	2000		2.1	7.14	17.33
	3	1066	548.2	1.9	2220		2.06	9.2	19.2
	4	1172	611.5	2.2	1305		2.09	7.65	17.79
5.5	1	1182	623.3	2.4	2140	2.23	2.10	6.2	17.41
	2	1170	614.5	2.1	1910		2.09	6.69	17.85
	3	1174	616.5	2.7	2570		2.09	6.69	17.85
	4	1142	599.1	2.4	2380		2.08	7.21	18.31
6	1	1198	628.6	2.7	2000	2.19	2.10	4.28	16.51
	2	1164	612.5	3.1	2800		2.11	3.79	16.08
	3	1174	616.1	2.5	2500		2.10	4.28	16.51
	4	1182	619.5	2.9	2550		2.10	4.28	16.51
6.5	1	1098	570.4	3.3	2190	2.17	2.08	4.32	17.44
	2	1084	570.1	3.4	1970		2.10	3.33	16.58
	3	1082	564.1	3.8	2400		2.05	5.85	18.78

VI. CONCLUSIONS AND FUTURE SCOPE

CONCLUSIONS:

- Bituminous mixes containing stone dust as fillers are found an optimum bituminous mix at 6% of the bitumen content.
- Bituminous mixes containing steel slag as filler displayed maximum stability at 3.5% of c of filler content having an increasing trend up to 3.5% and then gradually decreasing, the unit weight/ bulk density also displayed a similar trend with flow value being satisfactory at 3.5% of filler content at optimum bitumen content (6%).
- Bituminous mixes containing brick dust as filler showed maximum stability at 5% of filler content displaying an ascending trend up till 5% of filler content and then decreasing, the flow value showed an increasing trend and similar was the trend shown by unit weight/bulk density, the percentage of air voids obtained were seen to be decreasing with increase in filler content thus from here we can see that at 5% of filler content we are obtaining satisfactory results at optimum bitumen content(6%).
- These mixes were seen to display higher air voids than required for normal mixes.
- Higher bitumen content is required in order to satisfy the design criteria and to get usual trends.
- From the above discussion it is evident that with further tests steel slag and brick dust generated as waste materials can be utilized effectively in the making of bitumen concrete mixes for paving purposes.
- Further modification in design mixes can result in utilization of steel slag and brick dust as fillers in bituminous pavement thus partially solving the disposal of industrial and construction wastes respectively.
- Though stone dust being conventional filler however steel slag and brick dust can be utilized in their place effectively thus solving the waste material disposal substantially resulting in utilization of industrial space being consumed in disposal of industrial wastes.

- The cost effectiveness of these non-conventional filler specimens can be realized after performing a cost analysis of these non-conventional materials against the conventional specimen resulting in reduction of the construction costs considerably.
- It is evident that with further tests steel slag and brick dust generated as waste materials can be utilized effectively in the making of bitumen concrete mixes for paving purposes.

FUTURE SCOPE:

- Pavement mixes with brick dust and steel slag as fillers using modified binders such as CRMB (60).
- Indirect tensile test of bituminous mixes can give us an idea about the tensile strength of the bituminous mixes.
- Repeated load testing can give us an overview about the fatigue failure resistance of the specimen.

REFERENCES

[1] D. Larson Thomas Portland cement and Bitumen Concretes a. McGraw Hill Publication 1963.

[2] Henning, N. E. (1974). "Evaluation of lignite fly ash as mineral filler in asphaltic concrete." Report No. Item (2)-73, Twin City Testing and Engineering Laboratory, St. Paul, Minn.

[3] YoderE, J, Witczak M,W Principles of Pavement Design a. John Wiley son publications 2nd edition 1975.

[4] IRC: 29-1988 Specification for Bituminous Concrete for Road Pavement.

[5] John Wiley son publications Vth edition 1991.

[6] S.k.khanna&c.e.g. justo, highway material testing (laboratory manual), namchand& bros, roorkee 1997.volume4.

[7] J. Mater. "Coal Ash Utilization in Asphalt Concrete Mixtures" Civ.Eng.11, 295(1999).

[8] Das Animesh and Pandey,B B (2000) "Economical design of bituminous pavements with two grades of bitumen in the surfacing" seminar on Road Financing, Design, Construction and Operation of Highways in 21st Century, 24th and 25th September, IRC, pp.II-35-II-42.

[9] C.E.G. Justo, Dr. A. Veeraragavan Utilization of Waste Plastic Bags in Bituminous Mix for Improved Performance of Roads (2002).

[10] Bradley J. Putman and Serji N. Amirkhanian (2004), "Utilization of Waste Fiber in Stone Matrix Asphalt Mixtures", Resources, Conservation and Recycling, Volume 42, Issue 3, pp 265-274.

[11] S., Kamaraj C. and Nanda P.K. (2006), "Stone Mastic Asphalt (SMA) – A Long Life Pavement Surface", International Seminar on Innovations in Construction and Maintenance of Flexible Pavements, Agra, 2-4 September, Technical Papers, Volume 1, pp 169-17.

[12] Dr. R. Vasudevan, S.K. Nigam, R. Velkennedy, A. Ramalinga Chandra Sekar, B. Sundarakannan "Utilization of Waste Polymers coated Aggregate for Flexible Pavement And easy Disposal of Waste Polymers" Proceedings of the International Conference on Sustainable Solid waste Management, Chennai, India. pp. 105-111, 5-7September (2007).

[13] P Sreejith "Use of plastic waste in Bitumen Roads" Powered by WordPress.com(2010).

[14] PadaSabtu, Utilisationof Waste Plastic in Bituminous Mixes for Road construction, (2010).

[15] D S V Prasad, M. Anjan Kumar, G V R PrasadaRaju, V. Kondayya "A Study on Flexible Pavement Performance with Reinforced Fly ash Sub base" International Journal of Earth Sciences and Engineering 4ISSN 0974-5904, Volume 04, No 06 SPL, October, pp. 403-408(2011).

[16] Abdul Hamid Ahmad, "Waste Plastic for Road Construction" Feb 17, 2012.