International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 06, June-2019

EXPERIMENTAL INVESTIGATION ON PERFORMANCE OF DENSE BITUMINOUS MACADAM USING E-WASTE PLASTIC POWDER

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ABSTRACT*— Since, being a viscoelastic material, modification is sometimes necessary in bitumen for stability to withstand in adverse environmental conditions. Numerous researches have been carried out on modification of bitumen using nonconventional materials viz. crumb rubber, fibres, etc. In present study, Viscosity Grade (VG) - 30 bitumen is modified with e-waste plastic powder and termed as e-waste plastic powder modified bitumen (EPPMB). Perceptible developments in rheological properties of EPPMB are detected when tested with conventional tests. 5% E-waste Plastic Powder by weight of bitumen perfectly satisfies the recommendations of Indian specification, hence adopted for further study. Marshall Stability of Dense Bituminous Macadam (DBM) prepared using EPPMB, which is termed as EPPMDBM, was observed to be enhanced. All Marshall Stability test parameters like ductility, penetration value, flow value and viscosity were experimented and observed to be improved optimistically. Moreover the technical benefits, the study also extends social benefit by providing solution for the non-decomposable electronic waste which is generated in influx now-a-days. Nonetheless, the overwhelming improvements in the technical parameters like resistance to rutting, stripping, cracking, etc are the significant achievements of the study.

***KEYWORDS*:Modified Bitumen, E-waste Plastic Powder, Dense Bituminous Concrete, Mix Design, Fatigue cracking, Rutting, Stripping.**

I. INTRODUCTION

The bitumen as a raw material in flexible road construction and bitumen as a mix serves certain advantages, which prompt to use bitumen widely in road construction. Studies have revealed that properties of bitumen and bituminous mixes can be improved / modified with the incorporation of certain additives or blend of additives. Use of modified bitumen in the top layers of the pavement is expected to significantly enhance the life of the surfacing and extend the time of the next renewal. Over the years, different types of material have been investigated as additives for bitumen modifications. Some of them, which have been trial tested in India and countries abroad are polyethylene, ethylene vinyl acetate copolymers, ethylene methyl acrylate, ethylene butyl acrylate, styrene butadiene, styrene butadiene styrene block copolymer, natural rubber and crumb rubber from used truck tyres treated by gilsonite etc. Full-scale performance studies on overlay carried out by the various research institutions revealed that the use of Modified Bitumen in construction/maintenance of bituminous roads significantly improve the pavement performance and is cost effective, when life 'cycle cost is taken into consideration. Pertaining to this scenario, this study consists of bitumen modification using E-waste Plastic Powder and incorporating this modified bitumen in Dense Bituminous Macadam.

II. NEED OF MODIFIED BITUMEN

Bitumen is extensively used in roadway pavements, sealants, and water-proof coatings depending on its low cost, adhesive-cohesive nature, rheological properties, and thermal resistance. Generally, flexible paving used in the top layer of the roads is formed from bituminous binders and aggregates. This layer is exposed to a wide range of temperatures and great stresses due to seasonal changes and heavy truck traffic. Cracking can occur at low temperatures due to the shrinkage of the pavement while its cohesive strength decreases at high temperatures which lead to permanent deformation under traffic loadings. Flexible pavement distresses such as rutting, cracking, and stripping increase in severity with increasing traffic load. Performance and stability improvements of this top paving layer would enhance the quality of roads and appreciable savings would result through decreased maintenance costs. Since it is the material properties of bituminous binders and the aggregates that determine the quality of the paving in the condition of all other variables (i.e., workmanship, weather condition during paving) are constant, improving this quality by various modifications of bitumen is widely attempted.

III. E-WASTE PLASTIC POWDER MODIFIED BITUMEN (EPPMB)

E-waste consists of all waste from electronic and electrical appliances which have reached their end- of- life period or are no longer fit for their original intended use and are destined for recovery, recycling or disposal. It includes computer and its accessories, monitors, printers, keyboards, central processing units; typewriters, mobile phones and chargers, remotes, compact discs, headphones, batteries, LCD/Plasma TVs, air conditioners, refrigerators and other
household appliances. This study consists of the addition of E-waste Plastic Powder in Bitumen in three proportions, viz.

5%, 2% and 0% of total weight of bitumen. E-waste Plastic in powder form as shown in Photograph 1 is obtained from Anita Plastic, Dharavi Main Road, Near Railway Crossing, Mahim (E), Mumbai-17.

Photograph 1. E-waste plastic in Powder form

Grained size distribution (IS 2720 Part-IV) and Physical and Engineering properties of E-waste plastic powder are shown in figure 1 and table 1.

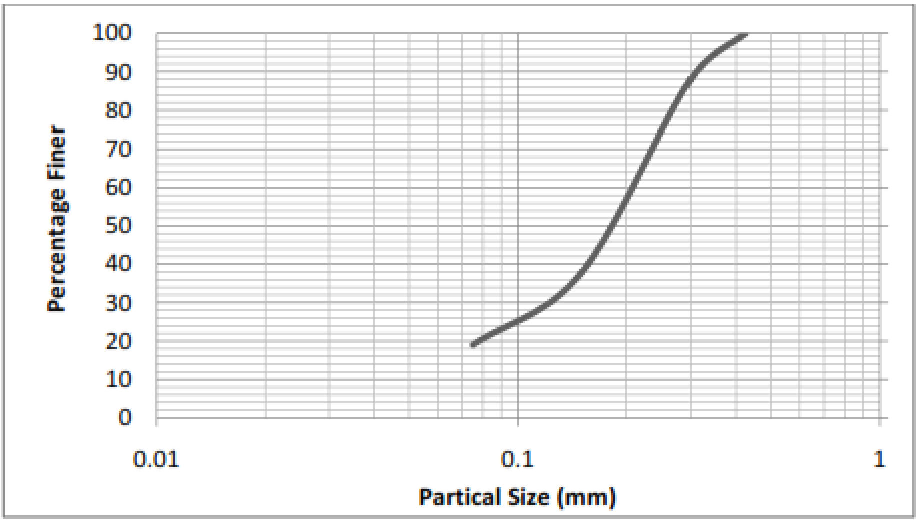

Fig. 1 Grain size analysis distribution curve of E-waste plastic powder

TABLE 1
PHYSICAL AND ENGINEERING PROPERTIES OF E-WASTE PLASTIC POWDER

Sr. No.	Property tested	Investigator results
1	Size	Passing Through 300μ IS Sive
2	Colour	Gray
3	Specific Gravity	1.06
4	Softening Point	130-175°C

IV. E-WASTE PLASTIC POWDER MODIFIED DENSE BITUMINOUS MACADAM (EPPMDBM)

Since, the modified bitumen is generally used for the wearing course of bituminous pavement, the scope of the present investigations is kept limited to asphalt concrete (AC) mix. The guidelines of Ministry of Roads Transport and Highways (MORT&H, 2012), as shown in TABLE 2, are followed for selecting AC mixes.

TABLE 2
GUIDELINES FOR SELECTION OF ASPHALT CONCRETE MIXES

Asphalt Concrete Mix	MORT&H (2012) recommendations		
	Design Traffic (million standard axle)	Thickness (mm)	Recommended Use
Dense Bituminous Macadam (DBM) (Grade II)	≥ 5	50 to 75	Binder Course
Bituminous Concrete (BC) (Grade II) with DBM as Base Course	≥ 100	50	Wearing Course
Bituminous Macadam (BM) (Grade II)*	≤ 5	50 to 100	Binder Course

***** BM has more air voids than DBM.

Dense bituminous macadam is mainly used as binder course for roads having much higher number of heavy commercial vehicles. In DBM mix there is a wide scope of varying the gradation to obtain the good mix without affecting the durability of pavement. Achieving adequate compaction of bituminous mixes is crucial to the performance of flexible pavement. Normally Marshall Mix design method is adopted for mix design of Dense Graded Bituminous Macadam, (DBM). DBM is also intended for use as road base material. DBM mixes are designed in the laboratories to strictly fulfil the specific properties and requirements that control the stability and durability under expected traffic, climatic and environmental condition. DBM layers are to be laid as single or in multiple layers each of thickness 50 to 100 m. Durable surface which performs well in almost all situations, suitable for all pavement layers and for all traffic conditions, good quality smooth surface and improved skid resistance are some of the additional advantages of DBM. In this study the DBM mix is designed considering the use of E-waste Plastic Powder modified bitumen in various proportions.

V. MORTH SPECIFICATIONS FOR DBM

A. *Bitumen*

The bitumen shall be viscosity grade paving bitumen complying with the Indian Standard Specification IS: 73 modified bitumen complying with Clause 501.2.1 or as otherwise specified in the Contract. The type and grade of bitumen to be used shall be specified in the Contract. Appropriate grade of bitumen is selected after considering the region, traffic and environmental condition.

TABLE 3
BITUMEN GRADE SELECTION BASED ON TEMPERATURE

Lowest Mean Air Temperaure, °C	**Highest Daily Mean Air Temperature, °C**		
	<20°C	20 - 30°C	>30°C
>-10°C	VG-10	VG-20	VG-30
<-10°C	VG-10	VG-10	VG-20

B. *Coarse Aggregate*

The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on 2.36 mm sieve. They shall be clean, hard, durable, cubical in shape, free from dust and soft or friable matter, organic or other deleterious substances. Where the Contractor's selected source of aggregates has poor affinity for bitumen, the Contractor shall produce test results that with the use of anti-stripping agents, the stripping value is improved to satisfy the specification requirements. The Engineer may approve such a source and as a condition for the approval of that source, the bitumen shall be treated with an approved anti-stripping agent, as per the manufacturer's recommendations, at the cost of the Contractor. The aggregates shall satisfy the requirements specified in Table 500-8 of MORTH, 2012. Where crushed gravel is proposed for use as aggregate, not less than 90 % by weight of the crushed material retained on the 4.75 mm sieve shall have at least two fractured faces.

C. *Fine Aggregate*

Fine aggregates shall consist of crushed or naturally occurring mineral material, or a combination of the two, passing the 2.36 mm sieve and retained on the 75 micron sieve. These shall be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleterious matter. Natural sand shall not be allowed in binder courses. However, natural sand upto 50 percent of the fine aggregate may be allowed in base courses. The fine aggregate shall have a sand equivalent value of not less than 50 when tested in accordance with the requirement of IS: 2720 (Part 37). The plasticity index of the fraction passing the 0.425 mm sieve shall not exceed 4, when tested in accordance with IS: 2720 (Part 5).

D. *Mineral Filler*

Filter shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement approved by the Engineer. The filler shall be graded within the limits indicated in Table500-9 of MORTH 2012. The filler shall be free from organic impurities and have a plasticity Index not greater than 4. The Plasticity Index requirement shall not apply if filler is cement or lime. Where the aggregates fail to meet the requirements of the water sensitivity test, then 2 percent by total weight of aggregate, of hydrated lime shall be used and percentage of fine aggregate reduced accordingly.

TABLE 4
GRADING REQUIREMENTS FOR MINERAL FILLER

IS Sieve (mm)	**Cumulative % passing by weight of total aggregate.**
0.6	100
0.3	95-100
0.075	85-100

E. *Aggregate Grading and Binder Content*

When tested in accordance with IS:2386 Part 1 (wet sieving method), the combined grading of the coarse and fine aggregates and filler for the particular mixture shall fall within the limits given in Table 500-10 of MORTH 2012, for grading 1 or 2 as specified in the Contract. To avoid gap grading, the combined aggregate gradation shall not vary from the lower limit on one sieve to higher limit on the adjacent sieve.

TABLE 5
PHYSICAL REQUIREMENTS FOR COARSE AGGREGATE FOR DENSE BITUMINOUS MACADAM

Property	**Test**	**Specification**	**Method of Test**
Cleanliness (dust)	Grain size analysis	Max 5% passing 0.075 mm sieve	IS:2386 Part I
Particle shape	Combined Flakiness and Elongation Indices*	Max 35%	IS:2386 Part I
Strength	Los Angeles Abrasion Value or Aggregate Impact Value	Max 35% Max 27%	IS:2386 Part IV
Durability	Soundness either Sodium Sulphate or Magnesium Sulphate	Max 12% Max 18%	IS:2386 Part V
Water Absorption	Water Absorption	Max 2%	IS:2386 Part III
Stripping	Coating and Stripping of Bitumen Aggregate Mix	Minimum retained coating 95%	IS:6241
Water Sensitivity	Retained Tensile Strength**	Min. 80%	AASHTO 283

*To determine this combined proportion, the flaky stone from a representative sample should first be separated out. Flakiness index is weight of flaky stone metal divided by weight of stone sample. Only the elongated particles are separated out from the remaining (non-flaky) stone metal. Elongation index is weight of elongated particles divided by total non-flaky particles. The values of flakiness index and elongation index so found are added up.
**If the minimum retained tensile test strength falls below 80 %, use of anti-stripping agent is recommended to meet the requirement

TABLE 6
COMPOSITION OF DENSE GRADED BITUMINOUS MACADAM

Grading	1	2
Nominal aggregate size*	37.5 mm	26.5 mm
Layer thickness	75-100 mm	50-75 mm
IS Sieve (mm)	Cumulative % by weight of total aggregate passing	
45	100	
37.5	95-100	100
26.5	63-93	90-100
19	-	71-95
13.2	55-75	56-80
9.5	-	-
4.75	38-54	38-54
2.36	28-42	28-42
1.18	-	-
0.6	-	-
0.30	7-21	7-21
0.15	-	-
0.075	2-8	2-8
Bitumen content % by mass of total mix	Min 4.0**	Min 4.5**

* The nominal maximum particle size is the largest specified sieve size upon which any of the aggregate is retained.
** Corresponds to specific gravity of aggregates being 2.7. In case aggregate have specific gravity more than 2.7, the minimum bitumen content can be reduced proportionately. Further the region where highest daily mean air temperature is 30°C or lower and lowest daily air temperature is -10°C or lower, the bitumen content may be increased by 0.5 percent.

F. *Mix Design*

The bitumen content required shall be determined following the Marshall Mix Design procedure contained in Asphalt Institute Manual MS-2. The Fines to Bitumen (FIB) ratio by weight of total mix shall range from 0.6 to 1.2. Apart from conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in Table 500-11 of MORTH 2012.

TABLE 7
REQUIREMENTS FOR DENSE GRADED BITUMINOUS MACADAM

Properties	**Viscosity Grade Paving Bitumen**	**Modified bitumen**		**Test Method**
		Hot climate	**Cold climate**	
Compaction level	75 blows on each face of the specimen			
Minimum stability (kN at 600C)	9.0	12	10	AASHTO T245
Marshall flow (mm)	2-4	2.5-4	3.5-5	AASHTO T245
Marshall Quotient (Stability/Flow)	2-5	2.5-5		MS-2 and ASTM 02041
% air voids	3.5			
% Voids Filled with Bitumen (VFB)	65-75			
Coating of aggregate particle	95% minimum			IS:6241
Tensile Strength ratio	80% Minimum			AASHTO T 283
% Voids in Mineral Aggregate (VMA)	Minimum percent voids in mineral aggregate (VMA) are set out in Table 500-13			

G. *Binder Content*

The binder content shall be optimized to achieve the requirements of the mix set out in Table 500-11 of MORTH 2012. The binder content shall be selected to obtain 4 percent air voids in the mix design. The Marshall method for determining the optimum binder content shall be adopted as described in the Asphalt Institute Manual MS-2. Where maximum size of the aggregate is more than 26.5 mm, the modified Marshall method using 150 mm diameter specimen described in MS-2 and ASTM 0 5581 shall be used. This method requires modified equipment and procedures. When the modified Marshall test is used, the specified minimum stability values in Table 500-12 shall be multiplied by 2.25, and the minimum flow shall be 3 mm.

VI. RESULTS FOR EPPMDBM

Here, in E-waste Plastic Powder Modified Dense Bituminous Macadam (EPPMDBM), three test specimens have been experimented with 5%, 2% and 0% E-waste Plastic Powder modification namely DBM 1, DBM 2 and DBM 3 respectively. Following are the graphs of results for the same.

A. *For DBM 1 (5% EPP)*

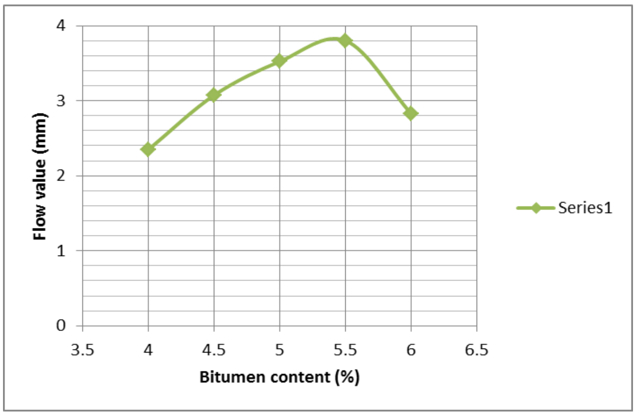

Fig. 2 Variation in Flow Value with Bitumen Content

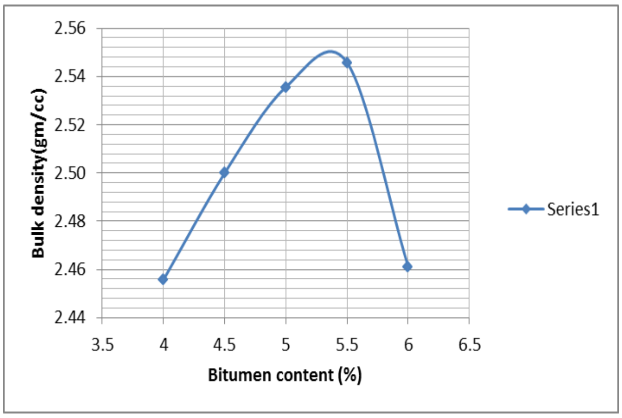

Fig. 3 Variation in Bulk Density with Bitumen Content

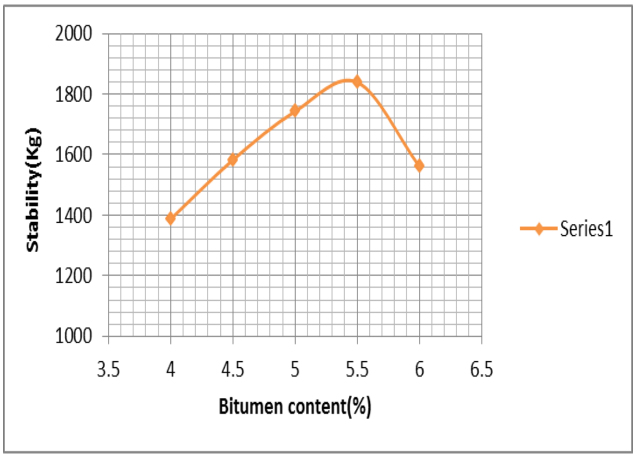

Fig. 4 Variation in Stability with Bitumen Content

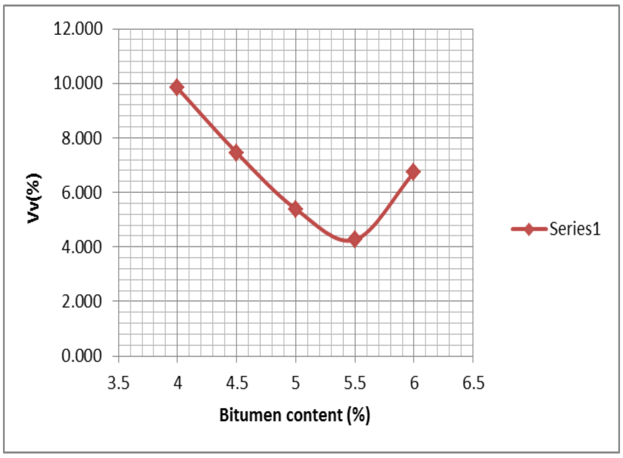

Fig. 5 Variation in Volume of Voids with Bitumen Content

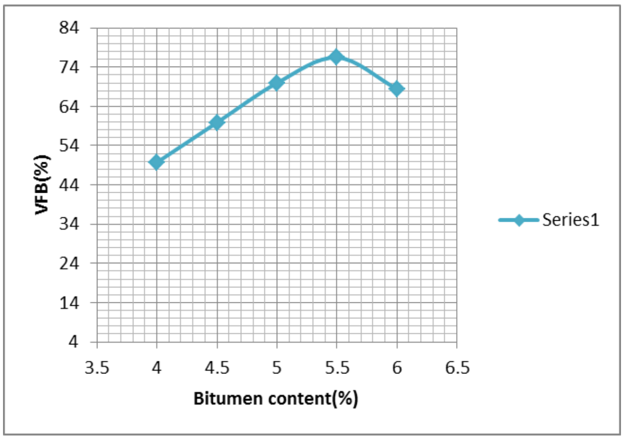

Fig. 6 Variation in Volume filled by Bitumen with Bitumen Content

B. *For DBM 2 (2% EPP)*

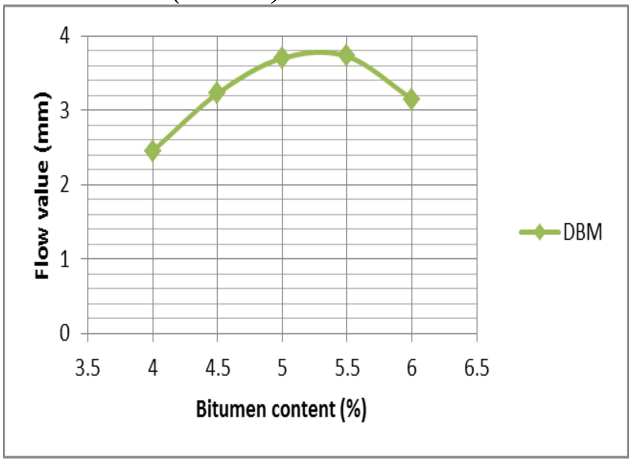

Fig. 7 Variation in Flow Value with Bitumen Content

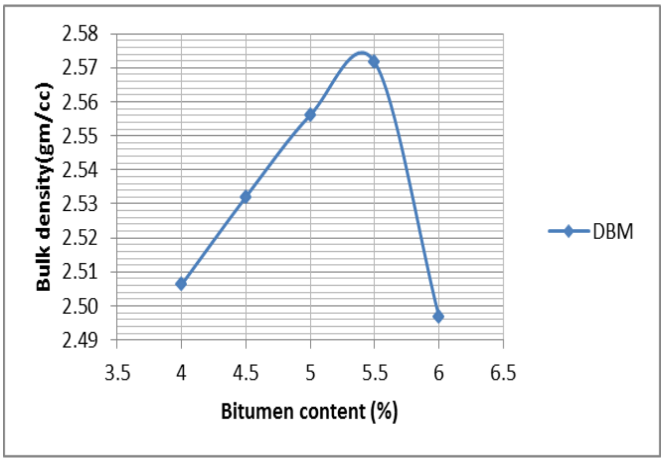

Fig. 8 Variation in Bulk Density with Bitumen Content

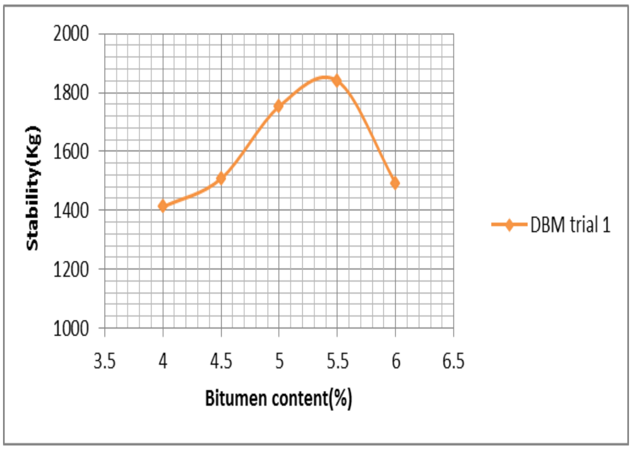

Fig. 9 Variation in Stability with Bitumen Content

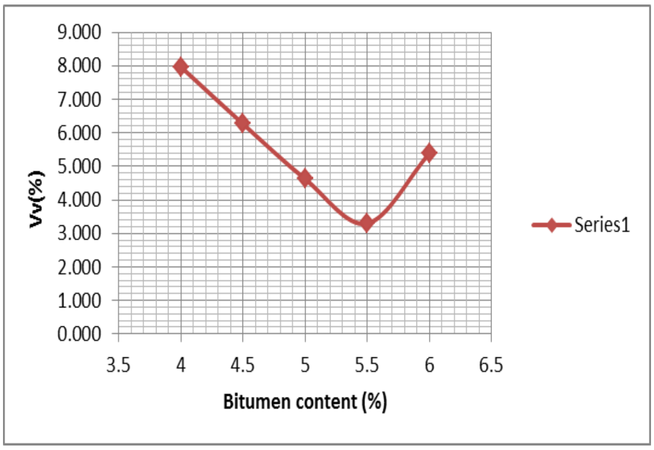

Fig. 10 Variation in Volume of Voids with Bitumen Content

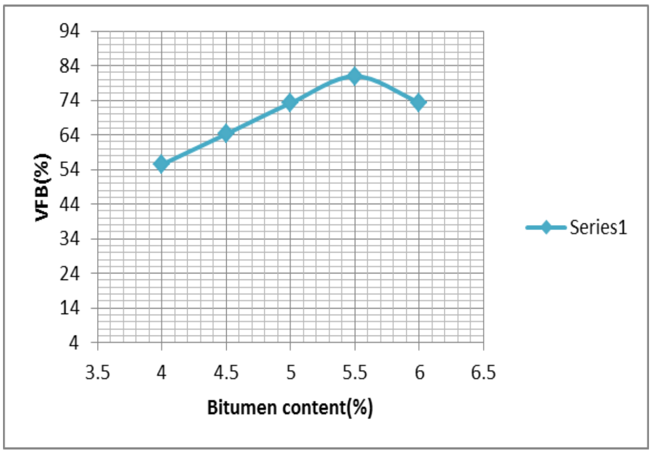

Fig. 11 Variation in Volume filled by Bitumen with Bitumen Content

C. *For DBM 3 (0% EPP)*

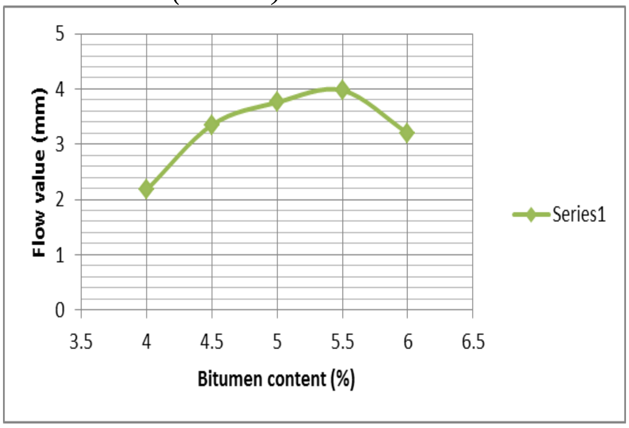

Fig. 12 Variation in Flow Value with Bitumen Content

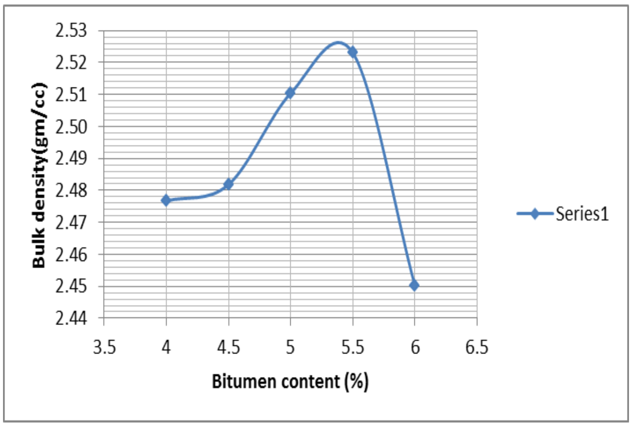

Fig. 13 Variation in Bulk Density with Bitumen Content

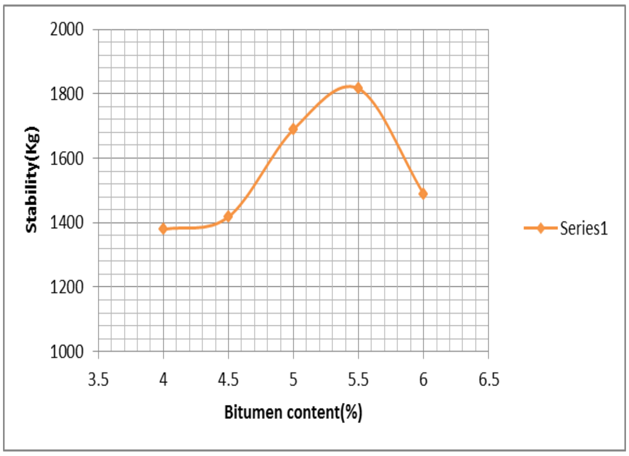

Fig. 14 Variation in Stability with Bitumen Content

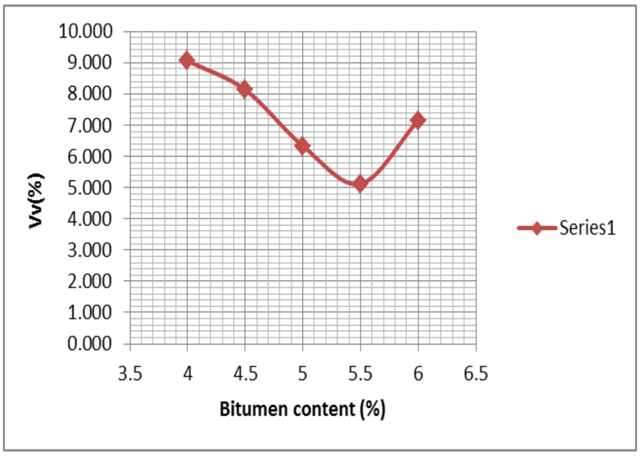

Fig. 15 Variation in Volume of Voids with Bitumen Content

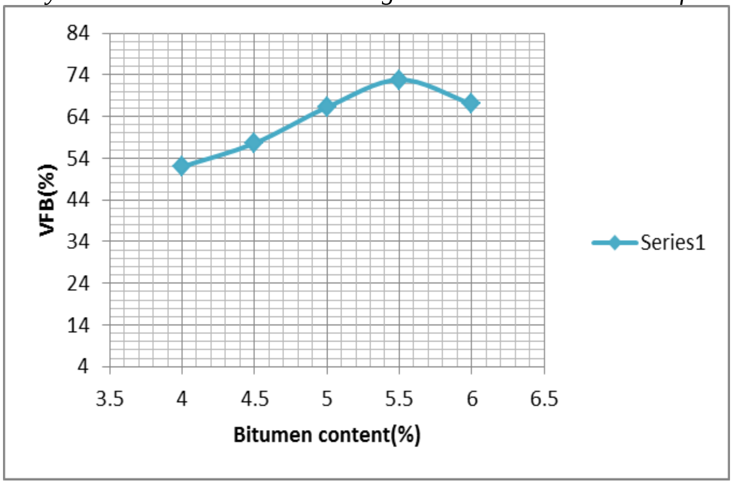

Fig. 16 Variation in Volume filled by Bitumen with Bitumen Content

VII. CONCLUSION

1. E-waste plastic powder has a potential to modify the bitumen, it can be successfully used as bitumen modifier.
2. EPPMB binders were more viscous verses virgin bituminous binder. The VG-30 bitumen thus behaves as if VG-40 grade bitumen.
3. EPPMB binders can be used in very high temperature i.e. up 55°C and heavy traffic areas (Delhi, Mumbai, Pune, Chennai etc.)
4. According to DSR test results it is observed that EPPMB shows better resistance to rutting as compared to neat bitumen (VG-30).
5. High elasticity is convenient at high temperatures to avoid viscous flow of the binder. The study has confirmed that modification of the binders facilitates this phenomenon at higher temperature.
6. It has been observed that the results obtained are optimum for 5% addition of E-waste Plastic Powder in bitumen in comparison with those of 2% and 0% i.e. no addition or pure bitumen.
7. It has been observed that 5.5% usage of bitumen in total weight of DBM mix gives the most optimum results for all the parameters.
8. DBM being the binder course is optimistically benefited by the use of E-waste Plastic Powder Modified Bitumen in it.
9. E-waste modification has enhanced all the physical and engineering properties of DBM including its flow, stability, voids content, bulk density and volume of voids filled by bitumen.
10. E-waste modification in DBM has improved the performance against rutting, cracking, scaling, stripping, fatigue, rupture and all other stresses and strains, even in creep.
11. The study has provided dual benefit for society, by putting forth the strength enhancing option for DBM by using E-waste and discovering a better option for the disposal of E-waste which has been a potential threat for the society, respectively.
12. E-waste powder modified bitumen can be produced economically and can be used for high traffic volume roads and high temperature areas.

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